Structural Analysis of Floating Net Cage Bracket in Current and Wave

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Abstract. Aquaculture becomes an important industry and associates with many targets of sustainable development goals. As the aquaculture industries go forward offshore, the design of the floating net cage must be able to withstand extreme sea conditions. One of the vulnerable parts of floating net cage is the floater, especially at the bracket. There is load transfer in the bracket from net drag force, mooring tension, and horizontal force of the wave. Thus, this study aims to analyze the bracket under current and wave using the finite element method. Hydrodynamic force is based on the Morison formula. The numerical model was validated with the data obtained from corresponding experimental and numerical tests. On the basis, using the environmental condition in Pangandaran, Indonesia, the structure is simulated globally to obtain the deformation and tension. The simulations of the fish cage consist of single and double pipes. Then, the bracket at the floater will be analyzed locally to get the deformation and stress distribution. The maximum stress occurs at the connection between the horizontal and outer pipe of the bracket.

1. Introduction
Aquaculture is one of the important sectors that emerged as the main driver to blue growth and directly relates to a few targets of sustainable development goals 2030. This industry is expanding to offshore. The trend of offshore aquaculture is caused by the availability of space and natural environmental conditions such as water flow, temperature, and light intensity, thereby increasing the quality of the fish that are cultured. Moreover, the pollution of the marine environment at the coast also suppresses the development of offshore aquaculture.

The system to maintain offshore aquaculture is the floating net cage. Extreme marine environmental conditions threaten the floating net cage structure mainly due to currents and waves which can change shape due to deflection and deformation. The most important components of the floating net cages are mooring systems, floating collar, and nets. The floating collar is directly exposed to wave force and can be deformed in high sea conditions, so it is necessary to consider the maximum stress that occurs [1]. To maintain the shape of floating collar, there is component called bracket. In this area, load transfer occurs from the net components, mooring moorings, and horizontal wave loads.

Considering the huge environmental and economic risks, it is necessary to carry out an analysis to ensure that the floating net cage structure can survive on the high seas. This can be accomplished by numerically analyzing the structure to calculate its strength. The challenge in analyzing floating net cages lies in the hydroelectricity of the flexible structure. Several studies experimentally, numerically, or both have been developed since 1990 [2]. Numerical modelling for floating net cages was carried out in various software, such as ANSYS [3], Orcaflex [4], ABAQUS [5], Code-aster [6].
Net as an important component in floating net cages began to be analyzed to find out more about the hydrodynamic behaviour and its influence on the global structure. Research on the structure of the net in floating collar cages due to current loads have been carried out [7] and then numerically modelled for industrial scale [5]. Both investigations concentrated on the net’s structure as a result of current loading.

Experimental and numerical research that focuses on floating collars due to wave loading was carried out [8] and due to current loads only [9]. Then the results of the validated numerical modelling are compared with the model added by the net. The research was carried out experimentally and numerically on floating net cages due to current and regular wave loads [10]. Numerical hydrodynamic modelling was carried out using the panel method. This research was then analyzed again numerically using the Morison hydrodynamic model and analyzed the model in current and irregular waves [4]. However, the study mentioned only modelled a buoyancy system consisting of a single floating cylinder. Numerical analysis for cages with two pipes in full scale has also been studied, but the focus is on the mooring system [1]. Most studies only consider floating truss pipes as rigid structures. This does not match the flexible characteristics of HDPE. Therefore, it is important to determine the right numerical model because the floating truss greatly affects the global force and motion of the cage when exposed to waves [10].

Therefore, this study aims to analyze the deformation and stress distribution of floating collar specifically at brackets in currents and waves using the finite element method based software. The model considers the net modelling and the environmental condition in Pangandaran bay. The numerical analysis results will be compared to the physical experiment and numerical model results from the prior study.

2. Theory and Numerical Model

2.1. Hydrodynamic load

The response of floating net cage in current only, regular, and irregular waves are to be investigated. The current profile used in this study is the shear profile, which described that the current velocity will gradually increase from the seabed to the mean sea level. Airy wave theory is adapted to describe regular waves. Airy wave theory explains that the assumption of wave height is very small when compared to wavelength or ocean depth. The wave period is considered to be a constant number that does not fluctuate over time. Then Stokes developed a second-order theory for waves that have small but finite wave heights. Some of these wave theories are then used to calculate wave loads.

For irregular waves, JONSWAP spectrum was used. The formulation is presented as

\[ S_\zeta(\omega) = \alpha g^2 \omega^{-5} \exp\left(-1.25(\omega/\omega_0)^{-4}\right) \exp\left(\frac{(\omega-\omega_0)^2}{2\sigma_0^2}\right) \]

where \( \alpha = 0.076(X_0)^{-0.22} \) or 0.0081 if the length of fetch is unknown, \( X_0 = gX/U_w^2 \), \( X = \) length of fetch, \( U_w = \) wind velocity, \( \gamma = \) peakedness parameter, \( \tau = \) shape parameter which 0.07 if \( \omega \leq \omega_0 \) and 0.09 if \( \omega > \omega_0 \), while \( \omega_0 = 2\pi(g/U_w)(X_0)^{-0.33} \).

Hydrodynamic forces over the floating net cage are calculated based on Morison equation. In fluid dynamics, Morison’s equation is used to calculate the hydrodynamic force that occurs in the direction of the incoming fluid flow about the structure in the oscillating flow with the condition that \( D/\lambda < 0.2 \), \( D \) is the diameter of the cylinder and \( \lambda \) is the wavelength. In general, the hydrodynamic force consists of three components, namely the Froude-Krylov force (dynamic pressure), the acceleration force, and the drag force. The inertial force is generated when the dynamic pressure force and the acceleration force are added together. The hydrodynamic force, according to the Morison equation, is made up of inertial and drag forces that are summed linearly. So, the force acting at the floating net cage is based on eq 2 and 3.

\[ F = \rho V \ddot{u} + \rho C_A V \ddot{u} + \frac{1}{2} \rho C_D A u |u| \]

(2)
\[ F = C_M \rho V \dot{u} + \frac{1}{2} \rho C_D A u |u| \]  

(3)

In Eq 2 and 3, \( \rho \) is the water density, \( V \) is the volume of the submerged body, \( A \) is the cross-sectional area. The particle accelerations and velocities are represented by \( \dot{u} \) and \( u \). In this formula, \( u \) considers the superposition of current and wave orbital velocities. While for the current contribution to fluid acceleration is defined as zero as the assumption for the current flow is steady. For the coefficient, there are added mass coefficient \( (C_A) \), inertia coefficient \( (C_M) \) defined as \( 1 + C_A \), and drag coefficient \( (C_D) \). The determination of these coefficients is described below in each floating net cage component.

2.1.1. Floating collar
The floating collar has a cylindrical shape and is generally considered to be half submerged under still water conditions. Wave load is the most dominant load on the floating collar. However, to get realistic conditions, the interaction forces of currents and waves were used in the analysis. Morison’s approach to calculating hydrodynamic forces on floating collar is quite general and will be used in this study.

Inertia coefficient for floating collar in each wave conditions is obtained by Keulegan-Carpenter Number (KC) and Reynolds Number (Re) as shown in Eq 4 and 5. \( U_c \) and \( U_m \) are current and maximum wave orbital velocities, \( OD \) is the pipe diameter, \( v \) is seawater kinematic viscosity, and \( T \) is wave period.

\[ Re = \frac{(U_c+U_m)OD}{v} \]  

(4)

\[ KC = \frac{(U_c+U_m)T}{OD} \]  

(5)

\( C_M \) ideally is defined by interpolating experiment data. Considering the Re ranges between \( 10^4 \) to \( 10^5 \), \( C_M \) is equal to 1.2 for fully immersed cylinder. For a floating cylinder in oscillatory flow, \( C_M \) has a similar trend with fully immersed cylinder, while \( C_D \) is equal to half of a fully submerged cylinder [11]. So, the drag coefficient for the floater is selected as 0.6 for all conditions.

2.1.2. The net cage
The hydrodynamic approach for the net cage can use the Morison model or the panel model. The Morison model calculates the net as several cylinder elements. While for the screen model, the net will be divided into several panels. These two methods will calculate the drag and lift forces of each element. The wake effect will be included in this analysis.

The hydrodynamic load of the net follows the hydrodynamic model of the floating collar. The hydrodynamic coefficients, on the other hand, differ. The net hydrodynamic coefficient is determined from experimental data and depends on Keulegan-Carpenter Number (KC), Reynolds Number (Re), the roughness of twine surface and net solidity ratio \( (Sn) \) [12]. The solidity ratio of the net cage for the square knotless net is defined as

\[ Sn = 2 \cdot \frac{d_w}{l_w} - \left( \frac{d_w}{l_w} \right)^2 \]  

(6)

where \( d_w \) is twine diameter dan \( l_w \) is twine length. Re formula is similar to the floating collar, except the diameter pipe is replaced by a twine diameter.

Considering the twine diameter is much smaller than the wave height, the inertia force can be neglected [13].\( C_D \) is defined based on Re number and solidity ratio as shown in Eq 7. This formulation is modified based on least squares fit of numerical and experimental results [2].

\[ C_D = -3.2892 \cdot 10^{-5} (Re \cdot Sn^2)^2 + 0.00068 (Re \cdot Sn^2) + 1.4253 \]  

(7)

The downstream part of the net has a lower flow velocity, which must be taken into account. So, the Blevins wake effect is taken to account as it gives a good result to model this effect in the net cage [2].
2.1.3. The mooring system

The hydrodynamic forces on the mooring lines are estimated by Morison’s equation. The mooring system is a combination of mooring line and buoys. The buoys are floating circular cylinders, and the motions are solved in an inertial coordinate system. There are assumed no coupling terms between the translational and rotational motions as pressure loads are dominant. The drag coefficient is assumed to be constant for simplicity with $C_D = 1.2$ [10].

2.2. Structural Model

2.2.1. Line Theory

Elements of lines are linear flexible used to create a model of the cable, hoses, chains, or other similar items. Lines are represented using lumped mass in the software OrcaFlex. The line is modelled as a series of mass points held together by a spring massless. The point of mass being modelled is called a node while the spring connecting the nodes is called a segment. A segment only models the axial and torsional properties of the line while other properties such as mass, buoyancy, and hydrodynamic forces can be represented by nodes at the ends.

Each node represents half of the two segments which are short straight bars on either side of the node. The final node has only half of a segment on one side. Each line segment is divided into two parts and the properties (mass, weight, buoyancy, drag, etc.)

A segment has axial stiffness and torsional stiffness represented by the combination of a massless linear damper and a torsional spring damper at the centre of each line segment that applies equal and opposite effective tensions to the vertices at each end of the segment. When bending stiffness is inputted into the model, rotational springs and dampers at the vertices are included in the model. Torsional stiffness and bending stiffness are included optionally to model highly flexible components.

2.2.2. Buoy

OrcaFlex has two types of buoys, namely 3D buoys and 6D buoys. The translational motion of the 3D buoy provides three degrees of freedom. The 6D buoy, on the other hand, has six degrees of freedom in terms of translational and rotational motion. With particular axial stiffness and bending stiffness, the 6D buoy is employed to convey the translational and rotational motion of the floating collar characteristics. On the buoy, the drag and lift forces are ignored. As a result, the buoy's mass, volume, CD, and CM are all zero. Line elements joined by 3D buoys are used to simulate the net cage and mooring system. The 3D buoy only transfers linear motion, so the bending stiffness is not modelled. The bending stiffness neglected assumption applies to highly flexible materials such as polyamide and polyester.

2.2.3. Net Equivalent

The net parameters are modelled with the equivalent model so that it has characteristics that resemble the physical model of the net. The net is not modelled the same as the physical model because of the large number of elements that require longer computational time and the capabilities of the devices used. The equivalent net model still consists of a line and a buoy with three degrees of freedom. One node represents several groups of nodes in the physical net as shown in Figure 1.

![Figure 1. Illustration to equivalent net](image_url)

It's important to note that, according to the Morison method, the weight of the comparable net must be equal to the weight of the original net. This can be achieved by adjusting the numerical model's
Young's modulus and mass. Thus, the equivalence net must satisfy the equation between the model and the physical in wet weight and density ratio.

2.3. Von Mises Stress

The value of the effective stress is the structural parameter obtained by the FEM approach in this research. This stress or called von Mises stress at each node of the object being analyzed by simply defining the boundary conditions. If a material reaches a critical value or encounters a small amount of plastic deformation, it generates Von Mises stress. This stress also has a combination effect formulation of hoop, axial, and radial stresses. If $\sigma_e$ is the equivalent stress, while $\sigma_1$ is the maximum stress, $\sigma_2$ is the mean stress, and $\sigma_3$ is the minimum stress. Given that, the effective stress formulation is stated as follows:

$$\sigma_e = \left(\frac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]\right)^{1/2}$$

(8)

3. Methodology

3.1. Data collection

3.1.1. Experimental data

The data used for model validation in this study are experimental and numerical data from research [10], [14]. The experiment was conducted at the Marine Cybernetics Laboratory at NTNU. The experimental model consisted of one net attached to the floating frame, a bottomless net, 16 sinkers, and four mooring lines. Table 1 presents the dimensions data for the floating net cage. Table 2 shows the load data provided to the experimental model. Table 3 lists the irregular wave parameters for validation.

| Description                        | Parameter | Model scale | Full scale |
|------------------------------------|-----------|-------------|------------|
| Floating net cage diameter         | D = 2R    | 1.5 m       | 37.5 m     |
| Floating net cage draft            | L         | 1.3 m       | 32.5 m     |
| Floater cross sectional diameter   | 2c        | 30 mm       | 0.75 m     |
| Floater mass per length            | m_f       | 0.127 kg/m  | 79.4 kg/m  |
| Floater bending stiffness          | EI        | 0.136 Nm²   | 1.33 × 10⁶ Nm² |
| Net solidity ratio                 | Sn        | 0.26 & 0.32 | 0.26 & 0.32 |
| Twine diameter                     | d_w       | ≈0.6-0.8 mm | -          |
| Twine length                       | l_w       | 6 mm        | -          |
| Mass of the sinker                 | m_bw      | 16 × 75 kg  | 16 × 1,172 kg |
| Spring stiffness                   | k_s       | 44 N/m      | 27.5 kN/m  |
| Mass of the net cage               | m_net     | 357 g       | 5,578 kg   |

Table 2. Regular wave load condition

| Solidity ratio, Sn | Current velocity, Uc (m/s) | Wave steepness (H/λ = 1/15) |
|--------------------|----------------------------|-----------------------------|
| 0.26               | 0.0                        | 0.6 – 1.6 s                 |
| 0.1                | 0.6 – 1.6 s                |
| 0.2                | 0.6 – 1.6 s                |

Table 3. Irregular wave load condition

| Current velocity, Uc (m/s) | H_{1/3} (m) | Tp (s) | γ  |
|---------------------------|-------------|--------|----|
| 0.0                       | 0.12        | 1.8    | 3.3|
| 0.1                       |             |        |    |
| 0.2                       |             |        |    |
3.1.2. Environmental data
This study investigated the floating net cage when subjected to environmental load in the Pangandaran bay, Indonesia. The exact location is at 7°45’8.90"S, 108°37’37.00"E with a water depth of 45 meters. Figure 2 depicts the location. The current condition is steady, and its profile is assumed shear. It is taken into account how current and irregular waves interact. The basis data of currents and waves in the Pangandaran bay are shown in Table 4.

![Figure 2 Location point of Pangandaran bay](image)

| Description                              | Unit     | 10 years | 100 years |
|------------------------------------------|----------|----------|-----------|
| Current velocity at mean sea level       | m/s      | 1.03     | 1.60      |
| Current velocity at seabed               | m/s      | -        | 0.41      |
| Maximum wave height (Hmax)               | m        | 6.50     | 13.40     |
| Significant wave height (Hs)             | m        | 3.50     | 7.20      |
| Maximum wave period (Tp)                 | s        | 10.00    | 13.00     |
| Mean wave period (Tm)                    | s        | 5.38     | 6.99      |

3.2. Validation
The numerical model of this study is first validated with a scaled experimental model in current only and current-regular waves interaction. Figure 3 shows the model illustration. Validation is carried out based on the deformation of the net, the drag force, and the mean tension of the fore and aft mooring lines. The validation of the deformation of the net is done qualitatively by comparing the visualization of the simulation with the experiment result. The deformation is only in 0.1 m/s current only condition. The drag force is obtained from the simulation results of a model scale numerical model with a current load variation of 0.1 – 0.3 m/s. The average tension of the fore and aft mooring lines was obtained from the simulation results of a numerical model with a current load (V = 0.1 m/s) and regular waves (H = 0.104; T = 1 s). The validation parameter employs the mean absolute percentage error (MAPE) parameter, which has the following formula:

\[
MAPE = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{A_i - F_i}{A_i} \right| \times 100
\]  

(9)
where $A_t$ is the experimental result at time $t$, $F_t$ is the result of modelling at time $t$, and $n$ is number of data. MAPE score must be less than 5%. If it does not meet these criteria, it is necessary to re-examine the numerical model based on the existing data.

The numerical model of the validated model scale will be subjected to the irregular wave load based on previous research. This is done to figure out how the numerical model's motion responds to the actual water conditions. The JONSWAP spectrum was chosen because it corresponds to the wave characteristics of closed waters or islands such as in Pangandaran bay. The results of the simulation in this step are the mean tension of fore and aft mooring lines.

The numerical model will then be enlarged to a Froude scale ($\lambda$) 25 after being validated at the previous step. This process is carried out on the dimensions and material characteristics of each component following the provisions of the Froude scale.

3.3. Global simulation
To meet field conditions, several changes to the configuration of the full-scale numerical model mooring system are required. This is due to the fact that the numerical model produced is based on a physical experimental model in which the mooring line is linked to a spring to give pretension. Of course, this type of setup cannot be immediately applied to real-life situations. The numerical model's mooring system will be modified to catenary mooring with a rectangular array configuration type and a 30° scattering angle. In this step, the developed floating net cage numerical model is simulated according to the characteristics of currents and waves in Pangandaran bay.

Figure 3 Floating net cage model for validation

Figure 4 Element numbering of floating net cage model with double collar
The numerical model is conducted employing the cut off method to reduce computation time by considering the wave preview in the OrcaFlex program. Simulations were run under extreme conditions (100-year return period) for 0° and 15° loading directions. The deadload is the weight and buoyancy of the three primary structures, namely floating frames, nets, and mooring system. Additional components such as brackets and handrails are not modelled globally and are compensated for in the global analysis by the additional weight of the connectors. Because the study is being conducted under extreme conditions, it is assumed that all operations are shut down and that no activities are occurring on the platform. Essentially, the structure under investigation is an unmanned offshore structure with no superstructure. The stress distribution of the floating collar, the tension of the net element, and the bridle line force are the simulation results in this process. The simulation includes a floating net cage with a floating collar made of an additional pipe. Figure 4 depicts the numbering of the element model.

3.4. Local simulation
Extrapolated data from the catalogue is used to configure a local model. This is done since the physical experimental model's full size is not based on market size. Extrapolation was carried out on several data, such as the distance between the outer and inner pipes, bracket diameter, handrail height, bracket width, and horizontal pipe. Estimation was carried out using Excel software by searching for linear equations and ensuring the size met the data by analysing regression R2 close to 1. The bracket adopted and the model for local analysis are in Figure 5.

The area studied locally considers the maximum stresses that occur in the floating collar in step previously. It is necessary to apply the right boundary conditions to resemble the actual conditions. The local model bracket is cut at the end points of the left and right brackets. This is based on the requirements for pipe analysis, which must have a minimum length of four times [15] or six times the outer diameter of the pipe [16]. This determination is necessary to ensure that the local analytical model is not too rigid and remains subject to adequate deformation.

![Bracket model for local analysis](image)

4. Results and Discussion

4.1. Validation
The floating net cage structure model was validated under current load conditions only, regular currents and waves, irregular currents and waves, and comparison from model scale to full scale. At current loads only, the drag force that occurs in the net due to constant current loads is seen through the tension in the front mooring line. This is because the tension in the front mooring line represents the global force of the structure [1]. Deformation validation is done qualitatively. Under current conditions and regular, irregular waves, and a comparison from the model scale to the full scale, the tension in the fore and aft mooring lines will be seen.
Table 5 shows how the comparison of experimental results by with numerical simulations. The numerical simulation results are not much different at the current velocity of 0.10-0.25 m/s. While, at the current speed of 0.1 and 0.3 m/s, the simulation overpredict the tension results more than 5%. However, the simulation results are still good and acceptable by the mean error. There needs to be further improvements in hydrodynamic modelling, especially the drag coefficient equation for the case with higher currents.

Considering the flexibility of the net, it is necessary to look at the deformation that occurs to ensure that the floating net cage model meets the requirements. In Figure 6, the left shows the results of the physical experiment [10] while the right figure shows the simulation maximum deformation results. Validation was carried out qualitatively by comparing the two visual results. The shape generated by numerical simulation already has a shape that resembles the results of physical experiments. The largest deformation of the net reaches 0.5 meters at the front of the floating net cage model.

![Figure 6 Deformation of the floating net cage in experiment (left) [10] and simulation (right)](image)

Table 5 Validation of drag force in current only condition

| Current Speed (m/s) | Drag Force (N) | Error (%) |
|--------------------|---------------|-----------|
|                    | Experiment [10] | Simulation |       |
| 0.10               | 5.775         | 6.149     | 6.47   |
| 0.15               | 10.274        | 10.560    | 2.79   |
| 0.20               | 13.982        | 13.996    | 0.10   |
| 0.25               | 16.717        | 17.099    | 2.28   |
| 0.30               | 18.803        | 20.278    | 7.85   |

Mean error 3.90

Table 6 Validation result for current and regular waves

| Mooring Line          | Mean Tension | Error (%) |
|-----------------------|--------------|-----------|
|                       | Experiment [10] | Simulation |       |
| Fore (Mooring line 3) | 3.95          | 4.13      | 4.655  |
| After (Mooring line 1)| -3.95         | -4.13     | 4.658  |

Mean error 4.657

The results for simulations with current and regular wave loads, in terms of the average mooring tension on the front and rear of the floating net cage model. The duration taken is the last 10 seconds by considering the stable simulation conditions. The obtained error is 4.657 percent, indicating that the model is acceptable. Table 6 shows a comparison between simulation and experimental data.

The simulation results are validated by numerical results [8] which also use the same model and environmental parameters. Obtained for the condition of current and irregular waves load, the model can be trusted with the error shown in Table 7. The tension result in the front and back is not equal to zero for zero current. This is because of the force drift produced by the waves on the cage.
Table 7 Validation result for current and irregular waves

| Current speed (m/s) | Previous numerical simulation [4] | Simulation | Error (%) |
|--------------------|-----------------------------------|------------|-----------|
| 0.0                | 0.3720                            | 0.3577     | 3.85      |
| 0.1                | 3.6702                            | 3.7630     | 2.53      |
| 0.2                | 7.9136                            | 7.8278     | 1.08      |
| Mean error         |                                   |            | 2.49      |

| Current speed (m/s) | Previous numerical simulation [4] | Simulation | Error (%) |
|--------------------|-----------------------------------|------------|-----------|
| 0.0                | 0.3726                            | 0.3759     | 0.89      |
| 0.1                | 3.5406                            | 3.7629     | 6.28      |
| 0.2                | 7.4366                            | 7.8264     | 5.24      |
| Mean error         |                                   |            | 4.14      |

Table 8 Validation result between model and full scale

| Current speed (m/s) | Previous numerical study [4] | Simulation | Error (%) |
|--------------------|-----------------------------|------------|-----------|
| 0.0                | 0.3577                      | 0.3529     | 1.35      |
| 0.1                | 3.7630                      | 3.6536     | 2.91      |
| 0.2                | 7.8278                      | 7.6262     | 2.57      |
| Mean error         |                             |            | 2.28      |

| Current speed (m/s) | Previous numerical study [4] | Simulation | Error (%) |
|--------------------|-----------------------------|------------|-----------|
| 0.0                | 0.3759                      | 0.3763     | 0.10      |
| 0.1                | 3.7629                      | 3.6556     | 2.85      |
| 0.2                | 7.8264                      | 7.6258     | 2.56      |
| Mean error         |                             |            | 1.84      |

Once the model scale has been validated, it is necessary to convert the model to a full scale that approximates the size of the general cage in open waters. The geometry is enlarged to a scale of 25 times and other parameters follow the provisions of the Froude scale. As indicated in Table 8, the tension results of the full-size mooring line are scaled down and compared to the tension of the model sizes.

4.2. Global Analysis

The focus of the analysis in this study is related to the distribution of the floating collar and the components that are directly related to the floating collar, namely the mooring bridle line and the vertical net A. The tension of two components is extracted then become the load that will be given to the local analysis bracket. Numbering related bridle and nets can be seen in Figure 4.

Simulation is carried out with 0° loading direction in extreme conditions (100-year return period) for 10,800 seconds to see the trend of the hydrodynamic model that occurs. The recommended duration of dynamic analysis in the form of time-domain is 3 hours [17]. The global simulation results show that during the time of 2200 to 4000 seconds, repeating patterns are obtained which indicates a repetition of the wave pattern. Considering the API recommendations, the simulation duration used to determine the load on the mooring system is at least 15 minutes [18]. So, for further analysis, a simulation cut-off was performed for 900 seconds.

4.2.1. Stress distribution of floating collar

The largest maximum stress occurred at the floating collar element number 17 reaching 14.63 MPa occurred when objected to the 0° load direction. This point is directly exposed to environmental loads
in the same direction. It is also connected with the bridle line that holds the cage position. Globally, the stress that occurs in the floating collar does not exceed the stress yield of the commonly used HDPE characteristic, which is 26 MPa. The stress distribution that occurs is shown in Figure 7. For the 15° load direction, the floating net cage maximum stress also occurs in the same place and the distribution trend is not much different. The maximum stress of the two-pipe model with 0° and 15° loading directions are 13.86 MPa and 13.42 MPa, respectively. The floating net cage with a two-pipe floating collar has lower stress than one-pipe model.

![Figure 7. Maximum von Mises stress distribution of floating collar with single pipe (left) and double pipe (right)](image)

4.2.2. Tension of net
The maximum net tension for one pipe that occurs in net element number 27 is 116.01 kN for 0° load direction and 90.68 for 15° load direction on net 9. The maximum tension occurs in net 27 and 9 because there are meeting points between the floating collar and the bridle line. So that there is a higher tension than other points. The distribution of the tension of the net in the 0° load direction in the first and fourth quadrants are higher than that in the second and third quadrants. While in the direction of the 15° load direction, the high tension occurs inclined to quadrants three and four.

The maximum net tension occurs in net 7 which is 113.93 kN for the 0° load direction and in the 11 net, it is 128.51 kN for the 15° load direction. The maximum tension occurs in nets 7 and 11 because these locations are the meeting point between the loads transferred through the bridle line. In direction 15 there is a greater tension due to the cross-sectional area of the nets exposed to greater environmental loads. The distribution of the tension of the net for the floating net cage with two pipes has the same pattern as the floating net cage for one pipe as shown in Figure 8. However, the maximum tensile strength of the net for the two pipes has increased by 10%.

4.2.3. The tension of the bridle line
The maximum tension of the bridle line occurs in moorings 5, 5.5, and 6 for the direction of the load of 00° and 15° which is connected to the anchor line 3. These points are also directly exposed to the given environmental load. The tension of the bridle line maximum reaches 228.71 kN. Meanwhile, for the mooring tension bridle smallest of less than 2 kN, it is located on the back of the cage, and it can be seen from the simulation results that the mooring is slack. There is a difference in the pattern of stress distribution between the directions of 00° and 15° which can be seen in Figure 9. While in the two-pipe model, the maximum tension of the bridle line occurs in moorings 3, 5 and 4 which are connected to mooring anchor 2. occurred in the 0° direction reached 155.58 kN and 156.29 kN for 3 and 4 moorings respectively. While in the 15° direction the maximum tensile strength was 167.67 kN and 165.26 kN for each mooring, 3.5 and 4.
4.3. Local Analysis

4.3.1. Boundary condition

The support used is a pin at the left end and a roll at the right end of the pipe thickness. In ANSYS Mechanical, pinned support is defined as a translational limitation of movement in the x, y, and z directions by setting a magnitude of 0 in the menu displacement. While the roll support resists translational motion in the z-axis direction. The contact behaviour between the inner pipe and the bracket is bonded or fused because, in the production process, welding is carried out in that area. While the outer pipe to the bracket is allowed to move freely without friction (frictionless).

The load applied to the model is the tension of the net and the bridle line. If considering the maximum load in the structural response analysis due to the tension of the net and the bridle line, it is necessary to consider giving a load in the form of point force to represent the local stresses that occur between the connected parts [19]. So, for the loading on the numerical model, the load point the intended is inputted as a remote force with the load point at the outer end of the bracket for the tension of the bridle line and the bracket inner for the tension of the net. It should be noted that for a local analysis like...
this, it is not necessary to enter the weight of each component again because it is already represented by the force on the element taken from the global analysis [20].

Load conditions (LC) were analyzed as much as 6 for each direction of environmental load with considering the maximum yield of stress distribution, the maximum tension of the bridle line and the net from the global simulation. LCs one, two, and three consider the maximum net tension while LCs four, five, and six consider the maximum bridle line tension. The results of global analysis on OrcaFlex give results in the form of large tensions without details of direction. Therefore, it is necessary to calculate the component of the tension of the net bridle on the X, Y, and Z axes using the vector equation of the position of the end of the line net and the bridle line and the resultant tension. So that the calculation results for the tension components are obtained in Table 9.

| 00° Load direction | 1   | 2   | 3   | 4   | 5   | 6   |
|--------------------|-----|-----|-----|-----|-----|-----|
| Net tension (kN)   |     |     |     |     |     |     |
| X                  | 85.8| 69.0| 88.7| 82.0| 78.7| 68.2|
| Y                  | 59.1| 15.1| 1.2 | 7.2 | 0.8 | 3.1 |
| Z                  | -46.2| -58.1| -42.6| -50.4| -31.6| -37.6|

| Bridle line tension (kN) |     |     |     |     |     |     |
|--------------------------|-----|-----|-----|-----|-----|-----|
| X                        | -67.7| -23.7| -3.0| -202.1| -154.9| -200.4|
| Y                        | -75.7| -51.3| -35.8| -50.4| 0.5| 49.3|
| Z                        | -19.4| -11.9| -9.2| -30.8| -26.9| -30.2|

| 15° Load direction | 1   | 2   | 3   | 4   | 5   | 6   |
|--------------------|-----|-----|-----|-----|-----|-----|
| Net tension (kN)   |     |     |     |     |     |     |
| X                  | 81.0| 101.2| 125.5| 115.8| 24.9| 65.6|
| Y                  | 4.8 | 12.3| 24.4| 2.8 | 7.6 | 8.0 |
| Z                  | -83.7| -61.7| -13.3| -25.4| -87.9| -36.2|

| Bridle line tension (kN) |     |     |     |     |     |     |
|--------------------------|-----|-----|-----|-----|-----|-----|
| X                        | -58.9| -18.8| -1.1| 219.8| -161.9| -211.6|
| Y                        | -19.1| -11.1| -11.6| 54.7| 1.0| 52.9|
| Z                        | -31.5| -11.3| -2.7| 31.6| -23.6| -38.5|

The local analysis in this research is a static structural analysis. The behaviour of the structure is considered flexible by considering the non-linear effect of the HDPE material. The elasticity of the material is considered isotropic and characteristics if the element is constant along with the element. In this analysis, conditions are selected where the structure can accommodate significant deformation.

4.3.2. Meshing sensitivity analysis
Before analyzing the local model, it is necessary to analyze the sensitivity of the meshing. This is done to ensure that the numerical calculations are stable. To shorten the computation time without reducing the accuracy of the results at the connection points, the meshing is reduced around the joint while the area far from the connection is enlarged [21]. For the outer and inner pipe, the meshing shape used is hexahedral, while in brackets, a tetrahedron is used. The varied variable is the number of meshing which is increased slowly until stable maximum stress is obtained. The meshing configuration used has 165607 elements. Details of the meshing image are shown in Figure 10.

Figure 10. Detailed mesh of bracket model
4.3.3. Stress of bracket

Analysis showed that all cases have maximum stress with the same trend, except for loading case 4 and 6. As shown in Figure 11, the maximum stress occurs in the neck bracket, which is between the vertical pipe with an inner pipe bracket. Meanwhile, for the 4th and 6th loading cases, the maximum equivalent stress is obtained at the connection between the outer pipe bracket and the horizontal pipe. Both conditions occur at the connection between the two brackets. It would be better to model the thickness of the weld in that area because, in that area, there is a high stress concentration [19]. Meanwhile, the minimum stress occurs in bracket the handrail.

At LC 4, 5, and 6, there is a higher von Mises stress than LC 1, 2, and 3 because the tension of the mooring bridle is almost perpendicular to the bracket. Meanwhile, at LC 1, 2, and 3, the tension of the bridle line tends to tilt due to a global offset 2.8 times greater than the cage diameter. However, there is a different tendency in the 4th and 6th loading conditions wherein the 15° direction the stress is higher than the 0° direction. This is because this condition has the maximum bridle line reaching 228.71 kN and 221.50 kN, while at LC 5 it is only 163.63 kN. The graph of the stress results for each loading condition is shown in Figure 12.

The case with the maximum stress at the connection of the outer bracket with the horizontal pipe occurs due to the tension of the bridle mooring almost in a straight line and having the opposite direction. As for the case with the highest maximum tension at the neck of the bracket, it occurs due to the direction of the pull of the bridle line being too extreme or having a small angle between the direction of the force and the x-axis of the bracket.
4.3.4. Deformation of bracket

The maximum deformation tendency that occurs is almost the same as the maximum stress for each loading condition. The maximum deformation itself occurs in the section bracket outer pipe where there is direct contact with the mooring, which bridle can be seen in Figure 13. While at the top, namely the part that supports the handrail, there is no deformation. The highest deformation result is 0.37 meters. The deformation pattern for LC 1 is high because of the tension of the bridle due to the extreme slope of the bracket so that there is a shift between the bracket and the outer pipe. While the maximum deformation of the LC 5 is 0.01 meters and 0.08 meters, lower than the others. This is due to the tension of the bridle line that is perpendicular and only causes ovality at the end of the bracket the outer. Ovality problem can be resolved by giving a stiffener on the bracket the outer to maintain the shape of the bracket. The graph of the deformation results for each loading condition is shown in Figure 14.

![Figure 13. Location of maximum deformation at bracket](image)

![Figure 14. Result of maximum deformation at bracket in each load condition](image)
5. Conclusion
Based on the results of the simulation and analysis that has been done, the conclusions are:

1. The numerical model of floating net cages after being validated by the physical experiments of the previous studies can be accepted under current only, a combination of currents and regular waves, and a combination of currents and irregular waves. Also, the model scale to full scale is accepted. The average validation error meets the validation criteria, which is below 5% so that the model can be used for further analysis.

2. The maximum stress on the bracket is located at the connection between bracket the outer pipe and the horizontal pipe also at the neck of the bracket. The loading condition with the highest bridle line has the largest maximum stress, reaching 109.2 MPa. The minimum stress occurs in the handrail. The tension of the bridle line has a significant effect on the stress that occurs in the bracket compared to the tension of the net.

3. The maximum deformation of the bracket with extreme conditions in Pangandaran bay occurs at the bracket outer pipe where there is direct contact with the bridle line. The maximum deformation that occurs is 0.37 meters.

4. The maximum deformation of the bracket with extreme conditions in Pangandaran bay occurs at the bracket outer pipe where there is direct contact with the bridle line. The maximum deformation that occurs is 0.37 meters.

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