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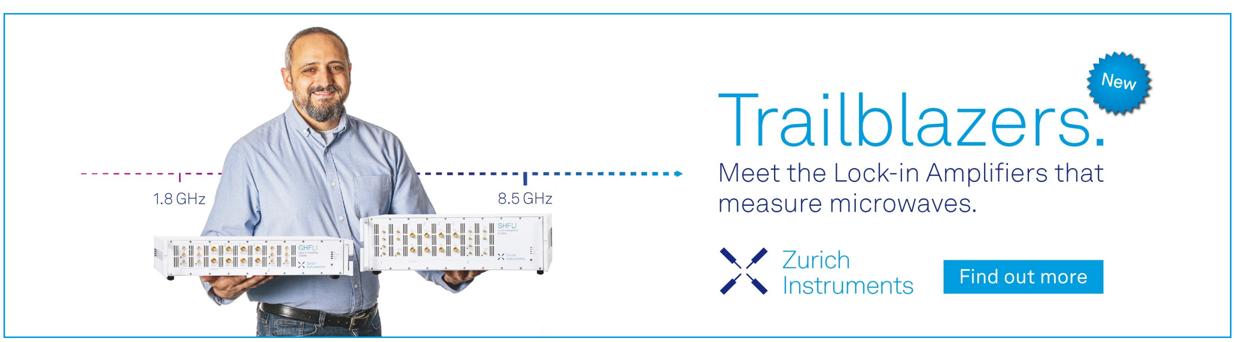

Load Characteristics of Cold Water Pipe Based on Fibreglass-Filled HDPE Composites

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Abstract. Cold water pipe (CWP) which is used in ocean thermal energy conversion stationary surface platform should be able to keep water at a temperature of ~ 5ºC, with the result that cold water could be used to liquefy ammonia vapor from a turbine generator to generate electricity. CWP has an inner diameter of about 3m to 4m that reach to 500m water depth. CWP on the stationary platform will experience stresses due to current and wave loads and the weight of the pipe itself. This paper will explain the loading that occurs. Seawater currents generate movement of CWP in the horizontal direction which causes the pipe to be subjected to bending stress. Bending loading fluctuates with different wavelengths and angles each time. In addition, seawater currents lead vortex-induced vibration. The properties of pipe material used should be lightweight, flexible and strength that subjected to wave and current loads. HDPE material is suitable for CWP than other polymeric materials. Because of lightweight and flexible. For the strength, it is filled with short fiberglass in order to withstand low temperature and corrosion. The CWP bending due to seawater current causes the structure of the pipe material to experience repetitive tensile and compressive loading. And due to waves occurs axial tensile load. So that the main load on the CWP is the tension and pull loading that occurs repeatedly or fluctuating in sinusoidal shape and the resistance of the CWP will be more accurately known by fatigue testing alternating load.

INTRODUCTION

Ocean Thermal Energy Conversion (OTEC) is a renewable energy that generates electrical energy based on the temperature difference between cold water from the deep sea and warm water at sea level. The difference is about 20ºC which is between ~ 5ºC and ~ 26ºC. Warm water can be obtained directly at sea level with a temperature of ~ 26ºC. while cold water must be obtained from the deep sea which is more than 500 meters [2]. Cold water from the deep sea is channeled to the OTEC power plant via pipes with a diameter of ± 3-4 meters (for power plants capacity of 2 MW) [3].

Pipes with a diameter of ± 3-4 meters are intended to keep the temperature of seawater flowing in the pipe from increasing due to the influence of water friction on the pipe wall and the difference in hydrostatic pressure in marine bathymetry [4]. Then, on large pipe diameter, cold water that is flowed in the pipe is able to maintain a temperature of 5oC to sea level (at the generator) and the pipe is installed hanging in a vertical position from the surface to the seabed in the floating structure. [5], [6].

Water-based OTEC is better than land-based OTEC because it does not require long pipe installations to get cold water, and the effect of environmental temperature is less on water in the pipes. But the issue is that the pipe must be flexible and strong enough to withstand by large currents, and it must be light weight to prevent overload to the floating structure. Therefore, the properties of the material for cold water pipes should be flexible, light weight, strong, and low electrical conductivity in order to keep ambient temperature which does not affect the water temperature in the pipe [7] [8].

Pipe material which suitable for cold water pipe is polymer material High Density Polyethylene (HDPE) [7] [9], because HDPE is more flexible than other polymers, lighter and low electrical conductivity [10] [11] [12]. HDPE

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material should have mechanical properties such high strength and flexible because it is used for water depth of less than 400 meters [13]. For water depth of more than 500 meters, HDPE material should be filled with fiberglass. HDPE composites with glass fiber have been used successfully at diameters of 0.7 meters and 2.4 meters [9]. Therefore, the use of HDPE composites for cold water pipes meets the requirements and suitable for OTEC construction, in addition, HDPE materials have good corrosion resistance [14] while glass fibers have higher resistance at lower temperatures [15]. In order to use HDPE composite filled with glass fiber, it is necessary to know the load characteristics experienced by the cold water pipe first.

This study aims to obtain load characteristics on cold water pipes due to current and wave loads, which will be applied in obtaining the right HDPE composite structure as cold water pipes in ocean-based OTEC. Cold water pipes based on fiberglass-filled HDPE composites are expected to be able to flow cold water without damage due to currents and waves, without increasing of temperature, increasing pipe resistance, low conductivity, reducing installation costs by 15-20%. The research results can be used as a guideline for other researchers, the world of education and the community in the further development of OTEC.

OBJECTIVE OF RESEARCH

The aim of this research is to obtain load characteristics on cold water pipes by analyzing the load that occurs due to current and wave loads, which will be applied in obtaining the right fiberglass-filled HDPE composite structure as cold water pipes on floating flatform of OTEC.

RESULT AND DISCUSSION

The cold water pipe installed on the platform has a length of 500 m towards the seabed, CWP will experience loading due to waves and currents, the weight of the pipe itself and the fluid flow in the pipe as shown in Figure 1. Due to waves, the platform will fluctuate causing the cold water pipe to be pulled up and down. As for the current load, the cold water pipe will be carried away by the large current, but because the pipe is tied to mooring line, the cold water pipe will curve like a sinusoid as in Figure 1.

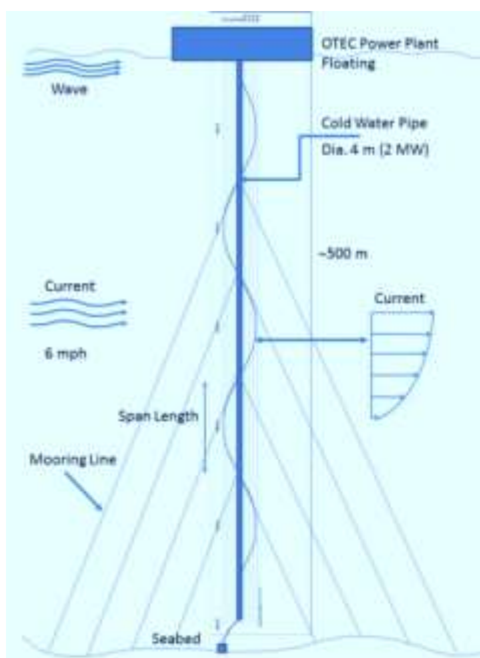

FIGURE 1. Cold water pipe construction, based on floating platform of OTEC

The ocean currents at certain depth are shown in Figure 2, which fluctuates over time.

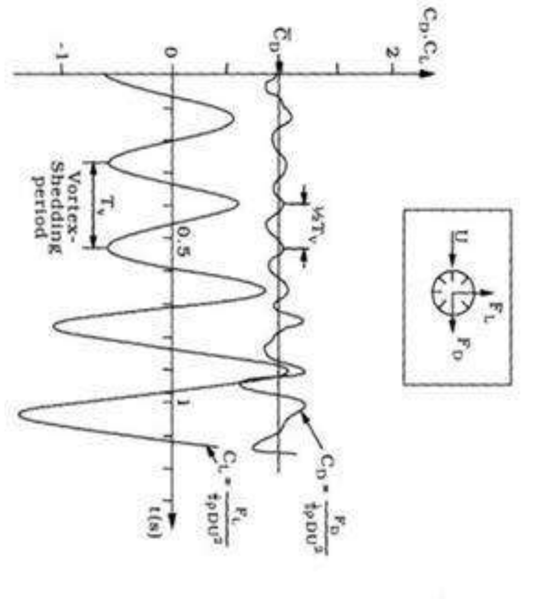

FIGURE 2. Oscillating drag and lift forces traces, adapted from Sumer [16]

Drag force (F_D) and lift force (F_L) are formulated:

$$F_D = C_D \frac{1}{2}\rho DLU^2 \text{ , } F_L = C_L \frac{1}{2}\rho DLU^2 \quad \text{……(2)}$$

Where : C_D is drag coefficient, C_L is lift coefficient, ρ is fluid density, L is length of cylinder, D is cylinder diameter and U is flow velocity.

The cold water pipe will receive the load according to the sinusoidal current load every time. Due to the vertical position of the pipe and the current moving horizontally, and the presence of vortex induced vibration, the CWP will bend and the CWP material will experience bending loads as shown in Figure 3.

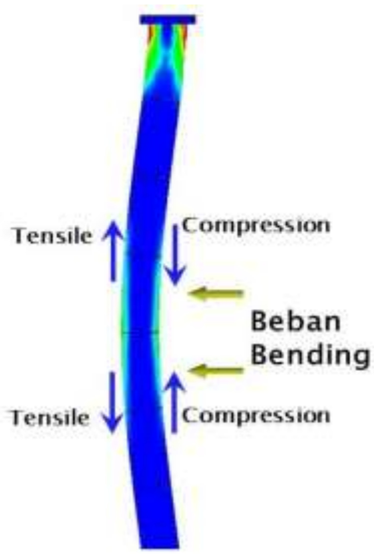

FIGURE 3. Stress distribution that occurs in pipes due to bending loads

In Figure 3 shows a pipe that is experiencing bending and stress distribution on the left and right, the pipe material structure on the left side experiences tensile stress and on the right side experiences a compressive stress. With a review of the microstructure of the pipe material, the bending load that occurs in the pipe will cause the structure of the material to experience tension and compression. When the current direction is from left to right, the pipe will curve to the right, and vice versa because of the mooring line, and if the current changes direction, the same thing will happen, so that the pipe will move and curve in a sinusoidal shape in various directions according to current conditions.

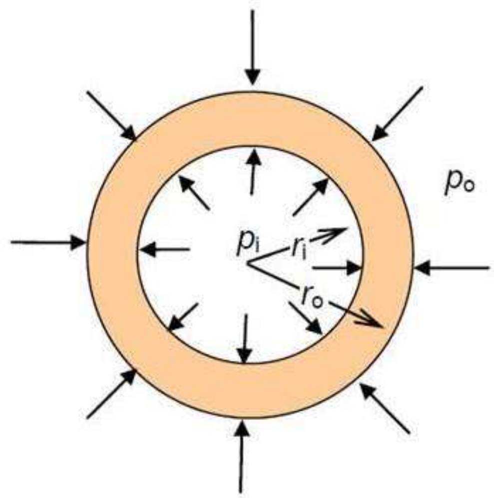

FIGURE 4. Thick Walled Pipe cross section with an internal pressure and external pressure.

$$\sigma_\theta = -\frac{(p_i - p_o) r_o^2 r_o^2}{r^2 (r_i^2 - r_o^2)} + \frac{p_o p_o^2 - p_i p_i^2}{(r_i^2 - r_o^2)} \quad (3)$$

The pipe load caused by the current will put pressure on the pipe which causes the microstructure the material is subject to tension and compression. Meanwhile, the pressure load from inside the pipe is neglected because the pipe is open at the water inlet and outlet. Therefore, consider only the external pressure (p_o).

Based on the load conditions experienced by the pipe, it can be stated that the pipe experiences tensile and compressive loads fluctuating every time with the load given by the current, water pressure around the pipe and due to waves on the surface. To determine the resistance of the pipe to the fluctuating tensile load is based on the analysis of the fatigue test results.

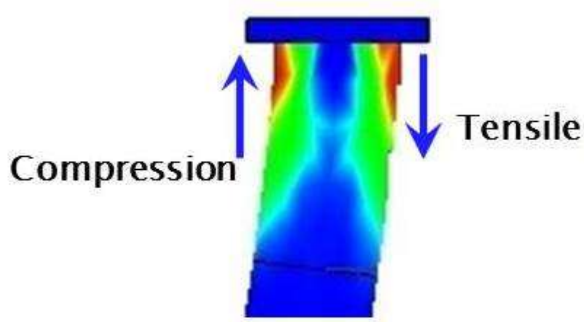

FIGURE 5. Stress distribution at the position of the pipe connection to the platform

In floating flatform OTEC construction, the greatest stress is at the position of the pipe connection to the platform compared to other positions. While the stress on the pipe that occurs is on the surface of the pipe compared to the inside of the pipe, so that to describe the fluctuation of the fatigue load is as shown in Figure 5.

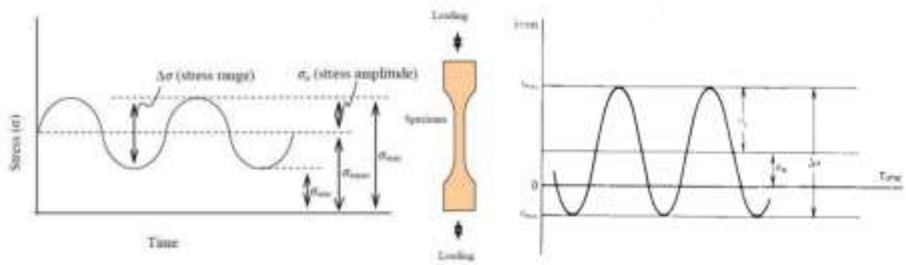

FIGURE 6. Repetitive stress cycle in the presence of an overload

The stress that occurs in the pipe is not the same all the time, and there is an excess load at times due to the tension and the current that the presence of waves which increase the tensile load on the pipe at the same time. Then the maximum and minimum loads can occur not equal or with R <1 and Amplitude = (1-R) / (1 + R). based on the current as shown in Figure 2, the amplitude at the fatigue loading ranges from 0 - 0.5 and the fatigue stress cycle in polymers of various R is determined by the equation:

$$N_{fR} = \left[\!\left[-\frac{1}{C_n} ln \left[\frac{\{2\sigma_{aR}/(1-R)\} - \{2\sigma_{aeR-1}/(1-R)\}}{\sigma_u - \{2\sigma_{aeR-1}/(1-R)\}} \right] \right]\!\right]^{1/mn} \quad (4)$$

CONCLUSION

Cold Water Pipe load that come from based on floating flatform of OTEC is bending load that occurs repeatedly. This load causes the pipe structure to experience tensile and compressive stresses, with the result that the resistance of cold water pipes is obtained precisely at the stress-compressive fatigue loading. Fatigue loading was applied to an amplitude of 0 to 0.5 with an R smaller than 1 to determine the fatigue resistance of CWP based on fiberglass-filled HDPE Composites.

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