Optimal Design of Wave Flume in Limited Space

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ABSTRACT

Under the 10th Malaysia Plan, National Defense University of Malaysia (NDUM) has developed a new naval architecture laboratory to suit the requirement as a niche and boutique university for new knowledge and competencies in defense related disciplines. This paper describes the optimal specification and design of a wave test flume in a confined space. The wave maker was specified with the constraints of limited budget and space, therefore optimization of the generated waves for this particular flume is paramount. The wave flume finally constructed to the specification is capable of producing regular and irregular waves controlled by computer programs, and is able to provide data logging. Result shows that the final design is a result of objective oriented design simplicity, but producing very accurate and effective results for a range of research and studies. The wave flume design also provides a basis to expand the facility to allow towing tests, as and when space allows.

KEY WORDS: *Flume wave maker, Optimum design wave tank, optimization of generated waves, Towing tank, 10th Malaysia Plan (RMK-10).*

NOMENCLATURE

RMK-10	*10th Malaysia Plan*
ITTC	*International Towing Tank Conference*
NDUM	*National Defense University of Malaysia*
H	*Wave height*
k	*Wave number*
h	*Water depth*
t	*Time*
l	*Elevation of hinged*
σ	*Wave maker frequency*

1.0 BACKGROUND

In today's globalized environment, maintaining competitiveness is a challenge. In this context, Malaysia has to ensure that there is constant competency building and the creation of 'new knowledge' so as to remain competitive. For Malaysian institutions of higher learning, it is envisaged that they will be in the forefront of this quest for excellence by being innovative and competitive whilst striving to be a regional powerhouse for leadership and cutting edge technologies [1]. Because of that, under the10th Malaysia Plan, RMK-10, a new naval architecture laboratory has been developed to suit the requirement of the university. This paper discusses the optimal design and specification of a test flume for the purpose of wave testing, with the option to upgrade to perform towing tests in the future.

Since the first commercial ship basin was commissioned in 1883, towing tanks have provided naval architects with a reliable method of predicting the performance of a ship and structure at sea. The performance of a vessel depends on the hydrodynamic interaction between the hull, its propulsion system and its rudder, which all combine to interact with the environmental conditions [2]. The development and knowledge of towing tank and its associated studies are being monitored by International Towing Tank Conference (ITTC). This conference is responsible to stimulate progress in solving the technical problems that are important to towing tank for the prediction of hydrodynamic performance of ships and marine installations based on the results of physical and numerical modeling [3, 4]. Ever since, many technical papers have been published covering a wide scope of studies including the methods of experiments, recommendation of procedures, validation methodologies and even policies [5-7].

2.0 CONSTRAINT

The biggest constraints in this specification work have been budget, space and information. Budget constraints mean that the affordable technologies available for the design are limited. Limited space means the flume length and depth is limited to the size of the available laboratory space where the flume could be located. In this case, the maximum room size was limited to 8.2m x 10m and a height to ceiling of 2.2m. This is very critical for the flume design because the produced wave must be matured enough for model testing, which could result in a reasonably short test area, which leads to the limitation on the scale of the models. Therefore, the design of the flume must optimize to maximize the relevance and accuracy of results. Surprisingly, there is very limited paper published about designing a flume wave [8-10]. This limits the knowledge on the design and construction criteria thus requiring an extensive knowledge-sharing effort with tank and flume designers across various industries in order to develop an optimal specification.

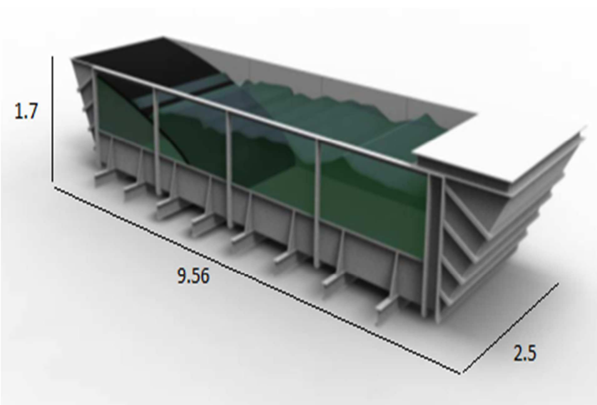


Figure 1: The overall dimension of Flume wave maker

3.0 THEORETICAL APPROACH

Hughes [11] outlined the theory to generate small amplitude sinusoidal waves with a desired period and wave height as follows:

$$\frac{H}{S_0} = \frac{4\sinh kh}{\sinh 2kh + 2kh}\left[\sinh kh + \frac{(\cosh kl - \cosh kh)}{k(h-1)}\right] \qquad (1)$$

Where H is the wave height, *k* is the wave number, and h is the water depth. However, for the wave board motion, the formula from Madsen quote from [11] was given as follows:

$$X(t) = \frac{H}{2m_l} sin\sigma t + \frac{H^2}{32h\left(1-\frac{h}{2(h+l)}\right)}\left(\frac{3\cosh kh}{sinh^3 kh} - \frac{2}{m_1}\right) sin2\sigma t$$

Where m_l =H/S_o given in the equation (1), t is time, l is the elevation of hinged, and σ is the wave maker frequency.

4.0 FINAL SPECIFICATION

The flume was required to have the capability to conduct several types of test programs including vessels, floating structures and wave energy convertors. The final specification is nominally pitched in the range of 1:50 to 1: 100 scale of North Atlantic seas, with internal working width of 2.5m, and nominal working depth of 1.3m.

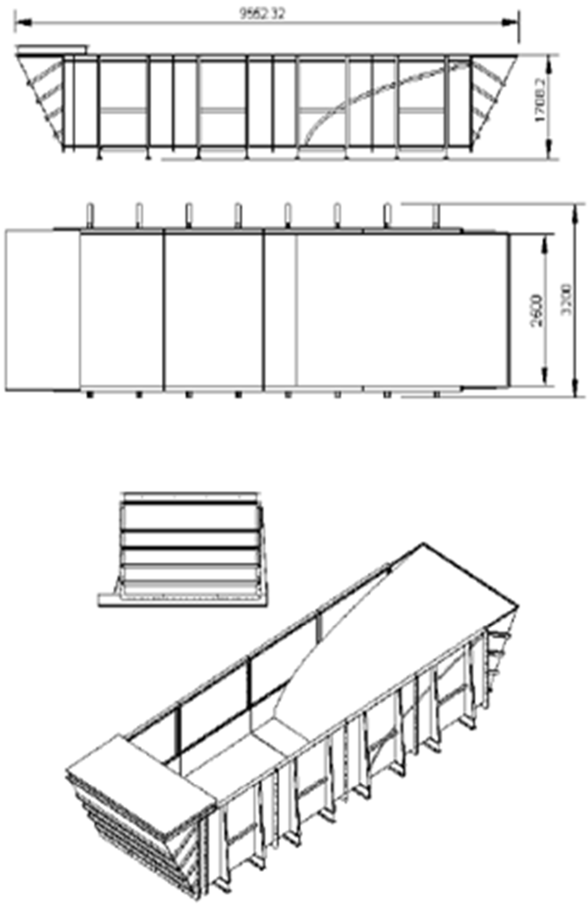


Figure 2: Schematic diagram

The specification of the flume wave consisted of parabolic wave absorber, four tank modules, a wave maker module (as shown in Figure 1 and Figure 2), various scale test models and a dynamic measurement system. The purpose of the parabolic wave absorber is to diminish the wave at the end of each wave run, providing a good quality set of waves in the basin.

Table 1: The flume wave parameters

Parameter	Unit (m)
Maximum Working Depth	1.33 (depth of water effects size of wave that can be created)
Working Width	2.5m
Internal length	8 m (from paddle face to end cap face)
Working Length	2-2.5 m
Maximum wave height	0.2m
Wave period	0.5 seconds to 2.5 seconds

5.0 OPTIMIZATION

The specified parameters of the wave flume are shown in Table 1. For the scaling effect, the Froude, the proportional of inertia and gravitational forces are same at all scales. A major advantage of this design is that it does not require a pump to generate wave cycles. This reduces the complexity of the design, and creates an easy-handling and low maintenance system. On top of all, it ensures the generated waves are not affected by any recirculation of water in the basin. For this design, the deep water device behavior is not affected by the viscous effect. The wave scale conditions that can be generated from this flume are shown in Table 2.

Table 2: Full scale wave conditions

Scale	Hs	Tp	Wavelength
1	14.5	17.0	451.2
10	1.45	5.38	45.1
20	0.73	3.80	22.6
30	0.48	3.10	15.0
40	0.36	2.69	11.3
50	0.29	2.40	9.0
60	0.24	2.19	7.5
70	0.21	2.03	6.4
80	0.18	1.90	5.6
90	0.16	1.79	5.0
100	0.15	1.70	4.5
110	0.13	1.62	4.1

For the purpose of the Wave energy convertors (WEC) in deep water, the seabed (tank floor) could give a significant effect of the WEC model depth. Therefore, a few evaluations were conducted to define the minimum, maximum and optimum sizes that can run on this particular flume wave maker. The results were shown in Table 3 and Table 4.

Table 3: Full scale devices sizes

	Point absorbers (ie Wavebob) (m)	Attenuators (ie Pelamis) (m)	Surge (ie Aquamarine) (m)
Depth	65	4	13
Width	22	4	17
Length	22	180	10

Table 3 shows the actual size for the WEC in real development, and Table 4 reflects the scales that are acceptable to conduct the scaled model matching the tank depth. It shows that the range of scales that are practical for model testing are between 1:70 and 1:90 scales. Meanwhile, a study on the matching width is shown in Table 5.

Table 4: The scales that are suitable for a 9.6 m long flume wave maker (matching the tank depth)

Scale	Point absorbers (ie Wavebob)	Attenuators (ie Pelamis)		Surge (ie Aquamarine)		Requirement for all types	
	Tank depth (m)	Model size (m)	Tank depth (m)	Model size (m)	Tank depth (m)	Tank depth (m)	Model size (m)
1	100.0	65.0	100.0	4.00	100.0	13.00	100.0
10	10.0	6.50	10.0	0.40	10.0	1.30	10.0
20	5.0	3.25	5.0	0.20	5.0	0.65	5.00
30	3.3	2.17	3.3	0.13	3.3	0.43	3.33
40	2.5	1.63	2.5	0.10	2.5	0.33	2.50
50	2.0	1.30	2.0	0.08	2.0	0.26	2.00
60	1.7	1.08	1.7	0.07	1.7	0.22	1.67
70	1.4	0.93	1.4	0.06	1.4	0.19	1.43
80	1.3	0.81	1.3	0.05	1.3	0.15	1.25
90	1.1	0.72	1.1	0.04	1.1	0.14	1.11
100	1.0	0.65	1.0	0.04	1.0	0.13	1.00
110	0.9	0.59	0.9	0.04	0.9	0.12	0.91

Table 5: The scales that are suitable for a 9.6 m long flume wave maker (matching the tank width)

Scale	Point absorbers (ie Wavebob)	Attenuators (ie Pelamis)		Surge (ie Aquamarine)		Requirement for all types	
	Tank width (m)	Model size (m)	Tank width (m)	Model size (m)	Tank width (m)	Tank width (m)	Model size (m)
1	71.81	22.00	255.61	4.00	143.63	17.00	225.61
10	7.18	2.20	22.56	0.40	14.36	1.70	22.56
20	3.59	1.10	11.56	0.20	7.18	0.85	11.28
30	2.39	0.73	7.52	0.13	4.79	0.57	7.52
40	1.80	0.55	5.64	0.10	3.59	0.43	5.64
50	1.44	0.44	4.51	0.08	2.87	0.34	4.51
60	1.20	0.37	3.76	0.07	2.39	0.28	3.76
70	1.03	0.31	3.22	0.06	2.05	0.24	3.22
80	0.90	0.28	2.82	0.05	1.80	0.21	2.82
90	0.80	0.24	2.51	0.04	1.60	0.19	2.51
100	0.72	0.22	2.26	0.04	1.44	0.17	2.26
110	0.65	0.20	2.05	0.04	1.31	0.15	2.06

From Table 5, it shows that the scaled model limits fall under the surge type model. It is envisaged that the practical scale that can be conducted with a width constraint ranges between the scale of 1:60 and 1:80. The matching length study is represented in Table 6. A parabolic passive beach is assumed in this study, which is represented by the parabolic wave absorber.

Table 6: The scales that are suitable for a 9.6 m long flume wave maker (matching tank length)

Scale	**Beach length**	**Point absorbers (ie Wavebob)**		**Attenuators (ie Pelamis)**		**Surge (ie Aquamarine)**		**Requirement for all types**
		Tank length (m)	**Model size (m)**	**Tank length (m)**	**Model size (m)**	**Tank length (m)**	**Model size (m)**	**Length (m)**
1	266.70	488.70	22.00	646.70	180.0	476.7	10.00	646.7
10	26.67	48.87	2.20	64.67	18.00	47.67	1.00	64.67
20	13.34	24.44	1.10	32.34	9.00	23.84	0.50	32.34
30	8.89	16.29	0.73	21.56	6.00	15.89	0.33	21.56
40	6.67	12.22	0.55	16.17	4.50	11.92	0.25	16.17
50	5.33	9.77	0.44	12.17	3.60	9.53	0.20	12.93
60	4.45	8.15	0.37	10.78	3.00	7.95	0.17	10.78
70	3.81	6.98	0.31	9.24	2.57	6.81	0.14	9.24
80	3.33	6.11	0.28	8.08	2.25	5.96	0.13	8.08
90	2.96	5.43	0.24	7.19	2.00	5.30	0.1	7.19
100	2.67	4.89	0.22	6.47	1.80	4.77	0.10	6.47
110	2.42	4.44	0.20	5.88	1.64	4.33	0.09	5.88

Table 6 shows the limitation of length for the flume wave maker which has a scale ranging between 1:60 and 1:80. The length of the passive beach consumed 3.5 m of the overall length of the wave tank. This results in a good for testing space length of around 2.5 m as shown in Figure 3.

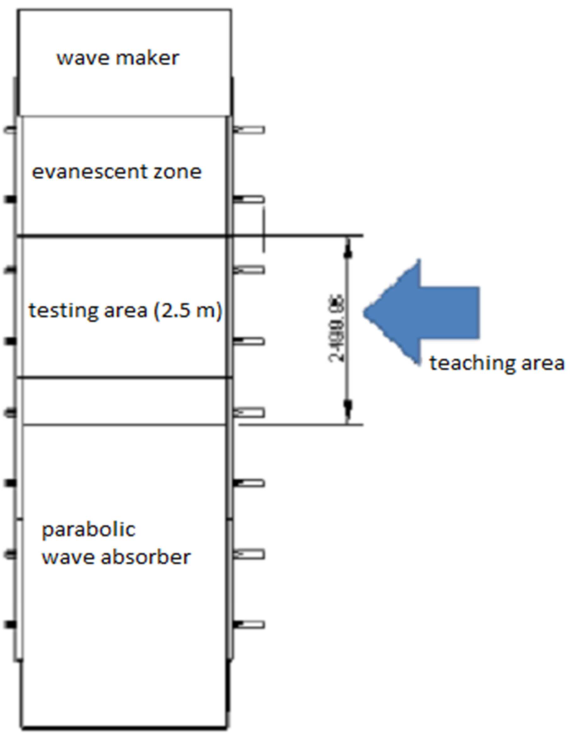
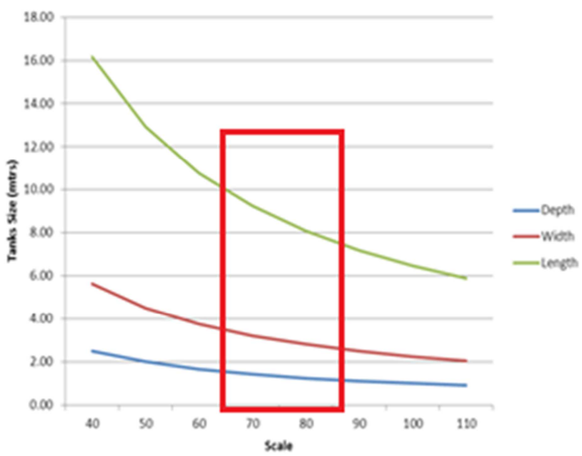


Figure 3: The good space of testing area

The combination of length, width and depth are shown in Graph 1. From the graph, one may derive that for this wave flume, the appropriate scale ranges from 1:65 to 1: 84 for the space constraints for this project. The selection of the size of the model must correspond to this range.



Graph 1: Size and scale range

6.0 CONCLUSION

This paper describes a process for the optimal specification and design of a wave flume given limited space and budget. The specification produced maximizes the scale of testing that can be performed in the space. It produced a simple design that offers the ability to test in waves with accurate results at a useful scale for research and studies. Various regular and irregular waves can be generated by a computer system controlling a hinged paddle, dry-back wave maker, with a passive parabolic wave beach at the end of the tank that is able to absorb the unwanted wave energy. Thus a large batter of tests can be performed in a short period of time, with short settle time between test runs.

This paper has described how the wave flume specification has limitations. Given more space, larger scale models would allow the validation of numerical models, survivability, and viscous effects, at 1:50 to 1:20 scale. Even more space would be required for the testing at 1:10 to 1:5 scale, of non-linear hydrodynamic effects and engulfment. Instead the wave flume design specification focused on future extensibility at 1:75 scale, with the addition of towing test capabilities, more appropriate for the nature of the university's work. This would be achieved in the planned future development of NDUM naval architecture laboratory whereby the current flume length would be extended to 50m or longer by simply adding more tank modules, so that a towing carriage can be installed. This would allow the testing of vessel hull drag, wake, propulsion tests, steering and so forth.

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