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STUDY SIMULATION OF UMBILICAL CABLE FOR UNDERWATER VEHICLE

BY

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Abstract. This paper presents a series of analyses regarding the tethered umbilical cable in uniform current cable from the composition of the underwater remotely operated vehicle (ROV). The remotely operated vehicle is used in different undersea operation when it is important to control and determine precisely the disturbance forces generated by drag due to currents that act either on the vehicle directly or indirectly on the tether umbilical cable. The dynamics of umbilical cable represent an important part in ocean environment being used for signal and power transmission application. To perform the simulation in Ansys Aqwa, two axis systems are considered. A coordinate system related to the earth, represented by the key in front of which the measurements are made and a second coordinate system related to the vehicle at a set depth relative to the surface of the key. The results obtained from the simulation show us the drag forces that are exerted on the chosen cable for a given length, drag that appear both the seaborne platforms and underwater remotely vehicle contact.

Keywords: ANSYS AQWA; remotely operated vehicle; uniform current.

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1. Introduction

The underwater vehicles are nowadays used to realize different and complex technical work such as exploration, inspection and engineering operations in the ocean and deep water industries. The unmanned underwater vehicles (UUVs) are divided into two categories, take into consideration their area of responsibility, shape, autonomy, etc. A higher degree of autonomy, also decrease the operation time for different mission, take into consideration only the dependence of weather conditions or human factors (Schjlberg and Utne, 2015).

The category that are divided the UUVs are: Autonomous Underwater Vehicle (AUVs) and Remotely Operated Vehicles (ROVs). As the name suggest, the vehicle autonomous AUVs have the possibility and ability to operate autonomously without any human intervention. On the other hand, the ROVs typically need human intervention or input help send it using an umbilical cable. The underwater tethered systems are underwater vehicles, tools or other packages attached to a tether (sometimes a cable) and suspended from a vessel or a pier. Generally, the deep-sea operated vehicle systems consist of a support vessel, a winch, umbilical cable and ROV. One of the important properties of all the unmanned underwater vehicle is represented by the hydrodynamic properties. The hydrodynamic properties could affect the performance and the manoeuvrability of the vehicle. This aspect was discuss in many article regarding the design and operation of vehicles.

Generally, most of the study regarding the numerical models for predicting the motion of ROV did not consider important the effect of the umbilical cable and current.

In the paper (Ablow and Schechter, 1983), was proposed an implicit finite difference method to simulate and underwater cable. In paper (Burgess, 1992), was presented several study regarding the current effect on different underwater cable. There are many other studies regarding the effect of the umbilical cable on an underwater flight vehicle.

The ROVs are operated only in weak current this is the reason that most of the design of ROV are realized with the anticurrent capability. In this paper are presented a hydrodynamic ROV design same to an AUV.

The underwater cables and connectors provide system flexibility and ease of service, for undersea equipment - including ROVs. The primary purpose of underwater cables and connectors is to provide a conductive path, without leakage, in a pressure-resistant or pressure tolerant package. Underwater connectors are used to connect the umbilical to a tether management system (TMS) and then from the TMS to the ROV.

The remotely operated vehicle is used in different undersea operation when it is important to control and determine precisely the disturbance forces generated by drag due to currents that act either on the vehicle directly or indirectly on the tether umbilical cable. The dynamics of umbilical cable represent an important part in ocean environment being used for signal and power transmission application.

2. Umbilical Modelling

In the case of the ROV umbilical system, this is defined by two coordinate systems. One coordinate system is fixed relative to the Earth and the other to the vehicle system. These two systems determine the global and local coordinates of the vehicle respectively. Further, the domain discretization represents a finite number of approximately N + 1 local coordinate elements, N representing the number of elements in which the cable was divided. In other words, each element (node) will have a local coordinate system (Fig. 1).

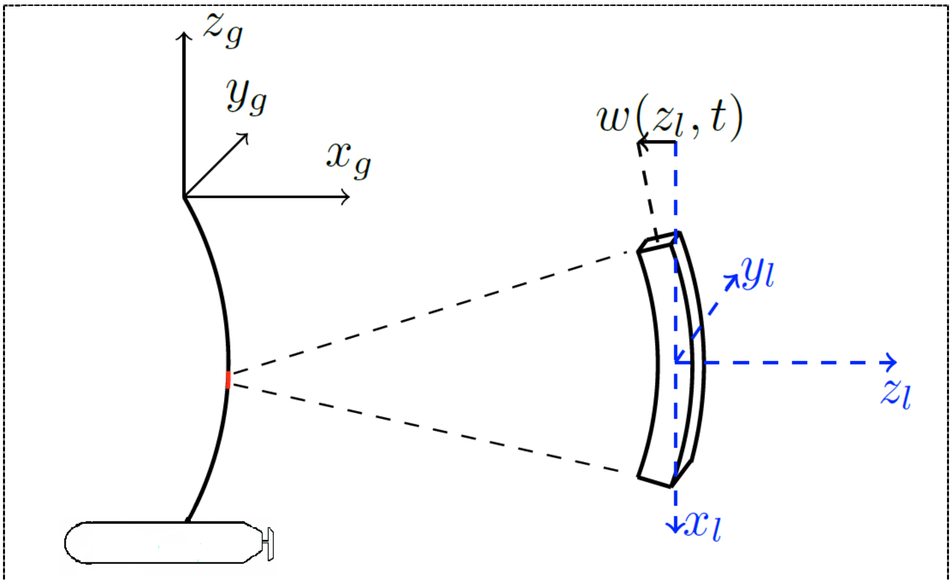

Fig. 1 – References frame for ROV and umbilical cable.

Regarding the governing equations, the cable have three equations (Huang, 1994) take into consideration the 3 dimension space. The longitudinal equation of motion was already described in paper (Weaver *et al*., 1974) for a beam with uniform cross-section:

$$S + \frac{\partial S}{\partial x}dx - S - \rho A dx \frac{\partial^2 u}{\partial t^2} = 0 \tag{1}$$

In Eq. (1) are presented the following notation: S represent the internal axial stress resultant on the cross-section at a point x on the beam, u represent the deflection, ρ represent the mass density and A is the area of the cross-section. Using Hookes law the equation can be presented as:

$$EA\frac{\partial^2 u}{\partial x^2} = \rho A\frac{\partial^2 u}{\partial t^2} \quad (2)$$

Using the Euler-Bernoulli beam theory, we determinate the transverse equation of motion in y-direction:

$$\frac{\partial^2}{\partial x^2}EI_y\frac{\partial^2 v}{\partial x^2} + \rho A\frac{\partial^2 v}{\partial t^2} = F_y(x) \quad (3)$$

where $F_y(x)$ represents the external load and I_y is the second moment of inertia with regards to the y-axis. Similarly the equation in z-direction becomes:

$$\frac{\partial^2}{\partial x^2}EI_z\frac{\partial^2 v}{\partial x^2} + \rho A\frac{\partial^2 v}{\partial t^2} = F_z(x) \quad (4)$$

3. Simulation

The simulation was realise using the Ansys Aqua Software. First of all, we create the geometry of pier, the urface body and the fixed points. The geometry of pier was then divided intro the submerged pier, ground, upper pier, pier axes, point mass and connection point 1. The surface body are represented by the surface body, point mass and connection point 2. The fixed point is represented by fixed point 3. We consider the water depth of 7 metre, water density 1025 kg/m^3, gravity 9.8 m/s^2 and the water size of domain 177 x 100 m.

The geometry of pier is presented in Table 1.

Table 1

The Geometry of Pier

Name	Pier
State	Fully Defined
Details of Pier	
Part Visibility	Visible
Activity	Not Suppressed
Part Color	14606046
Mass Properties from Solver	
Total Structural Mass	99999997952 kg
X Position of COG	17 m
Y Position of COG	15.0000009536743 m
Z Position of COG	-5 m
Moment of Inertia Ixx	1155999989760 kg.m^2

Moment of Inertia Ixy	0.0 kg.m²
Moment of Inertia Ixz	0.0 kg.m²
Moment of Inertia Iyy	4083200032768 kg.m²
Moment of Inertia Iyz	0.0 kg.m²
Moment of Inertia Izz	4422300073984 kg.m²
Advanced Options	
Generate Internal Lid	No
Current Calculation Position	At Fixed Depth
Current Calculation Depth	7 m
Submerged Structure Detection	Program Controlled
Override Calculated GMX	No
Override Calculated GMY	No
Fixity Options	
Structure Fixity	Structure is Fixed in Place
Force Multiplying Factors	
Drag Multiplying Factor	1
Mass Multiplying Factor	1
Slam Multiplying Factor	0.0
Shear Force/Bending Moment Options	
Calculate Shear Force/Bending Moment	Not Permitted for Multiple Structures

Also, there are defined the pier point mass in Table 2.

Table 2
The Geometry of Pier Point Mass

Name	Point Mass
State	Fully Defined
Details of Point Mass	
Visibility	Visible
Activity	Not Suppressed
Mass Properties	
Mass Definition	Manual Definition
X Position	17 m
Y Position	15 m
Z Position	-5 m
Mass	100000000000 kg
Inertia Properties	
Define Inertia Values By	Radius of Gyration
Kxx	3.4 m
Kyy	6.39 m
Kzz	6.65 m
Ixx	1156000000000 kg.m²
Ixy	0.0 kg.m²

Ixz	0.0 kg.m²
Iyy	4083210000000 kg.m²
Iyz	0.0 kg.m²
Izz	4422250000000 kg.m²

The connection point are one attached to structure, and other on the vehicle body. The position coordinate for the one attached to pier are [14.2, 12.5, 3.5].

The surface body geometry are defined in Table 3.

Table 3
The Geometry of Body

Name	Surface Body
State	Fully Defined
Details of Surface Body	
Part Visibility	Visible
Activity	Not Suppressed
Part Color	15454648
Mass Properties from Solver	
Total Structural Mass	768.049072265625 kg
X Position of COG	2.75000047683716 m
Y Position of COG	11.9949779510498 m
Z Position of COG	-2 m
Moment of Inertia Ixx	88.7864685058594 kg.m²
Moment of Inertia Ixy	0.0 kg.m²
Moment of Inertia Ixz	0.0 kg.m²
Moment of Inertia Iyy	108.006896972656 kg.m²
Moment of Inertia Iyz	0.0 kg.m²
Moment of Inertia Izz	116.820259094238 kg.m²
Advanced Options	
Generate Internal Lid	No
Current Calculation Position	At Fixed Depth
Current Calculation Depth	0.0 m
Submerged Structure Detection	Program Controlled
Override Calculated GMX	No
Override Calculated GMY	No
Fixity Options	

Structure Fixity	Structure is Free to Move
Force Multiplying Factors	
Drag Multiplying Factor	1
Mass Multiplying Factor	1
Slam Multiplying Factor	0.0
Shear Force/Bending Moment Options	
Calculate Shear Force/Bending Moment	Not Permitted for Multiple Structures

The point of mass for surface body is presented in Table 4.

Table 4
The Point of Mass

Name	Point Mass
State	Fully Defined
Details of Point Mass	
Visibility	Visible
Activity	Not Suppressed
Mass Properties	
Mass Definition	Program Controlled
X Position	2.75000023841858 m
Y Position	11.9949779510498 m
Z Position	-2 m
Mass	768.049059808254 kg
Inertia Properties	
Define Inertia Values By	Radius of Gyration
Kxx	0.34 m
Kyy	0.375 m
Kzz	0.39 m
Ixx	88.7864713138342 kg.m²
Ixy	0.0 kg.m²
Ixz	0.0 kg.m²
Iyy	108.006899035536 kg.m²
Iyz	0.0 kg.m²
Izz	116.820261996835 kg.m²

The connection point are located on body are [6, 12.5, -1.5] m.
The information regarding the cable are presented in Table 5.

Table 5
Cable Caracteristics

Name	Cable 1
State	Fully Defined
Details of Cable 1	
Visibility	Visible
Activity	Not Suppressed
General Attributes	
Type	Linear
Connectivity	Fixed Point to Structure
Start Fixed Point	Fixed Point 3 (Fixed)
End Connection Point	Connection Point 2 (Surface Body)
Initial Attachment Point Separation	9.60416576283438 m (Point to Point)
Cable Properties	
Stiffness	1400 N/m
Unstretched Length	9.5 m
Pulley 1	
Connection Point	Undefined...

In Fig. 2 are presented the design of pier and surface body realized in Ansys Aqua. Here is presented the case where the ROV is in a fixed position.

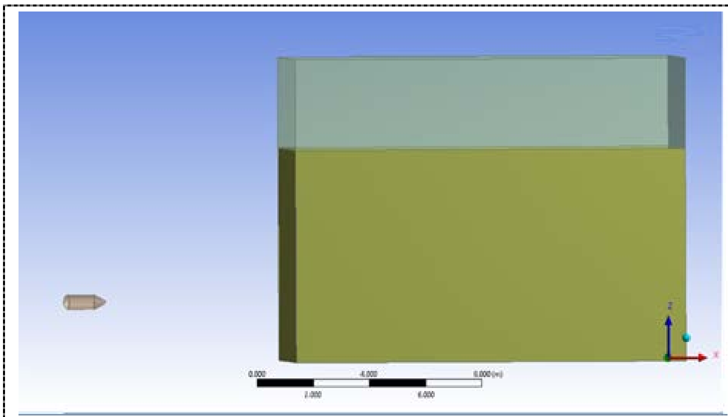

Fig. 2 – Design of underwater robot and pier.

Figure 3 present the mesh of the design.

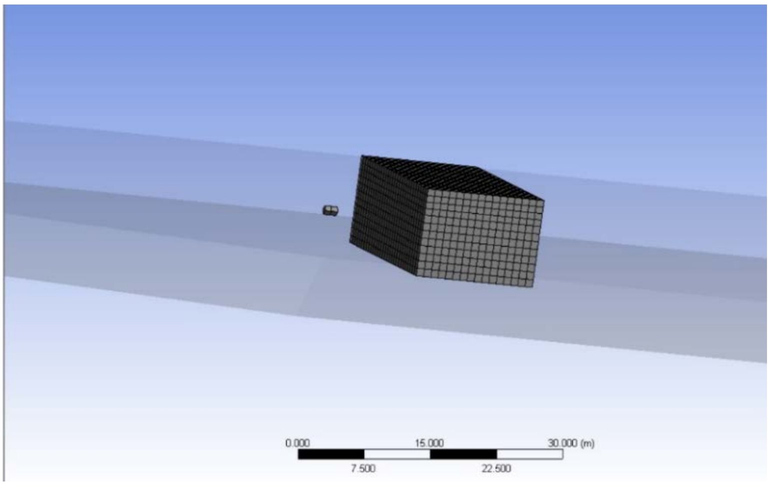

Fig. 3 – The mesh design.

The mesh parameters was set at 0.75 defeaturing tolerance, 1.5 maximum element size and 0.502 Hz maximum allowed frequency. We confirm a number of 2022 total nodes, 2018 total elements, 822 diffracting nodes and 730 diffracting elements.

Figure 4 present the simulation stade.

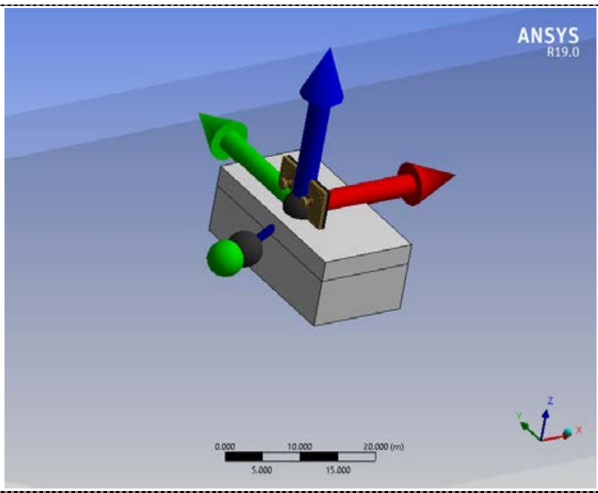

Fig. 4 – The simulation in Ansys.

Using the equation for structure body in Line A of RAOs type (Faltinsen, 1990) along the component Global X, frequency of 0.01592 Hz, the reference point considered in the center of gravity, and the abscissa position of minimum 60° to a maximum of -180° we perform for distance/rotation vs direction a minimum value of 2.512 m/m and a maximum value of 5.288 m/m (Fig. 5).

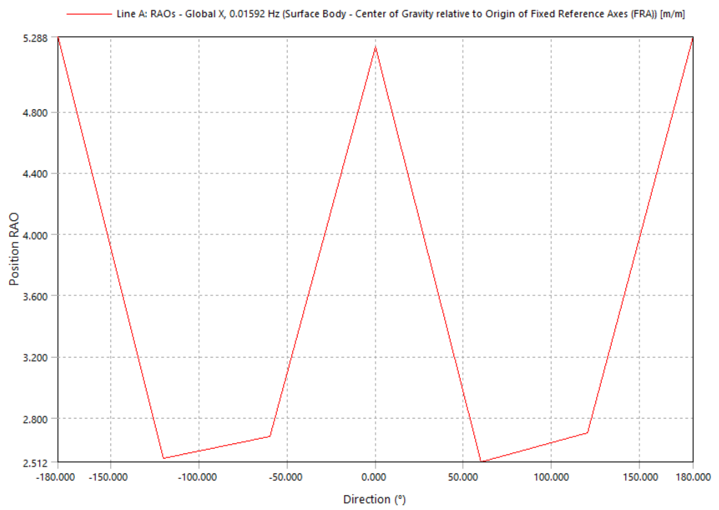

Fig. 5 – Distance/Rotation vs. Dirction – global X.

Consider the equation type RAOs, along the component Global RX, the frequency 0.01592Hz, the abscissa position of minimum of -120° to 000°, the minimum value of distance/rotation vs direction is 0.128°/m and the maximum value 0.133°/m presented in Fig. 6.

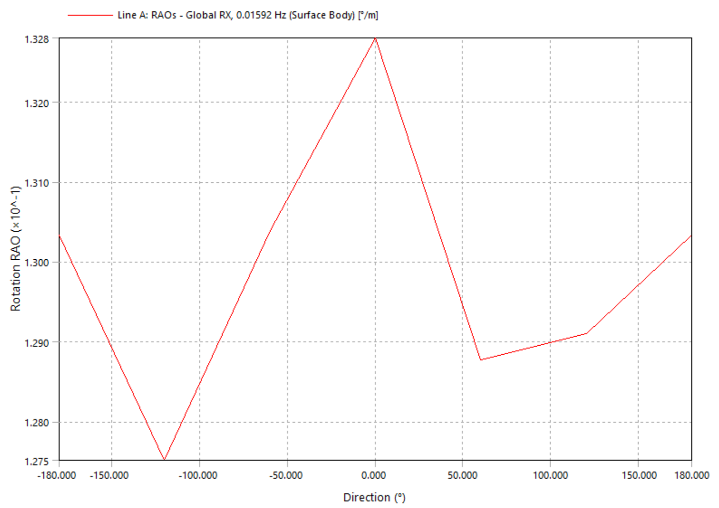

Fig. 6 – Distance/Rotation *vs*. Direction.

When we speak about the component along the Global RY, with the abscissa position of minimum situated at 60° and maximum 180°, we obtained a minimum value of RAOs Distance/Rotation vs Direction of 0.124°/m and a maximum value of 0.265°/m according to Fig. 7.

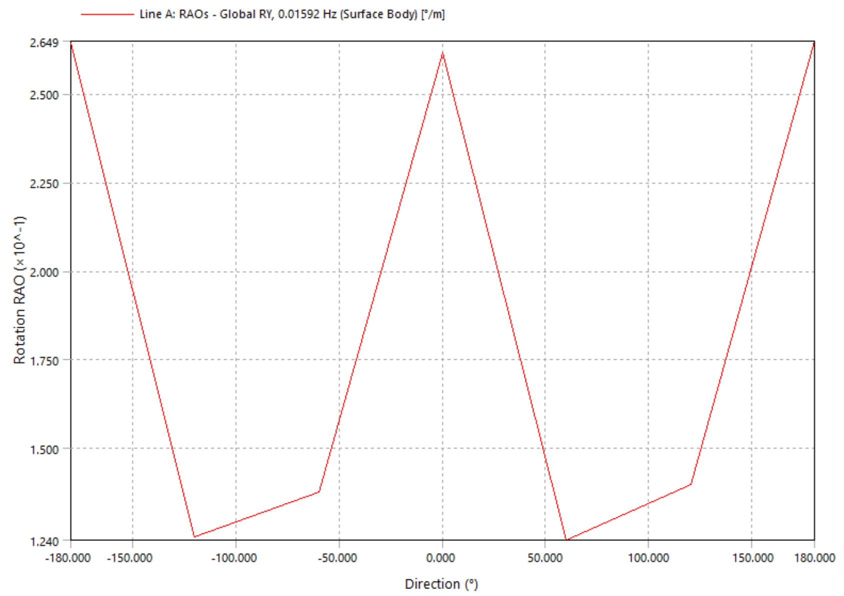

Fig. 7 – Distance/Rotation *vs*. Direction.

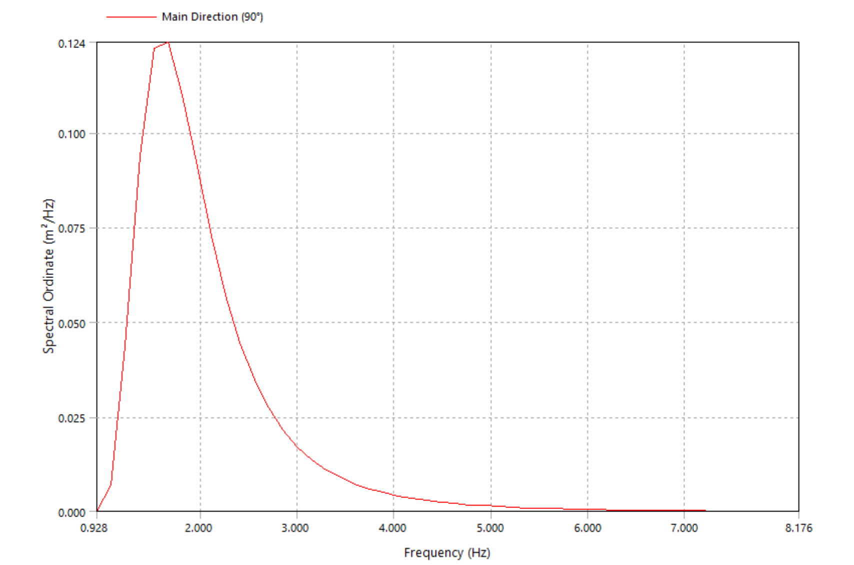

Fig. 8 – Hydrodynamic Response - Irregular Wave.

Take into consideration some details of irregular wave spectrum defined as JONSWAP (Hs) (Pierson *et al*., 1964), from 90° direction of spectrum, with a start frequency of 0.928 Hz and a finish frequency of 8.17616 Hz, the data obtained are presented in Fig. 8 and Table 6.

Table 6
Hydrodynamic Response -Irregular Wave

Frequency (Hz)	Spectral Ordinate (m^2/Hz)
Direction (°) ➔	90
Sub-Weight ➔	1
0.928	1.06815e-4
1.07592	7.07437e-3
1.22384	0.04355
1.37176	0.09384
1.51969	0.12238
1.66761	0.12388
1.81553	0.10991
1.96345	0.091
2.11137	0.07272
2.25929	0.05716
2.40722	0.04467
2.55514	0.03491
2.70306	0.02739
2.85098	0.02161
2.9989	0.01717
3.14682	0.01374
3.29475	0.01107
3.44267	8.98896e-3
3.59059	7.34986e-3
3.73851	6.05071e-3
3.88643	5.01375e-3
4.03435	4.18035e-3
4.18228	3.50607e-3
4.3302	2.95703e-3
4.47812	2.50719e-3
4.62604	2.13647e-3
4.77396	1.82923e-3
4.92188	1.57323e-3
5.06981	1.35885e-3

5.21773	1.17843e-3
5.36565	1.02591e-3
5.51357	8.96392e-4
5.66149	7.8595e-4
5.80941	6.91397e-4
5.95734	6.10137e-4
6.10526	5.40048e-4
6.25318	4.79382e-4
6.4011	4.26698e-4
6.54902	3.80799e-4
6.69694	3.40691e-4
6.84486	3.0554e-4
6.99279	2.74646e-4
7.14071	2.47422e-4
7.28863	2.23369e-4
7.43655	2.02065e-4
7.58447	1.83151e-4
7.73239	1.66321e-4
7.88032	1.51311e-4
8.02824	1.37897e-4
8.17616	1.25884e-4

The effect of the current force on the umbilical cable will affect ROV motions, because the umbilical cable is connected to the ROV body. In other words, both umbilical cable and ocean current indeed affect the motion behaviors of the ROV.

4. Conclusion

In the paper, was presented in the first part the Euler-Bernoulli equation beam to model the force of an ROV. This model is used most of the time to simulate the dynamics of an umbilical cable, exactly yhe rigid body forces and the hydrodynamic forces. Also, using software specialized, was realise the design of an underwater vehicle towered using a umbilical cable from the surface. The model can be easier extended included additional effects, for example, the ship motion in case of a tethered vehicle from the board of a ship. In the paper was presented the case where the ROV is in a fixed position. From the last simulation, it is show that the dynamics of an umbilical cable depend of current direction and velocity. The influence of current is simulated using Ansys software. Both umbilical cable and ocean current indeed affect the motion behaviors of the ROV, and this makes if necessary to paid careful attention.

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STUDIUL PRIVIND SIMULAREA CABLULUI OMBILICAL AL VEHICULELOR SUBACVATICE

(Rezumat)

Această lucrare prezintă o serie de analize privind influența curentului subacvatic asupra cablului ombilical al vehiculelor subacvatice telecomandante de la distanță (ROV). Vehiculul acționat de la distanță este utilizat în diferite operațiuni subacvatice atunci când este important să se controleze și să se determine cu precizie forțele de perturbare generate de forța de înaintare influențată de parametri meteorologici care acționează fie direct asupra vehiculului, fie asupra cablului ombilical. Cablul ombilical reprezintă o parte importantă din complexul vehiculului și are funcții importante, dintre care amintim de transmiterea semnalului și a puterii pentru manevrarea vehiculului. Pentru a efectua simularea în Ansys Aqwa, sunt luate în considerare sistemele cu două axe. Rezultatele obținute în urma simulării ne arată forțele de tracțiune care sunt exercitate pe o anuită lungime a cablului ales.