

# Analysis of floating concrete breakwater mooring tension by DualSPHysics

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**Abstract.** An analysis of the effect of the distance between a Floating Concrete Breakwater (FCB) with dual configurations on the tension of the catenary mooring line system is presented. The Smoothed Particle Hydrodynamics method in DualSPHysics software was used to analyze the maximum tension on FCB mooring lines at the 1:10 model scale. The results indicate that the gap between FCBs influenced the mooring line's tension. In the narrow FCB (40cm width), the mooring line tension was reduced by 20% when the gap is reduced to 20 cm (50% width) from 30 cm (75% width) and increased by 1% when the gap was increased from 30 cm (75% width) to 40 cm (100% width). With a few exceptions, the wide FCB (102.5cm width) shows an 8% tension increase at a gap of 50cm (50%) to 75cm (75% width) and a 16% tension drop when the gap was reduced to 75cm (75% width) from 1 m (100% width). The wave's height and periods also influence the mooring line tension. At a wave height of 0.18 meters and 2.21 seconds wave period of 2.21 s, the maximum tensions for a narrow single FCB were 187.54 kN at the fairlead and 185.189 kN at the anchor. At a wave height of 0.28 m and a wave period of 2.84 s, the maximum tensions of the wide single FCB is 359.75 kN at the anchor and 362.42 kN at the fairlead. In the dual configuration, the maximum tension was recorded when the gap between the floating breakwaters was 50% of the width, either for the narrow or wide FCB.

## 1 Introduction

Ports are important infrastructures that support a country's economy. However, the use of remote ports in Indonesia is sometimes not optimal. High sea waves hinder port optimization because they can damage port infrastructures, disrupting the loading and unloading of goods and passengers. In general, these problems can be solved by developing coastal protection structures such as breakwaters[1]. However, not all ports in Indonesia can be built with rubble mound breakwater. Some ports in Indonesia have a sufficiently deep-water depth; therefore, if a rubble mound breakwater is built, the volume of material will incur expensive costs and take a long time. To overcome these problems, the construction of floating breakwaters is a viable solution

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Floating concrete breakwaters (FCB) have brought significant innovations to protect ports from high waves in locations where conventional breakwaters have proven ineffective. Conventional breakwaters require complex planning and construction, and additional materials are required, resulting in high costs. Nevertheless, in deep waters, the construction of FCBs is less expensive than that of conventional breakwaters[2]. Other advantages of FCBs include their efficiency, which is not affected by tides and sea level changes, minimal environmental impact, low construction and demolition costs, short installation times, and the flexibility to adjust modules and layouts to accommodate future changes in use[3].

This study uses the SPH method with DualSPHysics software, which is proven accurate for simulating the movements of floating structures under the influence of regular waves[4,5]. FCB's performance is affected by immersion depth and wave conditions but is hardly affected by the density and gravity of the ballast water[6]. Dual FCBs are superior to single FCBs for wave reduction[7]. In addition, the distance between FCBs with dual configurations can affect the damping-wave performance and the tension on the mooring line[8,9]. This paper presents a model of a double-configuration FCB and catenary mooring system with distance variation. This study focused on a catenary mooring system so that the tension did not exceed the limit of breaking the load, as per the appropriate rules

## 2 Research Description

### 2.1 Research Data

The data needed in this study is the data of the numerical flume tank model used for the simulation. The existing FCB products were simulated in numerical flume tanks at 1: 10 scale for validation to ensure that the results of the numerical experiments reflect real-life situations as accurately as possible. Environmental data for the numerical flume tanks and existing FCB products are presented in Table 1.

**Table 1.** FCB dimension and environmental data.

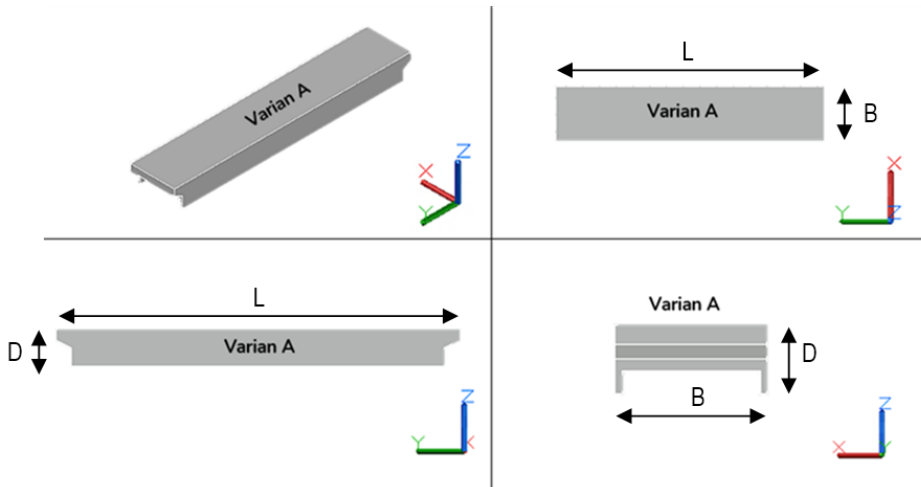
Data Type	Variables	Scaled Value	Unit
FCB Structure Data	Length	0,745	m
	Width	0,5	m
	Depth	0,3	m
Environmental Data	Water Depth	0,514	m
	Wave Height	0,05	m
	Wave Period	1,2	s

Two types of FCB models were compared to the simulation results. The dimensions of each type were scaled 1:10 according to the Froude Scale Law shown in Table 2, and the shapes and dimension symbols of each model are presented in Figures 1 and 2.

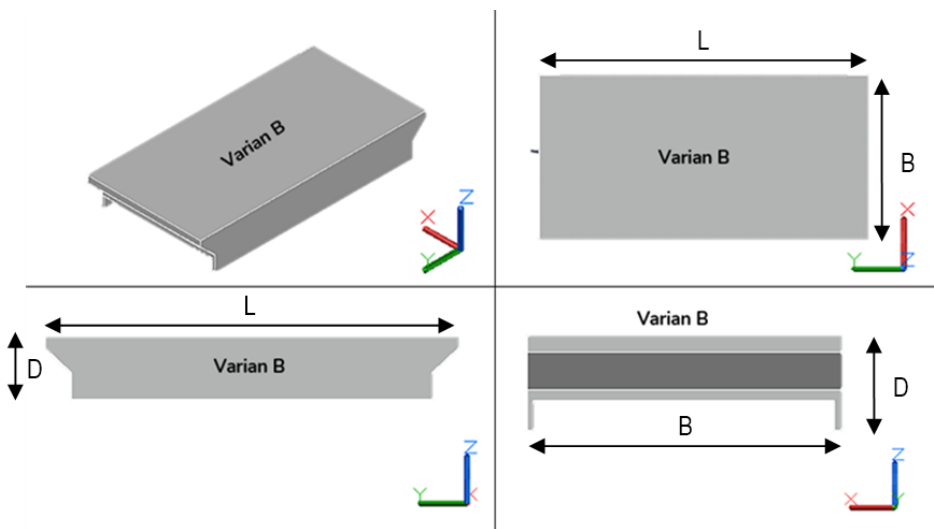
**Table 2.** FCB's dimension

FCB Types	Variables	Actual Value	Scaled Value
Varian A (Narrow FCB)	Length [L]	20 m	2 m
	Width [B]	4 m	0,4 m
	Depth [D]	1,8 m	0,18 m
	Weight [W]	55 ton	55 kg
	Freeboard [F]	0,5 m	0,05 m

FCB Types	Variables		Actual Value	Scaled Value
Varian B (Wide FCB)	Length	[L]	20 m	2 m
	Width	[B]	10,25 m	1,025 m
	Depth	[D]	3 m	0,3 m
	Weight	[W]	200 ton	200 kg
	Freeboard	[F]	0,8 m	0,08 m



**Fig.1.** Isometric view of a narrow FCB (Type A).



**Fig.2.** Isometric view of a wide FCB (Type B).

Environmental parameters were obtained and applied to potential FCB locations. The variation in the environmental data can be attributed to the type of FCB analyzed. The narrow-type, designed for calmer ocean conditions, will be tested using environmental data that tend to be smaller than those of the wide-type. The two main parameters to be applied are the wave height and the wave period as shown in Table 3.

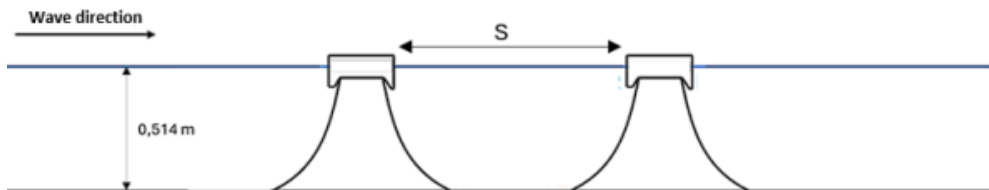
**Table 3.** Environmental data.

FCB Types	Variabels	Prototype	Model
A (Narrow FCB)	Wave Height	1,4 m	0,14 m
		1,6 m	0,16 m
		1,8 m	0,18 m
	Wave Period	1,4 m	0,14 m
		1,6 m	0,16 m
		1,8 m	0,18 m
B (Wide FCB)	Wave Height	2 m	0,2 m
		2,4 m	0,24 m
		2,8 m	0,28 m
	Wave Period	4 s	1,26 s
		7 s	2,21 s
		9 s	2,84 s

The reference dimensions of the FCB units are given in Table 3, and the distance between the structures was also adjusted to 1:10 based on the Froude Scale. For each FCB unit, three spacing configurations were used according to the structure width as presented in Table 4. The distance between FCB units and the water depth in the model is illustrated in Figure 3.

**Table 4.** FCB distance scenario.

FCB Types	Distance	S (m)
A (Narrow FCB)	0.5 B	0,2
	0.75 B	0,3
	B	0,4
B (Wide FCB)	0.5 B	0,5
	0.75 B	0,75
	B	1



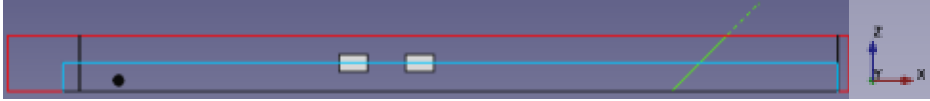
**Fig. 3.** The distance between FCB units

## 2.2 Numerical Flume Tank Model

A schematic of the numerical flume tank prepared by DualSPHysics is shown in Figure 4. After model preparation in DualSPHysics, a validation process was performed to determine whether the obtained model could be used for model exploration and further analysis. The FCB products to be simulated on the modeled tank flume are shown in Figure 5.

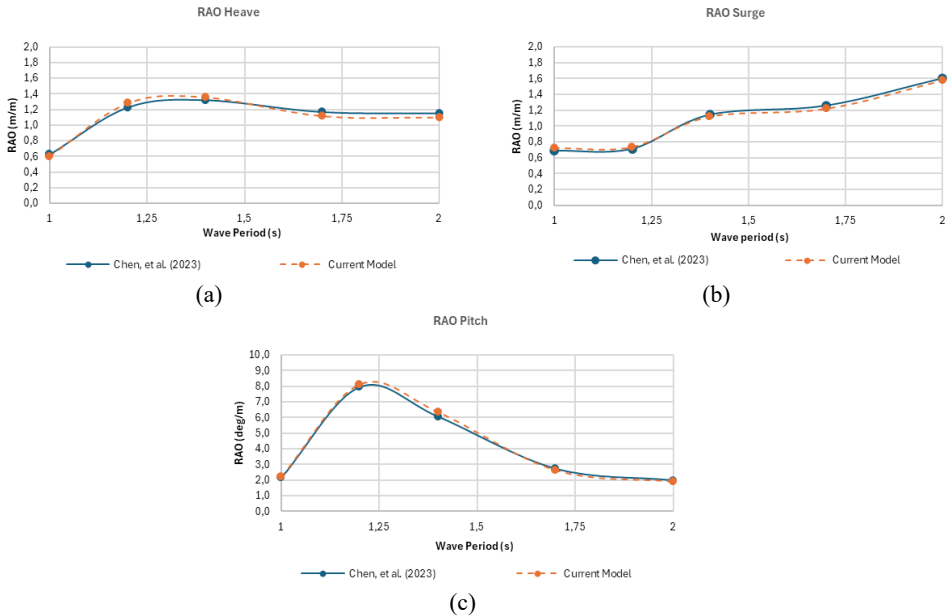


**Fig. 4.** Schematic of a numerical flume tank on DualSPHysics.



**Fig. 5.** FCB configuration model schematics on DualSPHysics.

The simulation results are presented in the form of the FCB structural movement and the response amplitude operator (RAO). The model’s movement characteristics were compared to those of the RAO model reported by Chen et al. (2023). The modeling is based on 2 dimensional, so the resulting RAO only includes the surge, heave, and pitch. The tolerance value of the RAO comparison difference must be less than 10% [10]. The validation results in Tables 5–7 show that the RAO results differ by less than 10%. The RAO comparison is also shown in Figure 6. Therefore, numerical flume tank modeling can be used for further analysis.



**Fig. 6.** RAO validation (a) heave (b) surge (c) pitch.

**Table 5.** Heave RAO validation results.

Wave Period (s)	RAO heave length (m/m)		Error	Remarks
	Chen et al. (2023)	Current Model		
1	0.628	<b>0.598</b>	4.81%	PASS
1.2	1.222	<b>1.281</b>	4.84%	PASS
1.4	1.314	<b>1.358</b>	3.34%	PASS
1.7	1.164	<b>1.115</b>	4.23%	PASS
2	1.147	<b>1.098</b>	4.27%	PASS

**Table 6.** Surge RAO validation results.

Wave Period (s)	RAO Surge (m/m)		Error	Remarks
	Chen et al. (2023)	Current Model		
1	0.691	<b>0.724</b>	4.71%	PASS
1.2	0.714	<b>0.736</b>	3.04%	PASS
1.4	1.143	<b>1.12</b>	2.00%	PASS
1.7	1.257	<b>1.218</b>	3.11%	PASS
2	1.6	<b>1.574</b>	1.63%	PASS

**Table 7.** Pitch RAO validation results.

Wave Period (s)	RAO Pitch (deg/m)		Error	Remarks
	Chen et al. (2023)	Current Model		
1	2.148	<b>2.236</b>	4.11%	PASS
1.2	7.977	<b>8.122</b>	1.81%	PASS
1.4	6.068	<b>6.347</b>	4.59%	PASS
1.7	2.727	<b>2.641</b>	3.16%	PASS
2	1.977	<b>1.921</b>	2.85%	PASS

### 2.3 Floating Concrete Breakwater (FCB) Modeling

The narrow and wide FCB geometric models were prepared using FreeCAD and further integrated with a previously validated numerical flume tank model. The dimensions, structure, and geometry of the scaled FCB are presented in Table 2. The models of the narrow and wide FCB structures are shown in Figures 7 and 8.



**Fig. 7.** Modeling scheme of narrow FCB on DualSPHysics.



**Fig. 8.** Scheme for modeling a wide FCB on DualSPHysics.

### 2.4 Mooring System Modeling

The mooring lines on the FCB were modeled using DualSPHysics in a configuration consisting of two symmetrical mooring lines. The specifications of the mooring line used in this study are given in Table 8.

**Table 8.** Specification of mooring line.

Description	Scaled Value
Line Length	1,2 m
Diameter	3,6 mm
Mass per unit length	66 kg/100 m
<i>Stiffness</i>	2900 N

Description	Scaled Value
MBL	1020.2 N
Material	High Modulus Polyethylene 'Dynema ® SK75'

The configuration of the mooring line on the FCB is symmetric on each side. To recognize the tension lines during the analysis, each line was defined with a name. The naming details of the mooring line are shown in Figure 9.

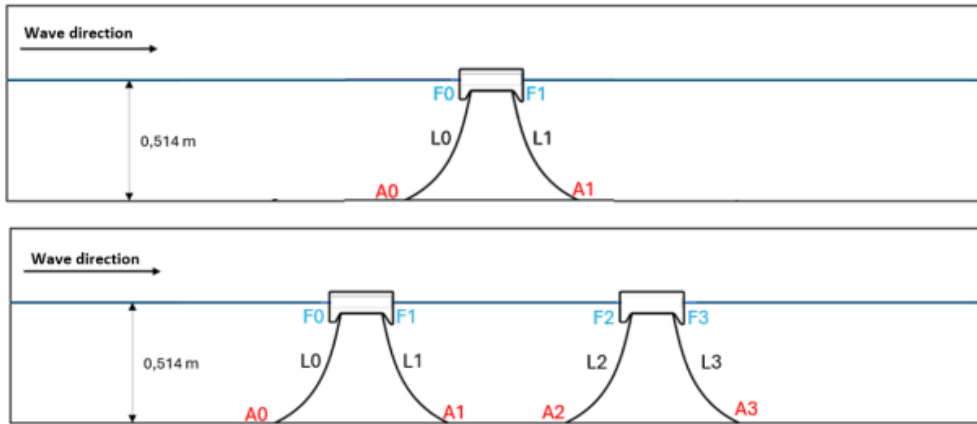


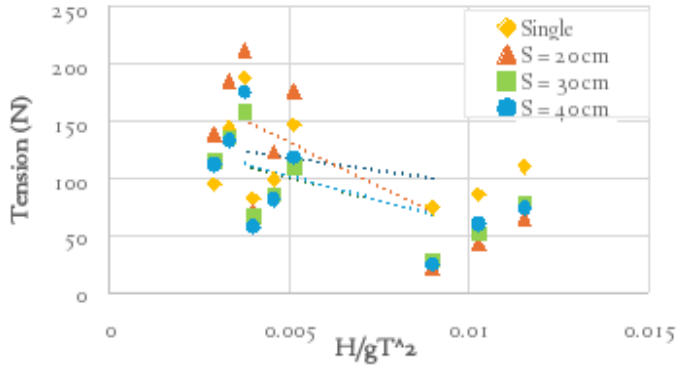
Figure 9. Single- and dual-configuration FCB mooring line labeling.

### 3 Results and Discussion

#### 3.1 The influence of hydrodynamic parameters

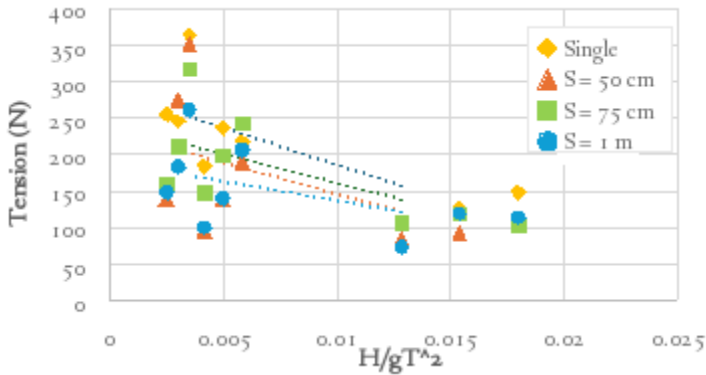
The tension on the mooring line is affected by hydrodynamic variables, i.e., Wave period and height. The variations in the hydrodynamic variables resulted in different tension values. Regardless of the FCB type, hydrodynamic variables influence the maximum tension of the FCB mooring line. This can be observed through the change in the nondimensional magnitude of the wave steepness ( $H/gT^2$ ) with respect to the mooring line tension.

Figure 10 plots the relationship between the wave steepness and the mooring tension in the narrow FCB model. The results show that the mooring line tension tends to decrease as the wave steepness increases. However, when examined in more detail, the mooring line tension exhibits a similar pattern. The pattern of increasing the maximum tension value of the mooring line can be observed for each wave height variation and a given wave period. This suggests that although the mooring line tension generally decreases with increasing wave steepness, there are specific moments when the maximum tension exhibits a consistent increase, reflecting the complexity of the interaction between the wave and the mooring line.



**Fig. 10.** Relationship between wave steepness and mooring tension in a narrow FCB (type A).

The wide FCB version has the same pattern as the narrow version, in which the trend of the mooring tension decreases with increasing wave steepness, as shown in Figure 11. However, there is still a pattern of increasing the maximum tension value of the mooring line at each wave height and for a certain period. This result shows that the steepness of the wave influences the tension of the mooring line. Thus, hydrodynamic variables (wave height and period) and parameters (wave steepness) affected the magnitude of the mooring line tension in both FCB types.



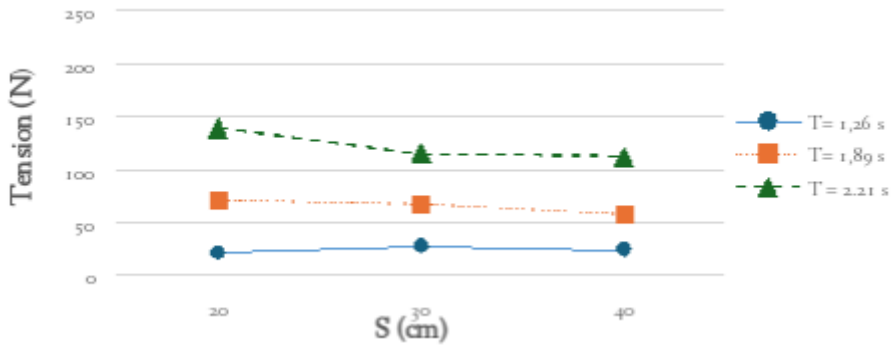
**Fig. 11.** Relationship between wave steepness and mooring tension for a wide FCB (type B).

### 3.2 Effect of FCB distance

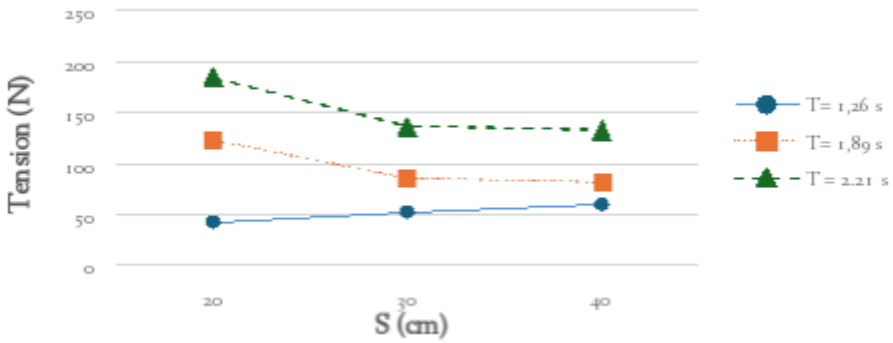
In addition to the wave height and wave period parameters, this study also discusses the distance between the FCBs, specifically analyzing its effect on the mooring line tension in a dual configuration. The comparison of the distance between the FCB structure and the mooring line tension is shown in Figures 12 and 13. Both types result in a trend toward the mooring-line style, which tends to be inconsistent with the distance between structures.

The narrow version of the FCB exhibits the same pattern at periods of 1.89 s and 2.21 s for every  $H_s$  condition, which decreases the mooring line tension by 6%–38%. from a change distance from 20 cm to 30 cm. Then, from a gap increment of 30 cm to 40 cm, the tension of the mooring line also decreased by 2%–13%, except for  $H_s = 1.8$  m, which increased by 8%–11%. Meanwhile, the trend for  $T = 1.26$  s differs from that of the other  $T$  variations. At a

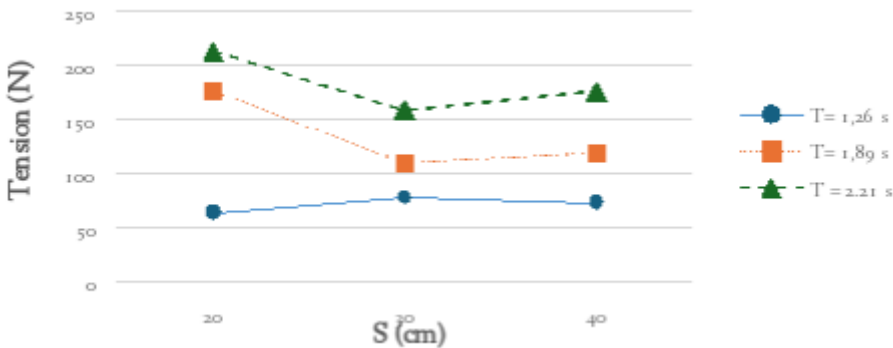
distance of 20–30 cm, the tension of the mooring line tends to increase by 21%–30% and decreases at a distance of 30 cm to 40 cm by 6%–12%.



(a). Hs = 0.14 m



(b). Hs = 0.16 m

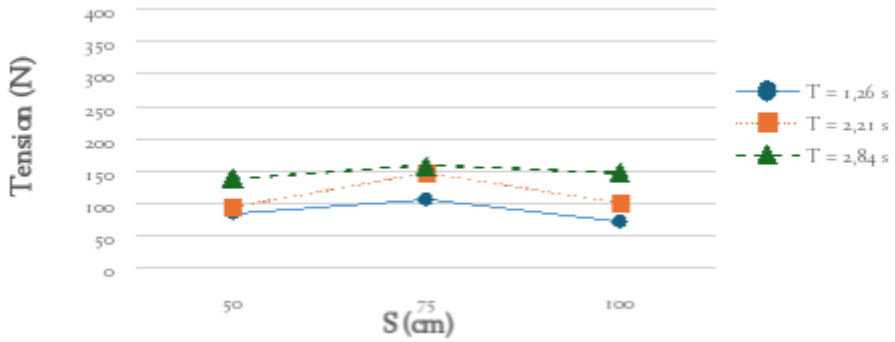


(c). Hs = 0.18 m

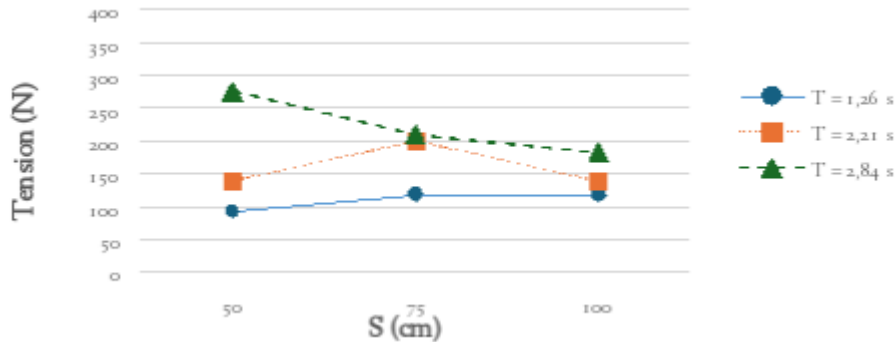
**Fig. 12.** Relationship between FCB distance and mooring tension of narrow FCBs (type A) (a) Hs = 0.14 m, (b) 0.16 m, and (c) 0.18 m.

The wide FCB version exhibits a different trend from the narrow. At a wave period of 1.26 s, the mooring line tension increased by 25%–28% as the gap increased from 50 to 75 cm and decreased by 32% when the gap increased from 75 to 1 m. There was an anomaly that occurred in the wave period of 1.26s, when the wave height was 2.8 m, where the mooring line tension decreased by 10% from a distance of 50 cm to 75 cm and an increase

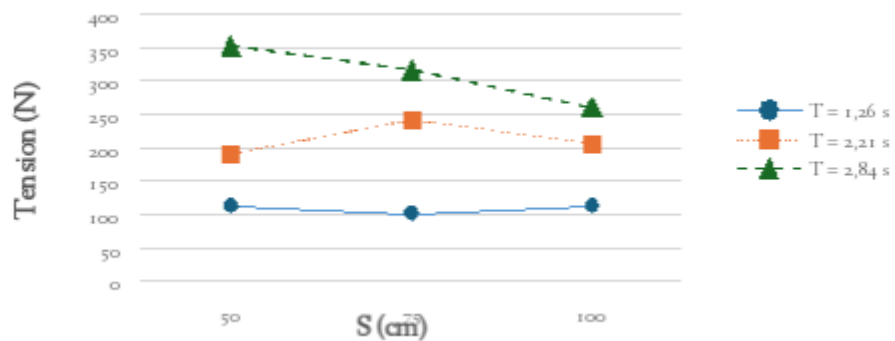
of 11% from a distance of 75 cm to 1 m. At wave period 2.21 s, the mooring line tension showed a similar trend: a 28%–56% increase in tension at gap increment from 50 cm to 75 cm and a 15%–32% decrease in tension when the gap increased from 75 cm to 1 m.



(a). Hs = 0.20 m



(b). Hs = 0.24 m



(c). Hs = 0.28 m

**Fig. 13.** Relationship between the FCB distance and the mooring tension of a wide FCB (type B): Hs = (a) 0.2 m (b) 0.24 m, and (c) 0.28 m.

Overall, the difference in distance significantly influenced the magnitude of the mooring line tension. In the narrow FCB, the average decrease in the mooring line tension was 20% from when the distance of 20 changed to 30 cm and an increase of 1% from the distance

change of 30 to 40 cm. In the wide FCB version, the average increase in the mooring line tension was 8%, and the decrease was 16% from a distance of 75 cm to 1 m. However, the large number of anomalies suggests that more research is needed to better understand this phenomenon and reduce the uncertainty of the results. It is important to ensure that the analysis reflects real conditions and can be used as a basis for more accurate decision-making in the future.

### 3.3 Comparison between single and dual configurations

The mooring tensions of the single and dual configurations are given in Tables 9 and 10.

**Table 9.** Comparison between single and dual configurations of narrow FCBs (type A).

Configuration Type	Average Maximum Tension (N)	Comparison to Single Configuration
Single	<b>113.54</b>	-
Dual, S = 20 cm	<b>114.80</b>	<b>1.11%</b>
Dual, S = 30 cm	<b>91.95</b>	<b>-19.01%</b>
Dual, S = 40 cm	<b>92.80</b>	<b>-18.27%</b>

**Table 10.** Comparison between single and dual configurations of a wide FCB (type B).

Configuration Type	Average Maximum Tension (N)	Comparison to Single Configuration
Single	<b>209.05</b>	-
Dual, S = 50 cm	<b>164.28</b>	<b>-21.42%</b>
Dual, S = 75 cm	<b>177.79</b>	<b>-14.95%</b>
Dual, S = 100 cm	<b>148.99</b>	<b>-28.73%</b>

Table 9 shows that the mooring line tension was almost always lower in the dual configuration than in the single configuration. The distance gap that best reduced the tension of the mooring line for the narrow breakwater was 30 cm (75% of the width), resulting in a reduction of 19.01%. However, when the distance between structures was 20 cm (50% of the width), the mooring line tension increased by 1%. Although this number is still relatively small, this increase indicates the variability in the response of the mooring line to changes in the distance between structures. Overall, the average mooring line tension reduction by the dual configuration of the narrow FCB was 12.06% that of the single configuration.

The mooring line tension of wide FCB's dual configuration was always lower than that in the single configuration, as shown in Table 10. The best configuration for reducing the tension of the mooring line was 100 cm (full width), which reduced the tension by 28.73%. The average mooring line tension reduction by the dual configuration of wide FCBs was 21.7% compared to that of the single configuration.

### 3.4 Safety Factor

In the mooring analysis of the narrow and wide FCBs, the maximum tension results were used to calculate the safety factor under all the loading conditions. According to the API [11], the safety factor of the mooring line configuration under dynamic conditions is 1.67. The safety factors for all FCB-testing scenarios are presented in Tables 11–14. Based on the results of the maximum tension of the mooring line, its safety factor was found to be greater

than 1.67, which means that the configuration of the mooring system and its configuration are suitable for operation.

**Table 11.** Safety factors for mooring line tension in a single configuration of a narrow FCB (type A).

Wave Height (m)	Wave Period (s)	Max Tension (N)	MBL (N)	Safety Factor	Status
0.14	1.26	73.990	1020.2	13.79	PASS
	1.89	82.075		12.43	PASS
	2.21	94.191		10.83	PASS
0.16	1.26	85.404	1020.2	11.95	PASS
	1.89	98.747		10.33	PASS
	2.21	143.531		7.11	PASS
0.18	1.26	109.832	1020.2	9.29	PASS
	1.89	146.574		6.96	PASS
	2.21	187.540		5.44	PASS

**Table 12.** A mooring line tension safety factor in a single configuration of a wide FCB (type B).

Wave Height (m)	Wave Period (s)	Max Tension (N)	MBL (N)	Safety Factor	Status
0.2	1.26	107.50	1020.2	9.49	PASS
	2.21	184.10		5.54	PASS
	2.84	254.41		4.01	PASS
0.24	1.26	126.94	1020.2	8.04	PASS
	2.21	236.25		4.32	PASS
	2.84	245.12		4.16	PASS
0.28	1.26	148.36	1020.2	6.88	PASS
	2.21	216.40		4.71	PASS
	2.84	362.42		2.81	PASS

**Table 13.** Safety factors for mooring line tension in a dual configuration of a narrow FCB (type A).

No.	Description	Wave Period (s)	Max. Tension (N)	MBL (N)	Safety Factor	Status
<b>A. Hs = 0.14 m</b>						
1	S = 0.2 m	1.26	35.95	1020.2	28.38	PASS
		1.89	70.75		14.42	PASS
		2.21	138.82		7.35	PASS
2	S = 0.3 m	1.26	44.33	1020.2	23.01	PASS
		1.89	66.33		15.38	PASS
		2.21	114.94		8.88	PASS
3	S=0,4 m	1.26	40.41	1020.2	25.25	PASS
		1.89	57.64		17.70	PASS
		2.21	111.73		9.13	PASS
<b>B. Hs = 0.16 m</b>						
1	S = 0.2 m	1.26	48.54	1020.2	21.02	PASS
		1.89	123.10		8.29	PASS
		2.21	184.36		5.53	PASS
2	S = 0.3 m	1.26	61.32	1020.2	16.64	PASS
		1.89	85.31		11.96	PASS
		2.21	135.83		7.51	PASS
3	S = 0.4 m	1.26	60.04	1020.2	16.99	PASS
		1.89	81.60		12.50	PASS
		2.21	132.67		7.69	PASS

No.	Description	Wave Period (s)	Max. Tension (N)	MBL (N)	Safety Factor	Status
<b>C. Hs = 0.18 m</b>						
1	S = 0.2 m	1.26	61.27	1020.2	16.65	PASS
		1.89	175.43		5.82	PASS
		2.21	211.93		4.81	PASS
2	S = 0.3 m	1.26	78.08	1020.2	13.07	PASS
		1.89	109.12		9.35	PASS
		2.21	157.98		6.46	PASS
3	S = 0.4 m	1.26	73.68	1020.2	13.85	PASS
		1.89	118.02		8.64	PASS
		2.21	174.86		5.83	PASS

**Table 14.** A mooring line tension safety factor in a dual configuration of a narrow FCB (type B).

No.	Description	Wave Period (s)	Max. Tension (N)	MBL (N)	Safety Factor	Status
<b>A. Hs = 0.2 m</b>						
1	S = 0.5 m	1.26	94.46	1020.2	10.80	PASS
		2.21	85.32		11.96	PASS
		2.84	131.44		7.76	PASS
2	S = 0.75m	1.26	106.51	1020.2	9.58	PASS
		2.21	147.20		6.93	PASS
		2.84	158.00		6.46	PASS
3	S = 1 m	1.26	99.46	1020.2	10.26	PASS
		2.21	72.47		14.08	PASS
		2.84	147.99		6.89	PASS
<b>B. Hs = 0.24 m</b>						
1	S = 0.5 m	1.26	139.56	1020.2	7.31	PASS
		2.21	92.69		11.01	PASS
		2.84	275.01		3.71	PASS
2	S = 0.75 m	1.26	118.99	1020.2	8.57	PASS
		2.21	198.80		5.13	PASS
		2.84	210.08		4.86	PASS
3	S = 1m	1.26	118.75	1020.2	8.59	PASS
		2.21	139.64		7.31	PASS
		2.84	182.70		5.58	PASS
<b>C. Hs = 0.28 m</b>						
1	S = 0.5 m	1.26	112.90	1020.2	9.04	PASS
		2.21	188.90		5.40	PASS
		2.84	323.27		3.16	PASS
2	S = 0.75 m	1.26	101.98	1020.2	10.00	PASS
		2.21	242.12		4.21	PASS
		2.84	315.63		3.23	PASS
3	S = 1 m	1.26	113.24	1020.2	9.01	PASS
		2.21	206.10		4.95	PASS
		2.84	256.24		3.98	PASS

## 4 Conclusion/Summary

Based on the analysis of the effect of distance between Floating Concrete Breakwaters (FCBs) with dual configurations on the tension of the catenary mooring line system, it is evident that the distance between FCB units significantly influences the magnitude of the

mooring line tension. For a narrow FCB (40 cm width), the mooring line tension decreased by 20% when the gap between the FCBs was reduced from 20 cm to 30 cm and increased by 1% when the gap extended from 30 to 40 cm. In contrast, the wide version of the FCB (102.5 cm width) shows an 8% increase in tension at a gap of 50–75 cm, followed by a 16% decrease when the gap was increased from 75 cm to 1 m. The wave height and period also have a notable effect on the mooring line behavior for both FCB configurations, with significant variations observed between the single and dual configurations despite similar overall trends. The maximum tension recorded for the single configuration of the narrow FCB was 185.189 kN at the anchor and 187.54 kN at the fairlead, with a wave height of 0.18 m and a period of 2.21 s. For the wide FCB, the single configuration reached 359.75 kN at the anchor and 362.42 kN at the fairlead at a wave height of 0.28 m and a wave period of 2.84 s. In the dual configuration, the narrow FCB exhibited a maximum tension of 221.93 kN on the L2 mooring line at the fairlead with a gap of 0.2 m, while the wide FCB reached 323.27 kN on mooring lines L0 and L2 with a gap of 0.5 m. The average reduction in the mooring line tension for the dual configurations was 12.06% for the narrow FCB and 21.7% for the wide FCB. Furthermore, the safety factors for all configurations remained above 1.67, indicating that the mooring system and its properties are adequate for operational purposes. These findings highlight the critical role of FCB spacing and environmental conditions in optimizing mooring line performance, suggesting areas for future research to address observed anomalies and enhance the understanding of complex interactions in floating breakwater systems.

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