Dynamic Behavior of 2-D Flexible Porous Vertical Structure Exposed to Waves and Current – A Numerical Simulation

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Abstract— The main objective is to find out the environmental effects on the Flexible porous vertical structure and its stability when exposed to different parameters of waves and current. A numerical model of 2D net is modeled and simulated to analyze the response of the structure and tension in the mooring lines in these conditions. The system included a flexible net attached to floaters on the top and weight suspended on the bottom and high tensioned mooring with fixed floatation. The analysis is performed by OrcaFlex software which is a 3D non-linear time domain finite element program capable of dealing with arbitrarily large deflections of the flexible from the initial configuration. Input forcing parameters in the model consisted of regular waves, with or without steady current. The results analyzed are the effect of different wave, wave height, wave period, influence of the floater movement on the structural forces in the net, current on mooring line tension, and how the bottom weight affects the mooring line tension.

Keywords— Flexible porous vertical Structure, Net, Mooring tension force, Numerical model, OrcaFlex, Waves and Current

INTRODUCTION

Flexible porous structure also use as breakwater to reduce the intensity of wave action in inshore waters as well as fishing net which used in a fishing cage system. This structure is mainly composed of supple net, mooring lines and floaters. Flexible structure undergoes large deformation under external and internal forces as compare to rigid structures with the same environmental conditions. For example, the shape of a net in a current readily changes with change in flow speed and the length of netting twine undergoes extensional deformation as a result of various loads during fishing, because material used in net is highly non-linear, small environmental change can produce large deformation. To make the structure more accurate and stable, it is important to be able to predict the behavior of such structures in different wave situations.

Until recently, the study of the interaction between water waves and net has been addressed mainly in the coastal engineering literature with respect to the wave trapping qualities of porous structures. Wave Interaction with a Flexible Porous Breakwater in a Two-Layer Fluid has been studied by P. Suresh Kumar and T. Sahoo. The wave reflection and transmission by the vertical porous barriers have been studied analytically and experimental by (Chwang and Chan, 1998; Garcia et al., 2004; Twu and Lin, 1991). An investigation of Water Waves on Flexible and Porous Breakwaters has been done by Keh-Han Wang and XuguiRen. Numerical methods are currently being developed to study the dynamical behavior of flexible net structures in waves and current (Lader et al., 2003). Furthermore, Wu et al. (1998) theoretically investigated a damping effect of a horizontally submerged perforated plate. With their research as a background Williams et al. (2000) studied a freely floating cylinder with partly permeable walls. The fish net as a breakwater structure was investigated by Chan and Lee (2001). With wave exposure becoming more and more critical, the understanding of the interaction between waves and structure is important. It is necessary to understand both the dynamic forces acting on the net structure and tension in the mooring system.

Today, much research remains before the dynamic behaviors of flexible porous structures are satisfactorily understood. It is therefore important to study the principal behavior of these structures in general, and in particular develop numerical models which can predict their behavior in different load conditions. This research presents a simple numerical model of a flexible porous structure. The model is used to study the behavior of the net panel exposed to waves and current. The motivation for studying only a single net sheet is to get a principal understanding of the complex dynamic and hydroelastic properties of flexible netting structures.

MODEL DESCRIPTION

ASSUMPTIONS

Model is composed of many meshes, and each mesh can be regarded as a construction of four mesh bars connected each other at their two ends as shown in Fig. 1. In order to build up the numerical model, the following assumptions are used:

(1) There is only tension in the axis direction of a mesh bar and the tension is constant across the cross-section of the mesh bar.

(2) The relative displacements of all points on the cross-section of the mesh bar are equal.

(3) The cross-sectional area of the mesh bar remains constant during deformation.

(4) The netting twine is completely flexible and easily bent without resistance.

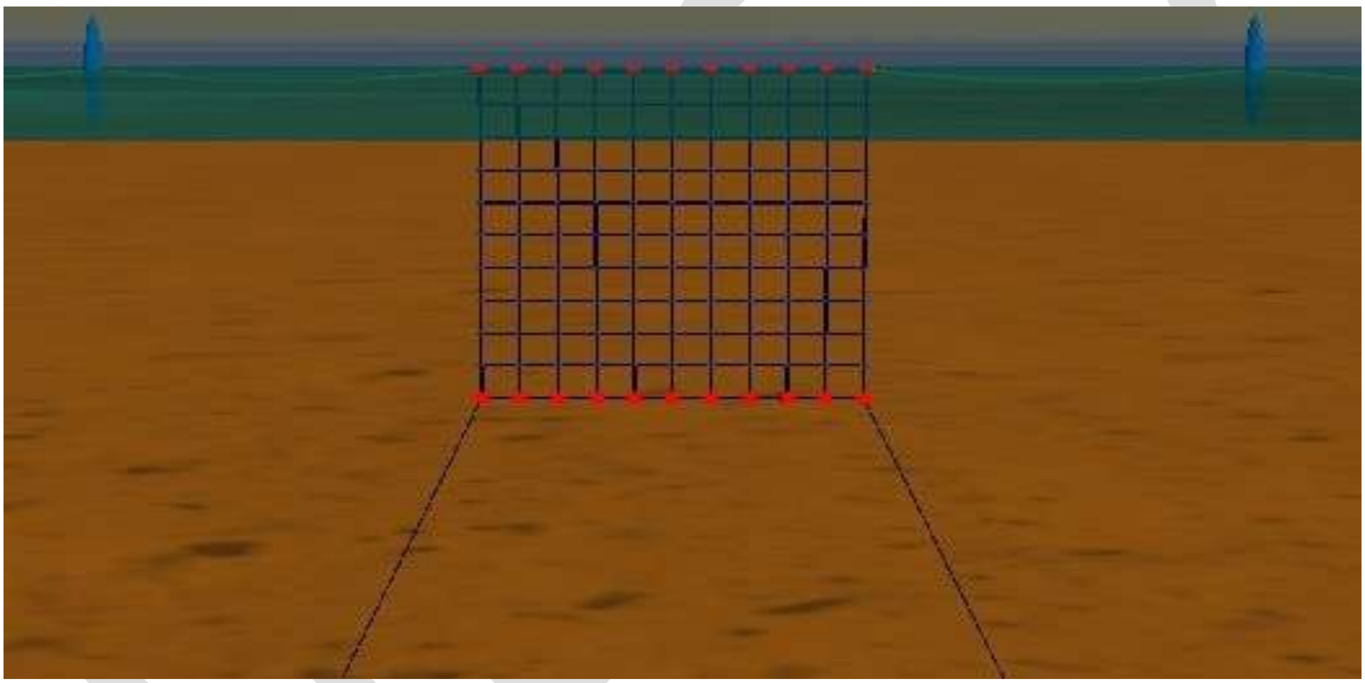


Fig. 1 Numerical model of 2-D Flexible porous vertical structures in OrcaFlex

MATERIAL USED

In making a net for a specific purpose many considerations are to be taken into account, such as the forces applying on the net, their distribution around the net, the kind of materials the net and mooring lines are made from, and the way in which these are used. The main forces on any net structure are those arising from winds, waves and currents, and from the interaction of the structure and its mooring system with the resulting movements. The rope and net industry has seen many changes in the last number of years. Initially only steel and natural fibers were on the market as raw material. In the 40s and 50s high tenacity polymeric fibers were developed, such as polyamides and polyester, with many advantages over traditional materials. This opened the way to new low weightconstructions with rot resistant materials. Because of their chemical composition, polyester and polyamides have intrinsic advantages for use in the marine environment. Water hardly affects their properties and cold-water shrinkage is virtually zero, so they can be regarded as a very stable material. Apart from its insensitivity to water, the chemical composition of polyester and polyamide results in properties such as UV weathering and wet abrasion. Material used in this model in Nylon 210D/96.

OVERVIEW

The model described here is a simple model of a single net sheet consists mainly of a netting system, floaters (Buoys), a weight system to provide the tension in the net and a mooring system to hold the structure with sea bed and fixed floaters. The structure, being flexible and porous, is held fixed in the sea bed with mooring lines. The net can be modeled as a series of lumped point masses that are interconnected with springs without mass. Lumped point masses are set at each knot and at the center of the mesh bar. Each knot point mass is assumed to be a spherical point at which the fluid force coefficient is constant in motion direction. Because the mesh bar is cylindrical, however, the fluid forces acting on the point masses at each mesh bar should differ in different directions. Therefore, it is assumed that the lumped points at each mesh bar have the fluid dynamic characteristics of cylindrical elements, and that the fluid force coefficients vary with the relative fluid velocity direction.

The importance of this model is the behavior of the net as a complete entity. The net mesh needs to be modeled in sufficient refinement to show the distribution of loading. This means an equivalent mesh can be generated that has the same resultant loads but does not need to show each individual knot and line. This is basically the same as defining the mesh refinement on a surface for an FE model. These nets are suspended below floating buoys and the whole structure is then moored using more lines.

BUOYS

Buoys can be classified into two categories:

3D Buoys are simplified point elements with only 3 degrees of freedom: X, Y and Z. They do not rotate, but remain aligned with the global axes as shown in the Fig .2 and 3. They therefore do not have rotational properties and moments on the buoy are ignored. They should therefore be used only where structure need to be still and also known as fixed floatation system.

Fig. 2 Numerical model of 3D Buoy

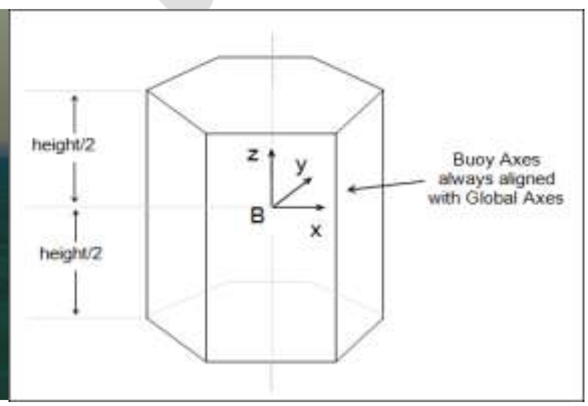
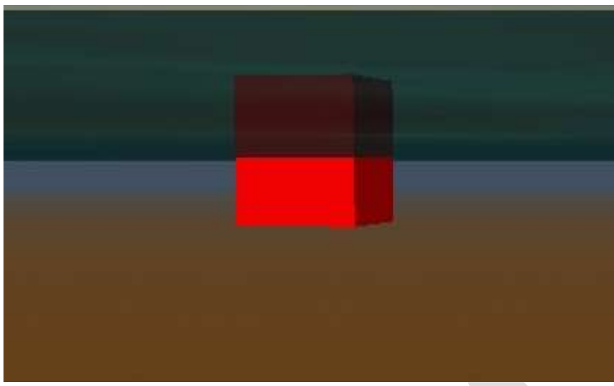


Fig. 3 3D Buoy

6D Buoys are objects having all six degrees of freedom – 3 translational (X, Y, Z) and 3 rotational (Rotation 1, 2, 3). Buoys have both mass and moments of inertia, and forces and moments from many different effects can be modeled.

Lines attached to a 6D Buoy can thus experience both moment effects and translations as the buoy rotates. Lines can be attached to an offset position on a buoy – this allows the direct study of line clashing, including the separation introduced by spaced attachment points.

Lumped type 6D Buoys (shown in Fig. 4 and 5) used in the model because it restricts the accuracy with which interactions with the water surface are modeled. Where a lumped buoy pierces the surface it is treated for buoyancy purposes as a simple vertical stick element with a length equal to the specified height of the buoy, and buoyancy therefore changes linearly with vertical position without regard to orientation.



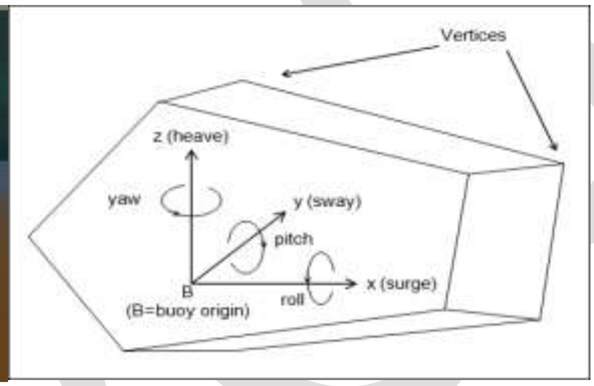


Fig. 4 Numerical model of 6D Lumped Buoy Fig. 5 6D Buoy

Buoys act as a cushion to absorb the hydrodynamic impact forces that impinge on the structure and as boundary markers to denote the size of the full system; the innermost buoys act as supporting floats. To avoid the environmental forces when a typhoon is coming, the floaters and the net are submerged under the surface of the water by manually opening the submerged collar valves in the floaters and letting sea water automatically flood in the floating tubes to gain extra weight; thus, the total buoyant forces of the innermost buoys must be sufficient to overcome the total weight of the netting system so that it does not sink to the sea floor and encounter some kind of abrasion problem.

MOORING SYSTEM

The main purpose of the mooring system is to fasten net at a specific location and to prevent it from drifting away as environmental loadings act on them. Therefore, the strength and durability of the material used for mooring lines are important factors. The material most commonly used by the local fishing industry is Nylon, PET (Polyester), and PP (Polypropylene). The specific gravity of Nylon is 1.14 and PET is 1.38; both are heavier than the water's specific gravity, and when installed in the field these materials tend to sink to the sea floor. The specific gravity of PP is about 0.91, and it may float on the water surface if disconnected from the bottom anchors. A mooring system failure can occur if the system encounters severe environmental forces, such as those that occur during a strong typhoon. Once a cable breaks, it may induce a ''domino effect'' so that other mooring lines pop and the whole net system may wash away instantly. To reduce the impact forces that affect mooring lines, distance buoys (fixed floatation) are installed to absorb these undesired forces. To anchor the system to the sea floor three types of anchor are commonly used in the field: embedment anchors, pile anchors, and deadweight anchors. Iron embedment anchors are only suitable on sandy or muddy bottoms, whereas pile and deadweight anchors can be used in rocky or sandy/ muddy bottoms. Pile anchors must be inserted deeply into the substrate to gain enough holding capacity, and deadweight anchors rely totally on the friction forces with the sea bottom to resist the horizontal tension forces acting on the mooring lines and the weight of anchors to take care the vertical tension force

SIMULATION

The net in the simulation is a 3 m wide and 3 m deep net sheet in water depth of 10 m, divided into 10 equally sized elements. The net was oriented parallel to the y-axis, and was subjected to regular waves and current running in the positive x-direction. The top point of the net was forced to follow the vertical displacement of the wave surface. The net behavior is simulated over multiple wave periods and the net behavior is shown at several time instances in the simulations

RESULTS AND DISCUSSION

The net sheet used in the case studies is described in table 1. Table 2 shows the parameters and parameter settings used in the different cases. In each case, one of the parameters was varied, while the other parameters were kept constant.

Table 1 Net specification.

Material	Nylon 210D/96
Depth (m)	3
Twine diameter (m)	0.0085
Mess size (m)	0.3
Elastic coefficient (kN/m2)	350900

Table 2, the parameter values for each of the six cases

Case	Parameter	Default values	Value settings		
1	Wave geometry	v = 0	H = 0.44, T = 2,	H = 1, T = 3,	H = 1.78, T = 4,
2	Wave height	T = 4, v = 0.5	H = 0.44,	H = 1,	H = 1.78,
3	Wave period	H = 1, v = 0.5	T = 3,	T = 6,	T = 9,

4	Current	H = 1, T = 3,	v = 0	v = 0.3	v = 0.6
5	Top point movement	H = 1, T = 3, v = 0	fixed	Follow with heave	
6	Bottom weight	H = 1, T = 3, v = 0.5	Weight=10kg	Weight=20kg	Weight=30kg

Where,

V = current speed,

H = wave height,

T = wave period.

Case 1: Wave geometry

It can be observed that the wave with the longest period (T = 4 s) and largest height (H = 1.78) produces the largest forces in the netas shown in Fig.6

Case 2: Wave height

When the wave period and current constant, wave with the highest height (H = 1.78) produces the largest force on the mooring as shown in Fig.7

Case 3: Wave period

From the result we can conclude that the shortest wave (t = 3), produce the largest load on mooring when compare to other waves as shown in Fig. 8

Case 4: Current

Three different levels of current in combination with waves (T = 3 s, H = 1 m) are applied to the net. The dynamic amplitude of the drag force is larger forthe current cases than for the no current case. This is dueto a change in the angle between the top element and thehorizontal plane because of the current. As illustrated in Fig. 9, the current causes the angle between the topelement and the horizontal plane to be smaller, andconsequently the drag force (horizontal component of thetop element force) becomes larger (assuming constantelement force). Thus, the presence of current results inhigher drag forces and higher loads on the mooring lines

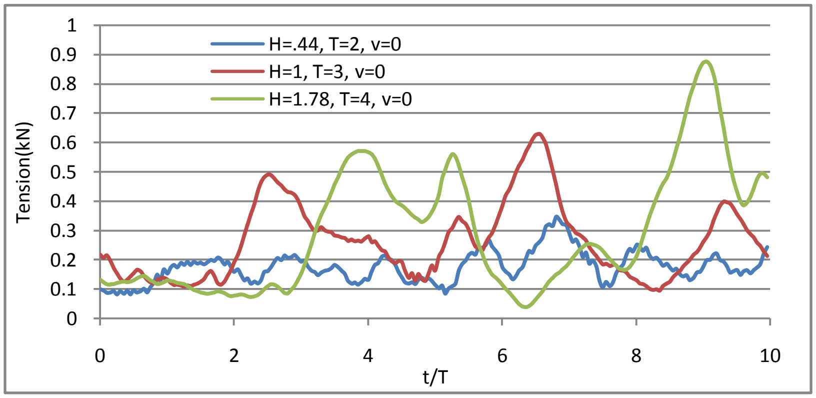


Fig 6 Effect of different waves on mooring line tension

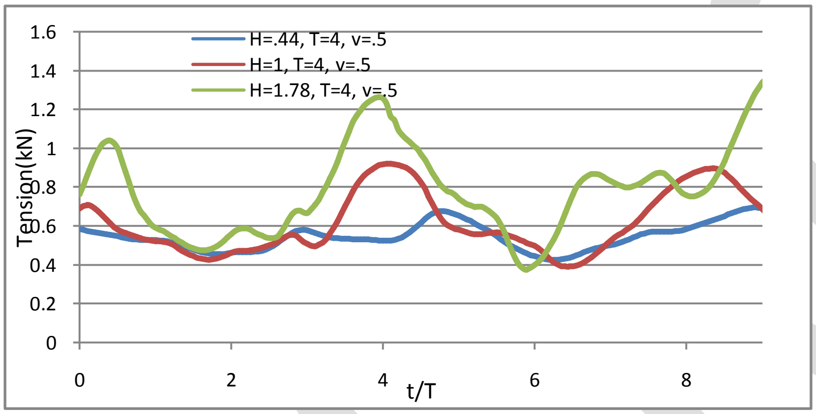


Fig. 7 Effect of wave heights on mooring line tension

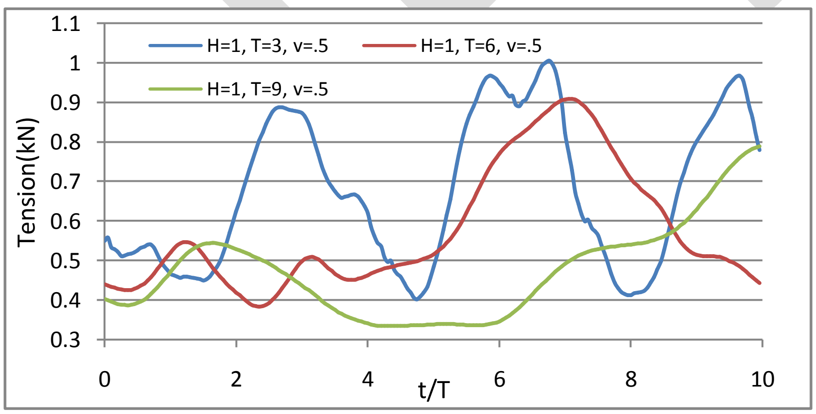


Fig. 8 Effect of wave period on mooring line tension

Case 5: Top point movement

This case illustrates clearly the maximum structural force between net/floater joint and net/bottom weight. Fig. 10 shows the time history of the element structural force in the top and bottom element when the structure is exposed to waves. The maximum element structural force in these two elements shows the structural forces in the joint between the net and the floater, and between the net andthe bottom weight. If the structural force between joints exceeds the limit specified by the material used then result will be failure of the system. The parameters used are Wave: 3 s/ 1 m, no current, bottom weight 10 kg.

Two cases analyzed here:

(i) calm environment when floater is fixed

(ii) Harsh environment when floater moves with the waves

The dynamic amplitude of the force is approximately five times larger in the floater/net joint and net/bottom weight point.

Therefore forces in floater when moving with waves contributes to analysis forces and tensions in the net.

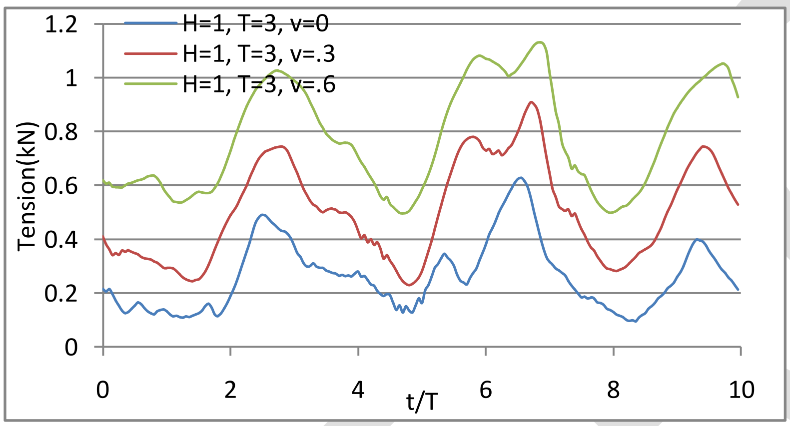


Fig. 9 Effect of current speed on mooring line tension

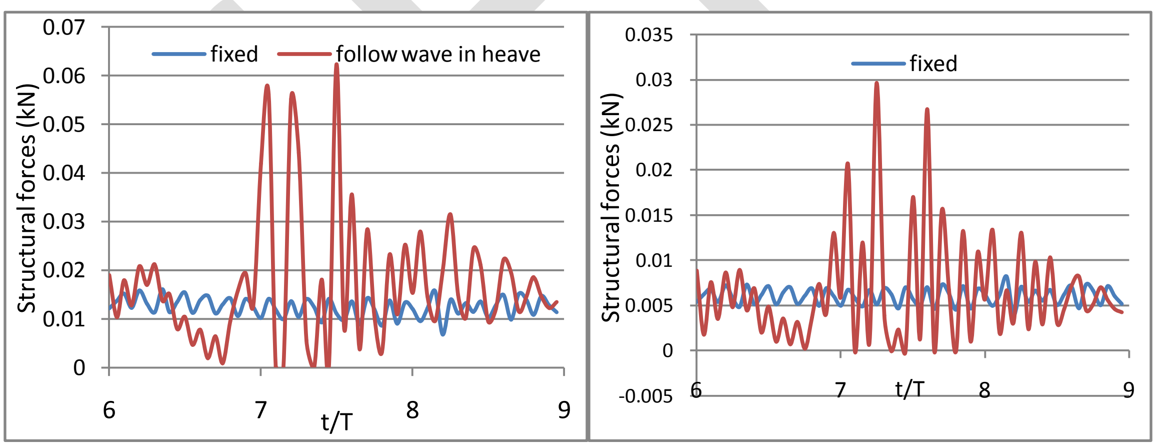


Fig. 10 Elemental structural forces in floater (left) and bottom weight (right)

For the net with the moving top point it can be observed that the force in the top element goes to zero, causes slack in the net when the movement of the floater is too large.

The large dynamic amplitude of the force in the bottom element is a direct consequence of this slack; the spikes in the curve representing the minimum and maximum force in the bottom element coincide with the beginning and ending of the period when the top element force is zero.

Situations where the net experiences slack should be avoided since this causes large forces which can result in net failure.

This implies the importance of modeling the behavior of the floater accurately in order to obtain good estimates for the structural forces in the net.

Case 6: Bottom weight

The main function of the bottom weight on a net pen is to prevent deformation of the net when exposed to waves and current. For this purpose, the weightshould be as large as possible, but a large bottomweight also increases the loads on the net as can be seen in Fig. 11. When the bottom weight increases from 10 to 30 kg dynamicamplitude increases approximately seven times. An increase in bottom weight will thus have a larger impact on the forces on the joint between the net and the bottom weight than on the joint between the net and the floater.

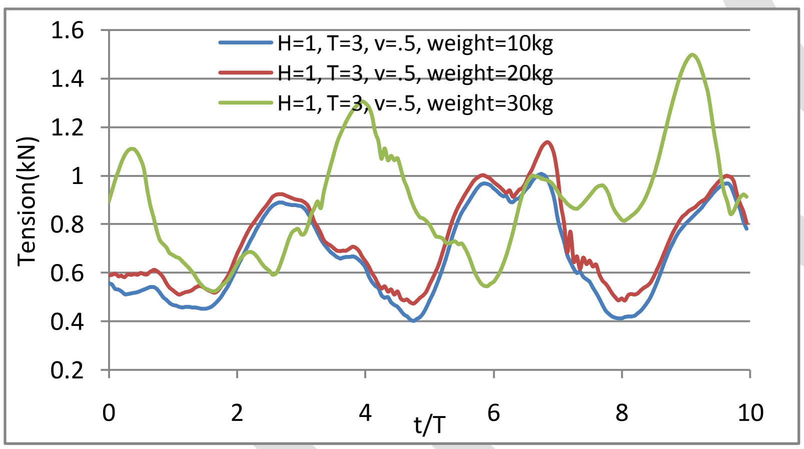


Fig. 11 Effect of bottom weight on mooring line

CONCLUSION

Based on the above simulation cases, several important features of the dynamic behavior of flexible porous structures exposed to waves and current have been identified:

Wave with the longest period and largest height produces the largest forces in the net. The floater motion can cause slack in the net structure. A slack in the top of the net structure results in large dynamic forces in the bottom of the net structure. Higher current speed can produce larger forces in structure so larger mooring tension. The dynamic amplitude of the wave induced force on the mooring is less when the net is exposed to a current in either direction. A short wave cause a more load on the structure. The motion of the floater is the main contributor to the forces in the net. An increase in the mass of the bottom weights lead to an increase in the dynamic force, especially at the bottom of the net

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