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Hydrodynamic Analysis of A Semisubmersible Fish Cage With Different Drafts Subjected to Regular Waves

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Abstract

Cage farming has historical roots spanning centuries, while its commercialization has only commenced within the past few decades. The unsustainability of captured fish production leads to the development of the aquaculture industry. The initial practice has been carried out in ponds, rivers and later moved on into sheltered zones of the sea as a part of nearshore farming. Nowadays, farmers are keen to relocate offshore due to space constraints and pollution-related issues. This article presents a hydrodynamic analysis of the semisubmersible square fish cage with a net solidity of 0.26 subjected to regular waves. The cage is studied numerically under different drafts of 17.5cm, 26.25cm and 35cm under regular waves with a water depth of 55cm. Frequency and time domain analyses are performed to investigate the hydrodynamic characteristics of the cage. Each case's motion responses and anchor line tension are studied and results are analysed. The results indicate that the increase in draft depths leads to decreased motion responses and anchor line tensions. The cage behaves well in three different submerged conditions and shows better performance at the draft of 35cm.

Keywords

ANSYS AQWA, Aquaculture, Numerical Methods and Sea cage farming

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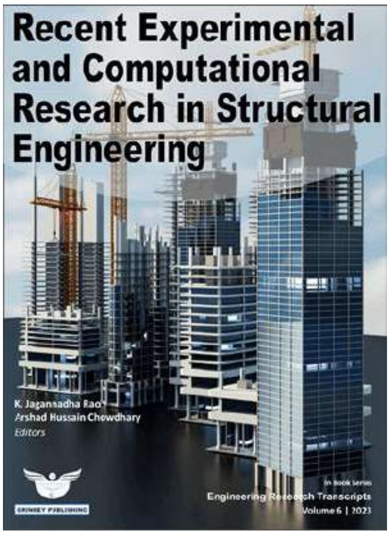

1. Introduction

Abundant research has been carried out on nearshore farming for different cage shapes, collars, bottom/sinker weights, net types, mesh types and buoys. The experimental studies were conducted on a scaled model in a uniform flow to study the net deformation and drag forces on the cage [1].The net deformation is nothing but a change in the total volume of flexible cage, when the cage is subjected to waves and currents. In general, HDPE, Nylon materials are used as net for nearshore cages. Drag force and net deformation are mutually dependent on each other and increase with current velocity. Higher bottom weights help to retain its original geometry. The experimental results were correlated with a numerical method developed based on the lumped mass method and considering that the current velocity was less than 0.32 m/s, the results were in good agreement [2]. The net deformation decreases with an increase in bottom sinker weights and an insignificant effect on drag force at low current velocity [3]. Later, a 3D numerical model was developed to study the net deformation for different fishing net mesh under uniform flow [4]. The results indicate that an increased structure size ratio reduces the net deformation and bottom collar sinker performs better in practical conditions than sinker weights. The submerged cage exhibited less net deformation than the floating cage, about 21% and 31%, respectively [5]. Velocity and bottom weight have a greater impact on net deformation than net solidity [6]. The copper alloy net cage model is studied under uniform flow and cage acting as rigid and exhibiting significantly less net deformation [7]. Polythene net with the wire-netting bottom shows less shape distortion than other combinations considered [8]. A single point mooring system is studied under both waves and currents and results indicate that adding a buoy to the cage system reduces the forces on net and collar deformation [9].

Further, research has been carried out on offshore farming along with nearshore cage farming. Experimental studies on a scaled model are performed for different-shaped cages and numerical studies are performed on both scaled and prototype models. Experimental and numerical studies are conducted on a single point mooring system to analyse the dynamic behavior of the cage under currents [10]. The cage is designed as a self-submerging system and performs well in uniform flow. Moreover, physical experiments are carried out on a scaled, floating cylindrical structure to examine its motion responses. Simulations are conducted using SESAM software and the results are compared with experimental values [11]. Experimental studies are performed on a scaled model of Oceanfarm 1 for three different drafts in regular waves and motion responses of the cage are analysed [12]. Later, a numerical method is developed based on BEM (boundary element method) to validate the experimental results of Oceanfarm 1 and the results were correlated well [13]. Later, studies were conducted on different shaped cages such as vessel-shaped, well-boat, hexagon, octagon, and innovative open net cages [14]–[17]. Further, research has been extended to multipurpose projects like cages combined with waves, wind energy converters, and breakwaters [18]–[21]. Researchers carried out a detailed review of offshore farming [22]–[24].

2. Numerical Methods

The present numerical study mainly concentrates on the numerical analysis of a square cage with net solidity of 0.26 for three different draft levels of 35cm, 26.25cm, and 17. 5cm.The hydrodynamic forces on the net are proportional to net solidity. Net solidity is described as the fraction of the projected area (Ap) that is covered by the threads, relative to the total area of the net panel. (A), i.e,

$$S_n = \frac{A_p}{A} \quad (1)$$

An emphatical formula employed to ascertain the existing numerical model for the net solidity of the fishing net. (Refer Fig.1).

$$S_n = \left(\frac{2l_\omega d_w \pm (d_\omega)^2}{(l_\omega)^2}\right) \quad (2)$$

In this context, S_n represents the solidity ratio, l_w signifies the twine length, and d_w denotes the diameter of the twine. For a knotted net, the net solidity is determined by adding the square of the diameter ('+') of the twine. Conversely, for a knotless net, the net solidity is calculated by subtracting the square of the diameter ('-') of the twine.

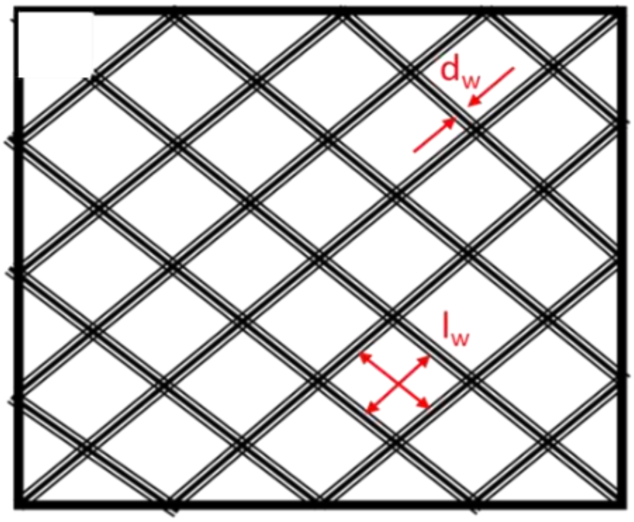

Fig. 1. Schematic view of Numerical net

ANSYS is commercial finite element analysis software and can be used for multiple problems in various domains. ANSYS AQWA tool is used for the present numerical study. The cage dimensions are provided in the Table1. The frequency domain analysis is performed using a hydrodynamic diffraction module and the time domain analysis is performed using a hydrodynamic response module in ANSYS software [25]. A 3D-Wave flume with a dimension of 10m x0.71mx0.55m is considered to reduce the computational time. A combination of Morison tubular and panel elements are considered with fine meshing. Linear and flexible mooring lines are adopted, and the length of the mooring line is altered depending on the drafts. A validation for present numerical study and protype model analysis is presented [26].

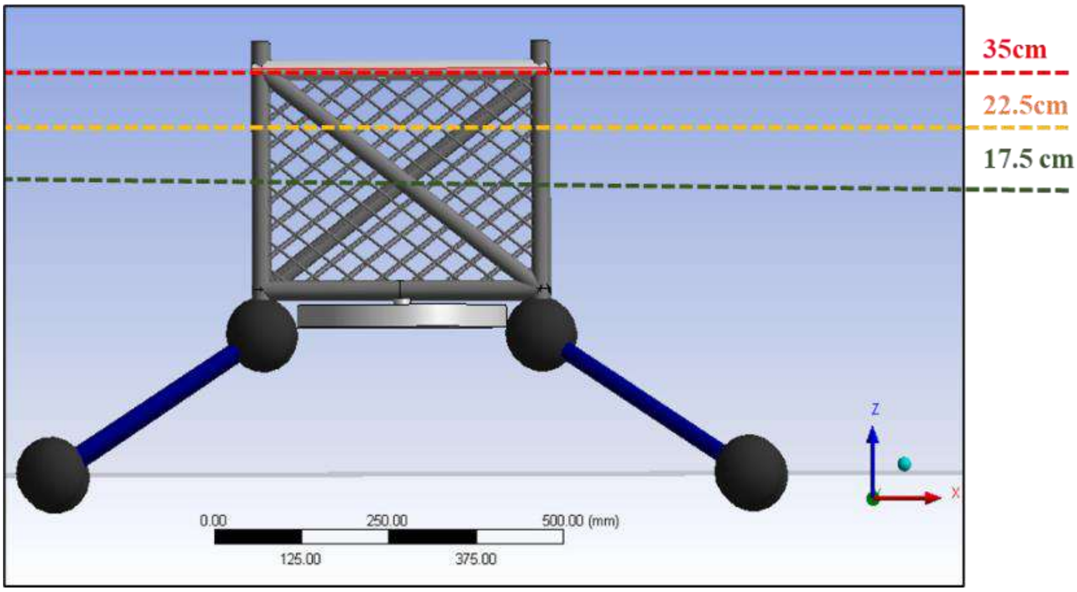

Fig. 2 Schematic diagram of a square cage with a net for different cage drafts

Twenty different frequencies are considered to perform frequency domain analysis and the dynamic characteristics such as added mass, radiation damping, excitation force and RAOs are obtained from it. A time domain analysis is performed for a set of wave heights and time periods. The actual responses and mooring line tensions of cages have arrived from the simulations of each case. The simplified diagram of the cage is presented in Fig. 2 and the methodology is provided in Fig. 3.

The fundamental schematic is created using AUTOCAD, and the drawing file is brought into ANSYS Workbench. Configuration of surface structures and tubular components takes place within the Design Modeler. Additionally, a point mass is incorporated into the model, derived from the static structural module. The meshing process employs a finer mesh, and an analysis in the frequency domain is executed with a specified range of frequencies provided as input. Hydrodynamic responses, or time domain analysis is performed through the utilization of Airy's wave theory. By inputting a designated series of wave heights and time periods, the hydrodynamic characteristics are obtained.

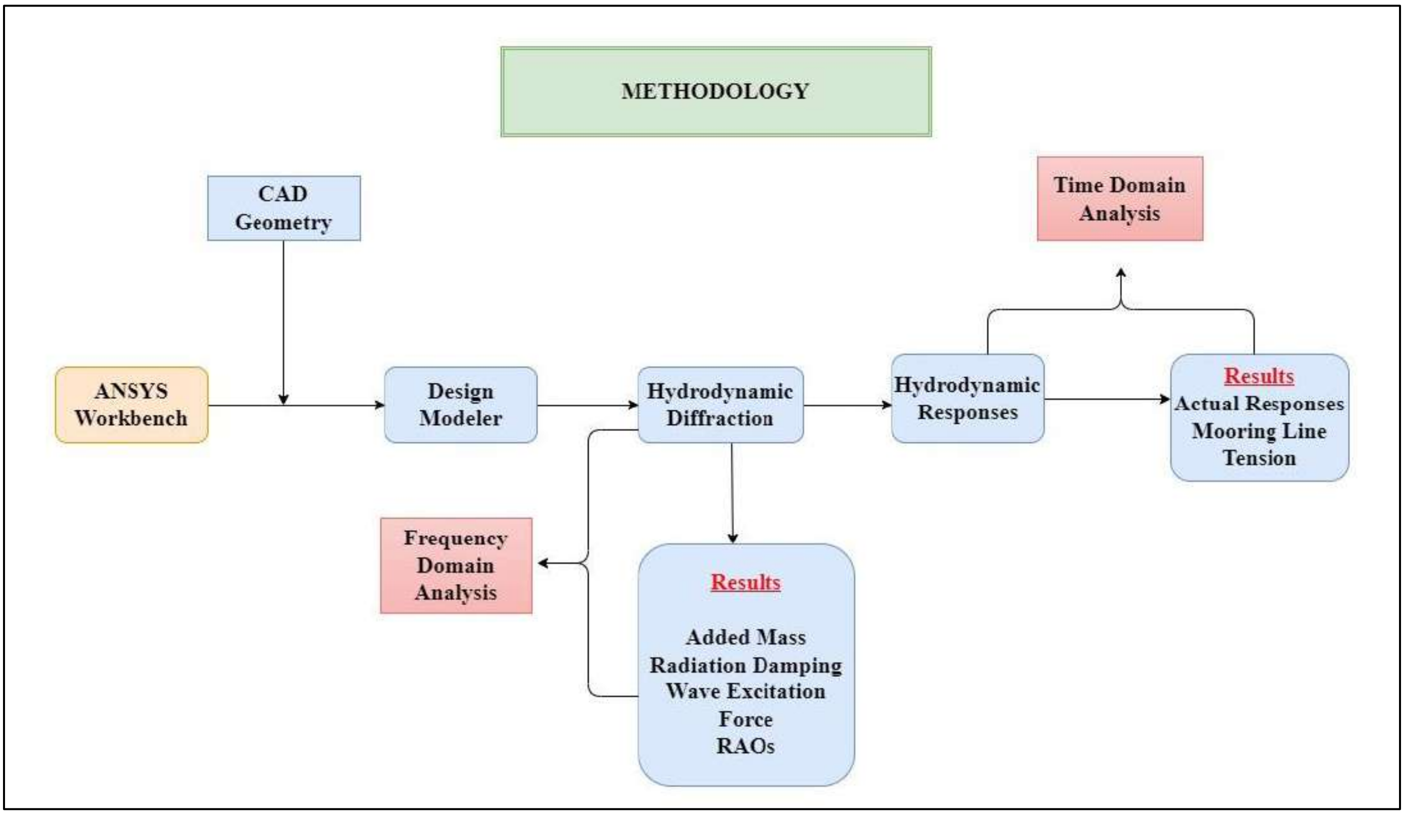

Fig. 3 Methodology for the present numerical study

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

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

It can be inferred that from Fig. 4, the added mass in both heave and pitch is highest for the 35cm cage draft. Pitch increases with frequency, reaching a peak at a frequency close to 1Hz and then decreasing and remaining constant. In the case of heave for a 35cm draft, the peak added mass is observed at 0.01592Hz and in pitch, the proximity of 1Hz (i.e., the resonant frequency of 0.8441Hz) and follows an irregular trend in both the motions. A peak of 26.25cm draft condition was observed at 0.59729Hz and a peak of 17.5cm draft was observed at 0.88617Hz and there is the same amount of response for remaining frequencies. For both 26.25cm and 17.5cm draft conditions, pitch added mass exhibited similar response and followed a similar trend. The added mass is higher for 35cm draft is due to greater surface contact area to water, which leads to higher surrounding volume of mass movement during structure oscillations.

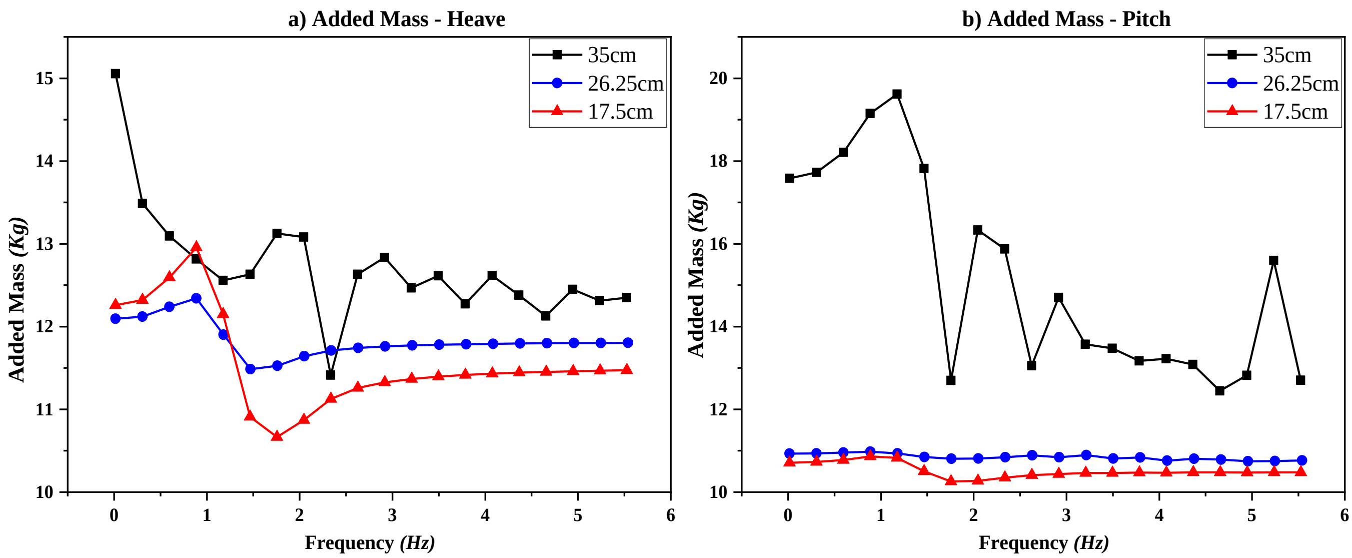

Fig. 4 Added mass of the cage with three different draft levels, a) Heave and b) Pitch.

3.1.2 Radiation Potential Damping

Radiation Potential Damping is described as dissipation of wave energy caused by the structure motions. Fig. 5 describes that as the frequency increases, the radiation damping increases and reaches its peak value in the proximity of 1Hz and decreases and remains constant. Radiation damping in case of heave is observed as higher for 17.5cm draft followed by 35cm draft. The percentage variation of peak is about 20-50% for both 35cm and 26.25cm drafts compared to the 17.5cm draft. The cage with drafts of 35cm and 26.25cm exhibit the highest damping in the frequency region of 1-2Hz. For the cage draft of 35cm, negative damping is obtained at a frequency of 5.23Hz due to coupled motions (i.e., heave induced pitch motions and pitch induced heave motions). For cage drafts of 26.25cm and 17.5cm, damping follows a similar trend for all frequencies in pitch motion.

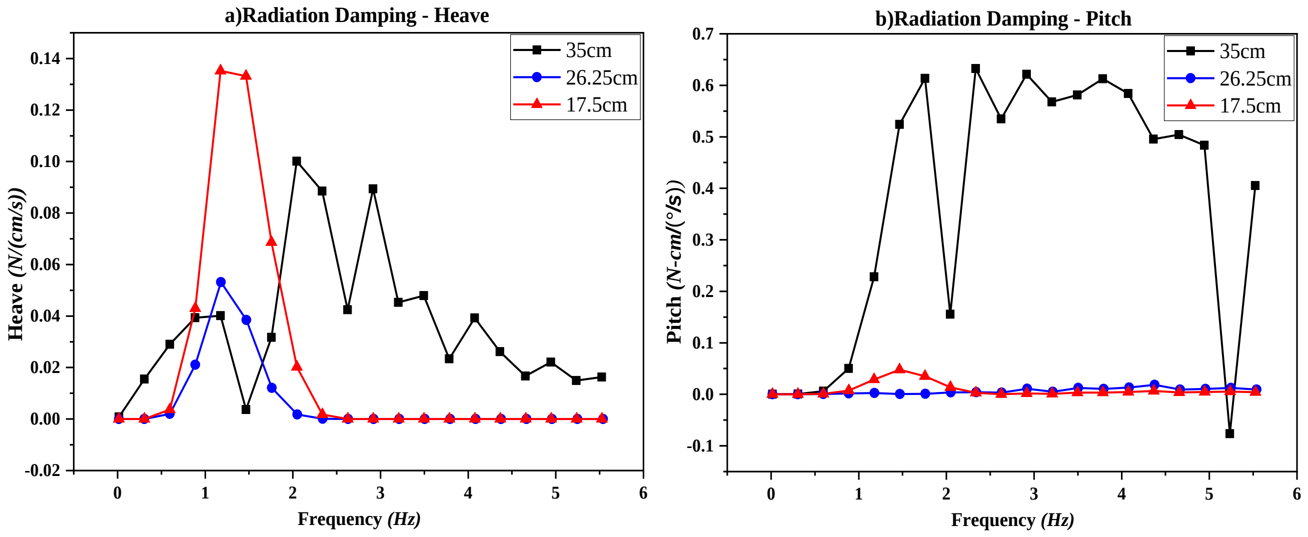

Fig. 5 Radiation damping of cage with different drafts, a) Heave and b) Pitch.

3.1.3 Wave Excitation Force

The wave excitation force, a combination of both the Froude-Krylov force and the diffraction force, is shown in Fig. 6. Wave-excitation forces emerge as a result of the immediate impact of incident waves on a structure. According to linear theory, these forces exhibit a direct correlation with the wave amplitude. It can be inferred that as the frequency increases, the wave excitation force increases and reaches its peak value in the proximity of 1Hz and then decreases and remains constant in both the motions. The cage draft of 35cm exhibits highest value in both the motions, followed by 17.5cm draft. The cage draft of 26.25cm gives the least wave excitation force in both the motions. The cage draft of 26.25cm and 17.5cm are following the similar trend in both the motions and exhibiting a peak percentage difference of 10-30% in magnitude.

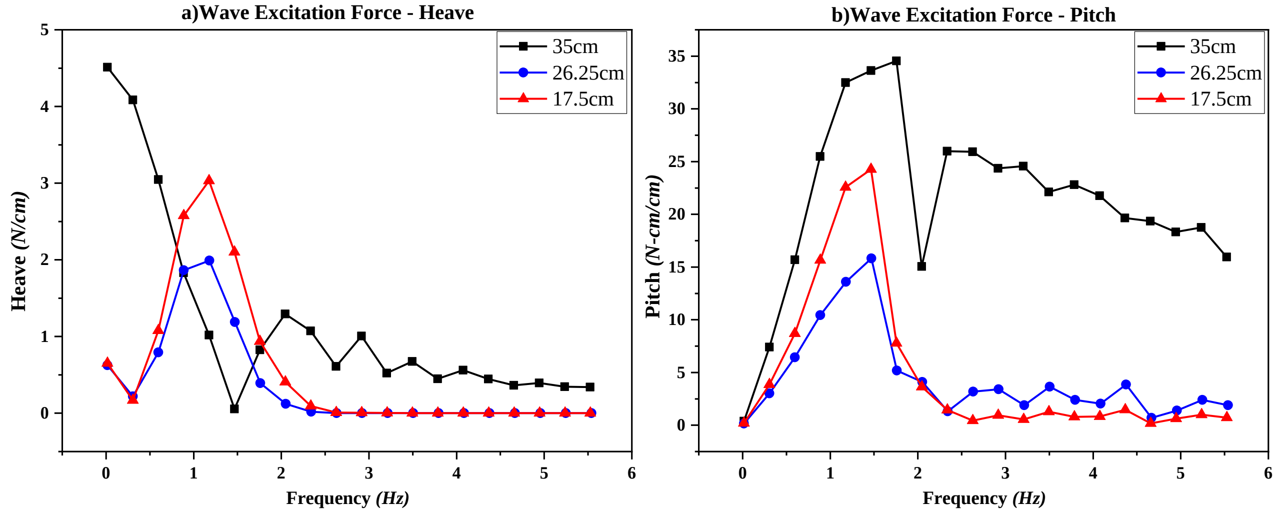

Fig. 6 wave excitation force of cage with three different drafts a) Heave and b) Pitch.

3.1.4 Response Amplitude Operators

RAOs quantity signifies the relationship between a structure movement and the amplitude of the wave responsible for inducing that movement. It is depicted across a spectrum of wave periods/ frequencies. The Response Amplitude Operators (RAOs) increase and reaches their peak value at a frequency range of 1Hz (Fig. 7) and then decrease and remain constant. The RAOs obtained for 26.25cm draft and 17.5cm draft conditions are almost the same in both heave and pitch with a percentage difference of 0-10%. The cage draft of 35cm gives the lowest RAOs in heave and highest in pitch motions.

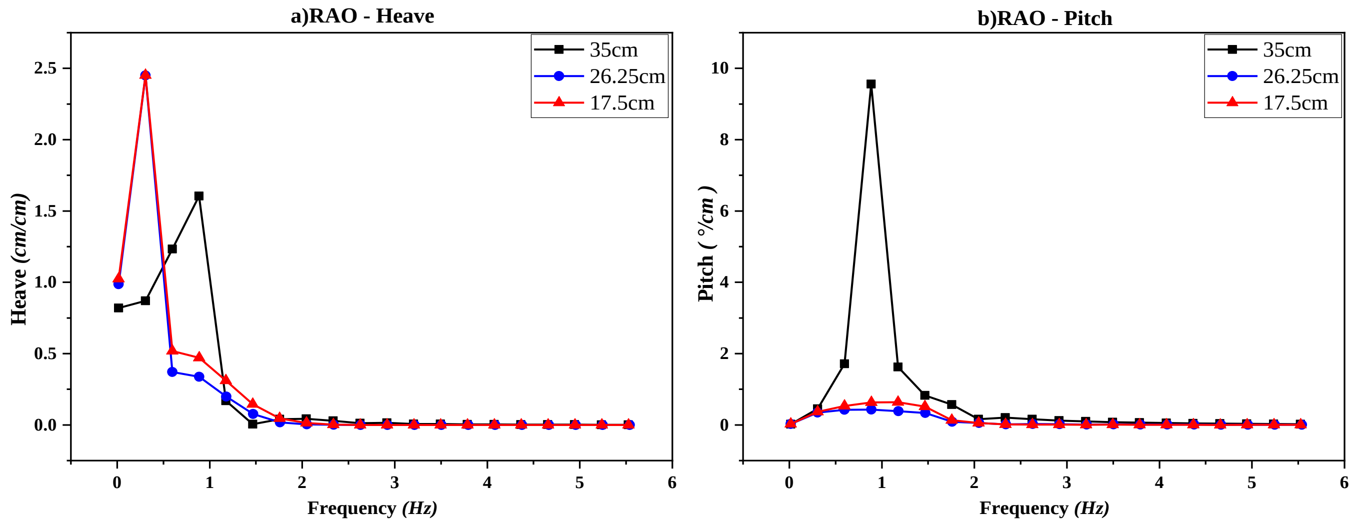

Fig. 7 Response Amplitude Operators of three different cage drafts, a) Heave and b) Pitch.

3.2 Time Domain Analysis

3.2.1 Motion Responses

The heave responses of cage drafts of 35cm, 26.25cm and 17.5cm are studied and plotted in Fig. 8. It is evident that the heave responses for four different wave heights follow a similar trend, and it can be inferred that the heave responses increase with an increase in wave height. The cage with a draft of 35cm and 26.25cm are exhibiting highest heave responses in the proximity of 10cm at a frequency range of 0. 75Hz.The cage draft of 35cm obtained least heave responses for all wave heights and the cage draft of 17.5cm exhibited the highest heave response in the range of 10-16cm, which is 10-50% magnitude variation.

The pitch responses of cage with different drafts for wave heights of 8cm, 10cm, 12cm and 14cm (refer Fig.9). The cage draft of 17.5cm obtained the highest pitch motions ranging from 12-20°, followed by the cage draft of 35cm. A cage draft of 26.25cm obtained the least pitch motions for all the wave heights considered. All the cages exhibit almost similar trends for all wave conditions considered.

3.2.2 Mooring Line Tensions

The windward and leeward mooring line tensions are studied for various frequencies and wave heights and the variation is shown in Fig. 10. Observations show that the windward side has always had greater tension than the leeward side of the mooring line and with an increase in frequency the mooring line tension decreases. Increasing wave height results in increased tension in the mooring line. The cage draft of 26.25cm obtained the highest mooring line tension of (4.75N – 5.75N) on the windward side for the frequency range of 0-0.6Hz. Later, for a frequency range of 0.6-1.4Hz, the cage draft of 17.5cm exhibited the highest, with a percentage variation of 10-30% with a draft of 26.25cm. The cage draft of 35cm exhibit the least mooring line tension on both windward and seaward side for all the wave heights considered.

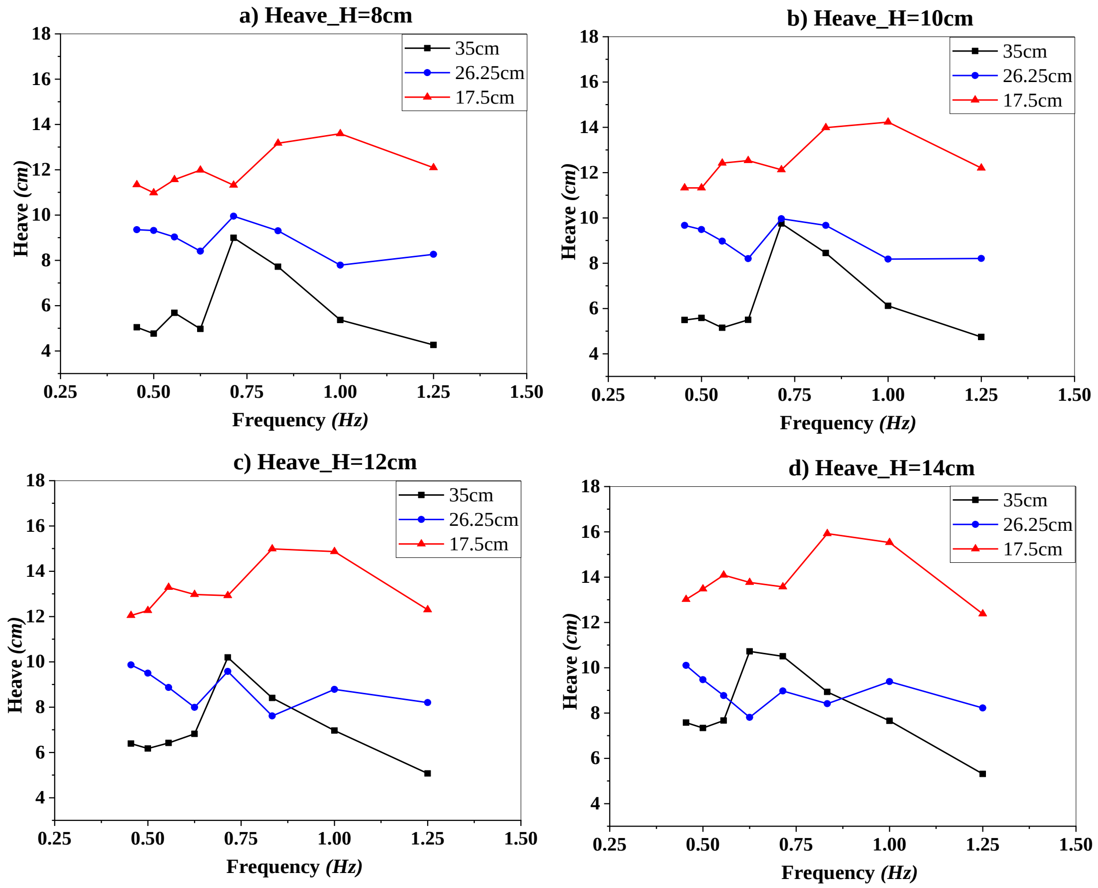

Fig. 8 Heave response of the cage with three different drafts

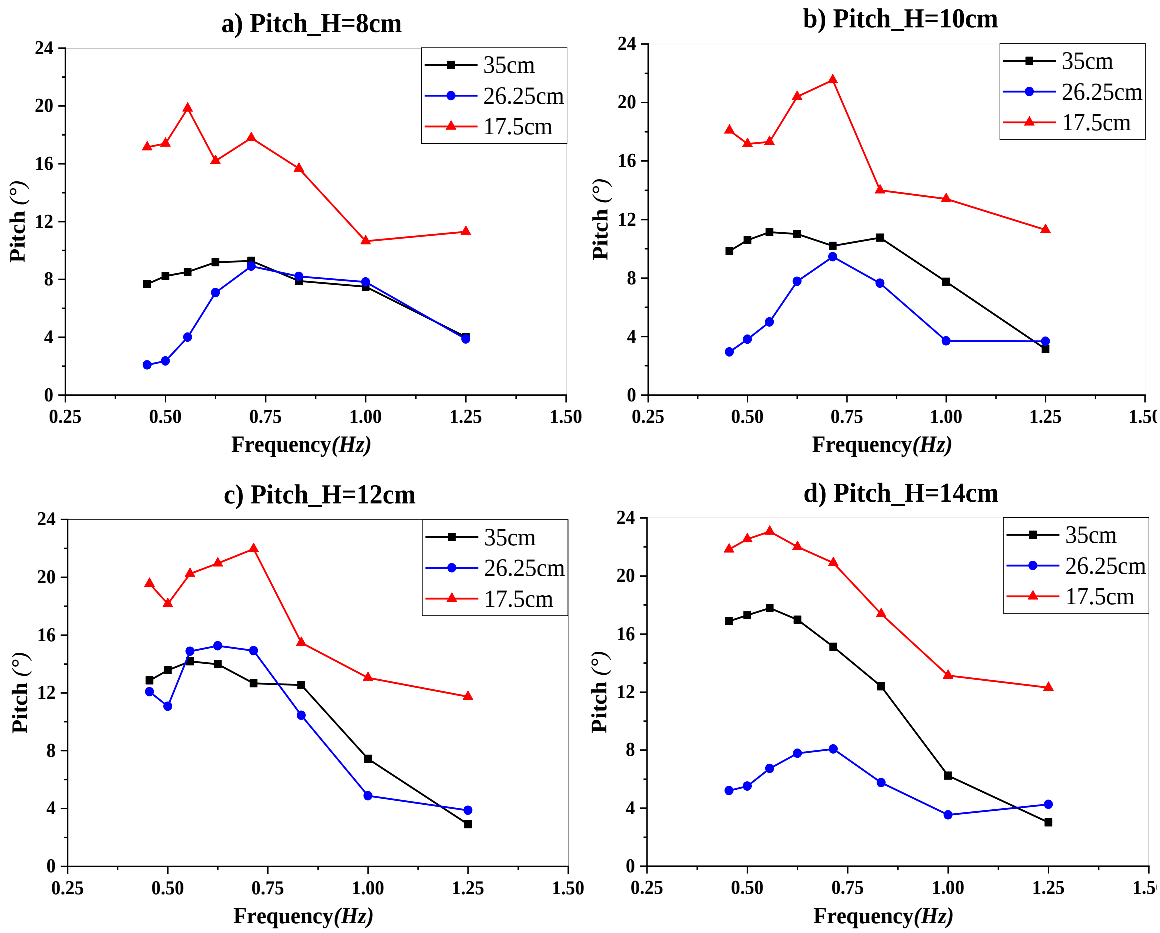

Fig. 9 Pitch response of the cage with three different drafts

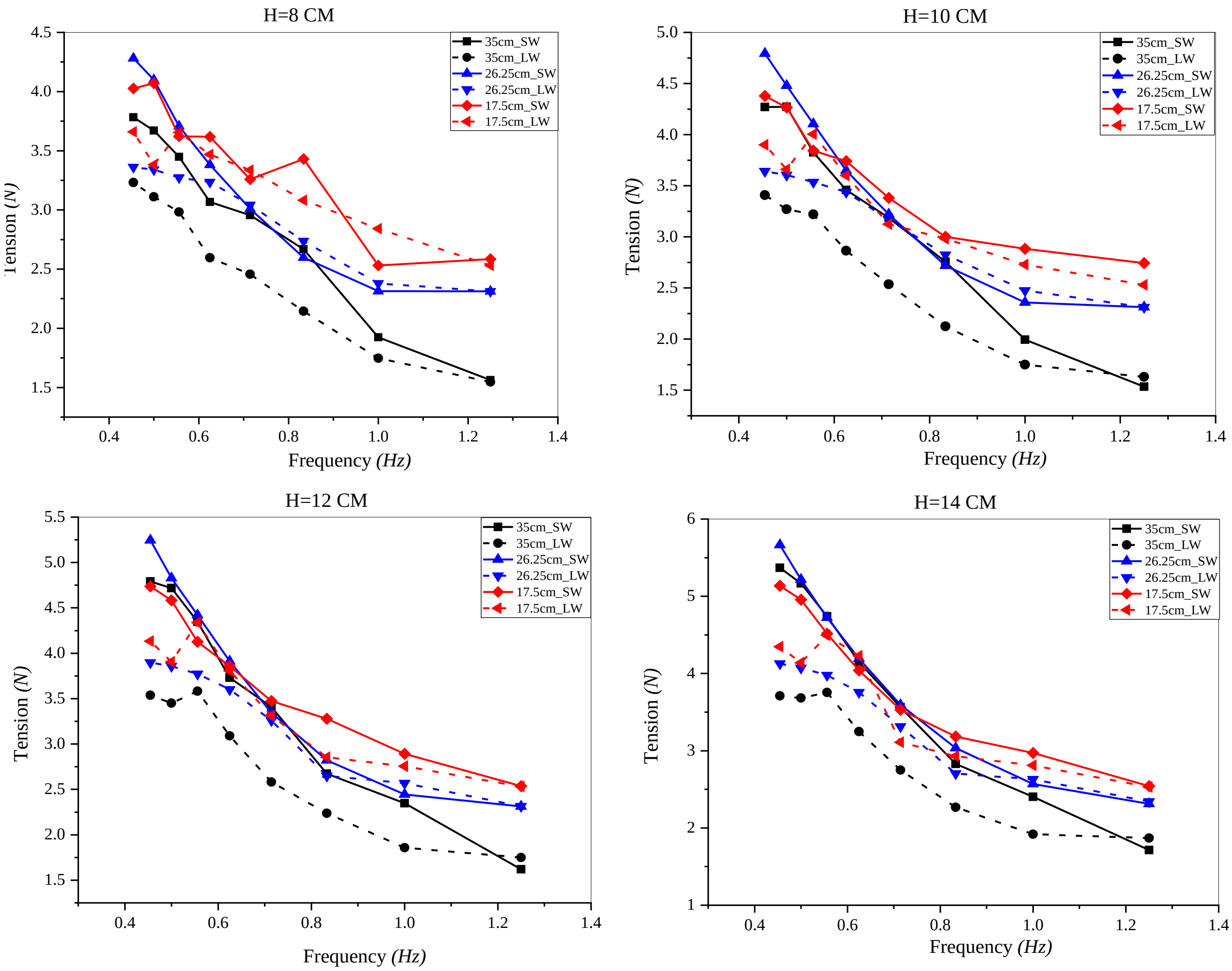

Fig. 10 Mooring line tension of the cage with three different drafts for wave heights of a) H=8cm, b) H=10cm, c) H=12cm and d) H=14cm.

4. Conclusions

To study the dynamic characteristics of the square cage with net solidity of 0.26, a detailed numerical study is conducted using ANSYS AQWA. The cage is subjected to a set of frequencies 0-6Hz to attain the dynamic parameters of added mass, radiation damping, wave excitation force and RAOs.

- The cage draft of 35cm obtained a highest added mass in range of 15-20kg (for a frequency range of 0-1Hz) heave and pitch motions with an oscillatory behavior.
- Even though the cage draft of 17.5cm obtained the highest radiation damping in heave, the cage draft of 35cm obtained a higher radiation damping for most of the frequencies, which is good in performance.
- The cage draft of 35cm exhibited the highest and cage draft of 17.5cm exhibited the lowest wave excitation force for both motion responses.
- The cage draft of 17.5cm showed the highest RAOs in heave and cage draft of 35cm obtained a highest RAOs in pitch motion.

- Time domain analysis also revealed that a cage draft of 17.5cm exhibited the greatest heave and pitch motions.
- The cage draft of 26.25cm obtained the highest mooring line tension of 5.75N for frequencies 0-0.6Hz and the cage draft of 17.5cm obtained the highest for most of the frequencies.
- The results indicate that the motion responses and mooring line tensions increase with wave heights.
- The cage draft of 35cm exhibits good performance for all wave conditions considered.

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