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Feasibility Study for the Reuse of a Steel Offshore Platform as the Base of a Wind Tower

Vencislau Manuel Quissanga[*1], Elson Antonio do Nascimento[1], Nelson Szilard Galgoul[2]

[*1]*Department of Post-Graduate Civil Engineering, Federal Fluminense University, UFF, Brazil*
[2]*Department of Post-Graduate Civil Engineering, Federal University of Rio de Janeiro, UFRJ, Brazil*

ABSTRACT
The reuse of fixed offshore platforms in fields that are no longer productive, is an alternative that has been frequently mentioned by the wind industry, but which, in practical terms, has not yet been used in Brazil and very little in other countries. In Brazil, there is a large number of fixed platforms, mainly along the northeastern coast of the country, whose production is nearly depleted. Considering that the decommissioning process represents high costs associated to the strict requirements related to environmental licensing, the reuse of the jackets of these structures as a base for wind turbines becomes an attractive alternative. In order to evaluate such a reuse, it is necessary to structurally analyze the jackets under the new operating conditions. Therefore, this research contains, the evaluation of a typical wellhead platform that has been used on more than 50 jackets, where the existing deck has been removed and replaced by a wind tower. The numerical model was developed in the software OrcaFlex V10.3, which enables the calculation of wind tower forces along with all other environmental loads.

KEYWORDS: *Fixed steel offshore platform, wind tower, structural verification, decommissioning.*

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I. INTRODUCTION

The offshore wind energy industry is presently growing at an incredible speed and has proven to be one of the most effective renewable energy sources. Scotland has made wind power their fastest growing renewable energy source, with almost 9000MW installed by the end of 2018 [1]. Europe, in general, and more specifically Germany, has been investing heavily in offshore wind platforms, which were originally subsidized but have gradually become profitable.Brazil has invested in onshore wind towers, but up to now, there have been no offshore implementations, although the first studies in this regard are presently being performed. However, none of these have passed the stage of financial feasibility. Nevertheless, it should be said that this onshore head start is totally intuitive because the corresponding wind fields have been much cheaper than their offshore equivalents. However, it is obvious, that this trend will soon be reversed because the larger offshore wind towers are making wind energy increasingly cheaper, but there is a limit on the size of the towers that can be installed onshore, because of their highway transportation (slightly beyond 5MW). Even in Brazil, therefore, the implementation of offshore wind farms is expected to become very common in the near future.

An article published in 2017 [2], evaluated and suggested the possibility of transforming a typical Brazilian structure into an offshore wind tower. In this study, they have investigated the wind conditions along the Brazilian coast, the structural conditions of this typical offshore platform and the financial conditions for its re-use. Based on these, results they have concluded that this small typical Brazilian platform can be used to install a 5MW wind tower, which at that time, was the one most frequently used for offshore purposes.

Only 3 years after that article hads been published (4 or 5 years after it was written), however, the 5MW wind tower is no longer used for offshore purposes. It is still available for the onshore market, but for offshore purposes, almost all platforms have 10MW towers and those that are still being planned are considering 12 and even 15MW towers.

Considering that the 5MW tower can no longer be purchased for offshore purposes, the question which must be answered is if this same typical Brazilian offshore platform, evaluated in [2], can resist the forces induced by a present day 10MW tower. Answering this question is our specific goal.

In Brazil there are over 50 of these typical small wellhead platforms, so one of them was used to perform the analyses required in order to answer the question asked above. In this case the chosen platform is installed in a field called Ubarana/Agulha, where about 30 of such platforms are producing only 1500bpd (all together) according to [3]. The deck will be removed and a wind tower installed in its place.

The analyses performed here will consider first the 5MW tower, just to confirm the results already obtained in [2] and then repeated with the 10MW tower, which is presently the one that is being used on most of the offshore wind towers. The Brazilian Government has drawn attention to the excellent wind conditions of the Brazilian coast, especially in the northeastern part of the country. Figure 1, taken from [4], presents the average annual wind speeds along the coast, at a height 50m above average sea level. The maximum value in the given graph is 9m/sec.Knowing that 9m/sec. is an excellent average wind speed for the implementation of wind towers, this means also that all points on the graph, which show 7.85m/sec. speeds at 50m, will have 9m/sec. speeds at 150m high, which is the height that the larger towers (12 and 15MW) are now reaching. This proves that the entire northeastern coast from João Pessoa up to São Luis is included in this region. Other segments, like the region between Sergipe and Bahia near Salvador, the entire state of Minas Gerais extending down to Rio de Janeiro and almost the entire Southern part of the country are also adequate for the installation of wind farms. According to [2], about 75% of Brazilian fixed platforms are already more than 25 years old. Among them are Potiguar (Ubarana and Agulha) and Sergipe and Alagoas (Piranema, Caioba, Camorim, Dourado, Guaricema and Salgo) Basins and there are 63% (out of a total of 55 platforms), which are already considered decommissionable (see Figure 2).

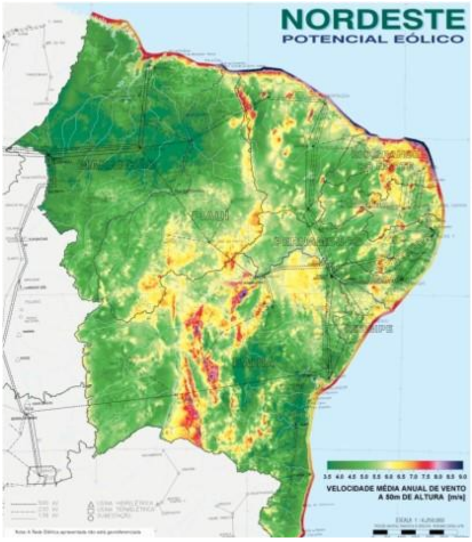

Figure 1: Average Annual WindSpeed at 50m above sea level (m/sec.) [4]

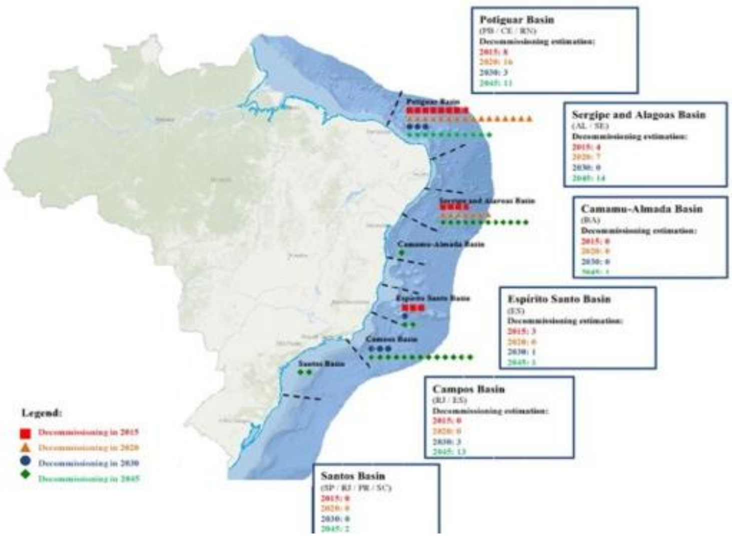

Figure 2: Foreseen decomissioning of the Brazilian offshore platforms [2]

II. ANALYSIS MODELS

The practical example considered in this study was a typical wellhead offshore platform used in the northeastern part of Brazil (called 1st Family by the owner). The 1st Family platform is a 4legged structure, whose legs are approximately 6.2m apart at deck level, which is meant to support the production of up to 6 wells. The 4 symmetric faces are inclined 1/8 and the main legs contain 86cm diameter piles. In this case the platform has 4 additional skirt piles, whose skirts are braced to legs. The typical platform deck is also shown in Figure 3, but the deck configuration varied considerably from one platform to another. The load capacity of the deck was limited to slightly over 2000tons, which is compatible with the weight of a 10MW tower.

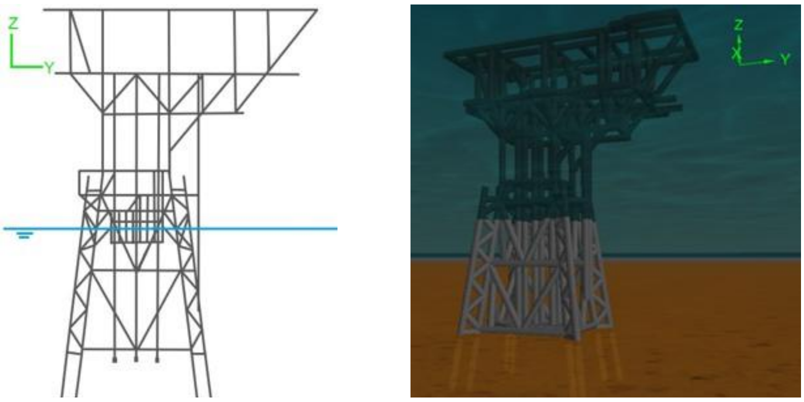

Figure3: A typical fixed offshore platform of 1st family

The structural model prepared contains all the platform members with their corresponding diameters and thicknesses. These structures are usually designed for in-place conditions considering a full nonlinear pile-soil interaction, but in this case a simplified equivalent embedded length of the piles was considered for the foundation. The ultimate compressive pile capacity estimated in the original design was 10694kN.

In this study, where the deck will be removed and replaced by a wind tower, a 5MW tower, already considered in the analyses performed in [2] will be is considered first, just for the sake of comparison of the order of magnitude of the results. It is then be replaced by a 10MW tower and the analyses repeated, in order to verify the feasibility of the reuse of these platforms for the offshore wind tower available in the market today.

The software considered for these analyses is called OrcaFlex, developed by ORCINA in Ulverston, England [5], which allows perfect modelling of the wind towers, generating the corresponding wind forces. Figure 4 contains plots of the models of the two platforms, used in OrcaFlex to evaluate the 5 and 10MW wind platforms, respectively.

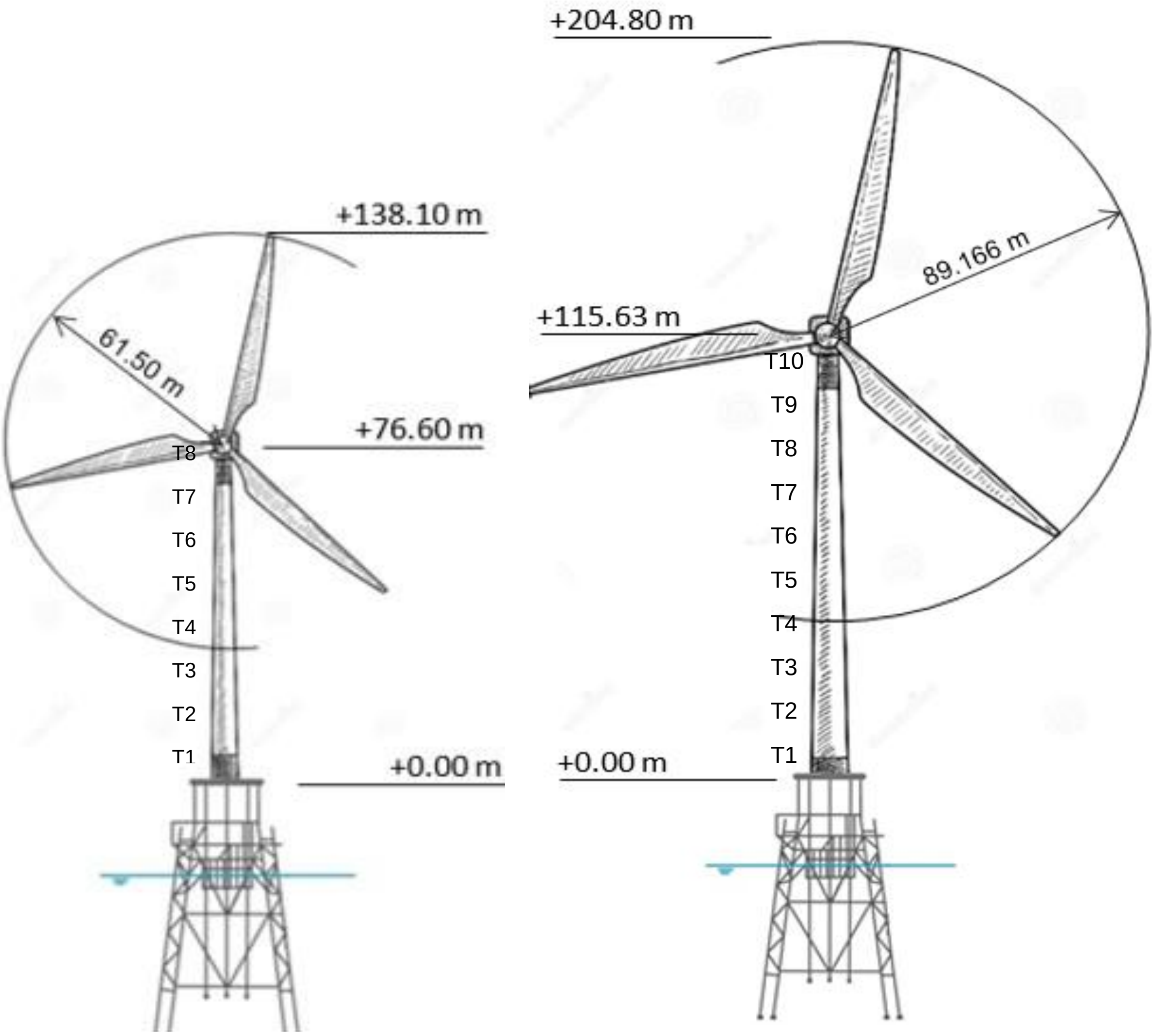

Figure 4:1st Family Platform with both a 5MW and a 10MW Wind Tower installed

Regarding the physical properties of the materials, steel has a yield stress (fy) of 248 MPa, an elastic modulus (Es) of $2.0x10^5$ MPa, a Poisson's ratio (ν) of 0.3 and a density (ρ) of 7850 kg/m³.Next, Table 1 presents the main information related to the sizes and weights of the towers, whose data were extracted from [6] and [7] for the 5 and 10 MW towers, respectively.

Table 1: Geometry Data of the 5 and 10MW Wind Towers.

Tower member (5MW Tower)			
Seccion	Height (m)	External Diameter (cm)	Thickness (mm)
T1	10	650	32
T2	20	600	30
T3	30	550	28
T4	40	500	26
T5	50	450	24
T6	60	425	22
T7	70	400	20
T8	76.60	387	18

Weight of wind turbine 5MW		
Element	Mass (kg)	Weight (kN)
Rotor	311127	3051.11
Nacelle	678823	6656.98

Tower member (10MW Tower)			
Seccion	Height (m)	External Diameter (cm)	Thickness (mm)
T1	11.50	830	38
T2	23	802	36
T3	34.50	774.30	34
T4	46	746.46	32
T5	57.50	718.61	30
T6	69	690.76	28
T7	80.50	662.91	26
T8	92	635.07	24
T9	103.50	607.22	22
T10	115.63	550	20

Weight of wind turbine 10MW		
Element	Mass (kg)	Weight (kN)
Rotor	227962	2235.54
Nacelle	446036	4374.12

III. ENVIRONMENTAL DATA AND LOADS

1.1.1 Wave and Current Data

The directions of wave incidence were defined based on the structural configuration. Due to the double symmetry of the structure, it was possible to choose only two directions of wave incidence (0º and 45º), relative to the X-axis of the global structural model.

Wave and current were assumed to be aligned and in the same direction. The operational and storm condition wave heights and current velocities are presented in Table 2 below.

Table 2: Wave and Current Conditions.

Wave				Current (m/sec.)			
Storm		Operation		Storm		Operation	
Height (m)	Period (sec.)	Height (m)	Period (sec.)	Surface Velocity(m/sec.)	Bottom Velocity(m/sec.)	Surface Velocity (m/sec.)	Bottom Velocity(m/sec.)
8.2	9.4	5.90	9	1.79	0.64	1.35	0.48

1.1.2 Wind

The wind velocities have been defined at 10m above average sea level:

Operational condition= 25.7 m/sec and Storm condition: 35.0 m/sec.

These velocities have been corrected automatically with height by the program for the calculation of the wind forces. The wind forces on the blades were assumed to be constant and equal to the highest forces generated for operational conditions (around 11m/sec.). For the higher velocities of storm and operation, it was assumed that the blades rotate in order to keep this force constant. In reality this assumption is a little conservative because the forces decline a little with the rotation of the blades.

1.1.3 Hydrodynamic Coefficients

The hydrodynamic coefficients of the jacket were established according to API-RP2A [8].

IV. RESULTS

The final objective of this study is to verify the feasibility of the reuse of the 1st Family jackets to support an offshore wind tower. A similar study performed in [2] prepared over 3 years ago, had concluded, based on a 5MW tower that it was both structurally and economically feasible. In the meantime, however, the 5MW offshore wind tower is no longer available, so this same structural feasibility has to be proven for the 10MW tower (the tower presently being used on offshore wind structures).

The analyses performed here were for both of these towers. The 5MW tower was used just to confirm the results obtained in [2]. These results are presented in section 5.1. The final results of interest are those obtained for the 10MW tower and these are presented in section 5.2.

1.2.1 Results Obtained for the 5MW Tower

Although the analyses performed in [2] and those carried out here both used a 1st Family platform as their starting points, the platforms evaluated were not the same, so the results are not directly comparable, but the main conclusion in [2] was that both the structure and the foundation had acceptable unity checks.

The maximum pile loads obtained for storm and operational conditions were 9196.39kN and 6084.25kN respectively. The corresponding safety factors for storm and operational conditions are 1.5 and 2 respectively, so the corresponding unity check values are:

Storm – UC = 9196.39 / (10694/1.5) = 1.29

Operation – UC = 6084.25 / (10694/2.0) = 1.13

These results show that the foundations of the jacket with the 5MW tower are already up against the limit, in fact slightly over it, but nevertheless tolerated.

The results of the jacket stresses will be limited to the main legs, at the position indicated in Figure 5. These results are presented in Table 3, which include second order effects, so the unity check can be obtained directly from the stresses, where the allowable stress is 198MPa (0.8 x 248).

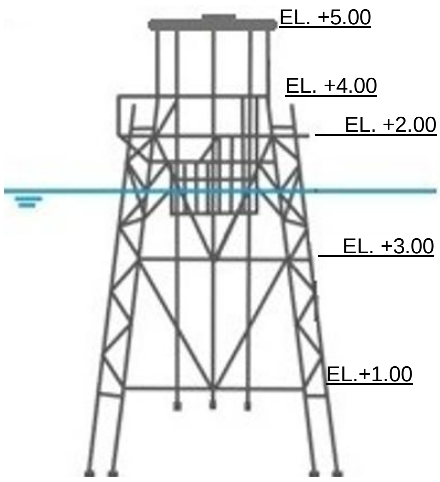

Figure 1: Position of the UCs calculated on jacket leg (5MW)

Table 5: Maximum Von Mises stresses on the leg with the highest value (5MW)

Elevation	Max. Von Mises Stress	Deflect	UC
	(N/mm2)	(cm)	--
EL.+1.00	107.31	0.54	0.54
EL.+2.00	120.60	1.09	0.61
EL.+3.00	77.83	1.40	0.40
EL.+4.00	147.85	1.41	0.74
EL.+5.00	194.06	1.68	0.98

The UC results of the stresses on the jacket legs show that the structure is adequate to withstand the loads imposed by a 5MW wind tower, although also up against the limit.

1.3.1 Results Obtained for the 10MW Tower

The maximum pile loads obtained for storm and operational conditions were 27259.06kN and 23850.61kN respectively. The corresponding safety factors for storm and operational conditions are 1.5 and 2.0 respectively, so the corresponding unity check values are:

Storm – UC = 27259.06 / (10693.6/1.5) = 3.82

Operation – UC = 23850.61 / (10693.6/2.0) = 4.46

These results show that the foundations of the jacket with the 10MW tower are totally overstressed.

The results of the jacket stresses is limited to the main legs, at the position indicated in Figure 6. These results are presented in Table 4, which include second order effects, so the unity check can be obtained directly from the stresses, where the allowable stress is 198MPa.

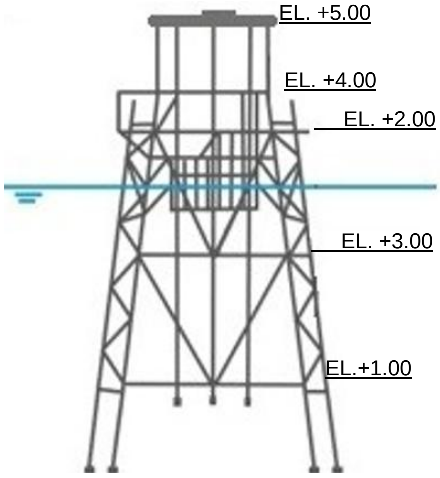

Figure 6:Position of stresses on jacket leg (10MW)

Table 6: Maximum Von Mises stresses on the leg with the highest value (10MW)

Elevation	Max. Von Mises Stress	Deflect	UC
	(N/mm2)	(cm)	--
EL.+1.00	762.91	0.54	3.85
EL.+2.00	711.86	1.09	3.59
EL.+3.00	724.60	1.40	3.65
EL.+4.00	710.37	1.41	3.58
EL.+5.00	485.22	1.68	2.45

Consistent with what we have already seen for the foundation, these results show that the jacket will be hopelessly overstressed for the loads imposed by the 10MW wind tower.At this point fatigue should also be investigated but this is no longer necessary because the in-place results have already failed to comply.

V. CONCLUSIONS AND SUGGESTIONS

Although the final results presented in [2] were favorable to the reuse of the 1st Family jacket for the installation of a 5MW wind tower, the offshore wind industry is evolving so rapidly that, no more than 5 years after this study was performed, the 5MW towers are no longer available for offshore platforms, although the onshore market is still using them.It is also important to emphasize that offshore towers are always installed as large as possible, because the larger they are the greater their efficiency. This is the main reason why the 5MW towers are no longer available offshore.This is the reason why it was necessary to evaluate the 1st Family jackets for the 10MW wind tower, because this is the tower available for all of the wind platforms that are being installed today.Unfortunately, the results presented above show that the 10MW wind tower cannot be used on a 1st Family jacket, because the overturning moments have grown much more than the corresponding weight loads.An attempt was made to solve this problem by stabilizing the jacket, both with cables stays and also using rigid bracing elements, but with no success, due to the excessive flexibility of these elements, in addition to the fact that they did not solve the problem of excessive tensions in the jacket. These results were not even presented, but they contribute to the main conclusion given below.

The final conclusion is that although the results obtained in [2] have been confirmed for the 5MW tower, the 1st Family platforms studied here cannot be reused as a support for a 10MW tower, so they must be decommissioned.This is a Brazilian conclusion because it refers to a typical wellhead platform that is being used in Brazil, but in general it can be used as an alert for other platforms both in Brazil and in other countries, since it helps to show that the jacket, which is going to accept a present day offshore wind tower (10MW or larger), will have to be larger than the typical Brazilian wellhead platform.

In addition to the in-place analysis, it would also be necessary to analyze jacket fatigue adding both the damage accumulated during its service as an oil platform to that which will be accumulated in the future as a wind platform.

REFERENCES

[1]. Wind Powerin Scotland. In: Wikipedia, The Free Encyclopedia, 13:50 UTC, <https://en.wikipedia.org/w/index.php?title=Wind_power_in_Scotland&oldid=941080808>. Accessed 05 February 2020.
[2]. Barros, J. C., Fernandes, G. C., Silva, M. M., Silva, R. P. (2017) "Fixed Platforms at Ageing Oil Fields – Feasibility Study for Reuse to Wind Farms" Offshore Technology Conference, Houston.
[3]. Agência Nacional do Petróleo, Gás Natural e Biocombustível. In: ANP, <www.anp.gov.br/exploracao-e-producao-de-oleo-e-gas/painel-dinamico-de-producao-de-petroleo-e-gas-natural>. Accessed in: 11 November 2019.
[4]. Amarante,O. A. C., BrowerM., Zack, J., Sá, A. L. (2001) "Atlas do Potencial Eólico Brasileiro", Ministério de Minas e Energia, Brasília/Brazil.
[5]. OrcaFlex. In: Orcina, <www.orcina.com/softwareproducts>Accessed 12 November 2020.
[6]. Jonkman, J., Butterfield, S., Musial, W., Scott, G. (2009) "Definition of a 5-MW Reference Wind Turbine for Offshore System Development", NREL/TP-500-38060, Golden, co: National Renewable Energy. U.S.
[7]. Bak, C., Zahle, F., Bitsche, R., Kim, T., Yde, A., Henriksen, L. C., Nataranjan, A., Hansen M. (2013) "Description of the DTU 10 MW reference wind turbine" DTU wind energy. Technical University of Denmark. Denmark.
[8]. American Petroleum Institute, (2014) "Recommended Practice for Planning, Designing & Constructing fixed Offshore Platforms API RP 2A", - Working Stress Design, 22nd ed. U.S. and Canada.