Marine growth colonisation process and profile in guinea gulf: from inspection data to load computing

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MARINE GROWTH COLONISATION PROCESS AND PROFILE IN GUINEA GULF: FROM INSPECTION DATA TO LOAD COMPUTING

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ABSTRACT

Reassessment of existing offshore structures needs rational aid tools to update new information (metocean data, new regulations, ...). This paper focuses on marine growth management on Jacket offshore structures. After years of exploitation, marine growth thickness reaches up to the initial beam diameter. Inspection and cleaning are actions to be optimized, keeping in mind that safety must be preserved according to cost reduction. The paper first presents the building of an exhaustive data base in view to use the whole available information. An illustration is given for structures placed in Gulf of Guinea: main species, colonization process as well as modeling of thickness increasing are discussed. A modeling of hydrodynamic coefficient is then suggested according to kinematics field and physical response surface.

INTRODUCTION

Reassessment of offshore structures leads to update design hypothesis which deals with topics such as structural behavior, environmental loading and structural integrity. The proposed paper takes place in the actual challenge for the reanalysis and lifetime extension of existing fixed steel offshore structures (jackets) where the uncertainties are to be controlled on the basis of inspection reports analysis.

Marine growth fouling on structures is of major importance as it increases screen effect and modifies hydrodynamic flow near the structures. This paper aims to improve the description of marine growth and its evolution in time in view to optimize inspections and to introduce its effects in loading computation. The final objective is to propose targets for cleaning and survey program planning. As structural reliability is very helpful for structural reassessment purposes, the paper focuses on uncertainty and sensitivity analysis especially in view to characterize the stochastic structure of the loading acting on the platforms. That means to consider the intrinsic randomness of waves and the modeling uncertainty of the fluid-structure interaction in their relative contribution to the response i.e. the load on the structure. Particularly, there is a need for taking into account the natural cluster of organisms on the components i.e. the marine growth fouling (kelps, mussel beds ...) via a probabilistic modeling. In fact, this settlement on the structure represents the major uncertainty source in terms of diameter increase and hydrodynamic coefficients level when computing environmental loads on the structure. Its corresponding uncertainty depends upon several factors (seasons, depth ...), evolves during the life of the structures and is greater at the design step. The main idea is to embrace the whole information coming from inspections. First a building of an exhaustive data base is suggested. It leads to suggest inspection report format as well as physico-chemical and metocean data recording and/or modeling. Gulf of Guinea is proposed for illustrations: main species, colonization process as well as modeling of thickness increasing are discussed. A probabilistic modeling of hydrodynamic drag coefficient obtained by a conditioning to kinematics field is then introduced and several basic assumptions are compared.

BUILDING AN EXHAUSTIVE DATA BASE

Optimal inspection strategy

Colonization process of marine growth is a complex phenomenon which requires specific care in data collection from submarine inspection and report analysis in view to compare thickness with pre-defined requirements or update environmental loading. Due to the size of structures and harsh inspection conditions there is no way to get data everywhere all the time with reasonable costs. There are also some operational restrictions as winter conditions hinder the diving or operating of Remote Operating Vehicles. Then the optimization strategy should be to inspect and/or clean at the right structural components, the right time with the right tool; the following stakes shall be considered:

- Type of inspection which can be the first inspection carried out on the platform (state 0), a general inspection programmed after the installation of structure or a specific inspection subsequent to damage or presence of default.
- Date (at least season) of inspection which can be useful for marine growth evolution modelling and to point out possible relationship between local climatology and apparition or decrease of fouling organisms.
- Date (at least season) of cleaning. During the first two or three years of installation of the structure, it is necessary to identify the species in presence. These elements, fundamental to forecast marine growth evolution, can be missed for very old structures. From this data we can relate initial process, evolution and speed of bio-colonisation.
- Several survey techniques used to assess marine growth characteristics including video survey, still photography and physical measurements using hand-held probes, tape measures, scale bars etc.

Two questions must be discussed to reach an overview of marine growth:

- are local inspection data representative of the whole structure at a given depth ?
- which factors do influence colonization processes?

In view to answer this last question, essential for inspections and cleaning planning , an exhaustive data base is required.

Exhaustive data base characteristics

Marine growth data base

The objective here is to compare marine growth type, thickness and cover versus depth with pre-defined requirements, given at the stage of structure design or inspection planning. Actually, Classification Societies provide little directive or standard procedure which would indicate the type of data to collect and the degree of precision needed. However, the oil company Total has developed it own standard for reporting marine growth during inspections. The main information required during the periodic inspection program concerns essentially identification, assessment of cover and thickness of fouling for several structural component typology and depth. These data allow to take into account the screen hydrodynamic effect of marine growth.

Attached animal offshore may be divided into two groups: hard and soft fouling. Hard fouling possess a rigid, hard external skeleton, in the form of a shell, tube or plates. Soft fouling have no such external skeleton. Hard fouling organisms are generally of greater concern to engineers than soft foulers, particulary in respect of their contribution to hydrodynamic loading but a review of hydrodynamic loading research has pointed out that the contribution of soft foulers to loadoing may not be insignicant [1]. Usual recommandations for optimisation of inspection strategy on offhore structures are: measurements of marine growth's thickness must be realized on the most representative part of structural component. An enumeration of more representative species and their percentage of cover must be specified for each category of fouling. A sampling can be realized by divers to define precisely species present on the structure [2, 3, 4].

Sometimes, competition of species of marine growth generates multi-layer colonization process. Measurement of thickness and estimation of percentage of cover for each species becomes, in this case, more complex. To overcome this difficulty and make easy exploitation of data by engineers, Det Norske Veritas (VERITEC) [5] had earlier proposed a nomenclature which classifies species into 5 homogenous groups. Code names are KELK, FILG, OSOF, MUSS and OHAR. Full group names and most important growth types in each group are stated in Table 1.

Code	Groups	Type of fouling
KELK	Long flapping weed	kelp, wrack
FILG	Fine filamentous growth	sea weeds, hydroids, filamentous bryozoans
OSOF	Other soft growth	sea anemones, soft corals, sponges, ascidians, soft tubeworms, starfish
MUSS	Mussels and other shells	mussels, saddle oysters
OHAR	Other hard growth	barnacles, calcareous tubeworms, hard bryozoans, corals

Table 1. Summary groups of marine growth

This classification seems accurate and complete enough for a reliability-based load computing study too.

Data base can be followed up with other informations as uncertainty on the measurement and identification of predator organisms. The decrease of fouling organisms can be caused by a change of metocean parameters but also in presence of predator organisms. For example, one of the predators of mollusc and shellfish is starfish, which may be the cause of decrease or disappearance of barnacles and mussels on site.

Extended marine growth data base

The objective is here to model the colonization process in view to optimize inspection/cleaning planning. General information on structures or fields must be easily accessible from the data base. Geographical location and depth of site allow, in first approach, to rank information on presence and evolution of marine fouling. To enrich data base in view to improve a modeling of biofouling evolution, we need environmental parameters.

Geographical location and distance from shore can provide indication on nature and extend of marine fouling. From literature, it appears that fouling is generally more intense in more tropical locations probably due to the continuous process of breeding and the warmer temperature of seawater. Some organisms fit to different environmental conditions and extend from large areas; other ones are limited to a restricted region [6].

Physico-chemical parameters of seawater such as salinity, temperature, organic content and light penetration evolve with depth and these changes greatly affect the type and growth of fouling. As the rate of fouling is generally more important in areas near to the shore, it also decreases with increasing depth. Generally marine growth colonisation is more important between 0-50 meters, a range rich in plankton and of high light level. Water temperature, salinity rate and fluvial regime play an important role in the distribution of fouling organisms too. Water temperature is an indicator of local climatology. So this data allows to suggest relationships between season variation and marine growth. An increase of a marine growth community is generally observed with an increase in temperature. We also have a strong growth and a variability of number of species during the warm seasons [7]. But some soft marine species as hydroids and bryozoans are not influenced by changing of temperature, they fluctuate at any season [2].

The challenge is to know how the knowledge of influence of physico-chemical parameters on colonisation/decolonisation process data, can be extended to other sites with similar characteristics. A recent study has been realized by Faber [8]. This one addresses effects on the structural response by assessment and quantification of uncertainties parameters as seasonal variation of marine fouling parameters, the wave loading (taking into account the seasonal variation in sea state statistics), and the effect of spatial variations and seasonal effects of marine fouling parameters.

To complete these informations, it is important to mention date of installation and type of platforms (4, 8 legs ...). Generally, when there is no cleaning on the structure, development of biofouling can be modified by disruptive phenomenon (important climatic event). From the installation date, it is possible to follow temporal evolution of marine growth for each structure and to recover climatic events. We can measure the influence of type of structure on marine growth colonisation. For example considering the high temperature on a torch jacket, it is likely that the thickness of biofouling will be less important in surface than on a classical jacket.

PATTERNS OF DEVELOPMENT FOR DOMINANT TYPES OF MARINE GROWTH IN GULF OF GUINEA

During every structure's life span, it may go through a succession of changes of fouling type that colonise its underwater surfaces. Initial organisms are bacteria forming a layer of slime over the platforms surface within two or three weeks. They cause a change in physical and chemical properties of steel surface and pave the way for colonisation by other organisms [7]. Colonisation processes which result after depend on several parameters such as geographical location, water depth, temperature, season, platform design and operations.

In this section, we describe major types of marine growth and their profiles present in the Gulf of Guinea (Figure 1). Marine growth here has a significant impact on the logistics and cost of structural inspection and maintenance.

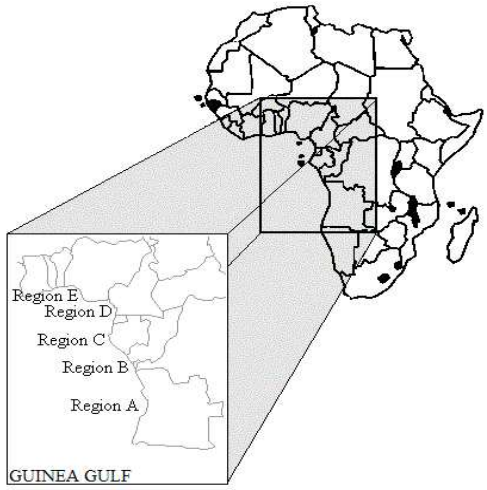

Figure 1. Studied regions in Gulf of Guinea

Characterisation of marine growth in Gulf of Guinea

Characterisation of marine growth proposed here, is based on informations obtained during inspections carried out by Total on Jacket structures at different depth levels between five and ten years. Results correspond to an envelope of thickness to make sure that they are conservative. Inspections are made on the same components, at the same time in the year, to allow future comparisons. Figures 2, 3, 4 and 5 show likely distributions of fouling organisms on typical structures established in Gulf a Guinea after 5 and 10 years. Regions locations are presented on figure 1.

Characterisation of marine growth in Region "A"

Figure 2 gives a general idea of typical colonisation encountered in region "A" between five and ten years. After five years, barnacles, seaweeds and hydroids are are the most representative species with depth and time. Oysters develop from surface to middle water. Sponges and bryozoans cover surface of structural elements in shallow water. After 10 years, sponges disappeared and some oysters are present in shallow water only. Extended of bryozans is more important in depth except in shallow water where they are absent. We find some corals too. This pattern of colonisation follows an irregular cycle of colonisation and decreases with time.

Characterisation of marine growth in Region "B"

Typical colonisation in region "B", betwenn five and ten years, is illustrated on figure 3. After five years, barnacles, seaweeds and hydroids, are main occupants with mixed colonies of oysters and some anemones. Barnacles, seaweeds and hydroids colonise the whole water depth and structure. Sponges and bryozoans are in feeble proportion and colonise shalow water. We observe, between surface and middle water, a beginning of corals colonisation (with time, they spread to the site and the depth). After ten years, we note presence of tubeworms. They grow from the middle level to deep water. Some sea urchins are in shallow water. Anemones disapear here. Generally marine growth starts to stabilise about 12 years.

Characterisation of marine growth in Region "C"

Figure 4 presents typical marine growth colonisation for fixed structures, in region "C", between five and ten years. During the first five years, barnacles and hydroids are dominant species. Corals, sponges and seaweeds are present but in weak proportion. Some oysters develop on shallow water. We observe rapidly a decrease of barnacles whereas colonies of corals take width quickly with time. In fact, from ten years surface of structures are quasi recovered by corals. For structures near coasts for example, they represent around eighty percent of organism and reach important thickness (about 150mm). Sponges and seaweeds are less important and colonise structures in marginal way. Some oysters are present in shallow wtaer. Colonisation follows an irregular cycle of colonisation and losses with time.

Characterisation of marine growth in Region "D"

Illustration proposed in figure 5 gives the typical colonisation obtained in region "D" between five and ten years. After five years, Barnacles and sponges are the most represented on offshores structures. Corals are present too but their cover surface are less than barnacles. Hydroids, bryozoans and seaweeds colonise the first twenty meters. They are some oysters in shallow water only. After ten years, proportion of corals and sponges decrease and some anemones appear. This pattern of colonisation follows an irregular cycle of colonisation and decreases with time.

We have little information on biofouling in region "E". The main data indicate that barnacles and seaweeds are the more representative organisms with depth.

There are common species colonising these various sites. For hard fouling, more representative organisms are *barnacles* and *corals*. Barnacles are dominant on all regions excepted region C. For soft fouling, *seaweeds* (brown and green), *hydroids* and *bryozoans* are major species. These organisms represent more than sixty percent of fouling population in Gulf of Guinea. *Sponges*, *tubeworm*, *anemone*, *oysters* and *sea urchin* are generally secondary species present in weak proportion on offshores structures. Colonisation process of marine growth is established in marginal way. It differs according to the site, type of offshore structures and water depth.

Profiles of hard fouling with depth

Analysis realised here is based on specific characterisation given in literature [1, 2, 3] for marine growth study (hard and soft fouling). Results for hard fouling are only presented. To analyse and make the most of marine growth data (thickness and percentage of cover), two approaches are considered:

- The first consists to analyse marine growth development versus structure age at inspection date. From this approach, we can relate biofouling process with water depth and time.

- The second consists to analyse marine growth evolution from date of installation of structures (civil year). From this approach we have historical marine growth evolution and we can emphasize a relation (if it exists) between environmental conditions and bio-colonisation process.

The method for quantitative analyses of marine growth has been standardized in the offshore petroleum sector according to Marine Technology Directorate [1]. Average thickness ($\bar{t}$) of marine growth is calculated according to following equation (1):

$$\bar{t} = \frac{\sum_{i=1}^{n} C_n \times \bar{h}_n}{100} \qquad (1)$$

Where n is the number of groups of marine growth (see for example table 1, where n=5), C_n the percentage cover and $\bar{h}_n$ the average height, both corresponding to group number i.

We present here results obtained for hard fouling in Gulf of Guinea.

Profiles plotted according to platform age

Profiles are plotted according to the age of structure, here 14 years old at the moment of inspection. Profiles established in each region are illustrated on figures 6, 7, 8 and 9.

Figure 6 represents variation of average thickness with depth for four structures in region "A". Fourteen years after their installation, the average thickness of biofouling has little varied in surface (25 to 40 mm) with great scatter in depth.

For region "B" (figure 7), the several profiles show that average thickness varies from 40 to 90 mm in surface. Mean thickness is more important than in region "A". Profiles decrease with depth.

For region "C" (figure 8), we have an important dispersion of mean thickness in surface (60 to 142 mm) and a great scatter with depth. This result is remarkable because the four structures are in the same zone and depth.

Profiles obtained in region "D" (figure 9) present in surface strong dispersion too. Depending on the structure, mean thickness varies from 1.5 to 100 mm. This result may be explained by influence of extern environmental factors or platforms design and exploitation but also by incertitudes on measurements. Evolution of profiles with depth is very heterogeneous too.

Increase of marine growth is influenced by environmental conditions and river regime. It is translated as a general rule by more important thicknesses in surface (favourable conditions) than in depth. If the climatic conditions vary (important detrital amount, water very diluted, and weak penetration of luminosity in surface due to river sediments) we can end in strong variations in surface or tidal zone. This may be the case for some structures as Ptf-A2, Ptf-C3, and Ptf-D2. We note on these ones that mean thickness is less important for surface zone than in depth. For an extended study which would deepen our understanding of process colonisation of marine growth, it is important to determine major events which might be the cause of decrease of marine growth. In studying biofouling variations from date of installation, we can emphasize them.

Profiles plotted according to civil years

For more convincing results, it could be useful to realize profiles in term of civil year, and even months. It can highlight correlation (if it exists) between variations of marine growth and climatic events. We can analyze if severe environmental events (storm of strong intensity, exceptional floods of rivers) are at the source of a natural "cleaning" of marine growth.

- Figure 10 is an example of marine growth variation with civil years, for region "C" at water depth 20 m. Six profiles have been superposed from the date of platform installation (1980 to 1986). We note an important increase of mean

thickness until 1990. From 1990 to 1996, profiles show different trends:

- For profiles corresponding to installation in 1980, 1981, 1985 and 1986, we have a diminution between 5 and 15 mm.
- For profiles corresponding to installation in 1983, we have an augmentation to 15 mm about.
- Profile corresponding to 1982 is the most surprising. It shows a first period of strong decrease of mean thickness from 1991 to 1994 (95 to 15 mm about) then an important increase, from 1994 to 1999, and finally it comes back to the precedent measurement (95 mm). Note that no platform cleaning was undertaken during this period.

These variations may be explained by a natural significant event which would have occurred during this lapse of time. To try to identify it, an analyse the variation of environmental events is needed (storm, exceptional floods of rivers), by screening physico-chemical parameters (temperature, salinity…) and metocean data. Then we may find a correlation between the afore-mentioned parameters and mean thickness variation.

Modelling of marine growth process: case of region B and C

Let us now come back to the evolution of marine growth as a function of the age of structure. It can highlight correlation (if it exists) between variations of marine growth and structure location considering only the main trends of biological process. Figures 11 and 12 aim to give an overview of the average thickness evolution respectively for regions "B" and "C" at 20 meters of depth. This average thickness is computed from inspection results available at a given age upon the total number of platforms. Uncertainty bars represent standard deviation computed when inspection number is more than 3. Figure 12 shows that in region "C" a linear model for thickness evolution, with a rate of 6.5 mm/year, is well adapted especially if we assume no extreme events disrupted the data base. This evolution cannot be extended to all regions; figure 11 is a good illustration where the assumption of a linear evolution is questionable. In such a case, a finest study must be performed in view to particularize some sites in the region.

PROBABILISTIC MODELLING OF CD

Main step of the probabilistic modeling

The previous sections give the main trends in view to quantify marine growth effects for overloading purposes. It appears that sources of uncertainty are various. First the data, based on circumferential measurement or R.O.V's picture interpretation, leads to uncertain estimation on thickness and percentage of cover. Then the force measurements in laboratory and the signal treatment lead to versatile results and to uncertain evaluation of loading. Finally, the use of Morison equations [7] for all orientations of components is an expansion of the standard case where the formula as been developed and lead us to introduce uncertainty on the model. These uncertainties are introduced in the Morison equations through hydro-dynamic coefficients C_X, C_D, C'_X, C_M, (respectively two drag and two inertia coefficients) for modelling the fluid-structure interaction. Ins this paper, we focus on C_d modeling in storms conditions as it has been shown to be dominant [8]. Using response surface of kinematics field [9][10], there is a way to find a causality relationship between waves parameters (extreme wave height H and period T) and hydraulic parameters (Re, Reynolds number and Kc, Keulegan-Carpenter number) defined by (2).

$$\mathrm{Re} = \frac{U * D}{\nu} \quad ; \quad Kc = \frac{U * T}{D} \tag{2}$$

where U stands for the velocity intensity of the particles of the fluid (m/s) in extreme conditions, T is the extreme wave period in such sea states (s), ν denotes the kinematics viscosity (m^2/s) and D the diameter of cylinders (m).

We considered here marine growth thickness less than 10% of diameter; it doesn't affect probabilistic modeling of Re and Kc[12]. In the following, Re remains in post-critical range and C_d modeling is mainly affected by Kc [11]. In view to simplify expression of probabilities, we adopt the notation :

$$P(X_i) = P(x_i < X_i < x_{i+1}) \tag{3}$$

According to the uncertainties connected to the tests and the reliability of the measures, the calculations are balanced by weights allocated depending on authors and expert judgment. It leads to the probability [10]:

$$P(Cd_i) = w_1 P_{A1}(Cd_i / Kc).P(Kc) + w_2 P_{A2}(Cd_i / Kc).P(Kc) \tag{4}$$

Then from (5), P is a probability.

$$P(Cd) = \sum_{i=1}^{n} P(Cd_i) = w_1 \sum_{i=1}^{n} P_{A1}(Cd_i) + w_2 \sum_{i=1}^{n} P_{A2}(Cd_i) = 1 \tag{5}$$

with $w_1 + w_2 = 1$. n is selected such as $P(Cd < Cd_1) = 0$, $P(Cd > Cd_n) = 0$. In fact, as tests of authors don't cover the whole range of Cd for a given range of Kc, equation (5) is not always verified and P(Cd)<1. We choice here to affect the residue of probability (1-P(Cd)) uniformly on each $P(Cd_i)$; weight of distribution tails are increased; it leads to conservative results.

Results

Let us consider a site in region A with a water depth of 50 m and a vertical component of diameter 1m located at depth 20 m under wave crests, submitted to extreme storms. Sea states parameters come from [10]. Rigid marine growth considered are barnacles according to figure 2; it leads to a relative roughness of 0.038. Figure 13 presents the discrete probabity density of Cd based on API regulations [13]: value obtained for Cd is 1.37. It is computed from average of Kc (23.47) computed from response surface of U and equation 2. Assuming that this value is a mean value, probabilistic modelling is then obtained by using two values of coefficient of variation (30 % on figure 14, 15 % on figure 15) consistant with custom in reliability analysis [14]. These results leads to conclude that the normal p.d.f. is not suitable for a CoV of 30 % and and that a standard approach based on API and a Gumbel p.d.f is more convenient in this case. Results are un conservative if a CoV of 15% is selected.

CONCLUSION.

The paper presents results of marine growth inspections in Guinea Gulf and suggests some ways for a best practice in view to introduce these data in a global scheme for inspection and cleaning planning and structural analysis. In particular some surprising profiles of marine growth thickness must be confirmed with a real objective of measurements error estimation. It leads to conclude that a more rational and detailed

standard is needed, if possible shared by the oil Industry, for Marine Growth reports. Further work is needed for correlation analysis between marine growth data and metocean data. If a correlation is found, possible extrapolation to new sites must be discussed. The use of metocean data for probabilistic modelling of hydrodynamic coefficients is introduced. The marine load computing needs to introduce these results in hydrodynamic design studies; in particular, an association of each marine growth category to specific hydrodynamic coefficients and density. Probabilistic description with evolution in time must be provided in view to perform reliability-based quasi-static and fatigue analyses and optimisation of inspections

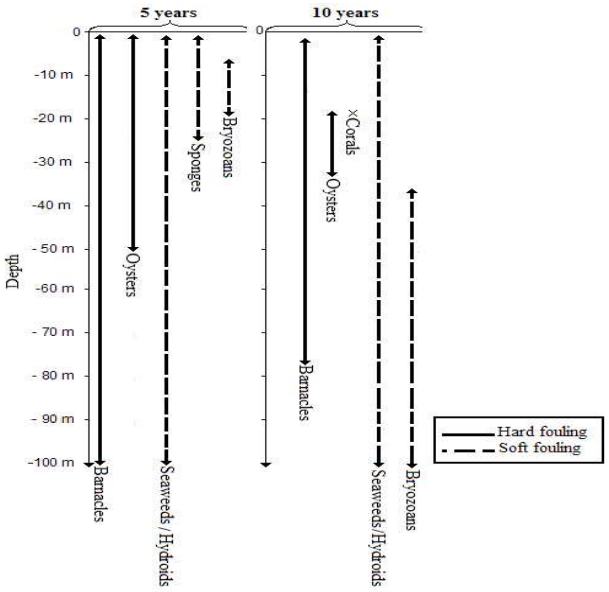

Figure 2. Distributions of fouling organisms with time on typical structures established in region "A"

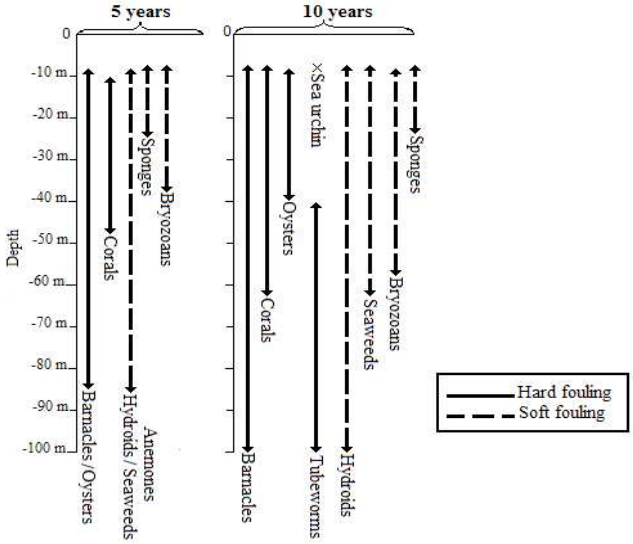

Figure 3. Distributions of fouling organisms on typical structures established in region "B".

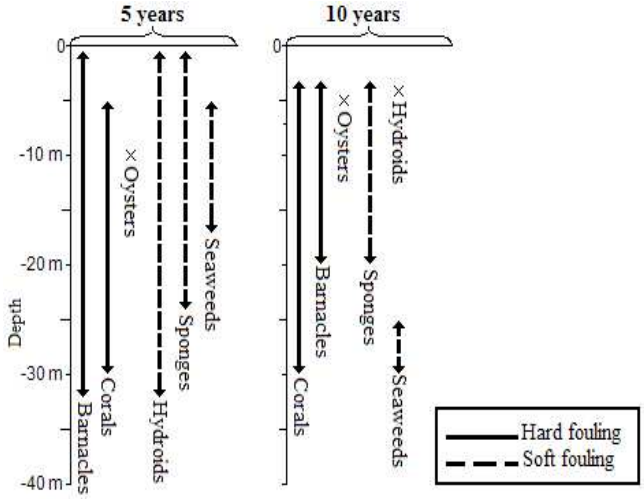

Figure 4. Distributions of fouling organisms on typical structures established in region "C".

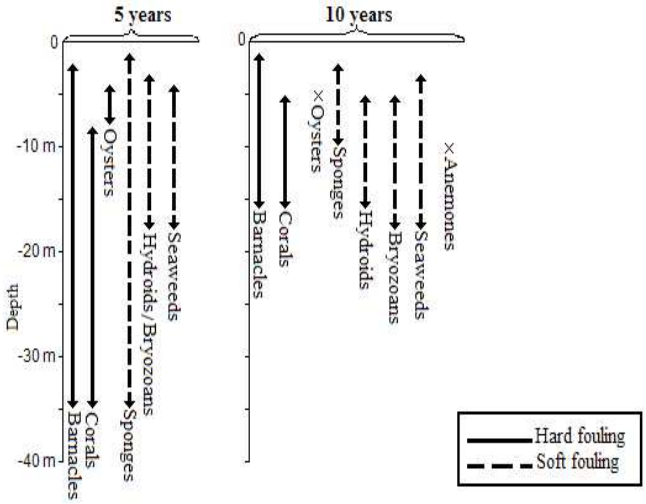

Figure 5. Distributions of fouling organisms on typical structures established in region "D".

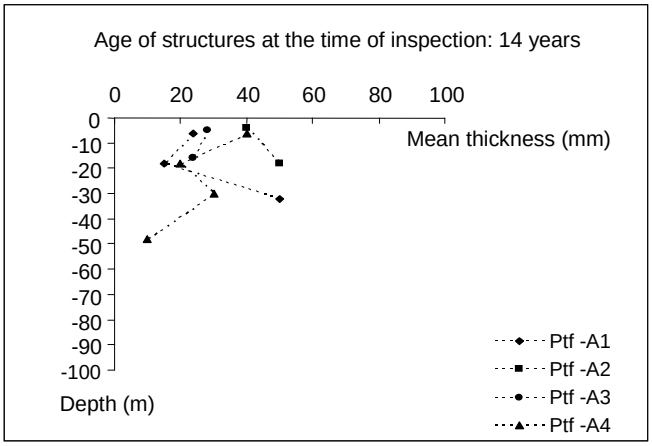

Figure 6. Profiles of hard fouling with depth at inspection date given, region "A".

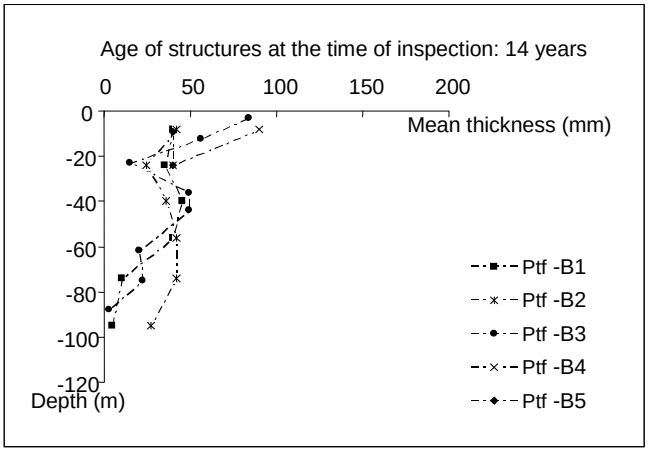

Figure 7. Profiles of hard fouling with depth at inspection date given, region "B".

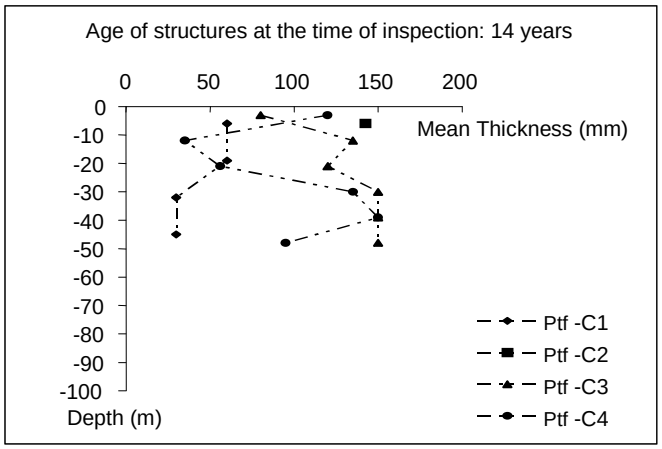

Figure 8. Profiles of hard fouling with depth at inspection date given, region "C".

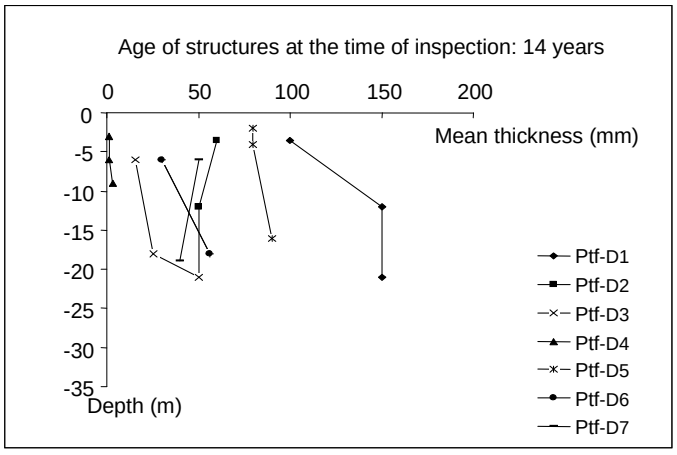

Figure 9. Profiles of hard fouling with depth at inspection date given, region "D".

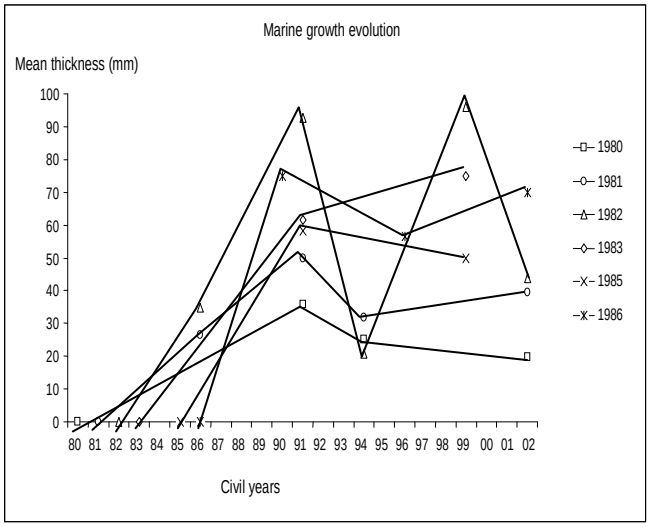

Figure 10. Profiles of hard fouling as a function of time in civil years ; each curve corresponds to a given date of implantation- depth 20m, region "C"

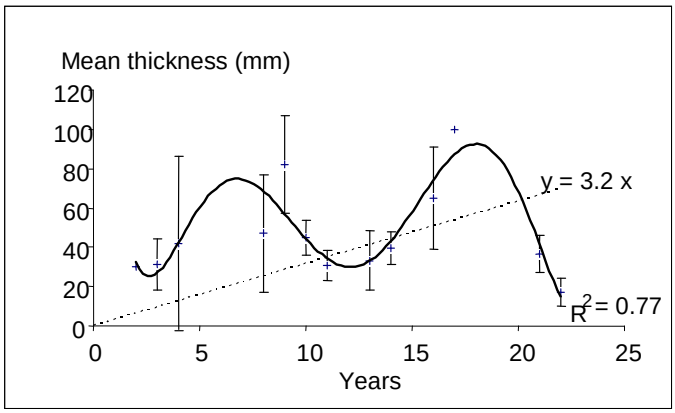

Figure 11. Modeling of marine growth in region "B" – Water depth: 20m

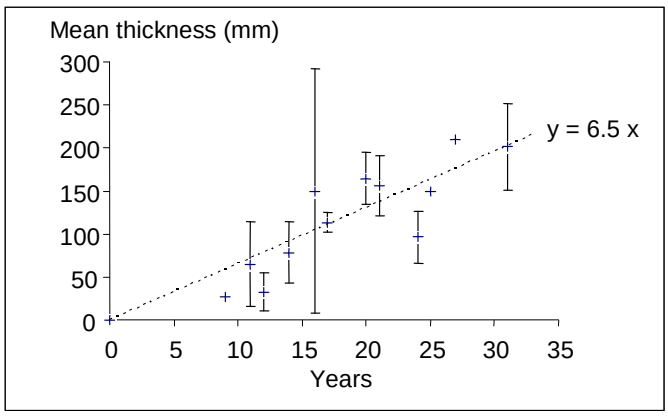

Figure 12. Modeling of marine growth in region "C" – Water depth: 20m

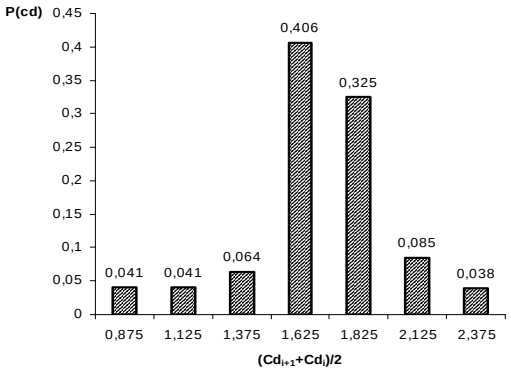

Figure 13. Drag coefficient probability

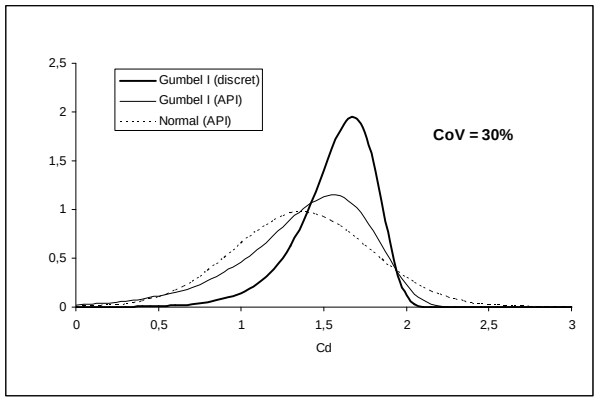

Figure 14. Probability density of drag coefficient (CoV 30%)

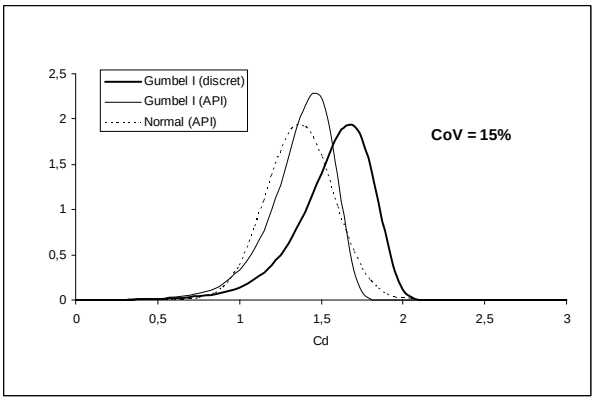

Figure 15. Probability density of drag coefficient (CoV 15%)

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