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1 message

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7 messages

Dr. Andi Trimulyono <anditrimulyono@lecturer.undip.ac.id> Thu, Jan 27, 2022 at 4:52 PM
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To: Andi Trimulyono <anditrimulyono@lecturer.undip.ac.id>

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Terimakasih

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To: Andi Trimulyono <anditrimulyono@lecturer.undip.ac.id>

Terimakasih, segera direvisi.

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[Kapal] [ID-44019] Revised Version Acknowledgement

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Hydrodynamic forces on submerged floating tube: The effect of curvature radius and depth level

Abstract

The discussion of hydrodynamic forces becomes an important issue in determining the dynamic behavior of the Submerged Floating Tunnel Bridge (SFTB) structure. As stated in the Morison Equation, the hydrodynamic forces are affected by the kinematics of water particles, but up to this date, there are only a few discussions for curved tube applications. This paper discusses the effect of curvature radius and depth level on hydrodynamic forces to get the correction factor for a straight tube. Tubes with variations in radius curvature (*R/L*) and diameter (*D*) were installed in a wave pool with a depth level (*z/d*). The hydrodynamic forces were detected by a load cell sensor placed on a pedestal at the end of the specimen. The data from the load cell was processed by the data acquisition system and displayed on the monitor screen. This study shows that the *z/d* ratio and the *R/L* ratio both affect the hydrodynamic forces. A larger z/d ratio (deeper) results in smaller hydrodynamic forces, while a smaller *R/L* ratio (more curved) results in smaller hydrodynamic forces. A correction factor (*C*) has been determined to calculate the hydrodynamic force on a curved tube based on the Morison equation.

Comment [AT1]: it's better to use subject In first sentences, delete this or use present study.

Keywords : SFTB; wave; curvature radius; depth level; hydrodynamic forces

1. Introduction

Tubular structures are commonly used in maritime structures, such as; structural support poles [1], submarine cable lines [2], oil and gas pipelines [3], [4], mooring cables for Tension Leg Platform/TLP [5], and so on. Today, the use of this structure has developed into various fields and requires increasingly complex studies. For example, the use of this structure is being studied for application as a submerged floating tunnel bridge/SFTB [6], [7]. One important issue that needs to be discussed is the hydrodynamic force. This force occurs due to the interaction between the fluid and the tubular structure through the waves. The analysis is developed based on theoretical approaches to defining the various type of waves, including small-amplitude wave theory and finite wave theory [8], [9].

Comment [AT2]: merge

Comment [AT3]: merge

The hydrodynamic forces are affected by the *KC* number and the drag coefficient, C_D [10]. The *KC* number is the ratio of the wave motion to the cylinder diameter, while the C_D value depends on the geometry and Reynolds number. This theory has been proved analytically and numerically [11], [12]. One example of the application of the *KC* number is to calculate the hydrodynamic force on a pipeline on the seabed using the wake II equation. This equation can predict the hydrodynamic force accurately [13].

Comment [AT4]: merge

Comment [AT5]: merge

Comment [AT6]: what is the wake II equatio

The hydrodynamic forces consist of two components; the drag and the inertial force, each of which is affected by the velocity and acceleration of the water particles, as proposed by Morison, well known as Morison Equation [14], [15]. Morison Equation is effectively used to predict the hydrodynamic forces on

Comment [AT7]: each of which is.?

a vertically or horizontally installed tube [16]. The numerical study of the hydrodynamic forces on a floating tube subjected to internal solitary waves also proves the accuracy of this equation [17], [18].

In certain constructions, a curved tubular structure is required for several technical reasons, such as the Submerged Floating Tunnel Bridge/SFTB [19]. One of the reasons for using a curved tubular structure is to gain flexibility during operation, especially anticipating changes in length caused by temperature differences [20]. Flexibility is needed to reduce cyclic loads that can cause fatigue failure in structures [21], [22]. The curved cylindrical construction also improves stability by increasing stiffness to reduce lateral movement. However, there is not much research on hydrodynamic forces on the curved tubular structure yet. For this reason, this article discusses the effect of the degree of curvature on the hydrodynamic forces that occur.

2. Methods

The research was conducted on an experimental pool, which is a modified model from our previous research [23], as shown in Fig. 1. Specimens are made of tubes with varying degrees of curvature, being assembled on a holder frame. At both ends of the specimen, the supports are equipped with load cells to measure the force received by the waves. The signal from the loadcell is read by a set of data acquisition system tools. Fig. 2 shows the design of the specimens with variations in the degree of curvature (*R/L*) and their sizes are shown in Table 1. The specimens are placed with varying degrees of depth (*z/d*).

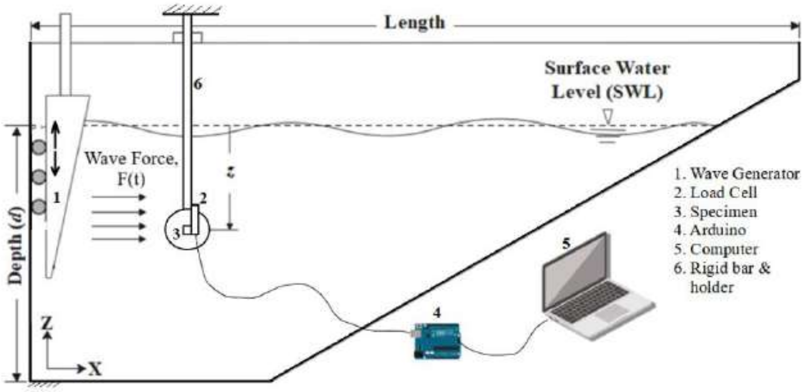


Figure 1. Experimental pool set-up

Comment [AT8]: this figure is the same figur[e] the previous paper, please cited it.

Tabel 1. Specimen specifications

Radius curvature, *R* mm	Tube length, *L* mm	Ratio, *R/L*	Tube Diameter, *D* inch (mm)	Total depth (mm)	Depth level, *z/d*
∞ (straight)		-	1 (25.4)		
400		0.8	1,5 (38.1)		
600		1.2	2 (50.8)		1/6
800	500	1.6	2,5 (63.5)	600	2/6
1000		2	3 (76.2)		3/6
1200		2.4			

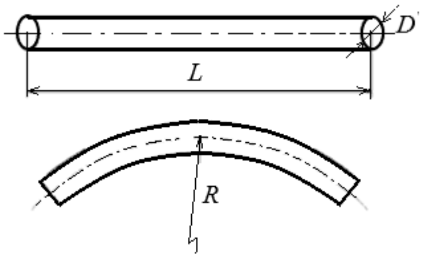


Figure 2. Specimens (tubes) with variations in the degree of curvature (*R/L*)

2.1 Kinematics of Water Particles and Hydrodynamic Forces

In this research, wave characteristics were developed based on Airy's theory. This theory is considered the most relevant because the waves that occur are relatively small and conform with (1), where η_0 is the wave amplitude and H is the total wave height, as shown in Fig. 3. The motion of water particles can be determined from the potential velocity using the Laplace equation, as shown in (2) [24]. Here, the x-axis represents a horizontal direction, while the z-axis represents a vertical direction.

Comment [AT9]: what is (1).?

Comment [AT10]: what is (2).?

$$\frac{\eta_0}{H} \langle 0.5 \qquad (1)$$

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial z^2} = 0 \qquad (2)$$

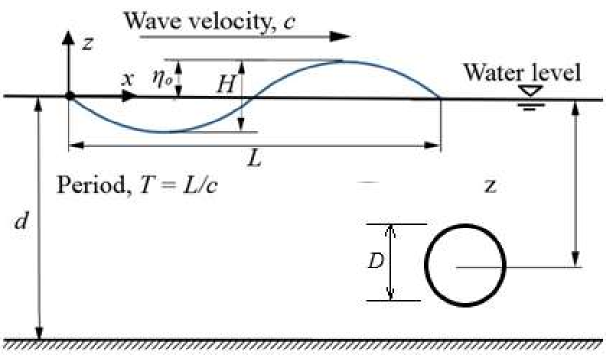


Figure 3. Wave and Specimen Specifications

Setting the boundary conditions on the seabed (at z/d=1), $\partial\phi/\partial z$=0, the solution for potential velocity can be solved by the variable separation method, as shown in (3). Here, k is the wavenumber, as shown in (4).

$$\phi = \frac{\pi H}{kT} \frac{\cosh[k(z+d)]}{\sinh(kd)} \sin(kx - \omega t) \qquad (3)$$

$$k = \frac{2\pi}{L} \qquad (4)$$

The velocity and acceleration of water particles for various depth levels based on Airy's theory can be seen in (5) and (6), respectively [25].

$$u = \frac{\pi H}{T} \frac{\cosh[k(z+d)]}{\sinh(kd)} \sin\theta \quad (5)$$

$$\dot{u} = \frac{-2\pi H}{T^2} \frac{\cosh[k(z+d)]}{\sinh(kd)} \cos\theta \quad (6)$$

The hydrodynamic force is obtained from the Morison Equation, as shown in (7), where *CD* is the coefficient of drag, Cm is the coefficient of inertia, ρ is water density, D is tube diameter, u and $\dot{u}$ is velocity and acceleration, respectively, as shown in (5) and (6).

Comment [AT11]: be consistent for using variable CD or C_d

$$f(t) = \frac{1}{2} C_D \rho u|u| + C_m \frac{\rho \pi D^2}{4} \dot{u} \quad (7)$$

2.2 Numerical Analysis

Comment [AT12]: this section deserves deta information numerical setup for VOF setup/ CFD

The numerical analysis is modeled as Volume of Fluid (VoF)-Open Channel Wave BC. The meshing element size is 30 mm with a Quadrilateral/Hexahedron shape. There are four boundary conditions; Cylinder Wall (Wall), Channel Wall (Wall), Inlet (Velocity Inlet), and Outlet (Pressure Outlet), as shown in Fig. 4.

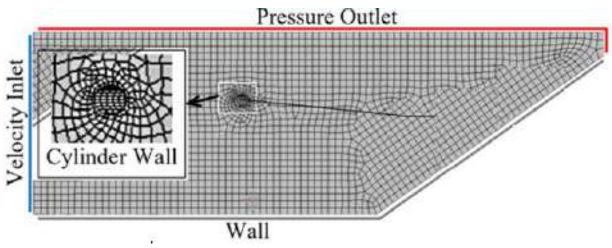


Figure 4. Meshing element and boundary conditions

2.3 Experimental set up

The experiment was carried out in an experimental pool equipped with a set of wave generators, as shown in Fig. 5. The dimensions of the pool and the characteristics of the waves are shown in Table 2.

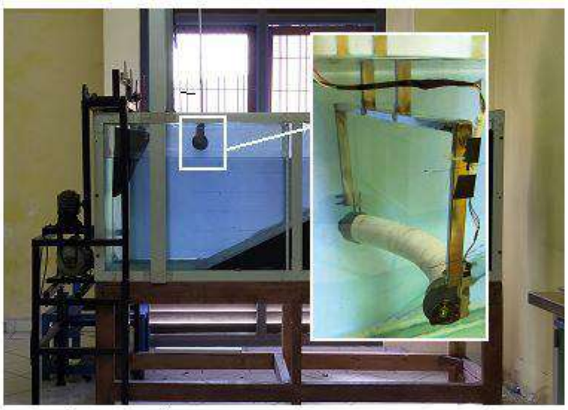


Figure 5. Test equipment settings

Tabel 2. The dimensions of the pool and the characteristics of the waves

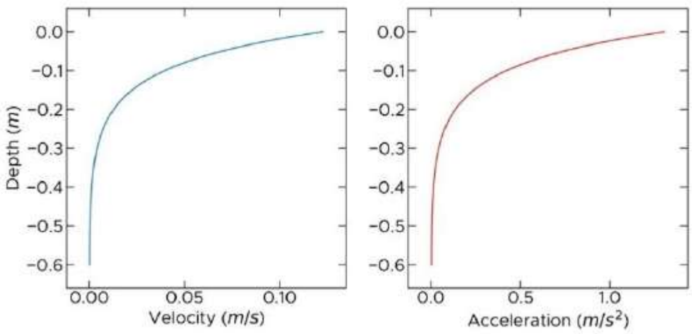
Description	Symbol	unit	Value
Length		mm	2000
Wide		mm	600
Depth	*d*	mm	600
Wave direction	*F(t)*		x-direction
Excitation frequency	ω	Hz (rad/s)	(9,77)
Wave Height	*H*	mm	23
Wavelength	*L*	mm	558

3. Results And Discussion

In this section, research results will be presented and discussed, including; velocity and acceleration of water particles and their effect on hydrodynamic forces. Then discussed the effect of curvature, the effect of depth level and the effect of tube diameter on the hydrodynamic force.

3.1 Profile graph of velocity and acceleration of water particles

At the surface of the water, the velocity and acceleration of the water particles are relatively larger than those in deeper positions. These profiles are obtained from solving equations (2) and (3), respectively. Based on this graph, at depths *z*=-2 to *z*=-6, the rate of reduction of the hydrodynamic force does not change significantly. Thus, it can be recommended that the optimum placement for SFTB is at the level of *z*=-2 (*z/d*=1/3), as shown in Fig. 6(a) and Fig. 6(b).



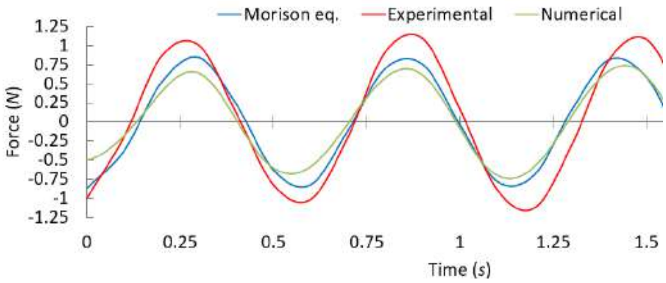
(a) *(b)*

Figure 6. Fluid particle kinematics (a) Velocity and (b) Acceleration

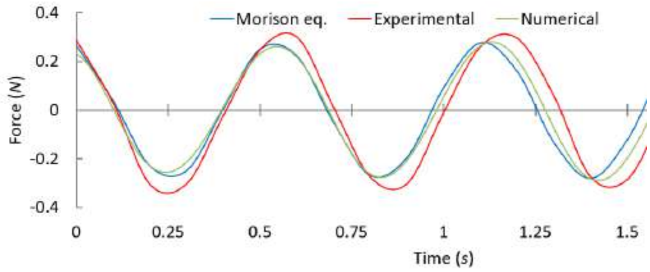
3.2 Verification of hydrodynamic force on straight tube

Fig. 7 shows the hydrodynamic force on a straight tube obtained experimentally and numerically. The analytical solution of the Morison Equation is also shown for comparison. Visually, all the graphs tend to have the same trend, although there are slight inaccuracies. The numerical graph is relatively more precise than the experimental one, compared to Morison's graph. The experimental graph is relatively higher than Morison's graph near the water surface (*z/d*=1/6). Otherwise, it is lower at the deeper position (*z/d*=3/6). It is due to the wave generator's closer placement to the surface and causes it unable to reach the pool's bottom.

Comment [AT13]: the different of the doma between experiment and numerical is missing in section. In the experiment it showed the numeri domain is short, This can be one of the reason w is the accuracy slight decrease. Please add more explanation or discussion in this section.



(a)



(b)

(c)

Figure 7. Hydrodynamic forces: (a) depth level *z/d*=1/6, (b) depth level *z/d*=2/6, and (c) depth level *z/d*=3/6

3.3 Effect of Curvature radius on Hydrodynamic Force

The hydrodynamic forces on the specimen are corrected by the curvature radius *R/L*, where the smaller R/L ratio given will results in the smaller amount of forces received, as shown in Fig. 8. If the Morison Equation applied to a straight tube is considered a reference, multiplying it by the correction factor (*C*) will make it applicable for a curved tube. The correction factor in each variation of curvature radius for the most recommended depth level (*z/d*=1/3) based on Fig. 6 is served in Table 3. This correction factor is calculated numerically, which is considered relatively more accurate. Thus, Equation (7) can be modified to calculate the Morison force on a curved cylinder, as shown in (8).

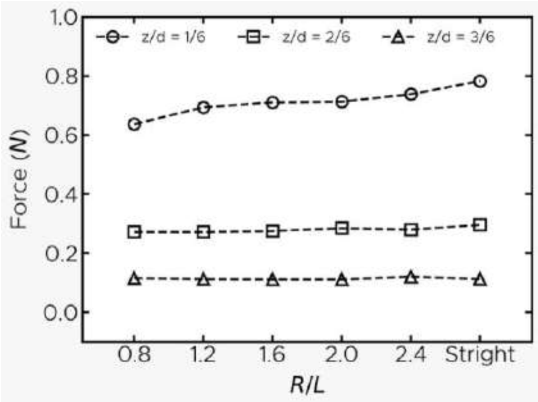


Figure 8. Effect of curvature radius on hydrodynamic force

$$f\left(\frac{R}{L}\right) = C\left(\frac{1}{2}C_D \rho u|u| + C_m \frac{\rho \pi D^2}{4}\dot{u}\right) \quad (8)$$

Tabel 3. The correction factor for variations in the curvature radius at optimal placement (*z/d* = 2/6)

R/L	**Hydrodynamic Force (N)**	**Correction Factor, *C***
∞(Straight)	0.296	1
0.8	0.284	0.96
1.2	0.279	0.94
1.6	0.275	0.92
2	0.272	0.91
2.4	0.272	0.91

3.4 Effect of depth level on hydrodynamic forces

Comment [AT14]: Please added more explanation this section

Fig. 9 shows the depth level's effect on the hydrodynamic force amplitude, both experimentally and numerically. Placing the specimen at a high depth level further reduces the amplitude of the hydrodynamic force. This result is in good agreement with the Morison force equation (Equation (4), where the hydrodynamic forces are directly proportional to the velocity and acceleration of the water particles. In the kinematics equations of water particles, Equation (2) and Equation (3), expressed in the deeper position, the velocity and the acceleration of the water particles get smaller.

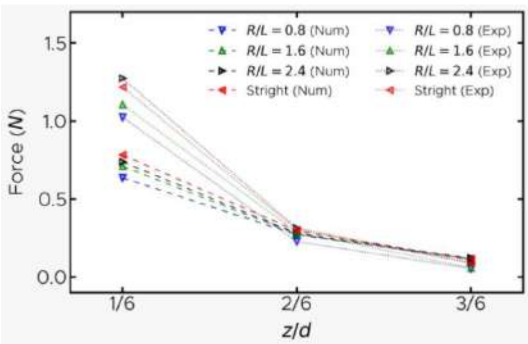


Figure 9. Effect of depth level on hydrodynamic forces

3.5 Effect of tube diameter on hydrodynamic forces

Comment [AT15]: Please add more explanat on this section based different R/L

Fig. 10 shows the tube diameter's effect on the hydrodynamic forces' amplitude, numerically. The diameter of the tube is directly proportional to the hydrodynamic forces it receives. This corresponds with the Morison Force Equation (Equation 7): the larger the diameter, the greater the drag and inertia forces received.

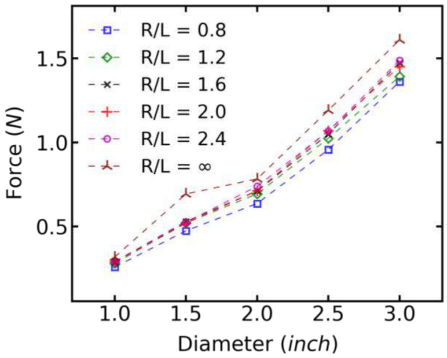


Figure 10. Effect of tube diameter on hydrodynamic forces

4. Conclusion

The hydrodynamic forces are influenced by depth level, curvature radius, and tube diameter. The hydrodynamic forces are the greatest near the water surface (z/d=0) and will gradually decrease at a deeper position until the bottom of the pool (z/d=1). The rate of reduction of the hydrodynamic forces is not linear but satisfies a hyperbolic function. At the depth level z/d≈2/6 to z/d=1, the hydrodynamic forces are not significantly reduced. Thus, we recommend z/d≈2/6 is optimal for SFTB placement. In addition, the smaller the curvature radius (*R/L*), the smaller the hydrodynamic force. A correction factor, *C*, has been determined to calculate the hydrodynamic force on a curved tube based on the Morison equation which applies to a straight tube.

Acknowledgment

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1. Write your comments about "Research Objectives and / or Benefits" *
- The objective and the benefit of this study were not be stated.
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2. Write your comments on "Research Objects and Treatment of Objects". *
- The methodology of the research was not deeply explained.
- Please explain step by step both experimental and numerical methods. What are the conditions and the setup? especially for numerical setup.
- This section is essential as the reader can adopt this method to be used.
- in Table 2. Which unit to be used in frequency, Hz or rad/s ?
3. Write your comments about "Research Results". (e.g. is it in accordance with existing theories, makes sense and so on) *
- - In chapter 3.1, author state depth with Z=-2 and -3. What is the unit? because in the graph the unit in metre, and the values between 0 to -0.6.
- - In Chapter 3.2, authors mention about the placement of wave maker influence the results. We can see it in Fig 7 c. Have you calibrated the experimental results before the test? Because, if

you've known that in this condition (z/d = 3/6) the results will be not accurate, why do you keep this condition on?

- Please give an explanation in this sub-chapter.
- - In Chapter 3.3, could you please explain in more detail how is the correction factor C (Table 3), obtained?
- in Figure 8, how could the force in Y abscissa transform from time dependent into single force? Did you mean the force in Y abscissa is the force amplitude?
- "The correction factor in each variation of curvature radius for the most recommended depth level (z/d=1/3) based on Fig. 6 is served in Table 3" this sentence was not clear and confusing. Because in table 3 the z/d=2/3, but you stated the most recommended z/d was 1/3. Which method in Table 3 did you use? Morison, experimental or numerical?
- - in chapter 3.4, please change this sentence to be more understandable. "In the kinematics equations of water particles, Equation (2) and Equation (3), expressed in the deeper position, the velocity and the acceleration of the water particles get smaller."
- You stated "the force" in the first sentence of this chapter as force amplitude. Could you please change the Y abscissa in Fig 9 from force to force amplitude?
- Please add more deep explanation, such as how many percent the force decreasing relating to the water depth.
- - in Chapter 3.5, Please add more deep explanation.
- Over all, in Chapter 3, the authors need to add more explanation relating the results. You can add the references to support your finding.

4. Write your comments about "Conclusions". *

- This statement: "Thus, we recommend z/d=2/6 is optimal for SFTB placement" should be explained in detail in Chapter 3 why do you determine z/d = 2/6 as the optimal placement?
- Please add the future work in this chapter.

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Revision Form

#Reviewer A

Title	Hydrodynamic forces on submerged floating tube: The effect of curvature radius and depth level
Reviewer	*#A*

Abstract

No	Reviewer comments	Revision
1#A	Comment [AT1]: it's better to use subject In the first sentences, delete this or use present study.	Revised: …,showed that…

1. Introduction

No	Reviewer comments	Revision
	Comment [AT2,3,4 &5]: merge	Done..
	Comment [AT6]: what is the wake II equation?	an explanation sentence has been added
	Comment [AT7]: each of which is.?	Revised

2. Method

No	Reviewer comments	Revision
	Comment [AT8]: this figure is the same figure in the previous paper, please cited it.	Done..
	Comment [AT9]: what is (1).	Revised to eq. (1)
	Comment [AT10]: what is (1).?	Revised to eq. (1)
	Comment [AT11]: be consistent for using variable CD or C_d	*CD*, revised to C_D.
	Comment [AT12]: this section deserves detailed information numerical setup for VOF setup/ CFD	has been added a paragraph of explanatory sentence

3. Results and Discussion

No	Reviewer comments	Revision
	Comment [AT13]: the different of the domain between experiment and	an explanation sentence has been added

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	numerical is missing in this section. In the experiment it showed the numerical domain is short, This can be one of the reason why is the accuracy slight decrease. Please add more explanation or discussion in this section.	
	Comment [AT14]: Please added more explanation this section	an explanation sentence has been added
	Comment [AT15]: Please add more explanation on this section based different R/L	an explanation sentence has been added

4. Conclusion

No	Reviewer comments	Revision

5. Overall Comments

No	Reviewer comments	Revision

Revision Form

Reviewer #B

No	Reviewer comments	Revision
1	1. Write your comments about "Research Objectives and / or Benefits" * • The objective and the benefit of this study were not be stated. • Please describe clearly the aims of this research and explain what do the readers get from this study.	in the last paragraph of chapter 1, added: "The study was conducted to obtain a correction factor *C* to calculate the hydrodynamic force on a curved tube based on the Morison equation."
2.	2. Write your comments on "Research Objects and Treatment of Objects". * • The methodology of the research was not deeply explained. • Please explain step by step both	has been added a paragraph of explanatory sentence: "The parameters used in the numerical analysis are the same as the specifications

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	experimental and numerical methods. What are the conditions and the setup? especially for numerical setup. • This section is essential as the reader can adopt this method to be used.	on the experimental equipment. The analysis stages consist of preprocessing, solution, and postprocessing. In the preprocessing stage, geometry and meshing are made. In the solution stage, boundary conditions and mechanical properties of the material are defined. The results of the analysis are presented in the Postprocessing stage."
	• in Table 2. Which unit to be used in frequency, Hz or rad/s ?	Tabel 2 Revised: ω Hz (rad/s) 1,55 (9,77)
3	3. Write your comments about "Research Results". (e.g. is it in accordance with existing theories, makes sense and so on) * • - In chapter 3.1, author state depth with Z=-2 and -3. What is the unit? because in the graph the unit in metre, and the values between 0 to -0.6.	• Revised to: at depths z=-0.2 to z=-0.6 (z/d=1/3 to z/d=1),
	• - In Chapter 3.2, authors mention about the placement of wave maker influence the results. We can see it in Fig 7 c. Have you calibrated the experimental results before the test? Because, if you've known that in this condition (z/d = 3/6) the results will be not accurate, why do you keep this condition on?	an explanation sentence has been added: In furture research, the difference of the domain between experimental and numerical can be solved by improving the design of the wave generator to get more accurate results.
	• Please give an explanation in this sub-chapter. • - In Chapter 3.3, could you please explain in more detail how is the correction factor C (Table 3), obtained?	an explanation sentence has been added: The value of C is calculated based on the ratio of the hydrodynamic force on the curved tube to the hydrodynamic force of the straight tube
	• in Figure 8, how could the force in Y abscissa transform from time dependent into single force? Did you mean the force in Y abscissa is the	Revised: Force in Y abscissa, revised to Force Amplitude

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	force amplitude?	
	• "The correction factor in each variation of curvature radius for the most recommended depth level (z/d=1/3) based on Fig. 6 is served in Table 3" this sentence was not clear and confusing. Because in table 3 the z/d=2/3, but you stated the most recommended z/d was 1/3. Which method in Table 3 did you use? Morison, experimental or numerical?	Revised to: Tabel 3. The correction factor for variations in the curvature radius at optimal placement (z/d = 1/3)
	• - in chapter 3.4, please change this sentence to be more understandable. "In the kinematics equations of water particles, Equation (2) and Equation (3), expressed in the deeper position, the velocity and the acceleration of the water particles get smaller."	Sentence has revised to: "In the kinematics equation of water particles as stated in Equation (2) and Equation (3), it can be seen that at deeper positions, the velocity and acceleration of water particles become smaller."
	• You stated "the force" in the first sentence of this chapter as force amplitude. Could you please change the Y abscissa in Fig 9 from force to force amplitude?	Revised: Force in Y abscissa, revised to Force Amplitude
	• - in Chapter 3.5, Please add more deep explanation.	an explanation sentence has been added: "In addition, the curvature ratio (R/L) affects the hydrodynamic forces, in agreement with those discussed in section 3.4."
4	• Write your comments about "Conclusions". * • This statement: "Thus, we recommend z/d=2/6 is optimal for SFTB placement" should be explained in detail in Chapter 3 why do you determine z/d = 2/6 as the optimal placement? • Please add the future work in this chapter.	explained in the following sentence: "At the depth level z/d≈1/3 to z/d=1, the hydrodynamic forces are not significantly reduced/"