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Numerical analysis of a floating artificial reef system with the net in combined wave and current flow

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Introduction

A numerical model study was conducted to investigate the dynamics of a submerged artificial reef system with net. The reef system is moored by a single, tensioned line. The main component of the system is comprised mostly of nets. In this study, the reef system is analyzed with a numerical model.

The objectives of this study are to determine the motion and tension characteristics of the floating artificial reef system with net in response to both regular and irregular waves with and without a co-linear, superimposed current.

Materials and methods

The reef system analyzed consisted of a subsurface cylindrical net structure with 12 flotation units. A detailed schematic is shown on Fig. 1. The net reef system is deployed in 50 m of water and moored to the bottom by high tension cable. Numerical model simulation was performed using a finite element computer program developed specifically for marine aquaculture applications. Wave and current loadings on truss and buoy elements were introduced by utilizing the Morison equation.

Special attention is made when modeling nets. In past studies, the numerical modeling approach used the consistent net element (Tsukrov et al., 2003). This model technique was utilized in an effort to represent drag, buoyancy, inertial and elastic forces without modeling individual twine. In this case, however, a different modeling approach is used where nearly all of the twine is represented. The net was modeled as a series of truss elements that were based upon the specified twine diameter, square mesh length and solidity. Each truss element represented a net twine length of 2 times the square length. This resulted in a net consisting of 1983 elements, ensuring the element discretization would not affect the movement of the structure.

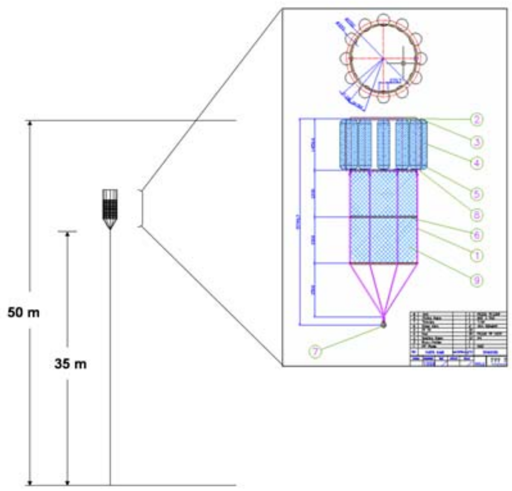

Fig. 1. Construction details of the floating artificial reef system with net.

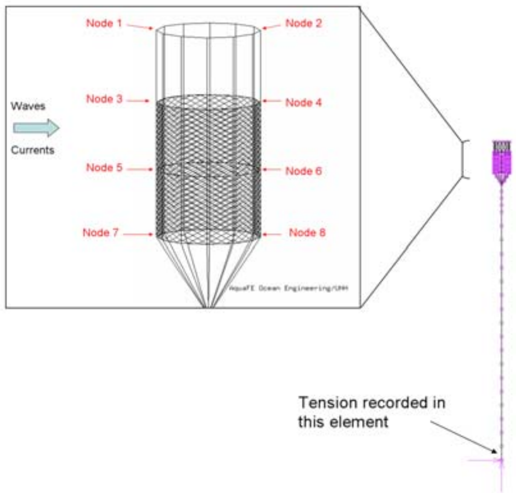

Fig. 2. Schematic of the node locations where the motion and tension data were analyzed

The first step in the approach was to build the net reef system in the model based on the components. The model was built using material and geometric properties. The model was then built with 1208 nodes and 2652 elements. The net was represented in the model using 1983 truss elements. The total system weight and buoyancy were calculated to be 8.77 and 16.72 kN, respectively. Note that these values do not take into account lines or net, only the major structural components, since they were used as a check versus numerical predictions.

Once the models were constructed, the first set of test conducted with the net reef system was performed with no forcing so that the static characteristics of each system were verified. The next set of test was performed with the numerical model in regular waves (wave heights: 2, 4, 6 and 8 m, wave periods: 6, 8, 10 and 12 sec) with and without a 1 m/s current. The currents were oriented in the same direction as the waves. The next set of simulations was performed using the net reef model in irregular waves. The numerical model was operated with and without a 1 m/s current. To obtain an irregular wave profile in the numerical routine, a spectrum is decomposed into multiple frequency components. The spectrum chosen was a form of the Joint North Sea Wave Project (JONSWAP) spectrum. In this study, the default shaping parameters are used, along with an H_s of 8.64 m and a T_p of 12.73 seconds.

For each simulation, motion data sets were acquired to characterize the dynamics of each the submerged reef structure. For the net reef system, 8 "nodes" were chosen for which horizontal and vertical movements were analyzed. Tension was also acquired at the point where the mooring connects with the seafloor. A schematic is shown in Fig. 2. Linear transfer function magnitudes calculated for the deterministic waves, referred to as response amplitude operators (RAOs), are obtained by dividing the amplitude of the response by the amplitude of the forcing for each wave frequency. For the irregular wave tests, linear transfer functions were calculated as a function of frequency using auto- and cross-spectral methods.

Results and discussion

The first set of numerical model simulations were performed without current and wave loading. In each of the simulations, the buoyancy of the artificial reef created vertical motion as the mooring lines stretched, pre-tensioning the components. The static simulation results in tension and heave for reef system are shown in Fig. 3.

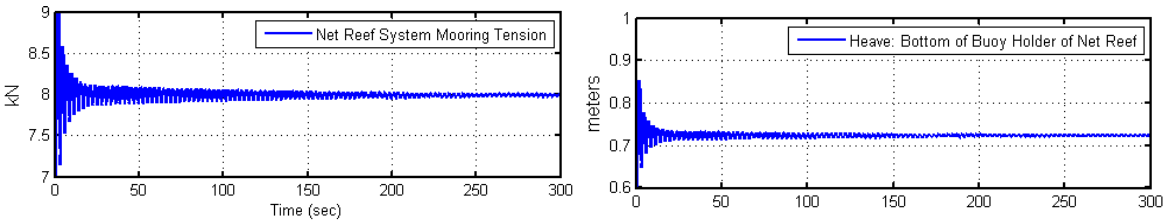

Fig. 3. The static response for tension (left) and heave (right) of the net reef system.

Using the average values in tension, heave, surge and pitch for each of the load cases, the tension and motion RAO values were found and are provided in Table 1. It must be noted the motions (especially heave and pitch) are likely coupled.

Table 1. RAOs for the net reef system normalized without the influence of currents

Load case	Tension (N/m)	Heave (m/m)	Surge (m/m)	Pitch (rad/rad)
H: 2m, T: 6 sec	262	0.0244	0.2658	0.1031
H: 4m, T: 8 sec	680	0.0653	0.3528	0.2315
H: 6m, T: 10 sec	898	0.0882	0.3814	0.2633
H: 8m, T: 12 sec	960	0.1014	0.4163	0.2834

Once the static and regular wave tests were complete, irregular wave tests were performed with and without the 1 m/s, co-linear current. The time series generated by the numerical model was processed to obtain the wave elevation auto-spectrum. The first step in analyzing the irregular wave results was to characterized tensions and motions by the zeroth moment of each spectral response. The results for this calculation, called the significant response of heave, surge, pitch, and the mooring element tensions, are provided in Table 2 for the net reef systems. The Table show the response differences between the wave input with and without a 1 m/s co-linear current.

Table 2. Significant wave response values of motion and tension in the net reef system

Current (m/s)	Waves (m)	Heave (m)	surge (m)	Pitch (rad)	Tension (kN)
0	8.62	0.76	3.98	0.088	7387
1	8.62	2.14	3.63	0.080	8328

Review of the dynamic simulations does not provide a strong indication of possible resonant conditions when subjected to the prescribed wave conditions. One of the most interesting results, however, of the numerical model simulations were from the static tests. Typically, the model is built with a predetermined mooring line length, but since the mooring line is actually a spring, upon the initiation of the model run, the buoyancy of the reef component stretches the against the restoring force of the mooring line causing an oscillation. The static heave result shown in Fig. 3 was further investigated with details shown by the solid lines on Fig. 4. The damped and natural periods of this oscillation were determined to examine if a resonating situation exists. Assuming an unforced, spring-mass system with linear damping, system characteristics can be determined by solving the standard, second order, harmonic differential equation (Note that the numerical model employs quadratic damping inherent in its formulation). The results were then plotted on Fig. 4 as the dashed line to show how the linear representation fit the numerical model results. Review of the plots shown on Fig. 4 shows system with relatively little damping (in heave) with damped natural periods of 2.8 seconds. This combination of system characteristics promotes a possible resonating situation in typical open ocean sea conditions with similar wave periods. Small damping values also indicate that oscillating amplitudes could be higher than expected.

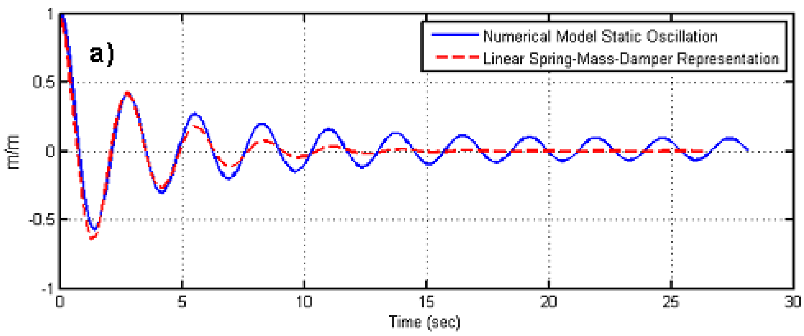

Fig. 4. Normalized oscillation results of the net reef system.

References

Tsukrov, I., O. Eroshkin, D.W. Fredriksson, M.R. Swift, and B. Celikkol, 2003. Finite element modeling of net panels using consistent net elements. Ocean Eng., 30, 251-270.