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Dynamic Response of Coupled Mooring Lines and Floating Wave Energy Devices in Waves / Currents

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***Abstract:** Various global studies have shown that ocean waves energy have large potential in renewable energy sector. Their role within renewable energy gets high priority in the future by the government of United Kingdom. The principle concept of wave energy is when wave energy is converted into potential energy by the wave energy devices to generate electricity. An understanding of the dynamic response of the devices and mooring lines is important for this paper. This paper deals with the analysis of the various effects that influence the different design of wave energy converter devices. The mooring design idea is also analyzed to show which mooring layout is suitable to fulfill the requirement. The design of mooring configuration also influence how wave power is extracted and how such system are operated and maintained. The effects investigated in this paper are regular and irregular waves, motion @ six degrees of freedom, maximum and minimum mooring tension, different waves direction, wave current, energy and power take off.*

I. INTRODUCTION

Renewable energy is the energy that generates from natural resources to create electricity without using fuel and which does not contribute carbon dioxide to the atmosphere. Natural sources such as wave, wind, and sun are part of renewable resources. Using these sources helps not only to reduce greenhouse gas emissions from energy generation and consumption but also to reduce the world's dependenceon oil and gas. Waves require some type of energy disturbance in order to be formed such as wind, displacement (earthquake, landslide), changes in atmospheric pressure and gravitational pull. Wind creates waves when it blows across the surface of the water, the resulting pressure distribution deflects the surface vertically which in turn is counteracted by gravity. Heave movement of water is formed and produces complex pattern of swell wave on the surface of water.

Wave energy can certainly be converted and used more or less directly to perform mechanical work.

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Energy from the wave can be generated using a variety of technologies that capture energy from the surface wave or pressure fluctuation below the surface. There are currently six main types of devices that convert wave energy.They are point absorber, overtopping, attenuator, oscillating water column, oscillating wave surge converter, and submerged pressure differential devices.

This paper investigates, by simulation results from OrcaFlex software. The various effect of dynamic response such as six degrees of motion of the device, mooring tension, and more are explained in this paper. The method of simulation includes design the existing prototype of wave energy converter. The devices with different mooring configuration such as taut and catenary are investigated. This will allow the influence of the mooring strategy on the performance of the wave energy device to be studied.

Geometry Model

For a start, I have modeled wave energy devices in OrcaFlex software. The model is the single body (cylinder calm buoy) reacting against the sea bottom with different mooring configuration. Details of the geometry are explained in table 1. The shape of the devices is cylinder and it is almost similar with the existing prototype devised by the Uppsala University. The cylinder wave energy extract energy by heaving oscillation and the principle is point absorber.

Table.1 Geometry and mass of the device

Description	Value	Unit
Mass	250.0	tonne
Cylinder Diameter, D	11.10	m
Cylinder Radius, r	5.60	m
Cylinder Draft, d	2.25	m
Cylinder Freeboard, f	2.74	m
Cylinder Length, L	5.00	m

Water Depth

The water depth that I'm focusing is on shallow water which is 25 m and deep water 100 m. The water depth is important to absorb energy. When it goes deeper, the wave height will be higher and have a longer period than shallow water.

Waves

Different type of waves is investigated in this research. Type of waves involve in this analysis are regular wave (single airy) and irregular wave (Jonswap). This will show at whether wave energy devices are suitable or not to be installed at extreme condition.

Wave characteristic depend on the water depth. On 25 meter water depth which is close to shoreline, wave height is smaller than deep water. Wave at the offshore has high wave height and long period which is better for wave energy devices. As the wave travel close to shore, the wave height is reducing and wave period is smaller until it breaks. Wave and water depth details are as follow:

Table. 2 Wave and depth

Water depth, d	25 m	100 m
Wave height, h	1.3 m	2.3 m
Wave period, s	6 s	8 s

Current

In this analysis, I want to analyze the effect of current on the device. The research are based on no current, uniform current and shear flow current (see figure 1). By knowing this result, we can know what it will effect on device or mooring and at which condition suitable to place the devices. Therefore, the current that I'm using is 0.5 m/s for all cases. In shear flow condition, deep water does not have current on the seabed but there is current on shallow water.

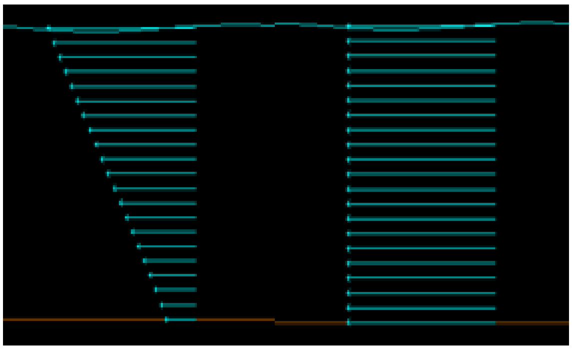

Fig. 1 Uniformand shear floe current

Mooring Layout

In this analysis, I want to analyze as to how the devices will react on different mooring configuration. The 7 different layout of the mooring are:

- Single taut
- Double catenaryand Double taut
- Triple catenary and Triple taut
- Four catenary and Four taut

The mooring has to maintain the position of the wave energy converter under loading condition and allows efficient conversion of wave energy in operational condition.

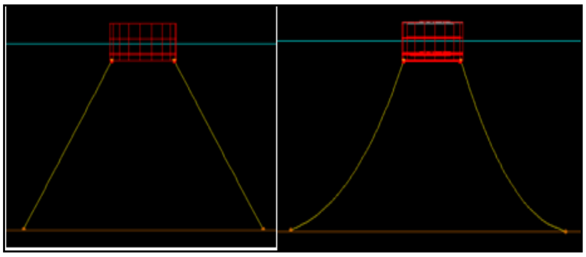

Fig. 2 Taut Mooring and Catenary Mooring configuration

Waves Direction

In this analysis, I want to discover which mooring configuration is suitable to act in different wave direction. In the two mooring, the angle different is 180 degrees. In the three mooring line, the angle is 120 degrees and for 4 mooring lines, the angle is 90 degrees. The wave's direction is 90 degrees, 135 and 180 degrees on 2 and 3 mooring. As for 4 mooring line, the angle is 90 degrees, 112.5 degrees, and 135 degrees (see figure 11). The result of this analysis will tell how the device motion and also the mooring tension act on different wave direction.

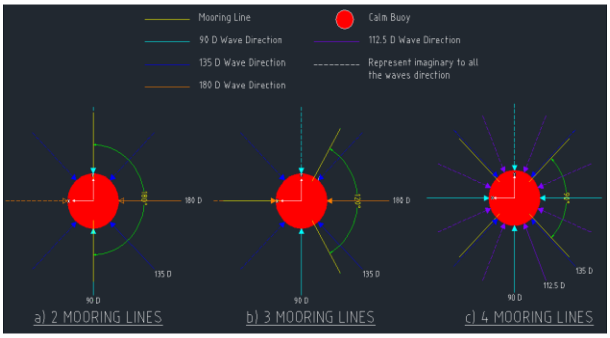

Fig. 3 Plan view of two mooring lines, three mooring lines, and four mooring lines layout

Results

The results for all the analysis shows that, four catenary mooring configuration responses better than the other layout. The results are shown in appendix.

II. RECOMMENDATION FOR FURTHER WORK

Different mooring has its own properties such as the stiffness. The stiffness of the mooring plays an important role in order to maintain the devices in equilibrium position. But the difference in the stiffness, it will make a difference in its performance. In future, I would like to use other mooring material such as chain, fibre, and cable mooring. Fibre mooring might be expensive but it's really good in deep-water wave energy converter. By using the different mooring, we can know which is the best or suitable to use.

The shape of buoy I used is cylinder shape. In future I like to research on other type of shape for example cone, cylinder with skirt. The research of effect of floating structure geometry on performance, the axisymmetric bodies will tell which type of geometry will absorb much energy from waves. The influence of performance on geometry shape is important.

The examined floaters are a cylindrical body withand without vertical and horizontal skirts at its bottom, a coneand a two – body, piston – like arrangement, which consists of an internal cone and an exterior torus.

Buoy geometry is also important. The results show that tall thin cylinder absorbs energy very well. In my opinion, wide buoy geometry will not absorb energy from the wave very well. This is because large area of waterplane on the surface is not good to absorb the wave energy compared to cylinder tall and thin with 80% of the cylinder is submerged. Large waterplane of the device will encounter large side to side motion.

In the future as well, I would like to analyze the dynamic response of the wave energy converter in ultra-deep water. In ultra-deep water, they have large period and amplitude of wave which can benefit wave energy absorption. This can also benefit oil platform operator where they can run the generator to power their platform electrical needs. By having this technology on or close to the oil platform, this will make environmental clean for the working environment and save cost in terms of oil. In the asses of ultra-deep water, the geometry of the device tends to be larger than the existing devices. So far, the technology is only been research on 40 m to 100 m water depth. And I think this is good idea to see the response of wave energy device in the future.

III. DISCUSSION

Buoy motion

The simulation results also show that the current only affect a slightly small different value of motion or rotation. When there is no current, the buoy motion move up and down calmly but in the current condition, it tends to make the buoy not stable. This is because it increases the drag force on the buoy.

In one taut mooring line, the device does not experience the sway motion at all. The sway and heave motion is higher when it goes to deep water. In two catenary mooring lines, the heave and surge motion is higher than two taut. Three catenary mooring have almost the same result in heave motion as in two catenary. Dependent device (taut configuration) shows that it is not suitable for wave energy. This is because the heave motion magnitude produce is really small amount. It is better to have two catenary than three catenary because this could save the cost.Taut mooring line configuration have low heave motion but greater in surge, therefore, taut mooring is not suitable for point absorber or heaving devices. Four catenary motions are suitable for shallow and depth water. It produces high heave motion with small surge and pitch motion that can be a barrier for energy absorption.

Water Depth

For the floating devices, deeper water is better than shallow water. As we discussed earlier, in deep water, the motion drops as it go deeper to the seabed. I think shallow water is suitable for devices below the water surface where the orbital motion in shallow water is not reduce rapidly to seabed.

The results show that high motions occur in depth water than shallow water. This clearly stated in the results when working in deep water, the waves are greater than shallow water. Obviously high tension occurs in deep water. The deeper the water, the bigger the tension on the device and seabed. Four catenary mooring is suitable for deep water.

Fast Fourier Transform

The result shows that the device is suitable to absorbed energy in regular wave or swell wave environment. In extreme condition, the device does act really well because the motion of the device is not stable.

The results show that in catenary mooring line configuration, the magnitude and frequency are almost similar with two, three, and four catenary mooring lines. But in two catenary, it can’t absorb the energy from the wave if the wave direction is different. For two catenary, if the wave parallel to the devices, it is great possibility that it can absorb energy higher. In three and four catenary mooring configuration, it can withstand the different wave direction.

Force

Cable moorings force acting on the device and seabed are common. They comprise moorings with different properties made up of different elements of elasticity, mass and buoyancy. These properties can be used in different ways to provide a horizontal restoring force and vertical pulling force. In this section, I will discuss on the horizontal restoring force and vertical pulling force. The result shows that the catenary configuration faces small force than the taut configuration.

The catenary mooring arrives at the seabed horizontally subjecting the anchor to horizontal forces. In a catenary mooring, most of the restoring forces are generated by the weight of the mooring line. It derives its compliance from the change in suspended line weight.

The taut mooring arrives at the seabed at an angle, meaning the anchor point has to resist both horizontal and vertical forces. The restoring forces are generated by the elasticity of the mooring line. An advantage of a taut leg mooring over the catenary mooring is that the footprint of the taut leg mooring is smaller than the footprint of the catenary mooring. A taut mooring leg will usually have an angle of between 30 and 45 degrees to horizontal at the buoy and exhibit fairly linear load-excursion characteristics. A further advantage is the better load sharing between adjacent lines than is typical of a catenary array, so improving overall efficiency of the system.

A taut mooring also has much shorter lines than a catenary system at similar depth. Crowded seafloor conditions present challenges where synthetics/taut systems have played a major role. These applications have been used to reduce the risk of steel mooring components suspended over pipelines or subsea equipment. Taut doesn’t have touchdown point where the mooring fatigue life is longer than catenary mooring.

Mooring Configurations

Catenary looks the best option than the taut mooring. Even though the cost and the difficult to install, it worth it. Independent devices seem to be much more effective for point absorber wave energy devices. The taut mooring configuration gives small amount of heave motion which is disadvantage for point absorber.

Power

It is found that maximum power is obtained whenthe device is tuned according to the incoming waveswell. At this tuning the natural frequency of the deviceis adjusted to the incoming wave frequency. Decay tests have been carried out to measure natural frequency. In the decay tests the device ispulled in still water toward maximum displacement andthen released while recording the time history of its position.

The results also show that the four catenary mooring configurations will produce more power output than other. It clearly stated that the magnitude is higher so it can produce high stroke to produce electricity.

IV. CONCLUSIONS

This paper has been of tremendous success for my enhancement and advancement in knowledge and understanding of the wave energy converter.

Among the entire mooring layout, the best option is with four catenary moorings. It shows that side to side motion is not created thus only allows heave motion. The tension is also consistent with this device and will produce a lot of power. With this heave motion, the technology used is point absorber to convert kinetic energy to power.

Harnessing wave energy can substantially reduce humanities emissions and harmful environmental impact. Wave energy is a clean and renewable energy that are reliable, realistic, sustainable and economical which can replace all current fuel sources used by the people of this planet. Our research balances many elements between people, prosperity and the planet. Our will and intention is not to use any more of theadditional land resources and to provide an emissions free energy source.

All people will prosper from wave energy because it is globally available in sufficient quantity to power all human energy consumption and needs in the foreseeable future. The project can reduce environmental impact beginning with the first commercial production model and grow toward a global shift in human energy use.

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I would very much like to recognize, with grateful thank you to DrNarakornSrinil from University of Strathclyde for his support, guidance and invaluable advice throughout this project. He led me to discover so many interesting findings, great ideas and open up my profound and deep thoughts into the subject. I am indebted to him in lending me his professional and learned supervision.

Summary

Table. 3 Summary from the analysis/discussion

Mooring Configurations	Observations
One taut	• Good in all wave directions • Low heave motion • High surge motion • High line tension on seabed and devices
Two catenary	• Suitable if the incoming wave parallel to the mooring or opposite • High power (kW) production • Low tension on seabed and devices
Two taut	• Low heave motion • High surge motion • High line tension on seabed and devices • High line tension
Three catenary	• Good in all wave directions • High heave motion • High power (kW) production • Low tension on seabed and device
Three taut	• Low heave motion • High line tension • High surge motion • High line tension on seabed and devices

Four catenary	• High heave motion • Low line tension on seabed and devices • Suitable for shallow and deepwater • Great wave energy absorption • High power (kW) production • High mooring cost • Good in all wave direction
Four taut	• Low heave motion • High surge motion • High line tension on seabed and device • High line tension

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APPENDIX A

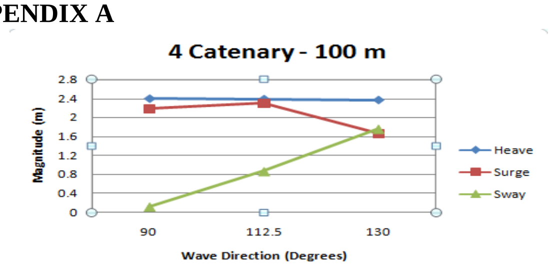


Fig. 1 Heave, surge and sway motion for four catenary in 100 meter water depth

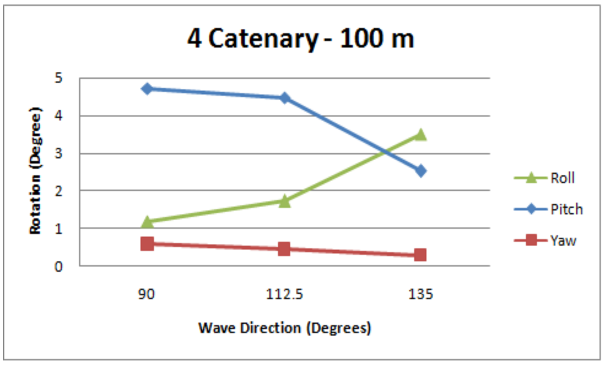
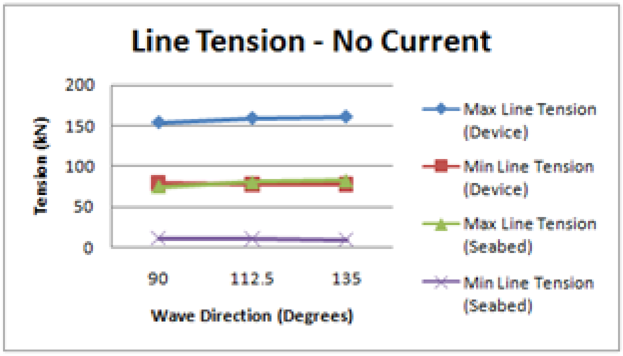
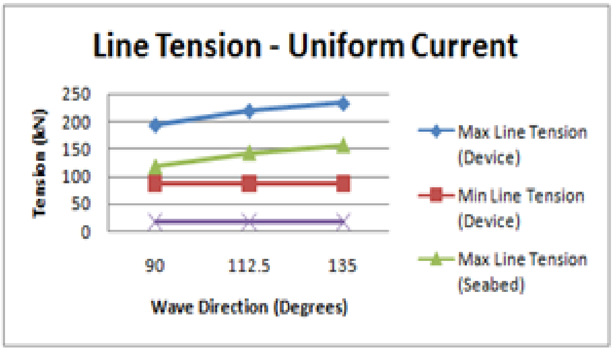


Fig. 2 Roll, pitch and yaw motion for four catenary in 100 meter water depth





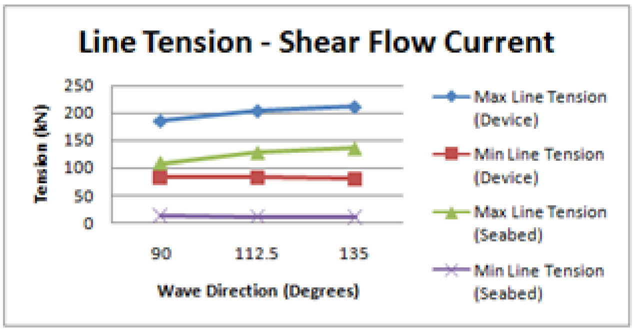


Fig. 3 Maximum and minimum line tension acting on the device and seabed with different current on four catenary mooring line (100 m)

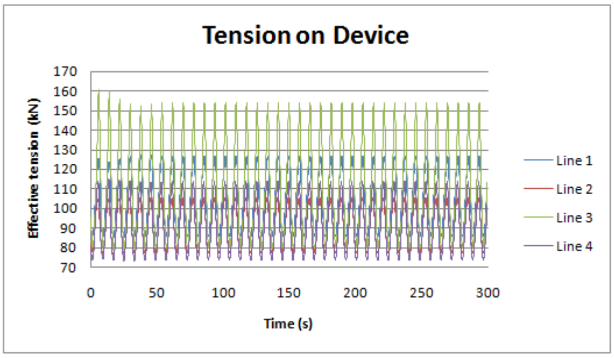


Fig. 4 Four mooring line tension on buoy in 90 degree wave direction

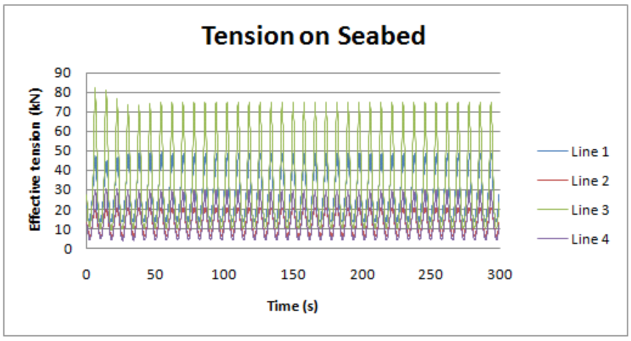


Fig. 5Four mooring line tension on buoy in 90 degree wave direction

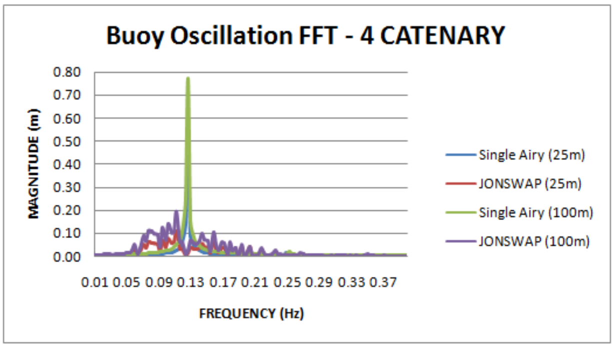


Fig. 6FFT for four catenary mooring line with different waves and different depth

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