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Contents

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-Scientists and Engineers-

Journal of Subsea and Offshore
-Science and Engineering-

Vol.3: September 30, 2015

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Vol.3: September 30, 2015

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Long-Term Variability of Wind and Waves in the Malacca Strait Based on ERA-Interim Data from 1980 to 2014

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ABSTRACT

Wave and wind climate information can serve as basis for design, research and policy making regarding ship safety and operability, potential renewable energy exploitation, design of off-shore installation etc. The objective of this paper is to determine mean annual significant wave heights and wind speeds in the Malacca Strait. Mean annual wave height and wind speed values have been statically analyzed based on ERA-Interim reanalysis data produced by ECMWF (European Center for Medium-Range Weather Forecasts) during 34 years period. This data has been processed resulting in monthly and annual observed significant wave heights and corresponding wind speed values. The obtained results show that wave speed and the significant waves height have an increasing trend at the location studied but both trends are statistically insignificant.

KEY WORDS: *wind, wave, ERA-Interim, variability*

1.0 INTRODUCTION

Malacca Strait sea lane is an important trade route for the main world countries of Southeast Asia. Due to the Strait of Malacca linking the Indian Ocean with the South China Sea and provide sea lanes for most of world trade. Over the years, tankers and bulk carriers move large quantities of oil, coal, iron ore, and minerals to the production centers in Southeast Asia and East Asia, while tens of thousands of container flows in the opposite direction to meet the needs of consumers worldwide market, Every year, more than 71,000 ships pass through the Strait of Malacca to carry a variety of commodities, ranging from crude oil to finished products from various regions of the world [1].

Therefore, it is no exaggeration when waterway is considered as one of the busiest sea lanes simultaneously functions as an artery of the world economy. The Malacca Strait serves as a shipping route for surrounding countries and an important role waterway to increase the economic and industrial development in the Asian region.

Thorough knowledge about possible sea states in a certain area is essential for all activities related to the maritime sector (e.g. offshore installations, ship design for safety and sea keeping, shipping routes planning, vessel management etc). Every increase in knowledge in this field for the Malacca strait is important as it serves as a busy shipping route with an increasing trend. Sea state analyses are available from in-situ measurement data, numerical modeling, and various forecast models derived on empirical or mathematical models giving relations between wind and waves.

The aim of present study is to contribute to the field by further developing the statistical analysis of the data available from forecast models derived on empirical or mathematical models throughout the Malacca strait. It aims primarily to identify mean annual wave heights, and to look in more detail the zone of maximum wave heights, researching its relation to the dominant winds. Such an analysis can serve as basis for design parameters of vessels, research and policy making regarding ship safety and operability, or for data source for possible wave energy evaluation projects in the region.

2.0 STUDY AREA OF MALACA STRAIT

Figure 1: Strait of Malacca (red dot is data sampling location)

Strait of Malacca is one of the world's trade lanes most strategic as shown in Figure 1. Not only for the countries directly adjacent to the waterway, but also other countries that have strategic interests, such as China, India, Japan, and the United States. Strait of Malacca and Singapore has a length of about 520 nautical miles and is the longest strait used for international waters. The entrance located on the west coast of Indonesia and Malaysia approximately 200-mile wide strait sea. This is where the sovereign territory of Indonesia and Malaysia be overlapping. Narrowest part is in the south western tip of the Malay Peninsula has a width of only 8.4 nautical miles [2]. The narrowest distance around the Straits of Singapore is 3.2 km along 15 miles with a depth of less than 75 feet. The type of ships that crossed the straits is container ships, tankers, bulk vessels, cargo vessels, ro-ro ship, passenger ships, ship Navy and fishing vessels. In late 2010, passing ship had reached 71.359 vessels and it is expected to increase reach 320.000 vessels in 2024 and will reach 1.3 million in the year 2083 [3].

3.0 ERA-Interim REANALYSIS DATA

The present study is based on the ERA-Interim global atmospheric reanalysis data that are produced by the European Center for Medium-Range Weather Forecasts (ECMWF) [4][5]. ERA-Interim is the first re-analysis using adaptive and fully automated bias corrections of satellite radiance observations [5] and contains improvements to ERA-40 such as the complete use of four-dimensional variation data assimilation from various kinds of sources such as scatterometers, altimeters, US wind profiler data, etc. The ERA-Interim reanalysis is produced with a sequential data assimilation scheme, advancing forward in time using 12- hourly analysis cycles [5].

In this study, wind speed and significant wave heights (SWH) downloaded for the period 34 years from 1984 to 2014 at 6-hourly intervals. Monthly and annual mean of wind speed and SWH were calculated from 6-hourly data to describe the variability of the wave climate over 34 years period. The annual mean of wind speed ($\overline{U_{10}}$) and significant wave height ($\overline{H_s}$) were derived from the mean of the 12 concsecutive monthly mean of the data.

$$\overline{U_{10}} = \frac{\sum_i^n U_{10_i}}{n} \qquad \overline{H_s} = \frac{\sum_i^n H_{s_i}}{n}$$

where n is sample data.

4.0 RESULTS

Variation in wind speed from 1980-2014

Temporal variation in monthly maximum and mean wind speed is plotted in Figure 2 and 3 for 34 years. Monthly maximum wind speed shows a decreasing trend from April to May as shown in Table 1. Other months show an upward trend in monthly maximum wind speed. The highest upward trend in maximum wind speed is observed during December with increasing of 5.93 cm s−1 year−1. Meanwhile, the monthly mean wind speed shows an increasing trend in all months, with higher values during January (2.23 cm s−1 year−1) and lower values observed during November with increasing trends of 0.05 cm s−1 year−1.

Table 6 and 7 show the result from temporal variation of annual maximum and mean wind speed from 1980-2014, respectively. An upward trend of 1.41 cm s−1 year−1 is observed for annual maximum wind speed in Figure 6 and an increasing trend of 2.1 cm s−1 year−1 is observed for annual mean wind speed as shown in Figure 7. The statistical trend analysis of annual maximum wind speed and mean of wind speed show statistically insignificant as shown in Table 2.

Table 1. Trend in wind speed and significant wave height (SWH) from 1980 to 2014

Month	Wind speed (cm/s/year)		SWH (cm/year)	
	Mean	Max	Mean	Max
January	2.23	5.33	0.20	2.31
February	1.73	0.76	0.20	-0.03
March	1.16	5.83	0.20	1.97
April	0.52	-4.16	-0.18	-0.81
May	0.80	-0.90	-0.19	-0.09
June	0.54	2.59	-0.37	-1.23
July	1.43	2.67	-0.29	-1.63
August	0.89	4.77	-0.27	-1.35
September	1.20	0.05	-0.20	-0.85
October	0.81	5.89	-0.84	-0.95
November	0.05	3.01	0.07	0.40
December	1.10	5.93	-0.45	3.06

Variation in wave height from 1980 to 2014

The monthly maximum and mean values of significant wave height (SWH) for 34 years are presented in Figure 4 and 5, respectively. The monthly mean SWH shows decreasing trends from April to October and during December, whereas during other months an upward trend is observed as indicated in Table 1. A maximum decreasing trend is observed during October with trend of 0.84 cm year−1. The west monsoon period (November to April) showed an upward trend in mean SWH, with an exception during December, and the upward trend is observed in the range 0.07–0.2 cm year−1.

Similar to monthly mean SWH, the monthly maximum SWH shows a downward trend for most of the months except during November, December, January and March as shown in Table 1. The monthly maximum SWH showed a higher downward trend, with a maximum during July (1.63 cm year−1). The increasing trend during November, December, January and March is observed in the range 0.4–3.06 cm year−1.

Table 8 and 9 show the result from temporal variation of annual maximum and mean SWH for period 34 years, respectively. The annual mean SWH shows a slight upward trend, with an increase of 0.11 cm year−1, whereas an increasing trend of 0.58 cm year−1 is observed for annual maximum SWH (Fig. 8), but both trends are found to be statistically insignificant as presented in Table 2.

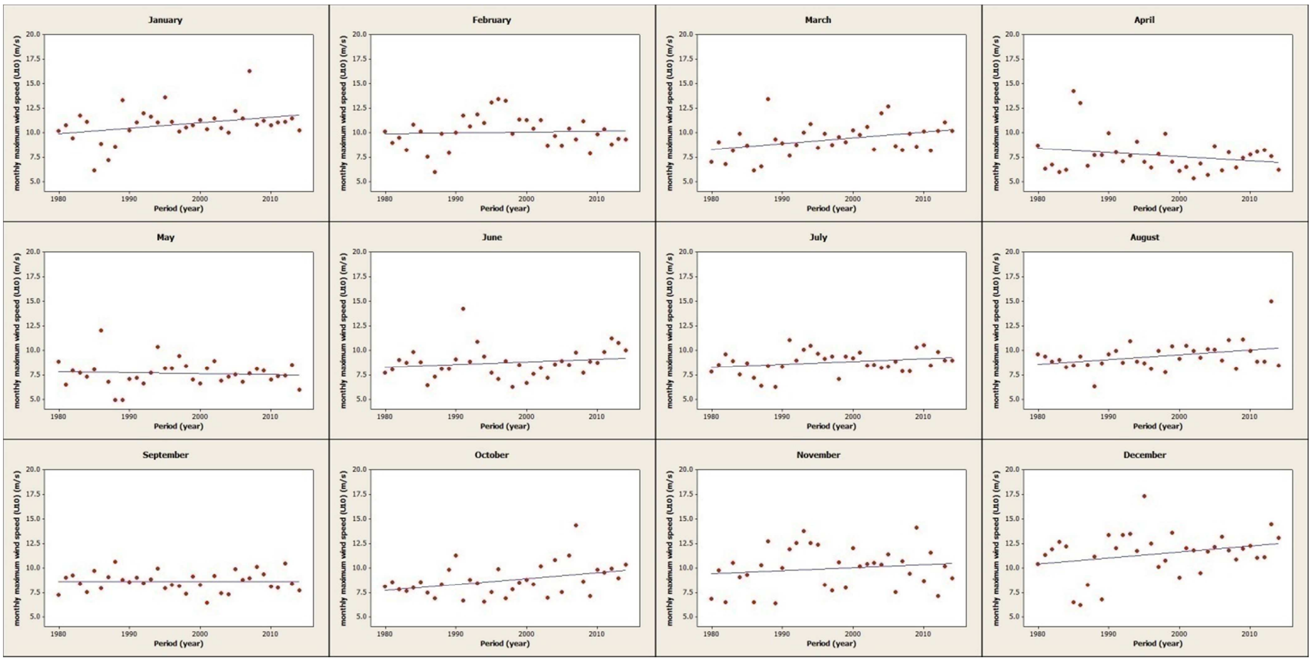

Figure 2: Temporal variation in the monthly maximum wind speed at Malacca strait

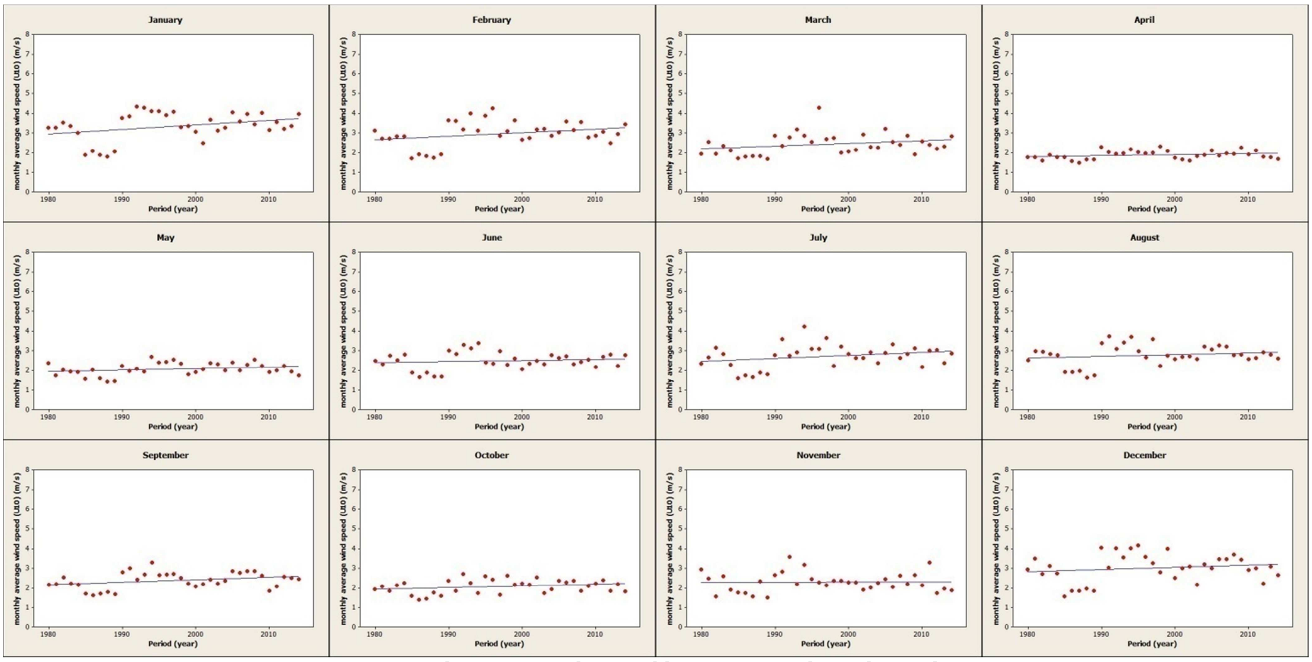

Figure 3: Temporal variation in the monthly average wind speed at Malacca strait

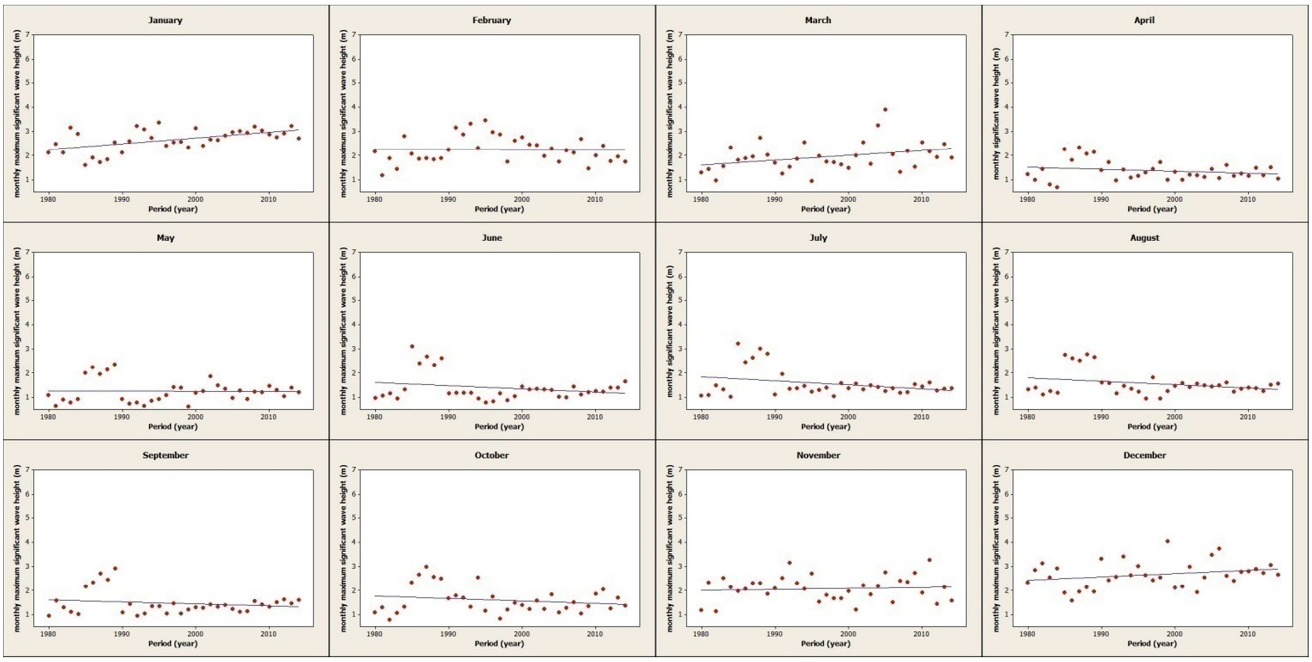

Figure 4: Temporal variation in the monthly maximum significant wave height (SWH) at Malacca strait

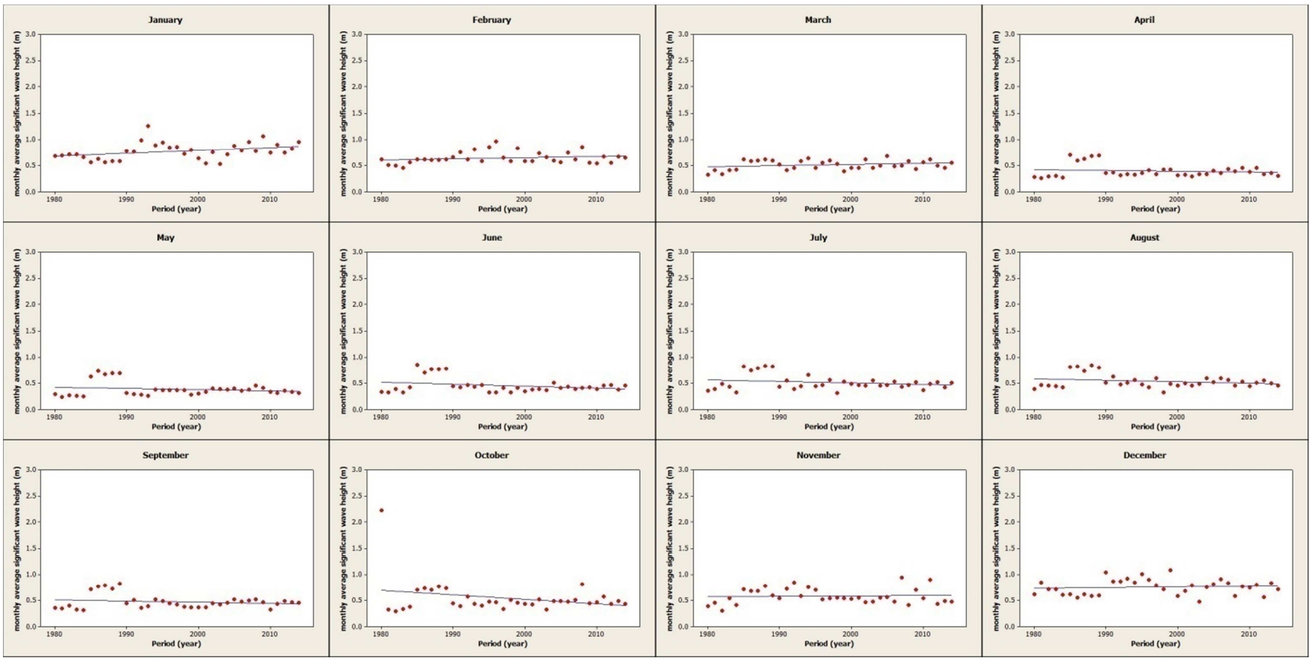

Figure 5: Temporal variation in the monthly average significant wave height (SWH) at Malacca strait

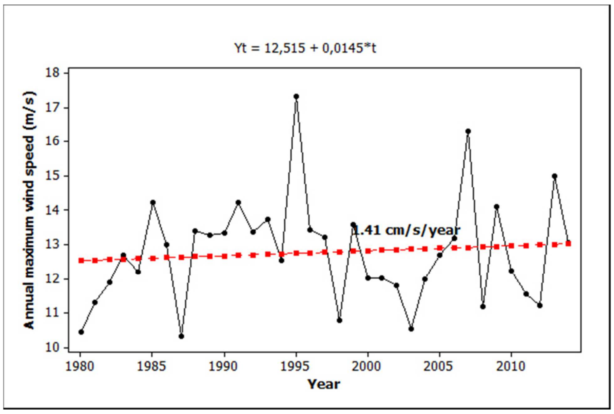

Figure 6: Temporal variation of annual maximum wind speed from 1980-2014

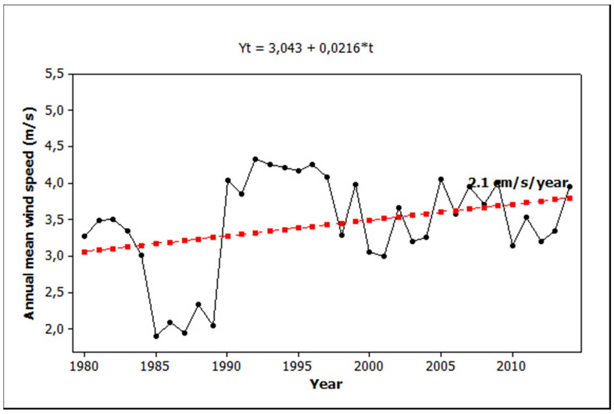

Figure 7: Temporal variation of annual mean wind speed from 1980-2014

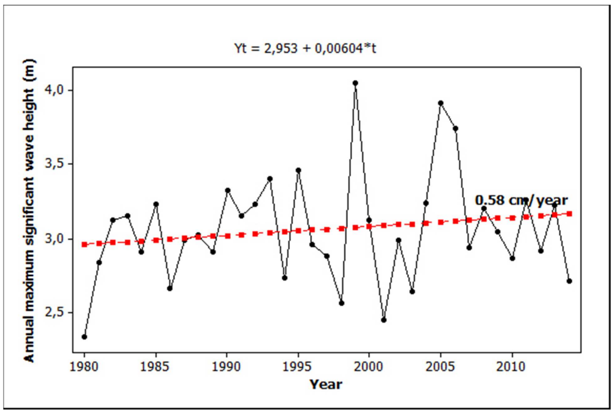

Figure 8: Temporal variation of annual maximum significant wave height from 1980-2014

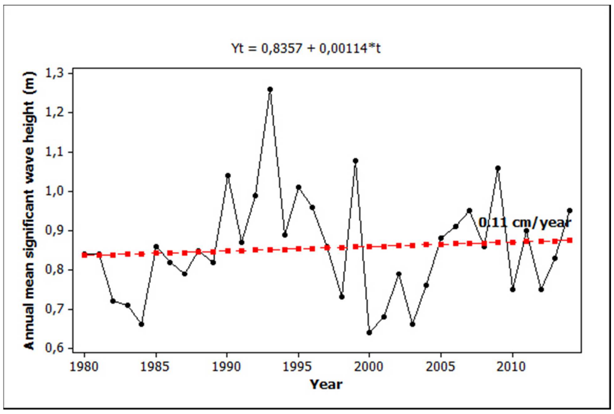

Figure 9: Temporal variation of annual mean significant wave height from 1980-2014

Table 2. Mann-Kendall test for trend analysis

Parameter	Variance	Mean	Standard Deviation	Mann-Kendall test		
				Sen slope	ρ value	Significance
Annual max wind speed	2.393	12.777	1.547	0.00767	0.3827	Not Significant
Annual mean wind speed	0.479	3.431	0.692	0.01133	0.2009	Not Significant
Annual max SWH	0.136	3.062	0.369	0.00392	0.2257	Not Significant
Annual mean SWH	0.072	0.896	0.269	0.00105	0.3558	Not Significant

5.0 CONCLUSION

In this study, a long-term trend in wind speed and significant wave height in the Malacca strait is analyzed using the ERA-Interim data set. This study is based on the data covering 34 years from 1980 to 2014. The study shows that during 34 years period, the annual maximum wind speed was characterized by a slight increasing trend (1.4 cm s−1 year−1), whereas the annual mean wind speed displays a small upward trend of 2.1 cm s−1 year−1. For the annual maximum and mean significant waves height from 1980 to 2014 has an increasing trend of 0.58 and 0.11 cm year −1, respectively. Overall, the results show that wave speed and the significant waves height have an increasing trend at the location studied but both trends of wind speed and significant wave height are statistically insignificant.

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Subsea Pipeline Assessment using Subsea Pro Simulation

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ABSTRACT

Subsea pipeline is a transport medium of oil and gas from offshore to onshore, and offshore to another platform. Subsea pipeline is subjected to extreme internal and external pressures. The differences of internal and external pressures caused by water depth are a critical issue in selection of wall thickness of subsea pipeline to be safe during installation and operation. Current standard practice codes to select the accepted wall thickness are based on tabulation of design factors. In this paper, a Subsea Pro Simulation is applied on selection of the accepted wall thickness of subsea pipeline based on safety zone. In the software, the safety zone is determined based on internal and external loads acting on subsea pipeline. The Subsea Pro Simulation is applied for different water depths such as shallow water (0 m to 400 m), deep water (400 m to 1500 m) and ultra-deep water (more than 1500 m) using data on the Medgaz subsea pipeline project. Results of simulation agree with current operating wall thickness.

KEY WORDS: *Safety Zone; Wall Thickness; Subsea Pipeline; Water Depth.*

NOMENCLATURE

σ_h	Tensile Hoop Stress
P_t	Burst Pressure
P_c	Collapse Pressure
P_o	External Pressure

1.0 INTRODUCTION

In the subsea oil and gas development continue into deep water and remote region, meanwhile offshore oil and gas companies are now being planned in water depths 2000 m and greater. At these depths the technical challenges of the subsea system become increasingly severe and the need for optimizing of production operations become more important in the industry.

The deep water is a severe condition that leads to a challenge to the subsea pipeline during installation and operation. In the installation, the subsea pipeline is subjected to external pressure that may cause to collapse the pipeline structure. When the pipeline is operated at high pressure and high temperature (HP/HT), the pipeline generate stresses axially and longitudinally, which comes from internal pressure that may lead to be burst in the pipeline. The difference of internal pressure and external pressure could have influenced the stresses along with the subsea pipeline that impact on the wall thickness of the subsea pipeline. Therefore, an evaluation of the pipeline behavior should be performed in order to ensure the pipeline structural integrity are safe during installation and operation and comply with the lifetime period of operation.

On the other side, buckling is inevitable for subsea pipeline because of the pipeline will attempt to expand and contract during extreme pressure and temperature of internal pipeline, moreover the line is not free to move due to friction effect between pipe and soil consequently compressive forces are axially distributed along the pipe. Buckling is considered as instability of pipeline leading to potential hazards for severe operation of the pipeline. A number of failures have experienced in pipeline such as upheaval buckling on buried pipeline, lateral buckling on the seabed and the like. It is important to study and predict the possible buckling of subsea pipeline at designated location. Many researchers have investigated the catastrophes of pipeline and the associated literatures.

Offshore pipelines are installed and operated in the harsh environments which have to withstand to the subsea environmental load coming from hydrostatic pressure, sea current and sea water temperature and soil friction at the seabed. The level of water depth is unequal in the seabed following the seabed contour. In this circumstance, subsea pipeline is subjected to internal and external pressure in the different of water depth, such as shallow water, deep water and ultra-deep water. The differences of internal and external pressures cause the selections of wall thicknesses are to be critical during installation and operation. In addition, the internal pressure causes the pipelines to be buckled, as well as the external pressure causes to collapse the pipeline structure.

2.0 DESIGN AND CHALLENGE CONSIDERATION OF SUBSEA PIPELINE

M.Babs Oyeneyin (2012) reported that the International Energy Foundation forecasts the increasing demand of oil consumption will be a shortfall of the petroleum industry, whereas the oil field of exploration will continue from deep water to ultra-deep water. The subsea production system will operate at severe internal and environmental condition have a need of advance technology to flow the crude oil. The major challenges for the companies are how to optimize production, minimize operational cost and guarantee multiphase flow in order to enhance the production and safety construction. Transportation of crude oil is one of challenge for subsea production system, there are some critical issue, especially in subsea pipelines which are need to be reviewed to guarantee flow assurance.

Maryam Maddahi et al (2011) stated that the prominent task in order to sustain the oil and gas production are the Selection of offshore facilities and flow assurance type. The offshore concepts offer the feature and advantage of offshore production facilities and introduces common component of the subsea completion system. The remoteness of production area with the harsh environment becomes a great challenge in the design of oil and gas production. The feasibility study will necessitate the development and implementation of technological solution to achieve the oil production. Different Area of oil production will cause different way to build the offshore production furthermore the right selection of facilities and subsea component are needed to avoid failure and high expenditure.

Ragnar T et al (2000) reported a pilot study for a DEEPPIPE project that the deep water has a great challenge to transport oil and gas production. This challenge imposes to high cost construction and operation. In consequence, the pipeline design must meet the tight requirement. The objective of the design was to provide more effective cost of installation and operation with regard to acceptance criteria for material selection, welded joint, service and testing for pipelines. Tension and fatigue test were carried out for the material to assure the mechanical properties. Allowable stress and strain refer to the DNV OS F101, whereas the global bending was considered as high strain and stress intensification occurred. For installation, The S-Lay method is effective cost to be applied where the pipelines are joint at welding station.

Hermann Moshagen (1998) said that the design of subsea pipeline must comply with the pipeline design codes such as ANSI/ASME B31.4, API RP 1111, DNV F 101 Design Guidelines. The pipeline standard gives the strict requirements for design, materials, construction, operation and maintenance to assure that the pipelines are safe to be operated during a lifetime period without any failures or structure instabilities occurred, such as buckling, fatigue, out of roundness and excessive free spans and etc. The DNV OS F101 gives the design requirement for pressure containment which is called Load Resistance Factor Design (LRFD). The LRFD principle is the design load is not exceed the design resistance of the pipeline.

Andrew Palmer (1998) reported that the conventional pipeline design in deep water must withstand to external hydrostatic pressure. The pipeline is laid with air-filled during installation to resist collapse and buckle propagation. The wall thickness of pipe will be high and other difficulties with welding, possible repair and corresponding to high cost. The need of medium-filled to pipeline will be a question for engineering, meanwhile the inside pipeline will not be permitted to be empty to prevent a collapse. When the water is used to fill in the pipeline, it will affect to submerge weight of pipeline induce high tension on the topside. Alternative lighter liquids might have advantages to reduce submerge weight such as pentane which it has a density of 626.2 kg/m3 and boils at 36.1°C. The density of liquid will influence the top tension of pipeline with the result that the thickness of pipeline is selected to withstand the load.

lndu K. Mahendran et al (1997) studied The API and ASME restrict the selection of pipe wall thickness for the application of High Pressure and Temperature by mean of Burst Limit State Design principles to design subsea pipeline. The burst pressure limit state is a model to predict the strength of pipeline against the internal load and to acquire the reliable structure of subsea pipeline. The objective of limit state design is to estimate the strength of the pipeline structure respect to internal loads

3.0 BASIC THEORIES ON SUBSEA PIPELINE

This section provides the description of subsea pipeline theory related to the design of subsea pipeline by considering internal and external pressure. The internal pressure induces an expansion and lead to buckle during operation. The external pressure causes the pipeline to be collapse during installation and operation.

3.1 Hoop Stress

The primary requirement of the pipe wall-thickness selection is to sustain the stresses for pressure containment. The tensile hoop stress is due to the difference between internal and external pressure, and is not to exceed the permissible value as given by the following hoop stress criterion (DNV - 2000):

$$\sigma_h = (P_i - P_e)\frac{D-t}{2t} \leq ή(SMYS - f_{y.temp}) \qquad (3.1)$$

Where: the usage factor for pressure containment is expressed as

$$ή \;=\; \frac{2.\alpha_v}{\sqrt{3}.\gamma m.\gamma sc.\gamma inc} \qquad (3.2)$$

where: α_v= Strength of material
γ_m= Resistance factor of material
γ_{sc}= safety class factor
γ_{inc}= incidental of design pressure ratio

The allowable hoopstress F_h the criterion of ABS (2000) to be expressed by the following equation:

$$F_h = \eta . SMYS . k_T \tag{3.3}$$

The hoop stress F_h in a pipe can be formulated as below:

$$\sigma_h = (P_i - P_e)\frac{D-t}{t} \tag{3.4}$$

3.2 Burst Pressure Design

The pipeline is filled with pressurized liquid or gas which is called the internal pressure. The internal pressure generates stresses in the pipeline. If the stresses exceed the limit strength, then the pipeline will be burst. Burst pressure can be formulated as follows:

$$P_t \leq f_d . f_e . f_t . P_b \tag{3.5}$$

$P_d \leq 0.80 P_t$
$P_a \leq 0.90 P_t$
f_d= burst design factor of internal pressure 0.90 for pipeline and 0.75 for riser
f_e= joint factor of weld
f_t= Temperature derating factor, 1.0 for temp less than 121^{0}C
P_b=Specified Minimum Burst Pressure
P_d=Pipeline Design pressure
P_t= Hydrostatic test pressure

$$P_b = 0.90(SMYS + SMTS)\left(\frac{t}{D-t}\right) \tag{3.6}$$

Where: D= outside diameter for D/t >15
Substituting the pressure test:

$$P_d = \leq 0.80 f_d f_e f_t P_b \tag{3.7}$$

$$P_d = \leq 0.80 f_d f_e f_t 0.90(SMYS + SMTS)\left(\frac{t}{D-t}\right) \tag{3.8}$$

3.3. Collapse Pressure Design

API RP 1111 provides a formula to determine the collapse pressure as follows:

$$P_c = \frac{P_y P_e}{\sqrt{P_y^2 + P_e^2}} \tag{3.9}$$

Where

$$P_y = 2.SMYS\left(\frac{t}{D}\right) \tag{3.10}$$

$$P_y = 2S\left(\frac{t}{D}\right) \tag{3.11}$$

Timoshenko and Gere (1961), propose the following design equation collapse pressure

$$P_c = \frac{2S_y}{1 + \frac{S(1-v^2)}{E}\left(\frac{D}{t}\right)^3} \tag{3.12}$$

3.4 External Pressure

External pressure is an important factor which should be taken into consideration in the design of subsea pipeline. The External pressure of subsea pipeline comes from hydrostatic pressure, which varies to every water depth level. The hydrostatic pressure is critical in the deep and ultra-deep water that may lead to collapse of pipeline structure. In order to determine a hydrostatic pressure for a certain water depth could be calculated as follows:

$$P_o = \rho . g . h \tag{3.13}$$

4.0 FIELD DESCRIPTION

This research uses Medgaz Gas Transmission Project by completion of subsea pipeline linking Algeria and Spain across the Mediterranean Sea as shown in figure.1, to overcome the challenges of 2,155 meters water depth. The pipelines are made of X70 API Grade Steel. The Medgaz subsea pipeline route traverses various contours of sea bottom as shown in figure.1. The route starts from Algerian Coastline to Spanish continental. The route has some area with sandy sediments and a clayey section between the shore approach and the outer shelf. Buckles potentially occurred from KP-22 to KP-37. The pipeline has been designed for 50 years life time period and using different thickness of concrete coating (45mm and 80 mm).

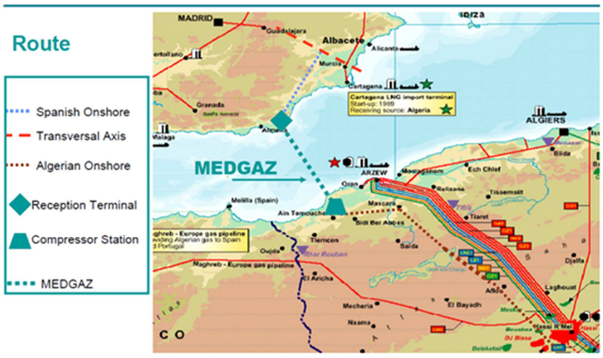


Figure 1: Route Map of Medgaz Pipeline (OTC20770)

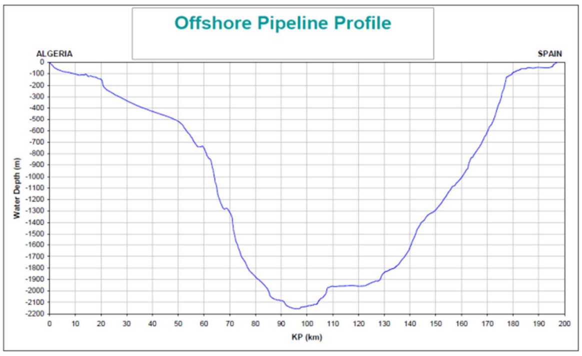


Figure 2: Seabed profile along the route (OTC20770).

4.1Design Parameters

This section presents the design parameters which include the data related to pipeline geometry, mechanical properties of the material and operation and environmental loads.

Table 1: Parameter Design

Parameter	Unit	Value
Outside Diameter	mm	609.6
Current Wall thickness	mm	22.9, 28.5, 29.9
Pipe Material Grade	-	X70
Steel Density	Kg/m^3	7850
SMYS	MPa	482
SMTS	MPa	565
Poisson ratio (v)	-	0.3
Young's Modulus (E)	GPa	207
Thermal Expansion Coef.(α)	C^{-1}	1.17x10E-05
Concrete Coating Thickness	mm	45, 80
Concrete Coating Density	Kg/m^3	3040
Content density (Gas)	Kg/m^3	0.668
Design Pressure	MPa	22
Operating Temperature	^{0}C	60
Seawater Density	Kg/m^3	1027
Water Depth of Shallow Water	m	350
Water Depth of Deep Water	m	1000
Water Depth of Ultra-Deep Water	m	2155
External Pressure	MPa	3.5
Target Project Life	Year	50
Ambient Temperature	^{0}C	15

5.0 RESULT AND DISCUSSION

Subsea pipeline wall thickness is crucial parameter when it interfaces with internal and external pressures in deep and ultra-deep waters. Figure.3 demonstrates wall thickness of subsea pipeline versus burst and collapse pressures. External pressure was calculated using hydrostatic equation (light green line for shallow, yellow line for deep and red for ultra-deep) and collapse and burst pressures were calculated using API rules as discussed in chapter 4.

Based on burst pressure results, the accepted minimum wall thickness of subsea pipeline is 14 mm for all water depths, which is shown by the crossing line between operating pressure and burst pressure as shown by a dash line in figure.3. In shallow water, it is indicated that burst pressure becomes dominant to be considered in the selection of wall thickness, when compared to collapse pressure. For deep water and ultra-deep water, collapse pressure becomes dominant, which is important to be considered in the selection of wall thickness. On the other hand, based on collapse pressure analysis, the minimum wall thickness differs for various water depths, as shown in the figure.3 an example: 12 mm for shallow, 18 mm for deep and 24 mm for ultra-deep. For deep water and ultra-deep water, collapse pressure is dominant to be considered to determine wall thickness of subsea pipeline.

Figures.4.a shows front page of Subsea Pro Simulation Software. This software was developed under Joint International Research Centre which can be download website as shown in Figure.4.b. Figures.5 and 6 show predicted wall thickness of subsea pipeline at shallow and ultra-deep waters using Subsea Pro Simulation Software. The predicted wall thickness showed good agreement with current operation wall thickness which is 23.4 mm and 31.8 mm.

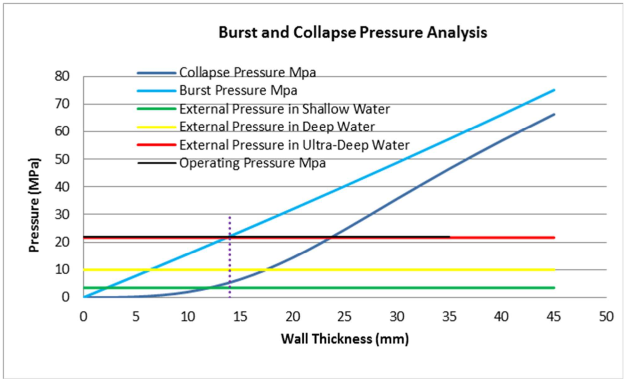
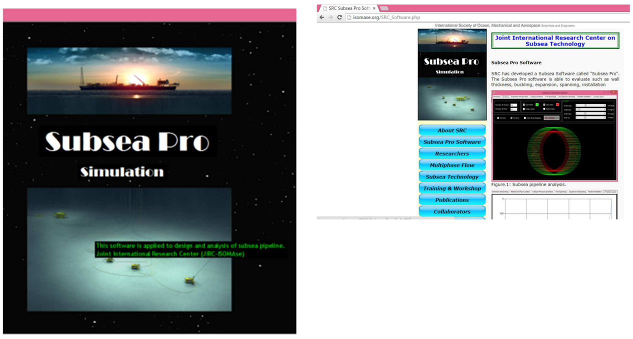


Figure 3: Safety Zone based on burst and collapse pressures analysis.



This software is applied to design and analysis of subsea pipeline.
Joint International Research Center (JIRC-ISOMAse)

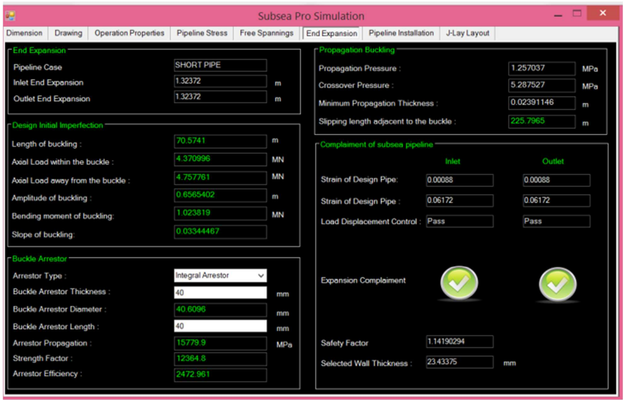
Subsea Pro Software

SRC has developed a Subsea Software called "Subsea Pro". The Subsea Pro software is able to evaluate such as wall thickness, buckling, expansion, spanning, installation

Figure.1: Subsea pipeline analysis.

(a) (b)

Figure 4: Subsea Pro Simulation Software.

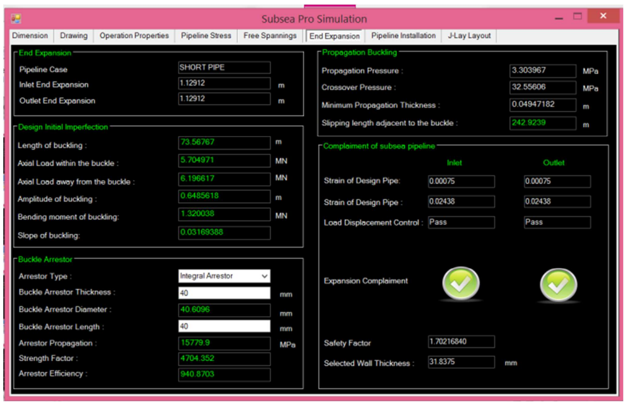


Pipeline Case SHORT PIPE
Inlet End Expansion 1.32372 m
Outlet End Expansion 1.32372 m
Length of buckling : 70.5741 m
Axial Load within the buckle : 4.370996 MN
Axial Load away from the buckle : 4.757761 MN
Amplitude of buckling : 0.6565402 m
Bending moment of buckling: 1.023819 MN
Slope of buckling: 0.03344467
Arrestor Type : Integral Arrestor
Buckle Arrestor Thickness : 40 mm
Buckle Arrestor Diameter : 40.6096 mm
Buckle Arrestor Length : 40 mm
Arrestor Propagation : 15779.9 MPa
Strength Factor : 12364.8
Arrestor Efficiency : 2472.961
Propagation Pressure : 1.257037 MPa
Crossover Pressure : 5.287527 MPa
Minimum Propagation Thickness : 0.02391146 m
Slipping length adjacent to the buckle : 225.7965 m

	Inlet	Outlet
Strain of Design Pipe:	0.00088	0.00088
Strain of Design Pipe :	0.06172	0.06172
Load Displacement Control :	Pass	Pass
Expansion Complaiment	✓	✓

Safety Factor 1.14190294
Selected Wall Thickness : 23.43375 mm

Figure 5: Selected wall thickness at shallow water using Subsea Pro Simulation software.



End Expansion
Pipeline Case: SHORT PIPE
Inlet End Expansion: 1.12912 m
Outlet End Expansion: 1.12912 m

Design Initial Imperfection
Length of buckling : 73.56767 m
Axial Load within the buckle : 5.704971 MN
Axial Load away from the buckle : 6.196617 MN
Amplitude of buckling : 0.6485618 m
Bending moment of buckling: 1.320038 MN
Slope of buckling: 0.03169388

Buckle Arrestor
Arrestor Type : Integral Arrestor
Buckle Arrestor Thickness : 40 mm
Buckle Arrestor Diameter : 40.6096 mm
Buckle Arrestor Length : 40 mm
Arrestor Propagation : 15779.9 MPa
Strength Factor : 4704.352
Arrestor Efficiency : 940.8703

Propagation Buckling
Propagation Pressure : 3.303967 MPa
Crossover Pressure : 32.55606 MPa
Minimum Propagation Thickness : 0.04947182 m
Slipping length adjacent to the buckle : 242.9239 m

Complaiment of subsea pipeline

	Inlet	Outlet
Strain of Design Pipe:	0.00075	0.00075
Strain of Design Pipe :	0.02438	0.02438
Load Displacement Control :	Pass	Pass
Expansion Complaiment	✓	✓

Safety Factor: 1.70216840
Selected Wall Thickness : 31.8375 mm

Figure 6: Selected wall thickness at ultra-deep water using Subsea Pro Simulation software.

6.0 CONCLUSION

In conclusion, this research determines and evaluates safety zone of wall thickness in design of subsea pipeline using Subsea Pro Simulation. As a case study, Medgaz project was applied. In the method, internal and external pressures are two parameters which are needed to be considered in selection of wall thickness. In shallow, burst pressure becomes dominant instead of collapse pressure. Safety zone of wall thickness is determined based on burst pressure. For deep and ultra-deep water, collapse pressure becomes dominant instead of burst pressure, hence safety zone of wall thickness based on burst pressure. This configuration provides a safety zone of wall thickness for every water depth. Predicted wall thickness using Results of simulation shows

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