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Dynamic Analysis of A Floating Fish Cage With Different Percentages of Submersion Under Regular Waves

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Abstract

The aquaculture industry is emerging exponentially because the demand for seafood is at its peak and the capture of fish production is reached its saturation point. Aquaculture is classified into nearshore and offshore farming. The nearshore cages are mostly flexible and subjected to calm to moderate sea conditions. Whereas offshore cages are robust and designed to withstand severe sea environmental conditions. The present article describes the hydrodynamic behavior of a semisubmersible square fish cage subjected to regular waves. The square cage is submerged by three different submergences of 50%, 75% and 100% overall depth with a constant water depth. A numerical analysis is carried out to study the hydrodynamic properties such as added mass, radiation potential damping, wave excitation force, motion responses and mooring line tension. The numerical work results are plotted and correlated with each case of different submergence. The cable tensions and responses of the cages are increasing with a decrease in the percentage of submersion. Among all the cases, the cage with full submergence showed better performance for all wave environmental conditions.

Keywords

ANSYS AQWA, Aquaculture, Numerical Methods, Sea cage farming, Floating Fish Cage

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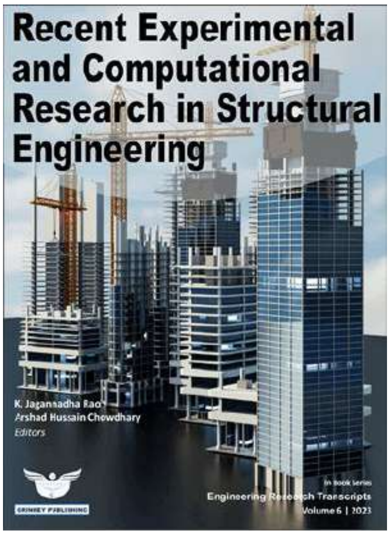


1. Introduction

The cage culture started centuries back in ponds and rivers on a small scale to produce a particular species. To fulfill the increase in seafood demand from the rise in population, farmers have started sea cage culture in nearshore areas. The production capacity from the sea cage culture has dominated inland production on a global scale production from past few decades. Aquaculture production plays a significant role in the economy of most countries. Even though nearshore cage farming is a good commercial success, water pollution and environmental conservation became the main problems to consider. Moreover, most nearshore sites are fully explored, leading to no further expansion and few countries do not permit nearshore cage farming. Farmers and industrialists are keen to explore offshore farming with a higher production capacity to overcome all these issues.

Considerable experimental and numerical studies are conducted on scaled model cages under both waves and currents, to study the responses and mooring cable tensions of cages. To investigate the mooring line tension for both waves and currents, physical and numerical tank tests were carried out [1]. The mooring line tension increases with an increase in uniform flow velocity and increases double when the current is combined with waves. A numerical method is developed entrenched on rigid body kinematics and lumped mass method to study the hydrodynamic responses of the gravity cage under currents, waves and united wave current conditions [2]. The numerical results were validated with experimental and field measurements, showing good agreement. Further, studies were carried out on cage under irregular waves for top one-tenth wave heights [3]. The study concludes, the responses of the cage decrease with an increase in frequencies and wave incident angle show a significant effect on surge motion compared to heave motions. When the wave incidence angle was 30°, the mooring line tension was at its highest.

The motion responses of heave and pitch are comparatively low for the submerged condition than for the floating condition [4]. The results also describe there was small difference between floating and submerged conditions for surge motions. A box shaped cage exposed to pure waves, currents and combined [5]. The relative error in motion responses was about 9% and 8% for pure waves and current-only conditions respectively. Later, experimental studies were conducted to study the mooring line tension by taking wave steepness as the main parameter [6]. Wave steepness shows less effect on total mooring force and it is doubled for the longest and steepest waves. The mooring line tension was measured for different buoy spacings and mooring arrangements under waves and currents [7], [8]. The results indicate that supporting buoy can reduce the mooring line tensions and prevents damage to the cage collar for severe storm conditions. Few researchers have reviewed the nearshore farming work in detail [9]–[12].

Further, the research has been expanded to offshore farming and multipurpose projects such as fish cages integrated with wave energy converters and breakwaters [9], [13]–[16]. To study the dynamic behavior of the offshore cages, experimental studies are conducted on scaled models [17]–[20] and numerical studies are carried out for prototype models [16], [21], [22]. The present work describes the hydrodynamic behavior of a cage in freely floating and moored conditions. Time and frequency domain analyses are carried out using a commercial package of ANSYS and the results are discussed in detail.

2. Numerical Methods

The present work mainly concentrates on the numerical analysis of square fish under three different submergence levels of 50%, 75% and 100% using ANSYS AQWA [23]. The modeling is carried out using a design modeler as per the dimensions provided in Table 1. The wave basin dimensions are considered as 10m x 0.71m x 0.55m to minimize the computational effort. A cage is modeled as a combination of panel and Morison tubular elements and fine mesh size is provided for the accuracy of simulations. Linear and flexible mooring lines are provided and mooring line length is altered based on the submergence levels. Frequency and time domain analysis are carried out using hydrodynamic diffraction and hydrodynamic response modules. The hydrodynamic properties of added mass, radiation damping, wave excitation force and RAOs are obtained in frequency domain analysis. Actual motion responses and anchor line tensions are obtained through the time domain analysis. The wave characteristics for time domain analysis are presented in Table 1 and three submergences schematically represented in Fig. 1, Fig. 2 displays the whole methodology of the present numerical study. A validation for present numerical study and protype model analysis is presented [24].

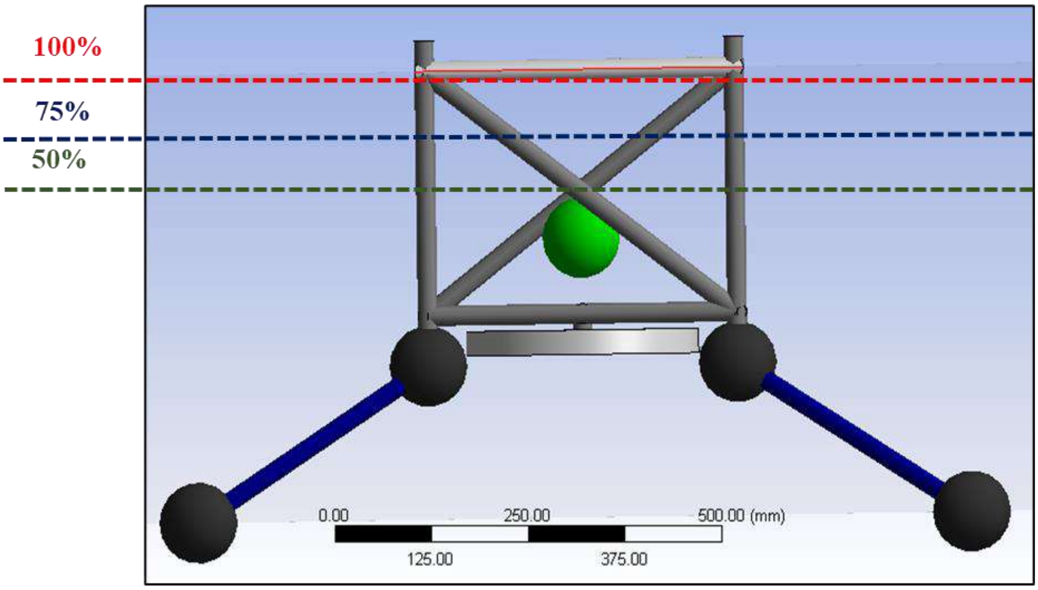


Fig. 1. Schematic diagram of the square cage with different submergence levels

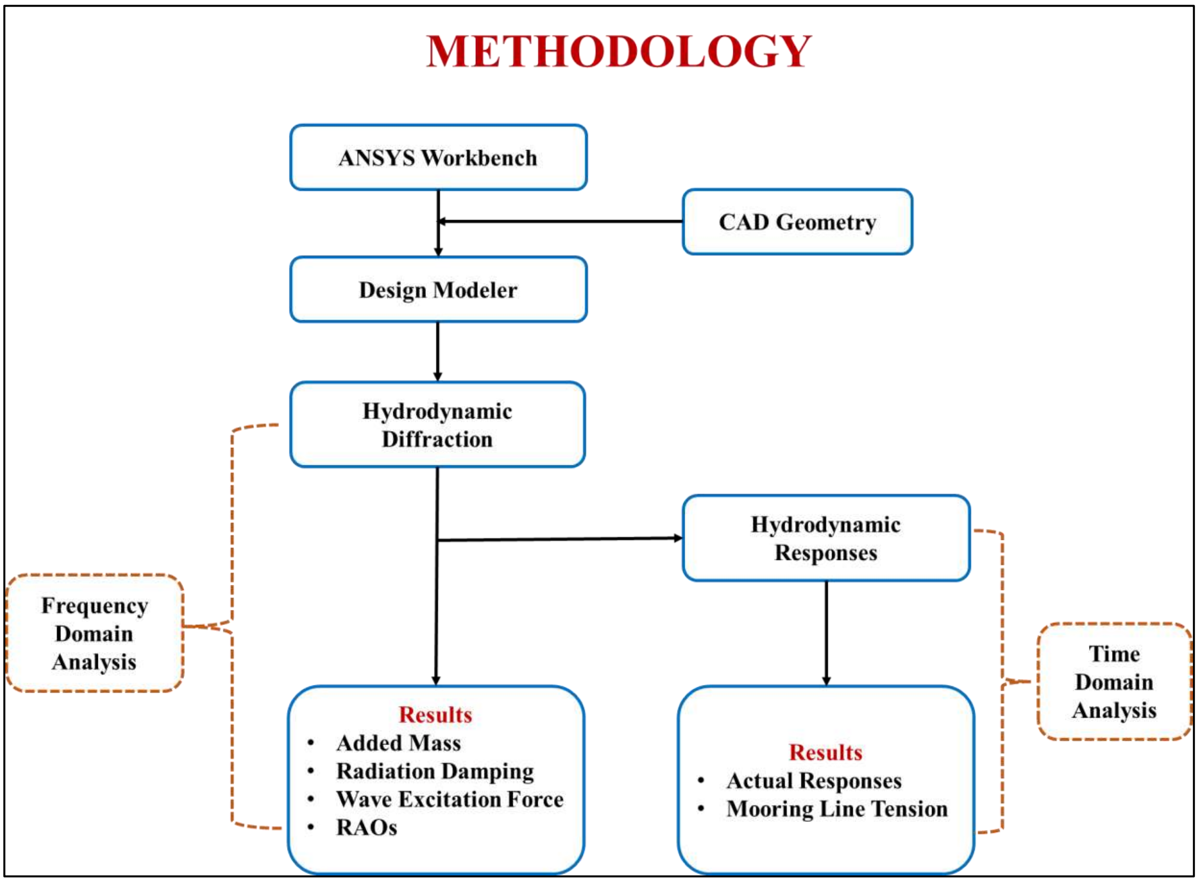


Fig. 2 Methodology of the present numerical work.

After modeling the fundamental line diagram in AUTOCAD, the drawing file is loaded into ANSYS Workbench. In the Design Modeler, surface bodies and tubular components are configured. Additionally, a point mass for the model is provided and it's extracted from the static structural module. The meshing operation is carried out with a finer mesh, and the frequency domain analysis is done by providing a set of input frequencies. Using Airy's wave theory, hydrodynamic response or time domain analysis is performed. In order to acquire the hydrodynamic characteristics, a collection of wave heights and time periods are provided as input.The schematic diagram of six degrees of freedom of a floating cage is provided for better understanding of results and discussions.

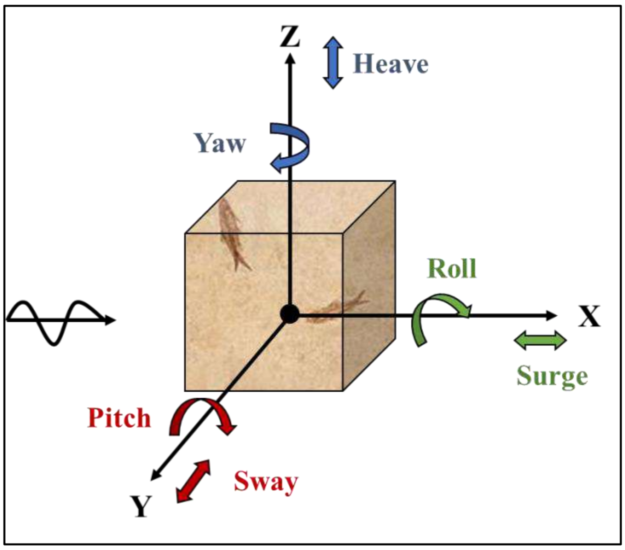


Fig. 3 Schematic diagram of 6 degree of freedom of a floating body.

Table 1. Cage dimensions and wave boundary conditions for numerical analysis

Geometric Properties				**Wave environment conditions**	
Member (No's)	Diameter (cm)	Length (cm)	Plate thickness (cm)	Wave Height (cm)	Wave period (Sec)
Pontoon (4)	6.4	3	0.12	4	0.8
Top horizontal girder (4)	2.5	40	0.12	6	1.0
Bottom horizontal girders (4)	2.5	40	0.12	8	1.2
Diagonal girders (4)	2.5	50	0.12	10	1.4
Side vertical column (4)	3.2	37	0.12		1.6
Bottom cross girder (4)	2.5	40	0.12		1.8
Top cross girder (4)	0.6	40	0.6		2.0
					2.2

3. Results and Discussions

3.1 Frequency Domain Analysis

3.1.1 Added Mass

The added mass is the inertia of the surrounding fluid on the system when the system oscillates. The cage with 100% submergence has the highest added mass in both the motions at frequencies of 0.01592Hz (heave) and 1.17528Hz (pitch), respectively, exhibiting an oscillatory behavior. The other two 75% and 50% cages exhibit a similar trend in both motions, and the cage with 100% submergence shows a spiky trend compared to others. Submergence of 75% and 50% cages obtained a higher and steady added mass in heave motion once the frequency reached 2Hz. The added mass of the structure increases with the depth of submergence. The cage with 75% is exhibiting good behavior in the added mass for both motions.

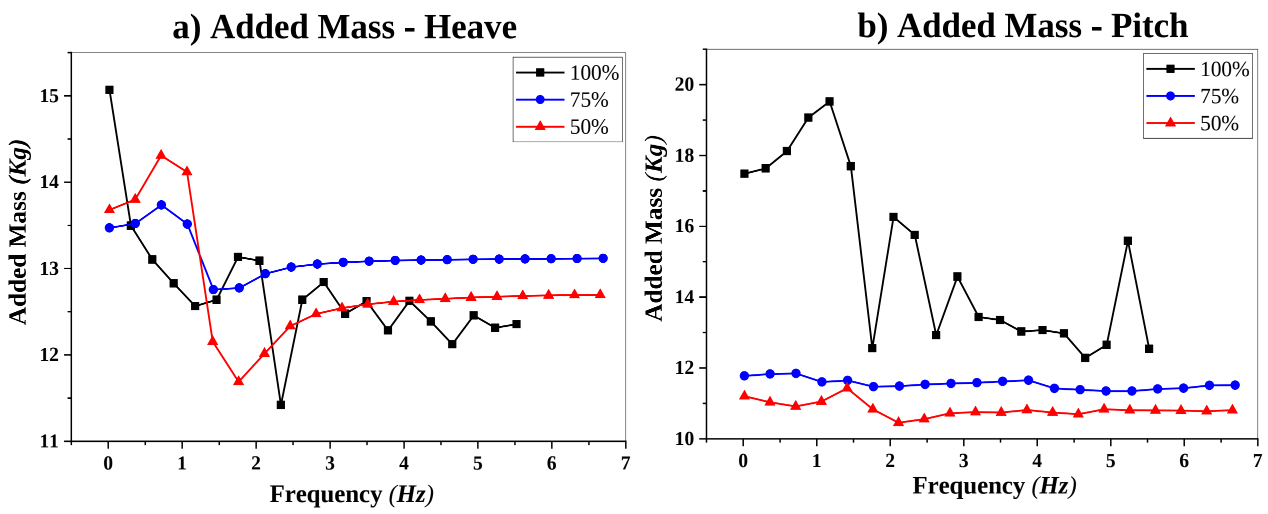


Fig. 4. Added mass of the square cage with three different submergence levels a) Heave and b) Pitch.

3.1.2 Radiation Potential Damping

Radiation potential damping is nothing but dissipating the wave energy caused by the structure motions. Behavior of a cage with three different submergences in radiation potential damping is presented in Fig. 5. The cage with submergence of 50% shows the highest peak in heave motion and 100% submergence cage attains the highest damping in pitch motion. The cage with 100% submergence is exhibiting an oscillatory behavior in both motions and remaining two cages are exhibiting a similar trend. The radiation potential damping of the cage with 50% and 75% submergence gradually increases with frequency, reaches the maximum in the range of 1-2Hz and decreases to a constant value in heave motion. In Heave's case, the radiation damping peak for 50% submergence is 49.23% higher than 100% submergence and 68.69% higher than 75% submergence.

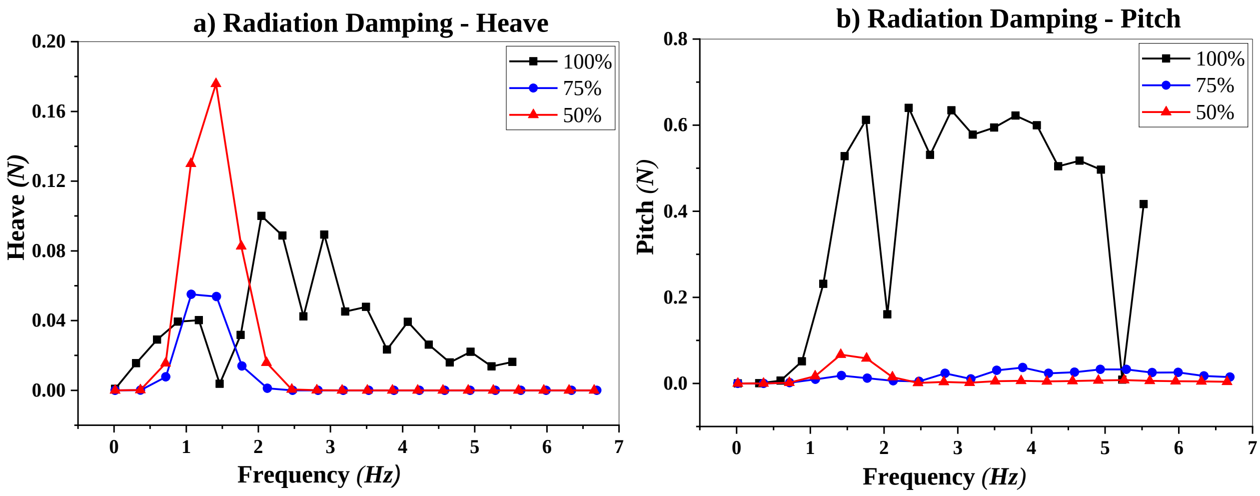


Fig. 5. Radiation Potential Damping of the square cage with three different submergence levels a) Heave and b) Pitch.

3.1.3 Wave Excitation Force

The wave excitation force is nothing but the consolidation of Froude-Krylov and Diffraction force and wave excitation force for three different submergences are presented in Fig. 6. All the cage submergences follow a similar trend in both the motions. The cage with 100% submergence obtained the highest wave excitation force in both conditions, whereas the cage with submergence of 75% showed the lowest excitation force among all the wave conditions considered. In the case of both Heave and Pitch, as frequency increases wave excitation force increases and reaches its peak value for a particular frequency range of 0.5-1.5Hz, then decreases, and finally remains constant over frequencies of 2-7Hz. The cage with 100% submergence in heave has a peak value at the initial frequency and then decreases, later exhibiting an oscillatory behavior.

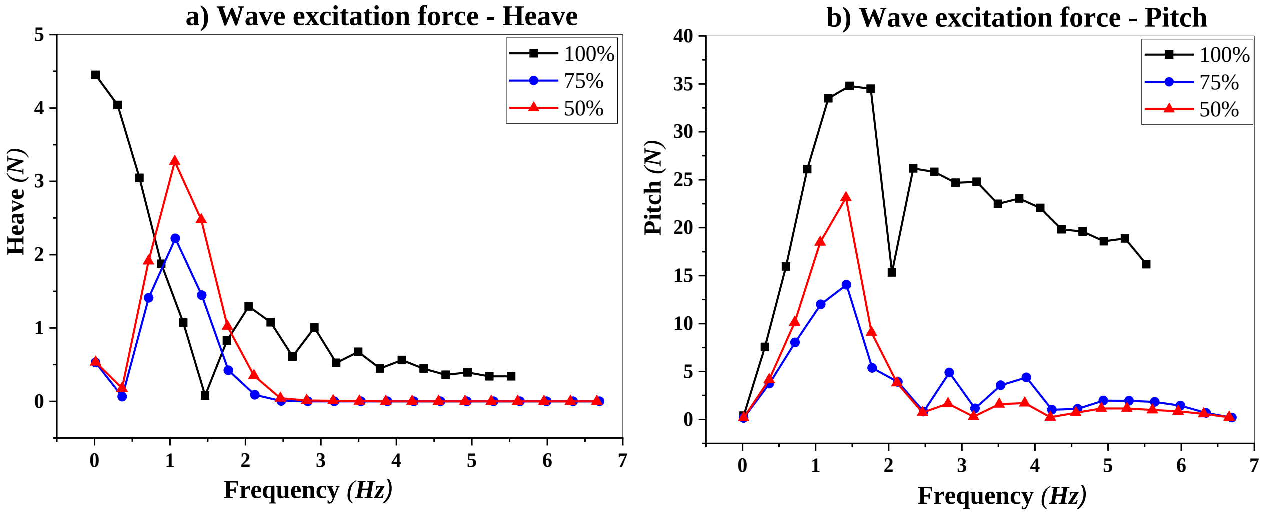


Fig. 6. Wave excitation force of the square cage with three different submergence levels a) Heave and b) Pitch.

3.1.4 Response Amplitude Operators

The Response Amplitude Operators (RAOs) for three different cage submergences are presented in Fig. 7. Except for the cage with 100% submergence, all cage submergences exhibit a similar pattern of heave and pitch motions. The cage with 100% submergence exhibited the peak RAOs in both the motions and whereas the cage with 75% submergence exhibited lower RAOs in all the wave conditions considered.

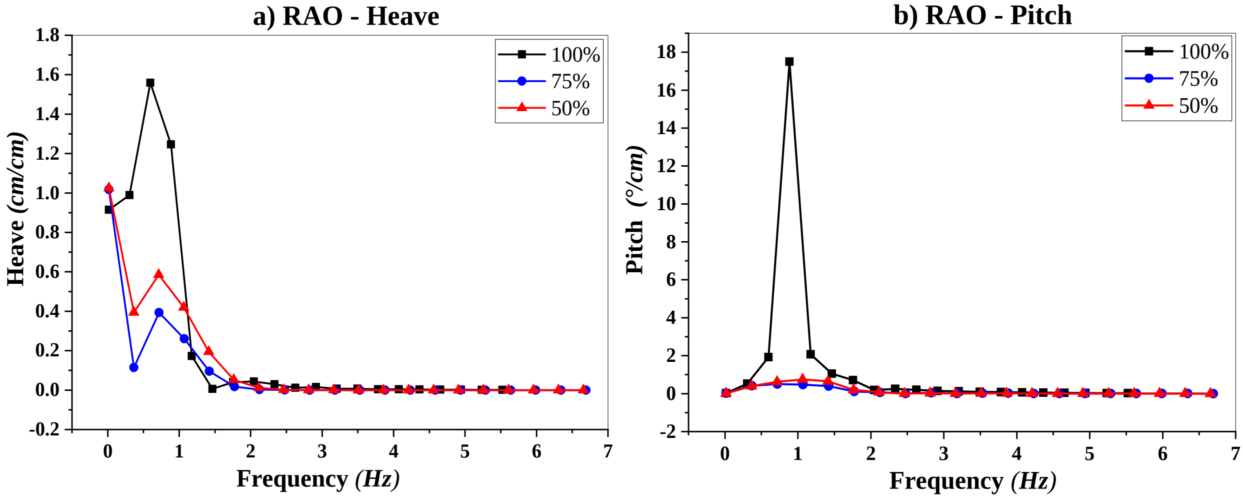


Fig. 7. Response Amplitude Operators of the square cage with three different submergence levels a) Heave and b) Pitch.

3.2 Time Domain Analysis

3.2.1 Motion Responses

The heave motion responses of the cage of three different submergences, which are subjected to regular waves. The wave heights of 4,6,8 and 10cm and time periods of 0.8-2.2s with an interval of 0.2s are examined for the present numerical work. From the Fig. 8, it is evident that the heave responses are following a similar trend for various wave heights. It is also observed that 50% submergence has a higher Heave response, followed by 75% submergence and then 100% submergence. It can also be inferred that heave responses increase with an increase in wave height.

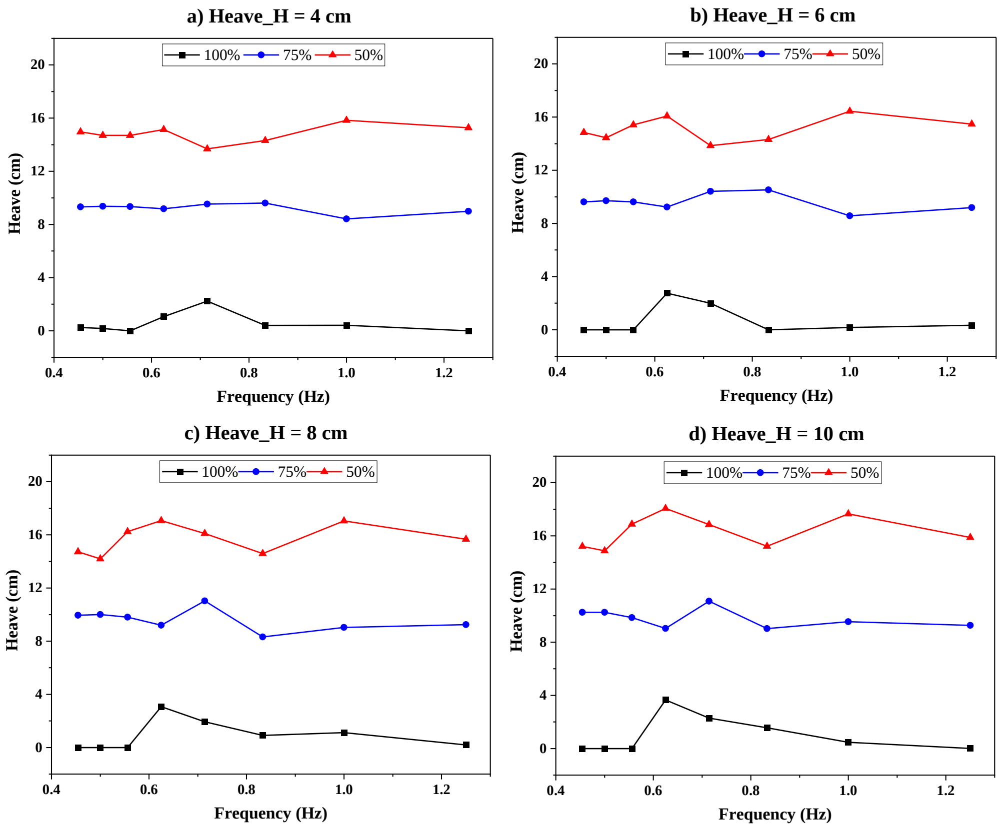


Fig. 8. Heave responses of the square cage with three different submergence levels for wave heights of a) H=4cm, b) H=6cm, c) H=8cm and d) H=10cm.

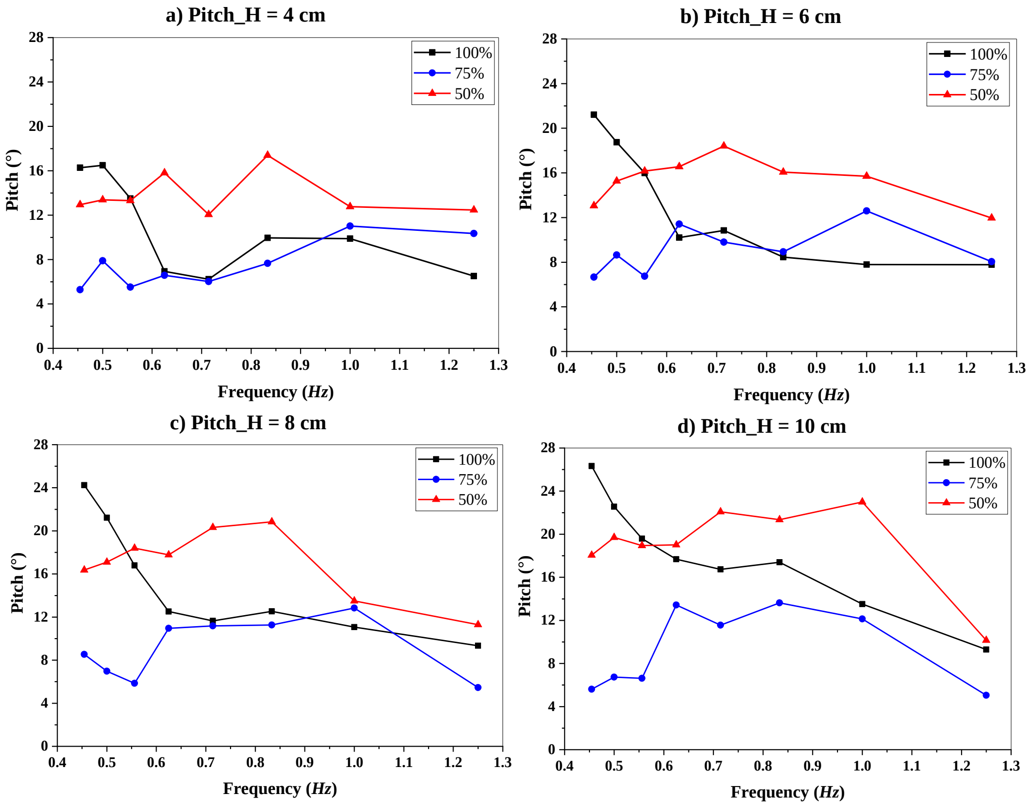
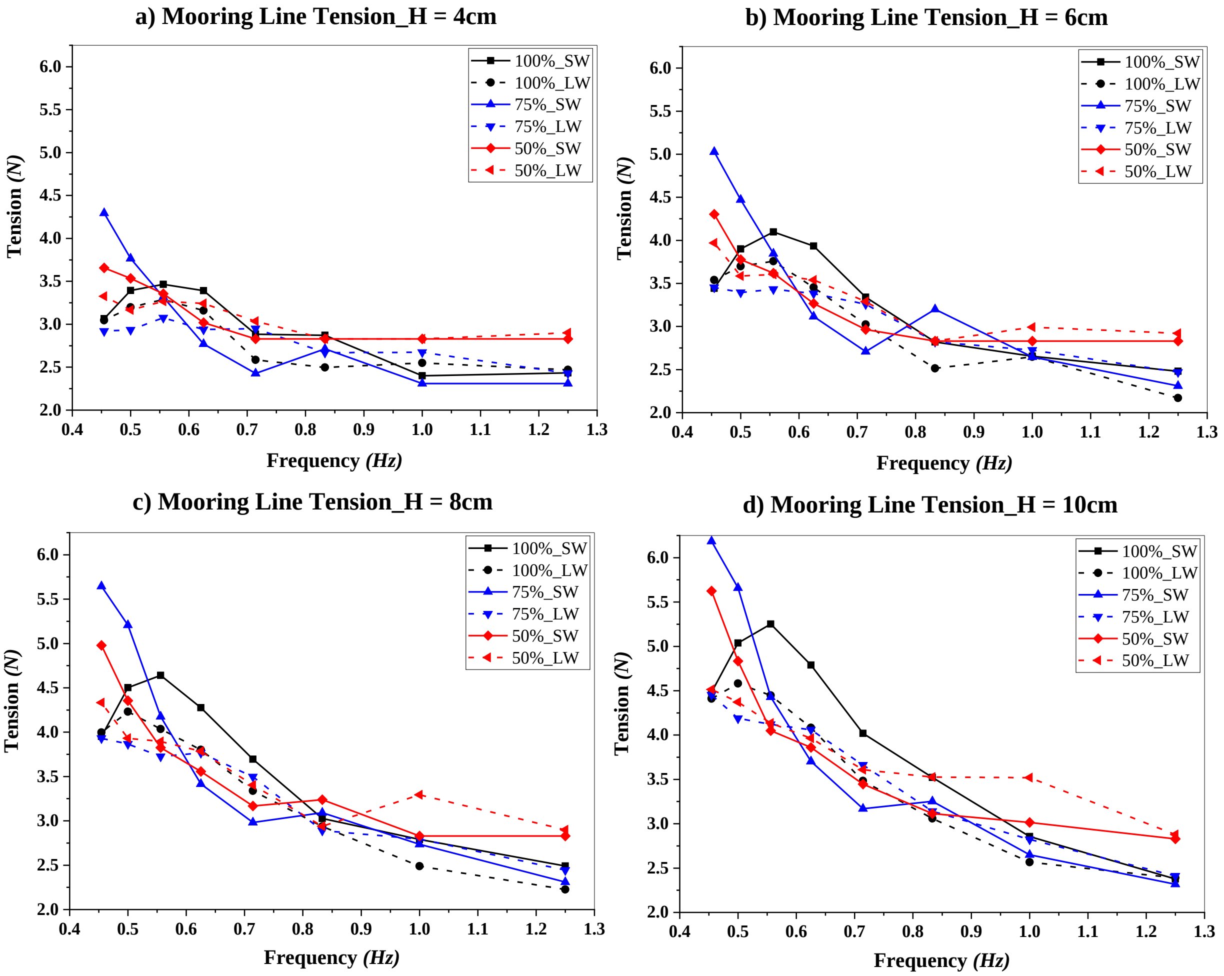


Fig. 9. Pitch responses of the square cage with three different submergence levels for wave heights of a) H=4cm, b) H=6cm, c) H=8cm and d) H=10cm.

The pitch responses are following an almost similar trend for various wave heights. It is observed that 100% submergence has a higher pitch response for an initial frequency range of 0-0.5Hz and the cage with 50% submergence exhibits the highest pitch responses for remaining frequencies. Submergence of 75% cage exhibits the lowest pitch response compared to remaining two submergences. Results indicates, Pitch response increases with wave height. The cage with 75% submergence exhibits a good performance among three different submergences.

3.2.2 Mooring Line Tensions

The mooring line tension of the cage with three different submergences subjected to four different wave heights of 4,6,8 and 10cm (refer Fig.10). It is observed that the mooring line tension on windward side is invariably higher compare to leeward side. The mooring line tension increases with wave heights and vice-versa with frequency. The cage with 75% submergence obtained the highest seaward mooring line tension ranging from 4-6.5N for all wave heights, followed by 100% and 50% submergences for frequencies of 0-0.5Hz and all the cages exhibited a similar pattern. Even though the cage with 75% submergence obtained the highest mooring line tension for frequencies of 0-0.5Hz, it shows good performance for the overall conditions considered.


a) Mooring Line Tension_H = 4cm

b) Mooring Line Tension_H = 6cm

c) Mooring Line Tension_H = 8cm

d) Mooring Line Tension_H = 10cm

Fig. 10 Mooring line tension of the square cage with three different submergence levels for wave heights of a) H=4cm, b) H=6cm, c) H=8cm and d) H=10cm.

4. Conclusions

A numerical analysis is carried out on a square cage without the fishing net for three different submergence levels. The frequency domain analysis is performed to analyze the dynamic parameters of added mass, radiation damping, wave excitation force and RAOs.

- The cage with 100% submergence obtained the highest added mass in both heave and pitch motions in the range of 15-18kg (for frequencies of 0-0.5Hz) and the 50% submergence cage exhibits the lowest around 10-12kg (for frequencies of 0-1Hz).
- The cage with 50% submergence is showing good behavior in heave radiation damping and 100% submergence is performing well in pitch.
- The cage with 100% submergence obtained the highest value in wave excitation force and RAOs.
- For all hydrodynamic factors taken into account by frequency domain analysis, the cage at 75% submergence performs better than other submergence levels.
- The motion responses of heave and pitch increase with an increase in wave heights. The cage with 50% submergence exhibits highest in both heave and pitch responses and cage with 75% submergence exhibits the lowest.
- Even though the cage with 75% submergence obtained the highest mooring line tension for frequencies of 0-0.5Hz, the cage with 100% submergence shows good performance for overall conditions considered.

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