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Comparison of On-Bottom Stability of a Subsea Pipeline under Different Wave Spectra and Currents.

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ABSTRACT: *Pipelines in a subsea environment are exposed to a very rough system of hydrodynamic action. The soil type, wave and current conditions as well as the structure itself are considered to be the main focus of the on bottom stability analysis for a subsea pipeline. The aim of this study is to determine under water pipe self weight under different wave spectra and water currents with the aid of MATLAB source code, by calculating the wave maximum height using the Pierson-Moskowitz spectrum, Bertschneider spectrum and the Jonswap spectrum. The source code is further used in calculating the wave forces on the entire offshore Seabed pipeline which lead to calculating the wave inertia force on the pipeline, wave drag force on the seabed pipeline and Lift force due to water current on the pipeline. The three forces help to determine the weight of the seabed pipeline under different seabed elevations. Also, the pipe self-weight is further designed for different soil types like clay, sand and gravel while the water current velocity and water wave phase angle remain constant, in one cash and the water current velocity and water phase angle vary on the other case. The cost of acquiring or purchasing Naval Architecture and Offshore structure software today, runs into thousands of Dollars and millions of Naira and to the fact that those companies that produce offshore structure equipment rely on spectrum model analysis to manufacture there equipments. Owing to this fact, and many more, this research work was carried out; as this will form the basis for design in both academic and industry use with less cost by considering which of the spectra perfectly fit the region of installations and as time goes on interested researchers in this field can add to the development of this Matlab source code until it gets to a stage where it will be commercially approved. To achieve this objective, specific areas of interest were reviewed; Computer and software utilization in Naval Architecture and Offshore Structure with respect to wave load (wave force) and pipeline self weight as it applies to both academic and industry use, general computer programming (Matlab). Conclusively, it can be said that the results and graphs produced by this Matlabcode are in line with what is obtainable in practice. However, some recommendations were made that irregular wave approach should be applied to get the actual wave forces on the offshore subsea pipeline despite its difficulties because the irregular wave shows the exact wave force on the pipeline when compared with the regular wave force and that this source code should be developed further to incorporate dynamic load due to fluid movement.*

KEY WORDS*:Offshore pipe, Spectrum, Inertia force, Drag force, lift force, Pipe self-weight, Current velocities.*

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I. INTRODUCTION

Transportation of liquids by pipelines has been used for thousands of years. Offshore pipelines are an important facility of any offshore oil and gas project. Marine pipelines transport oil and gas from subsea wells to platform and subsequently from platform to the shores or stations for further processing and distribution. There are also large pipeline for the transportation of gas or oil from one country to another. These pipelines are classified in three categories as infield pipelines, export pipelines and transmission pipelines.

The infield pipelines transport fluids within field. They are often called flow-lines or feeder lines. Infield pipelines carry a mixture of oil, gas and water from the subsea wells to a manifold or directly from the well to the process platform. A smaller number of infield lines carry processed water from the platform to injection wells for disposal. The export pipelines transport processed oil or gas from the platform to the coast and if the export pipeline carries a mixture of oil and gas then it is refer to as a multi-phase, but if the export pipeline carries only oil or only gas it is called a single-phase pipeline, while the transmission pipelines carry oil or gas from one coast to another just the way a tanker transfers oil for trading purposes.

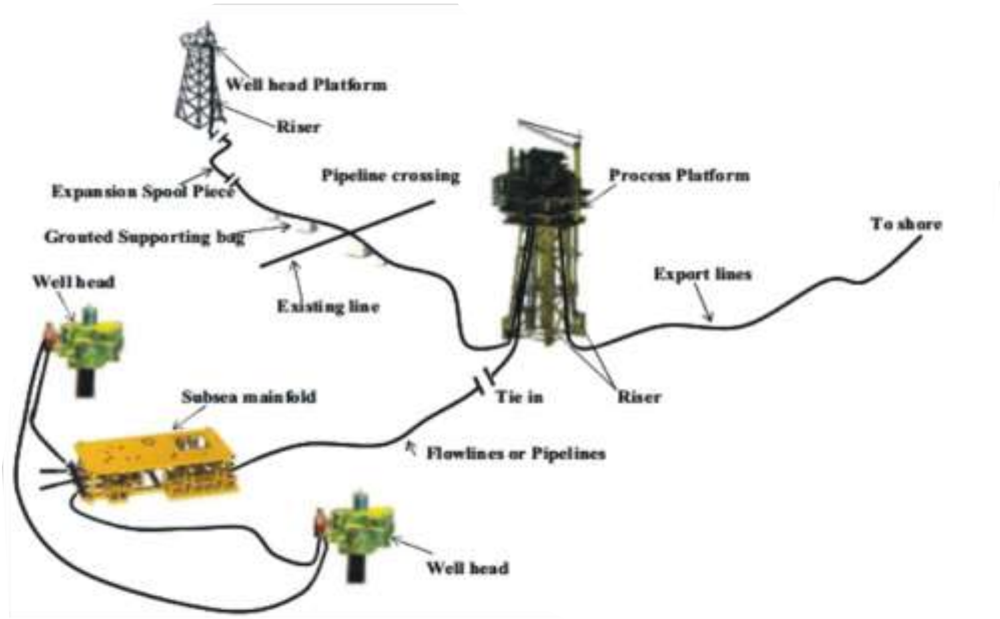

Figure 1: Subsea Systems and Flowlines

Interest on offshore energy resources has been increasing globally in most developing countries. The marine world in 2030 will be almost unrecognizable owing to the rise of emerging countries keying into the available resources. As development activities for energy demand move to deep water, many offshore pipelines to transport oil and gas will be installed on the seabed ranging from very soft to very stiff hard soil surfaces. This paper deals with pipeline on the bottom of the seabed which is exposed to forces exerted by wave and current.

The behavior between pipeline and soil is a relevant aspect of this study; the heave soil and resistance forces are hence important aspect. It is important to properly model pipe-soil interaction effects [1]. Pipe self-weight embedment depth in relation to hydrodynamic forces acting on it has become a critical design parameter to design offshore pipeline. Such as free span and thermal expansion as well as on-bottom stability. On-bottom stability analysis that a pipeline maintains stability on seabed against hydrodynamic load of wave and current has to be considered with a relevant pipe-soil interaction analysis.

Wave Spectrum

This work aims at describing and comparing three selected wave spectra to analyze the effect of waves on seabed pipelines. The selected models are:

Pierson & Moskowitz spectrums, Bretschneider spectrum, and JONSWAP spectrum, several forms off wave spectrum have been carried out in the latter half of the last century on formation and proceedings of sea waves, resulting in describing a rarity of their mathematical models. There have been a constant development and improvement based on the phenomenal behaviour of the wave and its effect on rigid bodies either on the sea or beneath. Scientific centers have suggested several number of wave spectrum models, which are as follows; Bretschneider, ITTC, Pierson-Moskowitz, Neumann, Philips or JONSWAP were all worked out for different water areas and purposes.

Implanting the diversified wave models to their environment contributes to increasing possibility of applying simulation methods and of the level of the tests results credibility. Most ocean wave spectra may be described in a form of the standard formula, which has to be applied only in case wave height is known:

This is the general form of the ocean wave consequent differences in fetch geometry and history.

Pierson & Moskowitz spectrums

The Pierson-Moskowitz (PM) spectrum is an empirical relationship that defines the distribution of energy with frequency within the ocean. The PM spectrum was developed in 1964, and is one of the simplest description for the energy distribution. It assumes that if the wind blows steadily for a long time over a large area, then the waves will eventually reach a point of equilibrium with the wind. This is known as a fully developed sea. Pierson-Moskowitz developed their spectrum base on parameters from the North Atlantic during 1964, and presented the following relationship between energy distribution and wind [1].

Brestschneider Spectrum

The Brestschneider spectrum also called the modified two-parameter Pierson-Moskowitz spectrum is a fully developed sea spectrum, carried out at the North Ocean. Is useful for undeveloped or developing sea, which are more generally met with, a difference between the original Pierson-Moskowitz, spectrum consist in the fact that Bretschneider spectrum is function of the both-wave height and peak period. This spectrum replaced the pierson-Moskowitz spectrum as the ITTC standard. It allows the user to specify the modal frequency and the significant wave height, this spectrum can be used for sea state of varying severity from developing to decaying.

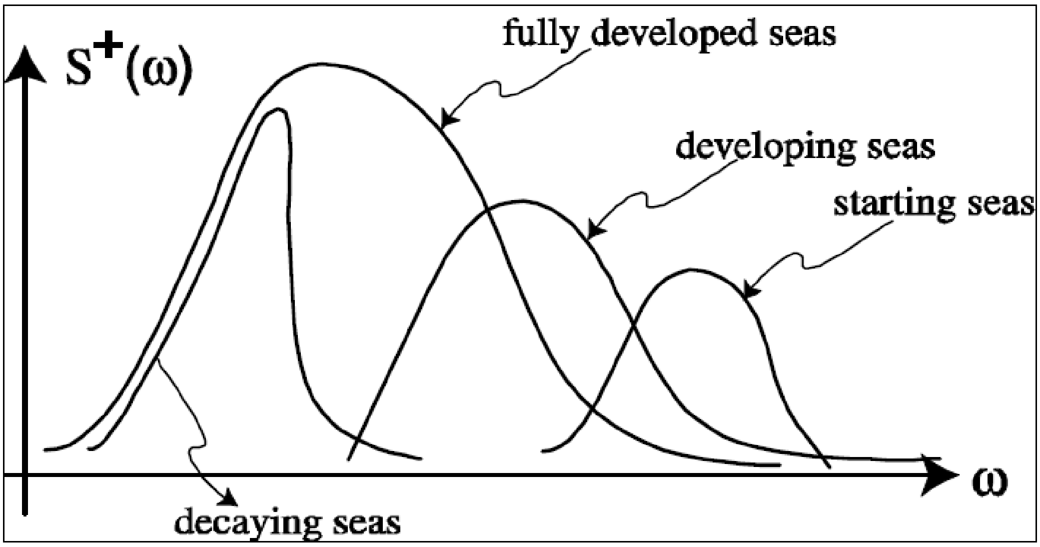

Figure 2: Sample Sea Wave Spectrum

Jonswap Spectrum

The Joint North Sea Wave Project was carried out in the early 1970sto systematically record the North sea wave patterns, for offshore or coastal research industries, which are characterized by shallow or limited water areas. In effect of analysis of data from more than 2000 measurements, the scientists discovered that the wave spectrum is not fully developed. However, in view of its characteristics, it is often use for the purpose of studies and analyses referring to coastal navigation at limited water areas. The spectrum is two-parameter and dependent on two input parameters, which are modal frequency and amplification coefficient. It was discovered that the North Sea under estimated the spectral peak, which was assumed to be a fully developed sea conditions. Therefore, a new sea form of spectrum that incorporates a peak enhancement factor (γ) was suggested [2]. This spectrum is significant in account of its consideration in the growth of wave over a limited fetch and wave attenuation in shallow water.

Pipeline Self-Weight Stability

A pipeline laid on the seabed is subjected to wave and current forces. The pipeline faces an intense stream of high-energy forces from the ocean environment, which causes unstable movement of the pipeline if proper attention is not given to its stability. The ability of the pipeline to withstand the wave and current forces by friction, and the submerged weight of pipeline is an important design need. If pipelines self-weight is insufficient, there is the tendency of the pipeline 'floating-up' or 'moving off' the intended position on the seabed.

Pipelines are basically designed to lie on the seafloor, or in a trench in the seafloor, with more or less continues support. However, unsupported spans may occur in rough, rocky seafloors depending on the ocean environment this pipeline is placed on the seabed. The designer will have set limits on the unsupported span lengths, which the manufactures must not exceed; this may require either prior, seafloor leveling or post-installation support [3].

Pipeline on-Bottom Stability Analysis

Pipeline on-bottom stability is checked for the installation case with the pipe empty using the 1-yr return period condition and for lifetime using the 100-yr storm. Additionally, a minimum pipeline specific gravity of 1.20 during installation is desired. On-bottom stability is maintained using substantive quality of concrete coating on larger pipeline and high steel wall thickness for smaller pipelines, these are important features in the design of marine pipelines. This analysis is of prime importance to ensure pipeline stability, when exposed to extreme situations of waves and current loading.Sufficient pipe weight thickness gives additional support on the grounding of the pipe in position, and sustains its bottom on the seabed. If pipe self-weight is insufficient to maintain the stability requirements, the stability design must consider improving the pipeline stability by increasing the weight or by using one of the secondary stabilization techniques, such as rock dumping, concrete mattress, anchors and trenching [4].

On-Bottom Stability Analysis Components

The analysis of a reliable on-bottom pipeline stability should consider accurate modeling of the pipe structure, modeling of the pipe; soil interaction prediction of the hydrodynamic loads and the coupling effect of the hydrodynamic loading and pipe-soil interaction [3]. With an accurate analysis, probability of failure or exceedance of limit state can then be considered with reliability and uncertainty methodologies.

Offshore Pipe Structure

Offshore pipeline are basically classified categorically into two main parts: Flexible and Rigid pipes. The flexible pipe has a layered construction of steel strands separated by polymer layers that result in a relatively small bending stiffness [4]. The flexible pipe is capable of being bent without breaking, and this feature makes the pipe suitable for locations where the pipe is expected to be under continuous curve bending. The rigid pipe is more generally used as it produces finely in a larger diameter and operates under high pressure. It is composed of a steel pipe with concrete coating and insulation layers. These features make the rigid pipe suitable for flow-line, export-line and trunk-lines. Generally, the most, common steel grade used for deep-water subsea pipeline is X65, regarding its cost- effectiveness and adequate welding technology. This thesis considers the on-bottom stability of pipelines of rigid cross section.

The offshore pipeline is classified according to the installation method which is sub-divided into two categories; trenched (buried) or untrenched. The untrenched pattern is more rampant as extensive investigation conducted in the early 1980s indicated that a properly designed concrete coated steel pipe is strong enough to provide pipeline stability [5].

The entire weight of the pipe in stability is all the constituent layers, which in its basic form, includes the pipe steel wall and concrete coating. However, other weight components can be considered to give the gross weight of the pipe which include if they exists; internal corrosion liner, internal coating, insulation coating, marine growth and the internal content [1].

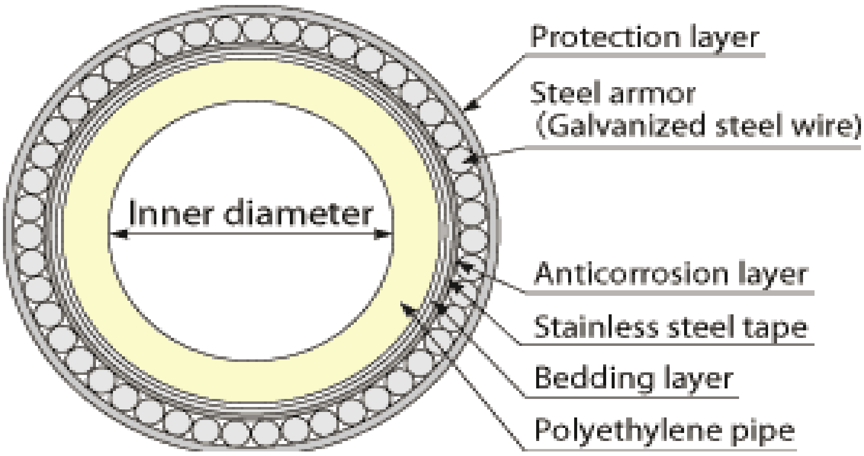

Figure 3: Pipeline CoatingsHydrodynamic Loads and the Morison's Model

Offshore pipeline industry has as its major challenge the prevailing hydrodynamic load of combined wave and current estimation on the on-bottom pipeline. The Morison's model is quite able to describe the magnitude and the phase shift of the horizontal force components, showing small discrepancies in the accurate. The Morrison's equation stands out as the most used starting point [6].stated that the hydrodynamic force exerted on a cylindrical object due to wave and current can be expressed in terms of the wave particle velocity, acceleration and the drag and inertia co-efficients. The uplift force component was not included in [6] equation because the cylindrical object used was a vertical pile projected from the seabed upward above the wave crest. Nevertheless, the inclusion of the uplift force in the calculation of the forces on a pipe resting on the bottom of the seabed was achieved alongside the drag and inertia components. The three hydrodynamic force components are shown [7].

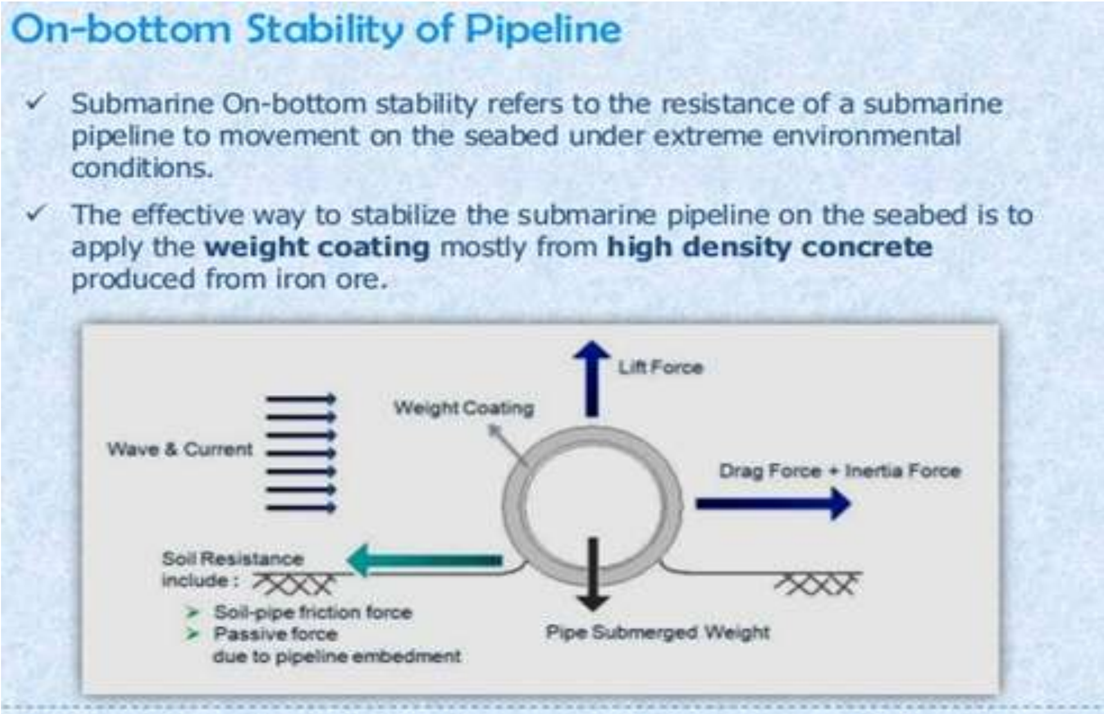

Figure 4: Hydrodynamic Force Components on the on-bottom Pipeline

Analysis based on deterministic and probabilistic procedure for pipeline on-bottom stability. Deterministic analysis is based on one single value as it is assigned to the input parameter.

II. MATERIALS AND METHODS

Wave Spectrum Equations

The self-weight of the pipe depends on the drag force, inertia force, lift force, coefficient of friction and phase angle. The drag and inertia force highly depend on the significant wave height significant, the wave height is often used as the main parameter to define a sea state. Statistically, significant wave height is the average of the one-third highest waves and is denoted as H_s or $H_{1/3}$. Empirically, $H_s$is significant wave height in a sea state and is the value most often assigned by visual observations. Some other reference is sometimes used such as H3% in the USSR. The maximum expected wave height *(H_{max})* can be derived from the significant wave height where No is the number of observed waves. Typically for 1000 waves, H_{max} ¼ 1:68H_s. In addition to wave height, a characteristic wave period must also be given to define a sea state.

Pierson-Moskowitz Spectrum

The standard wave spectrum equation formulations used are shown below.

$$S(\omega) = \frac{8.1}{10^5} \cdot \frac{g^2}{\omega^5} \exp^{-0.032} \left(\frac{g}{H_{1/3} \times \omega^2} \right)^3 \qquad (1)$$

Where:

$H_{1/3}$ is significant wave height

ω is wave frequency

g is acceleration due to gravity

Bretschneider spectrum

$$S(\omega)=\frac{1.25}{14}\;\frac{\omega_m^4}{\omega^5}\;(H_{1/3})^2\times\exp^{-1.25\left(\frac{\omega_m}{\omega}\right)^4} \qquad (2)$$

$$\omega_m=0.4\sqrt{\frac{g}{H_{1/3}}}$$

Where, ω_m is the modal frequency.

Jonswap Spectrum

$$S(\omega)=\frac{a\,g^2}{\omega^5}\exp^{-5/4}\left(\frac{\omega_m}{\omega}\right)^4\times\;\delta^d\;\;\gamma^d \qquad (3)$$

γ is peak enhancement factor

$$H_S=\sqrt{8\times Area\times\sum S(\omega)} \qquad (4)$$

Area = $\frac{\omega_1}{2}\left(S\left(\omega_0\right)+2S\left(\omega_1\right)+2S\left(\omega_2\right)+2S\left(\omega_3\right)+\ldots\ldots S(\omega_n)\right).$

Pipeline Self Weight Equation

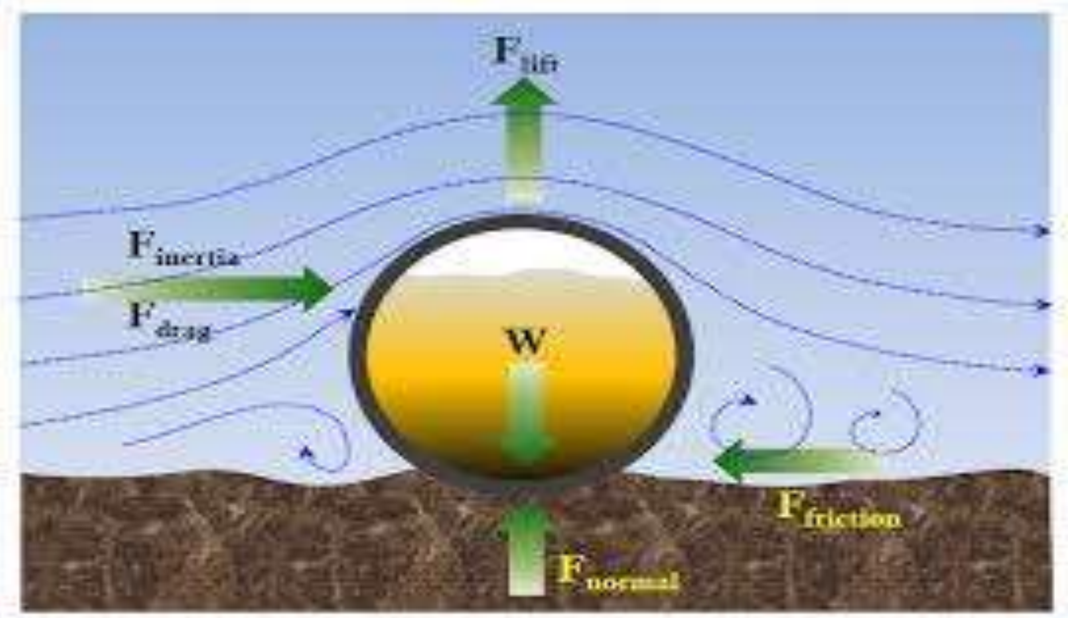

Figure 5: Pipeline Hydrodynamics

Horizontal forces

$$\sum f_x=0\;\Rightarrow\;F_d+F_I-F_f+\;W\sin\theta=0 \qquad (5)$$

$$\sum f_y=0\;\Rightarrow\;F_N+F_L-\;W\cos\theta=0 \qquad (6)$$

Applying static equilibrium law;

Equating the $\sum f_x=\sum F_y$ forces

$$\sum F_x=\sum F_y=0$$

$$W = \frac{F_d + F_I + \mu F_L}{\mu \cos\theta - Sin\theta} \tag{7}$$

$IF\ \theta = 0$; Minimum submerged weight of pipe for stability

$$W = \frac{F_d + F_I + \mu F_L}{\mu} \tag{8}$$

Pipeline Wave Forces

Drag force F_d

The drag force depends on the radius of the seabed pipe diameter, the density of the sea water, wave parameters (i.e. the wave length, wave period and wave height). Together with drag coefficient is the wave acceleration constant A_2. The drag force is that wave force that comes as a result of contact force between the pipeline and the seabed.

$$F_d = \frac{2H^2 r\ \pi\ \lambda\ \ell}{T^2} A_2\ C_d / Cos\theta / Cos\theta \tag{9}$$

Inertia Force F_I

Inertia force depends on the radius of the seabed pipe diameter and the density of sea water, wave parameters (i.e. the wave length, wave period and wave height); Together with the inertia coefficient and the velocity constant A_1, which depends on the wave length and the wave height.

$$F_I = \frac{2H^2 r\ \pi\ \lambda\ \ell}{T^2} A_1\ C_m\ \sin\theta \tag{10}$$

Lift Force F_L

The lift force depends on the pipe dimension, which is the diameter, the water density, lift coefficient and effective velocity. Nevertheless, the lift coefficient is a function of the Reynolds number. The effective velocity depends on water depth, pipe diameter and the water current velocity. Lift force is a product of the wave, which is normal to the flow direction. This force slides friction resistance from the seabed and it's also responsible for the countering of pipe weight.

$$F_L = \frac{C_L}{2} \ell D / U_e / U_e \tag{11}$$

But each of the force has criteria

Wave length

Wave length depends on the wave period and acceleration due to gravity i.e. for linear flow and deep sea.

$$\lambda_O = \frac{gT^2}{2\pi} \tag{12}$$

Wave Number *K*

Wave number *K*, depends on the property of the wave length. It can be defined as the revolution per wavelength.

$$K = \frac{2\pi}{\lambda} \tag{13}$$

Maximum Horizontal Velocity V_{max}

This depends on wave height, wave period, acceleration due to gravity and wavelength. It's also the speed at which a wave travels in horizontal component.

The maximum horizontal velocity depends on the chosen wave profile and the phase angle.

$$V_{\max} = \frac{HTg}{2\lambda} \tag{14}$$

Keulegan – Carpenter Number KC

This depends on the wave height, wave period, acceleration due to gravity and pipe diameter. It's a dimensionless quantity that defines the drag coefficient and the inertia coefficient.

$$KC = \frac{V \times T}{D} \tag{15}$$

Reynolds Number R_e

This depends on horizontal velocity pipe diameter and the kinematic viscosity of the water. Reynolds number and Kelugan –carpenter can be used to determine the drag coefficient and inertia coefficient.

$$R_e = \frac{V \times D}{\upsilon} \tag{16}$$

Constant of Drag A_2

This depends on the wave number and sea water depth. It is a product of integration constant when acceleration is combined with Morison's Equation.

$$A_2 = 2kd + \sinh\left[16\sinh^2(kd)\right] \tag{17}$$

Constant or Inertia Coefficient A_1

This depends on wavelength and wave height, it is a product of integration constant when velocity is combined with Morison's Equation.

$$A_1 = \frac{\pi\ r}{2H} \tag{18}$$

Effective Velocity U_e

This depends on the pipe diameter, the distance from the top of the bottom pipe, to the sea water level (SWL) and the current velocity.

$$U_e^2 = 0.778\ U_0^2 \left(\frac{D}{y_0}\right)^{0.286} \tag{19}$$

III. RESULTS and DISCUSSIONS

Maximum to a wave frequency when the wave spectral density tend to be moving at without a significant change in the wave spectral density until maximum wave frequency.

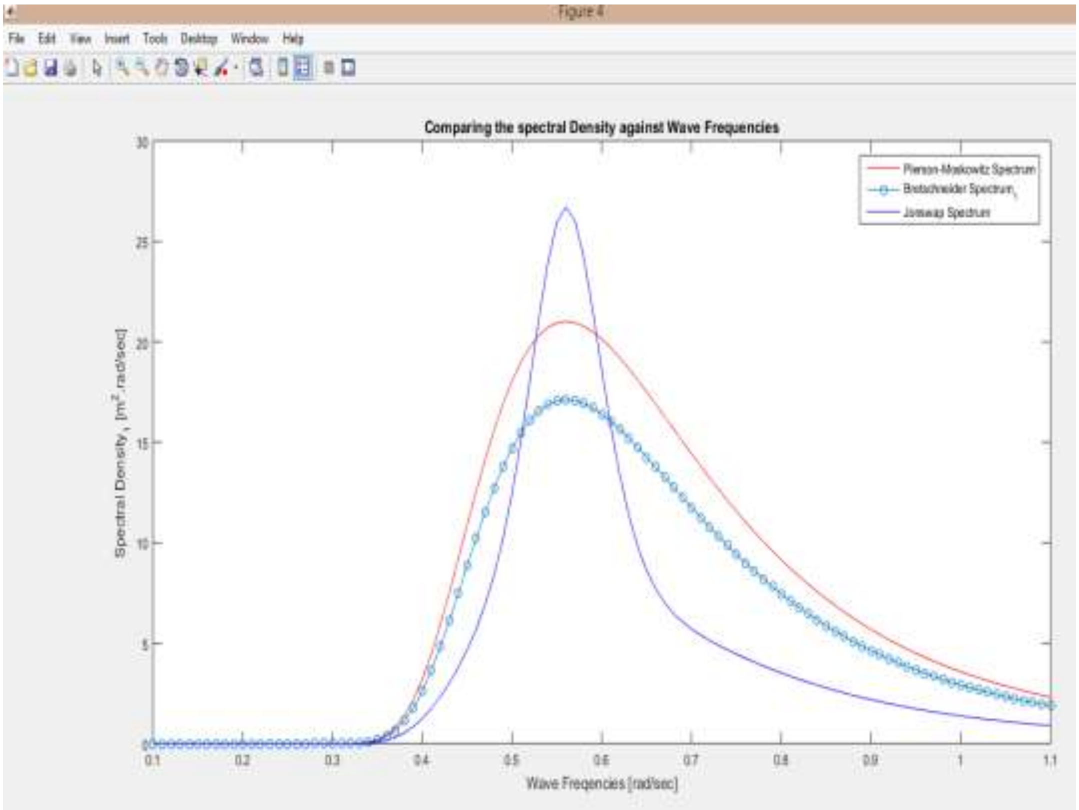

Figure 6: Pierson-Moskowitz, Bretschneider and Jonswap Spectral Density against Water Wave Frequencies

Figure 6 show the Pierson-Moskowitz, Bretschneider and Jonswap Spectral density against Water Wave Frequencies as the wave frequency move from 0.1 the spectral density remain at zero until the wave frequency get to 0.35 in all the three spectrum case, then the spectral density begin to rise to the maximum at wave frequency of approximate 0.6 before the spectral density begins to decline rapidly as the frequency moves from 0.6 to 0.8, then the wave spectral density show no significant change in decline as the wave frequency move from 0.8 to the maximum wave frequency. Also when Figure 6 was compared with the combined spectral density as plot in Appendix A shows a lot of agreement as the curve also start from the origin until a certain level of frequency when the wave spectral density start to increase to the maximum before the wave spectral density begin to fall from maximum to a wave frequency when the wave spectral density tend to be moving at without a significant change in the wave spectral density until maximum wave frequency.

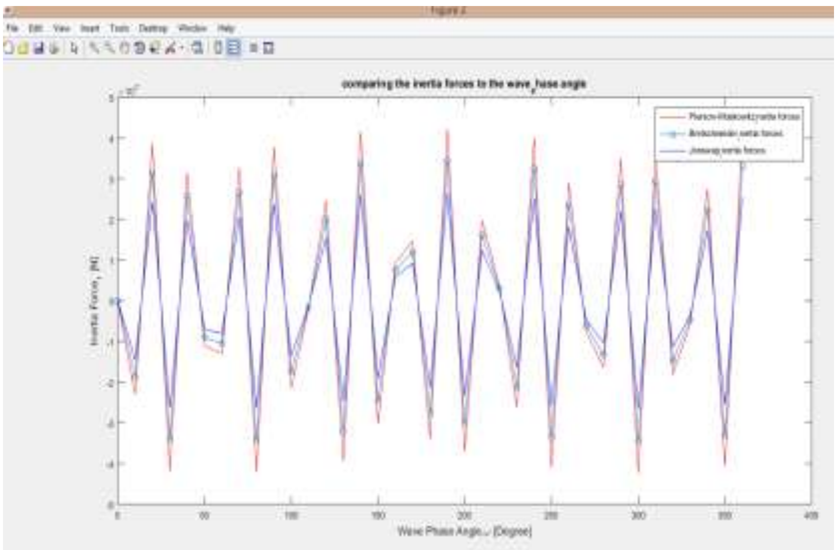

Figure 7: Pierson-Moskowitz, Bretschneider and Jonswap Inertia Force against Wave Phase Angle

Figure 7 show the Pierson-Moskowitz, Bretschneider and Jonswap Inertia Force against Wave Phase Angle with the inertia force beginning from the origin to a maximum positive value at 90°, as the wave phase angle moves from 90° to180° the inertia force moves from the maximum positive to maximum negative value, also as the wave phase angle moves from 180°to 270° the inertia force moves from the maximum negative value to zero while as the wave.

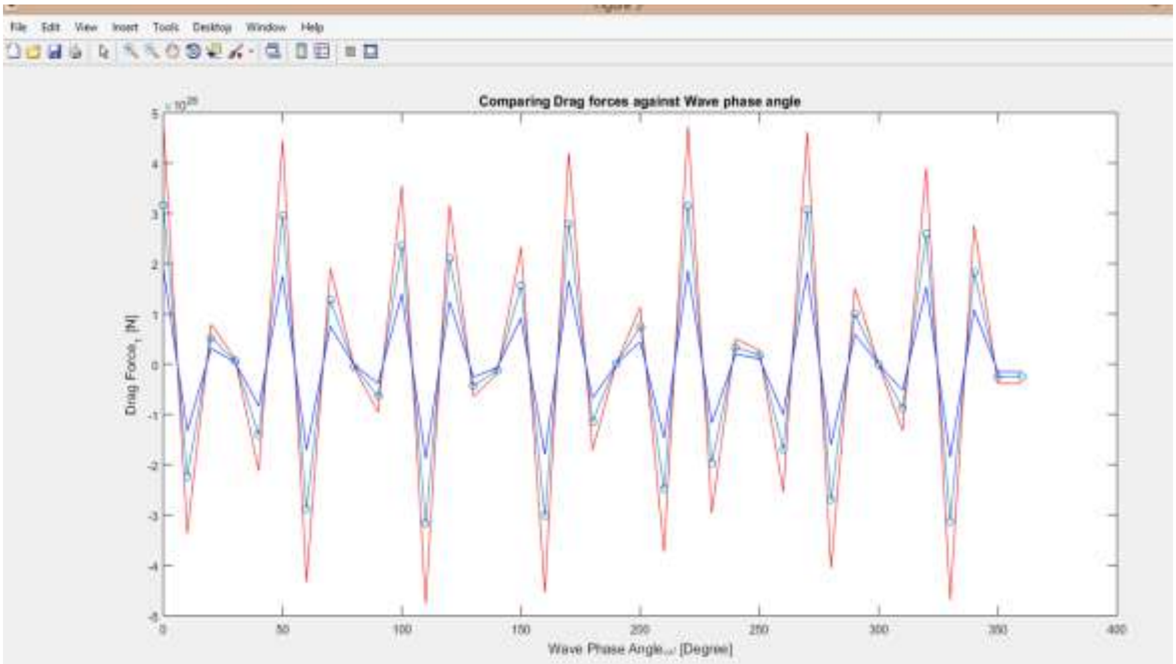

Figure 8: Pierson-Moskowitz, Bretschneider and Jonswap Drag Force against Water Wave Phase Angle

Figure 8 show the Pierson-Moskowitz, Bretschneider and Jonswap Drag Force against Wave Phase Angle with the drag force beginning from the maximum to zero value at 90°, as the wave phase angle moves from 90° to180° the drag force moves from zero to maximum negative value, also as the wave phase angle moves from 180°to 270° the drag force moves from the maximum negative value to maximum positive value while as the wave phase angle moves from 270°to 360° the drag force moves from maximum positive to zero.

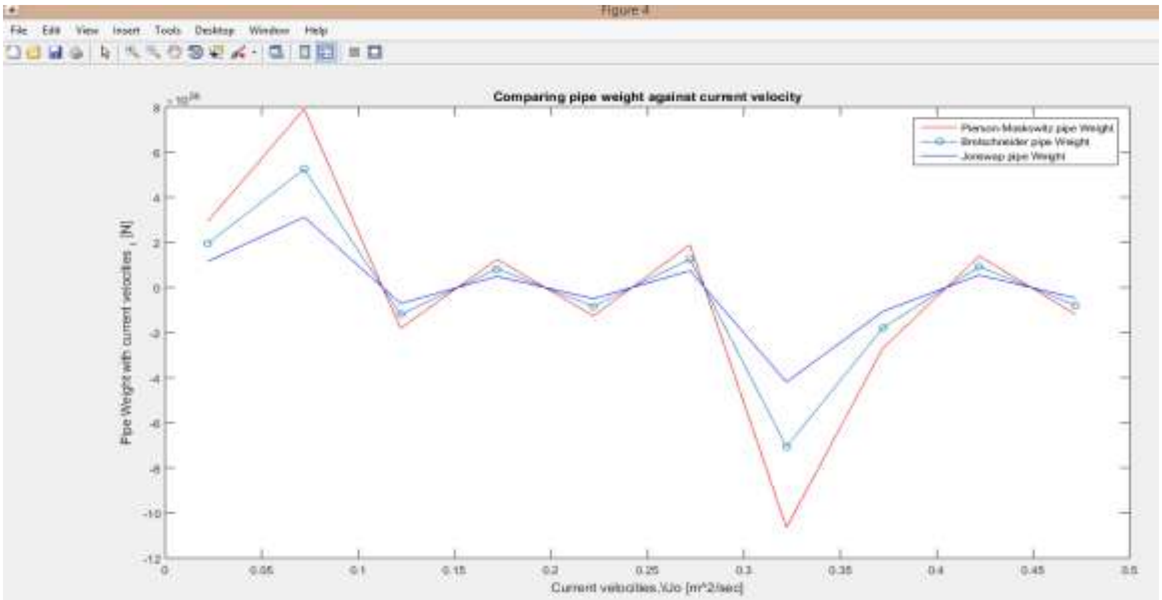

Figure 9: Pierson-Moskowitz, Bretschneider and Jonswap Pipe Weight against Current velocities

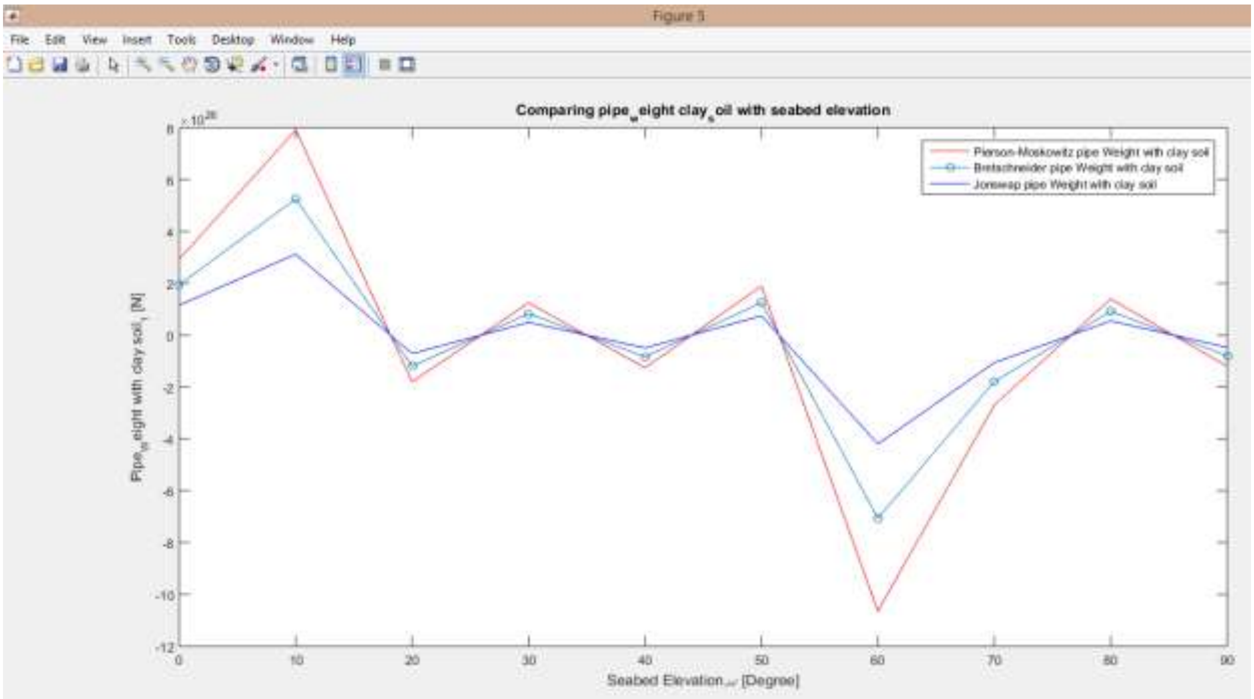

Figure 10: Pierson-Moskowitz, Bretschneider and Jonswap Pipe Weight with Clay Soil against Seabed Elevation

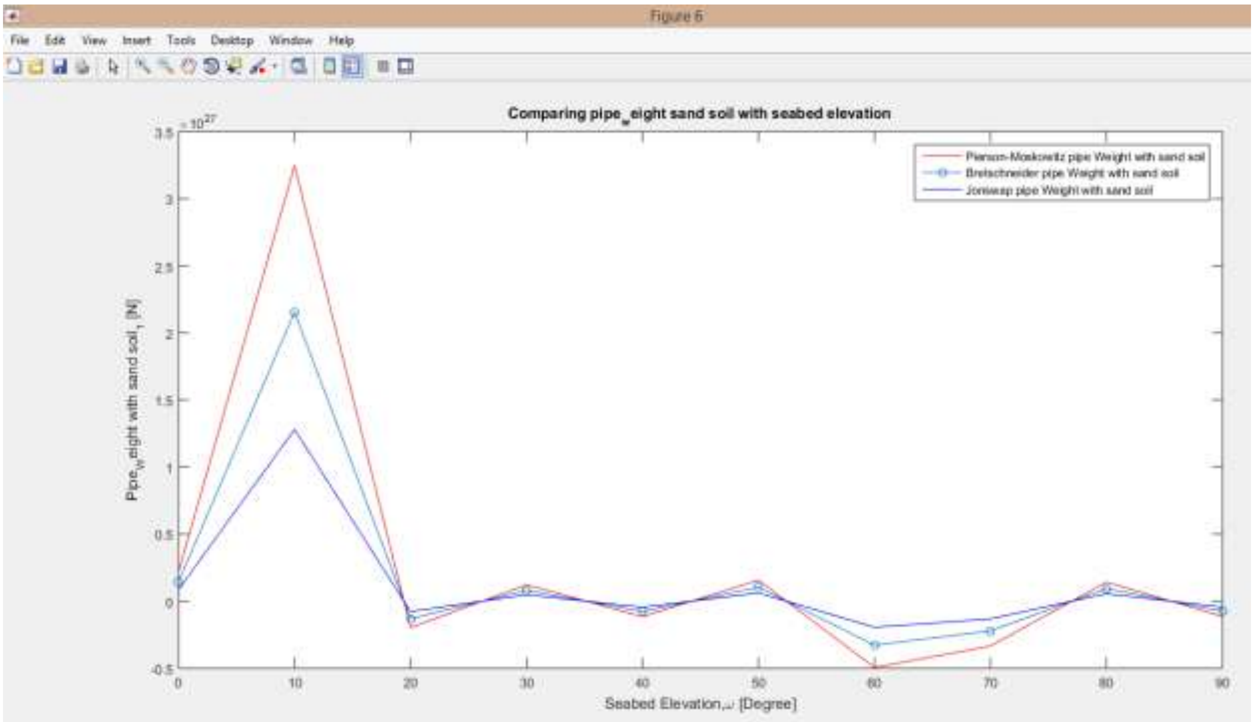

Figure 11: Pierson-Moskowitz, Bretschneider and Jonswap Pipe Weight with Sand Soil against Seabed Elevation

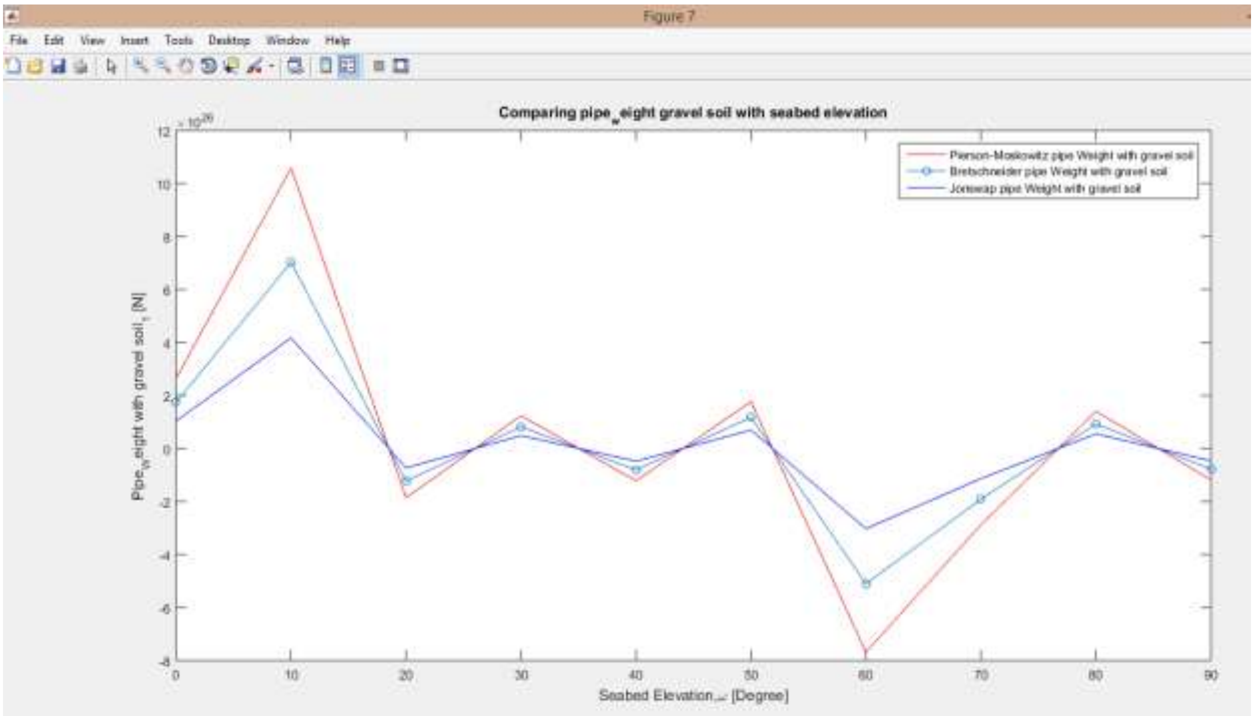

Figure 12: Pierson-Moskowitz, Bretschneider and Jonswap Pipe Weight with Gravel Soil against Seabed Elevation

IV. DISCUSSIONS

This section discusses the resulting graphs presented in Figure 6 which shows the wave spectrum in the different spectral graphs as present by Pierson-Moskowitz, Bretschneider and Jonswap , this spectra graph plotted by Matlabcode can be compared as presented in Figure 4.4 and what is obtainable from other text, and Table 4.1 which is the input data to the Matlab source code and this input when used resulted in the wave spectral graphs. The spectral graphs are further analysed by integrating the areas under the wave graphs using simpson's multipliers to get the different wave height by using Pierson-Moskowitz, Bretschneider and Jonswap. The different wave heights are further used with other input to get Pierson-Moskowitz inertia force, Bretschneider inertia force and Jonswap inertia force. Figure 7, the inertia force acts on the seabed pipe and vary in magnitude due to wave phase angle thus when compared Figure 7, starts from the origin and follows the sinsuodial wave pattern approach when compared with a typical sine wave plot on other text. Also when the different wave heights are further used with other input the Pierson-Moskowitz drag force, Bretschneider drag force and Jonswap drag force graph Figure 8 are plotted, this drag forces act on the pipe due to water fluid and also vary in magnitude due to wave phase angle with a cosine plot that starts from the maximum when compared with a typical cosine graph on other text. With further analysis the pipe self weight can be plotted as shownin Pierson-Moskowitz clay soil, Bretschneider clay soil and Jonswap clay soil Figure 9 this pipe self weight comprises of the inertia force, drag force and lift force, while the inertia force and the drag force are represented by sine and cosine graphs respectively, the lift force is represented by a straight line graph and this forces are summed together to get the pipe self weight which are plotted on varied seabed elevations base on concrete coating materials being used. Since sine and cosine are added it is relatively safe to say that the graph cannot start from origin which was noticed in Figure 9. Also Pierson- Moskowitz sand soil, Bretschneider sand soil and Jonswap sand soil Figure 10 follows the same curves as that of clay discussed above with just changes in the magnitude of the result. Also for the gravel pipe coating Pierson Moskowitz gravel soil, Bretschneider gravel soil and Jonswap gravel soil Figure 11 follows the same curve as that of clay discussed above with just changes in the magnitude of the result. While Figure 12 shows Pierson-Moskowitz clay soil with varied water current, Bretschneider clay soil with varied water current and Jonswap clay soil with varied water current as the effect of water current on the seabed pipeline is considered in this case, the pipe self weight comprises of the inertia force, drag force and lift force, while the inertia force and the drag force are represented by sine and cosine graph respectively the lift force is represented by a straight line graph and is a function that depends on water current and the water current when varied shows a creep in magnitude but the curves are the same with that of constant water current.

V. CONCLUSIONS

From the research work, It can be concluded that the graphs of spectrum plotted at Figure 6 are in agreement with the standard spectrum drawn from similar wave parameter, this can be validated when the wave spectrum is compared with that provided from text as both start from constant origin until a certain wave frequency before the spectral density start to increase.

It can also be concluded that since the inertia force graphs from the Matlab (Figure 7) all start from the origin, it could be concluded that the inertia force graphs are in agreement with world practice as can be compared since sine graphs always start from the origin, this also can be said of drag force graphs from the Matlab (Figure 8) as all the graphs start from maximum positive value. In the same vain, it can also be concluded that the drag force are in agreement with known practice when compared with graphs from text since all cosine graphs usually start with a maximum.

It can also be further concludedthat the pipe self-weight is fully depended on the wave current, this can be seen as shown if figure 9, when the pipe self-weight are plotted against water current and the results show some level of agreement when figure 9 is compared with other results obtained online which shows that an increase in current velocities causes a corresponding increase in pipe self-weight, this can also be verify from the effective velocity formular which is directly depended on current velocity, such that an increase in current velocity causes an increase in effective velocity which in turn causes a corresponding increase in lift force and an increase in lift force will cause an increase in subsea pipeline self-weight.

Lastly, It can be concluded from figure 10 to figure 12 that the soil type and seabed elevation have great effect on the pipeline self-weight, this is so because the coefficient of friction used in the computation of the pipeline self-weight varied for the different soil types (sand, clay and gravel), and this soil types when varied with the seabed elevation shows that the minimum pipe self-weight is recorded at $0^{\circ}$and 90°. This is so because literally, acompletely vertically or horizontally laid pipe are more stable than an inclined pipe on the seabed, and the stability of the pipeline when laid on the seabed is directly affected by the pipe self-weight, this can be completely deduced from the pipe self-weight equation which shows that the pipe self-weight is indirectly proportional to the coefficient of friction.

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