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EFFECTS OF MARINE GROWTH AND HYDRODYNAMIC LOADING ON OFFSHORE STRUCTURES

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ABSTRACT

Marine growth is known to give adverse effects on the performance of offshore structure. It presents will roughened the surfaces of the structure hence increase its drag coefficients. Structures with the best protection scheme from marine organisms would after few years start to be covered by various types of growth. Generally, it was also recognised that the most important source of loading exerted on offshore structure comes from hydrodynamic action which are influenced by C_D *and* C_M *values.*

In this paper type of marine growth usually found on offshore structures are mentioned and their effects on hydrodynamic loading are highlighted. Usual ways of controlling and removals of marine growth are also discussed. Data of marine growth distribution on a typical structure are presented and discussed.

1.0 INTRODUCTION

Offshore structures are complex type of installations placed in the sea for several purposes. They usually intended for either oil exploration, production, processing or accommodation. These structures can be presented in Fig. 1 [5]. During their lifetime, they will usually experience several types of loadings. These loading among others are operational loading, gravity loading, environmental loading as well as accidental loading.

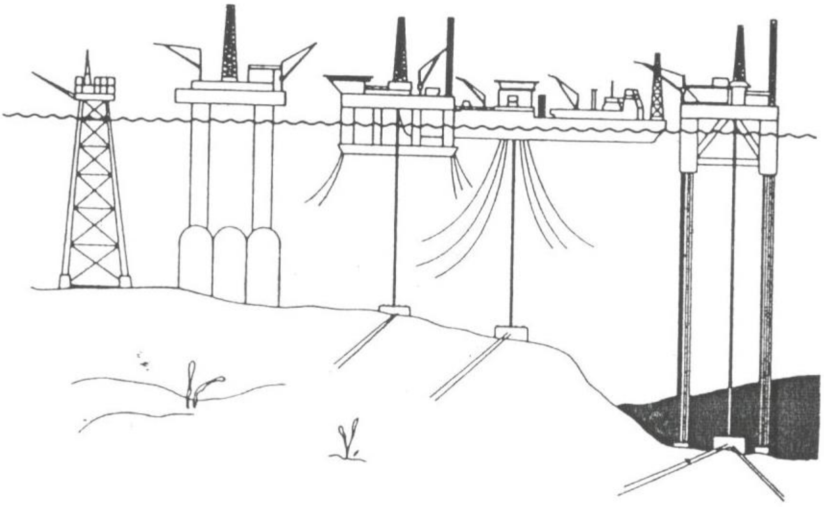


Fig. 1 Types of Offshore Structures

This paper presents briefly the types of marine growth that fall into category of prolific fouling that usually found in the North Sea. Basics consideration of the estimation of hydrodynamic loading is discussed in Section 3. In Section 4, effects of marine growth on hydrodynamics loading as well as overall performance of the structure are addressed. Only major effects are presented, thus omitting any chemical or biological effects of marine fouling may have on the structure.

There is still considerable uncertainty in the correct values of C_D and C_M appropriate for offshore structure design. Consideration of C_D values, as suggested by Codes of Practice, are highlighted in Section 5. In Section 6, methods usually adopted for controlling and removal of marine .growth on offshore structure are discussed. Marine growth data obtained from 11 steel jacket structures are presented and discussed in Section 7.

2.0 MARINE GROWTH

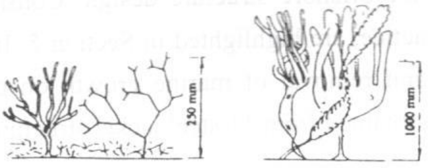
2.1 Type of Marine Growth

On any structure installed offshore, numerous type of marine fouling organism may be found on its submerged member after a certain time. Their distributions on structural members vary according to several factors; among others are geographical location, water depth, water temperature and season, ocean current, platform design and operation.

Marine growth can be classified into three main categories, namely hard growth, soft growth and long and flapping weed. Hard growth includes mussels, oysters, barnacles and tubeworms. Soft growth includes seaweeds, soft corals, sponges, anemones, hydroids, sea-squirts and algae. Long flapping weed is kelp that could also come under soft growth but it is single out because of its much larger size. Descriptions of the above fouling organisms and the way they attached themselves to the structure may be found elsewhere [8 and 13]. Their typical shapes and sizes are shown in Figs. 2 and 3, [7].

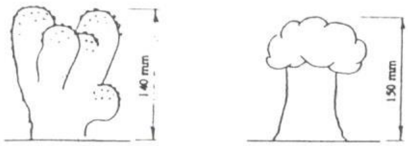
2.2 Distribution of Marine Growth

All marine organisms mentioned earlier are actually in direct competition for space, food and light and in most cases each established communities appear at distinct depth zones. Figure 4 shows depth/thickness profile of marine growth on a typical North Sea jacket platform [8]. In the above competition, a certain type of fouling is found to grow not only on clean surface but also other types of fouling. Some just grow on other fouling for the sake of space and some for sake of food. Fig. 5a shows a typical cross section of climax fouling on a typical structure.



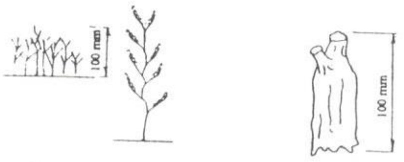
(a): Some of the shorter seaweeds.

(b): Three varieties of kelps.



(c): Soft coral.

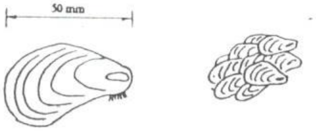
(d): Sea Anemones.



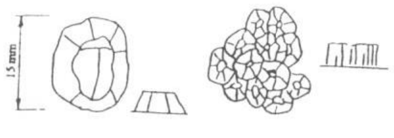
(e): Featherly appearance of hydroids. On the right shows a typical single hydroid.

(f): The soft bodied sea squit, eg. *Ciona* can some times grow in vast numbers.

Fig. 2 Soft Marine Growth



(a): The mussel showing byssal thread attachment. These threads are very tough. On the right shows a group of densely attached mussels. This dense attachment is fairly typical situation.



(b): Plan view of a barnacle, side view inset. This species is *cranatus balanoides*. On the right shows a honeycomb structure formed by dense barnacle cover, side view inset.

(c): Calcareous serpulid tubeworm. A persistent hard fouler, difficult to remove. Can some times grow vertical to the surface. On the right shows densities obtainable in the calcareous tubeworm.

Fig. 3 Hard Marine Growth

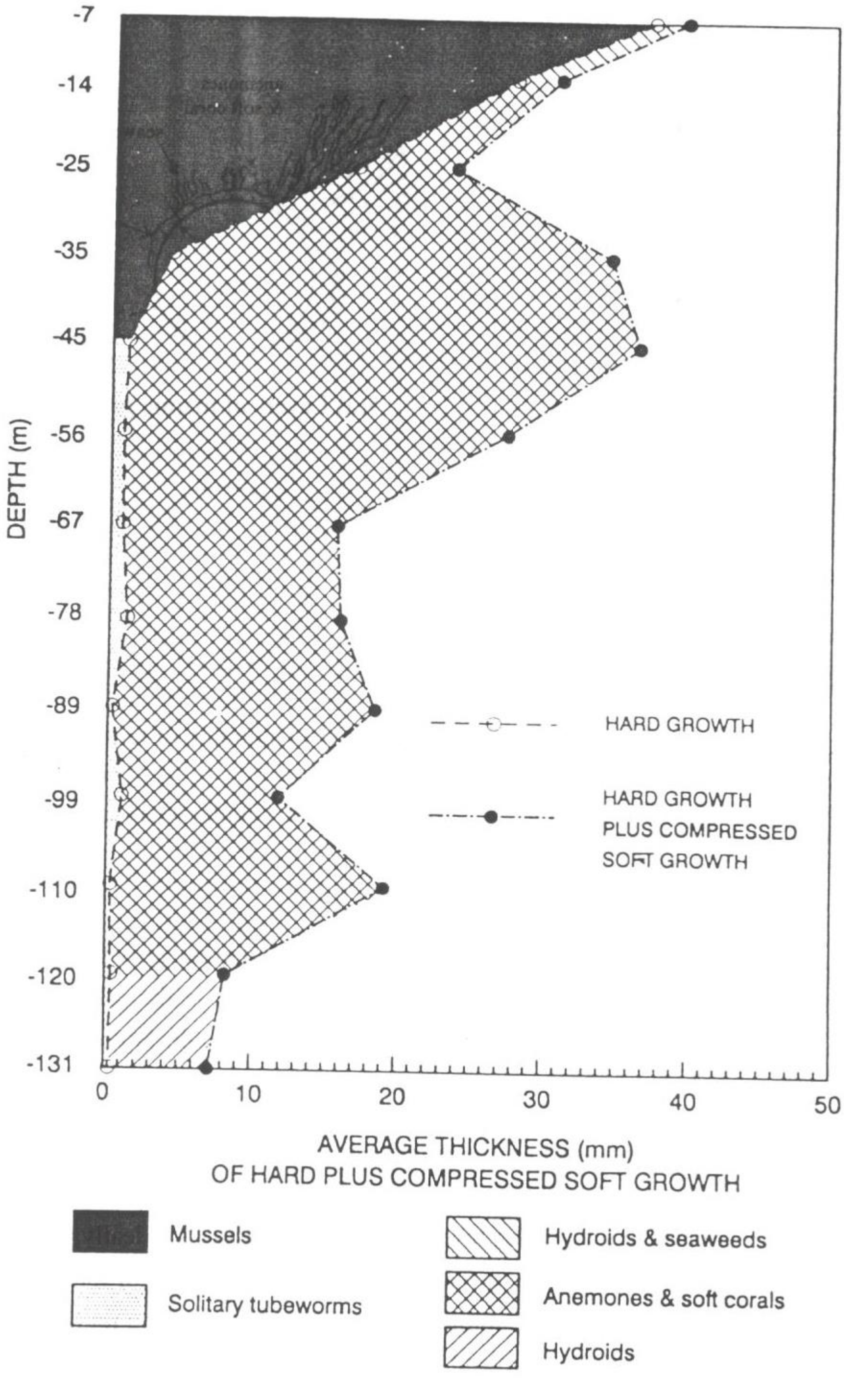
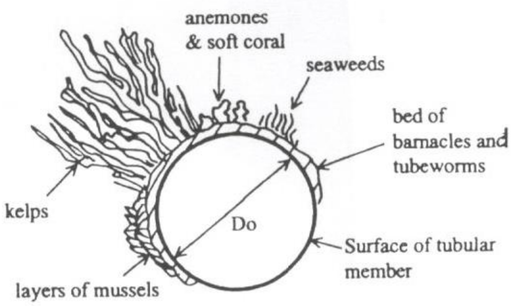
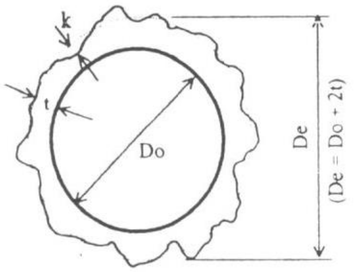


Fig. 4 Depth/Thickness Profile for a Typical Jacket in the North Sea



5(a) Layers of marine growth



5(b) Definition of terms

Fig. 5 Cross-section of Tubular Member with Marine Growth

For the purpose of quantifying marine growth and its effects the measurements defined graphically in Fig. 5b are used. D_e is the effective diameter, k is the roughness height and t is the thickness of marine growth. Both k and t are average values for the whole tubular.

In practice the thickness and distribution of marine growth on the structure are measures by divers or alternatively by interpreting the recorded scaled videotapes and/or scaled photographs taken by diver's or ROV's. Ideally the type , density, thickness and pattern of surface cover are recorded for all types of marine growth; as are the extent and order of the overlapping of the various layers of the fouling [12]. Survey of steel platforms usually performed with considerations of the orientation of the members. Particularly, observations of outer, inner, upper and lower surfaces of the members are usually noted as such.

3.0 HYDRODYNAMIC LOADS

Hydrodynamic loading resulting from the interaction of waves with structural members known to be a key factor in the design of offshore structures. Generally, offshore structure may be categorised into three main groups, namely; (1) Structure with slender tubular member (e.g. Steel jacket structure). (2) Large volume structure (e.g.. Concrete structure). (3) Structures with significant motion (Semi-submersible or floating structure).

The applicability of the theory for wave loading estimation are based upon the ratio of member's diameter, D, to wave length, L, as the following;

$$\frac{D}{L} < 0.20 \qquad \text{Morison's equation is applicable.}$$

$$\frac{D}{L} \geq 0.20 \qquad \text{Diffraction theory is applicable.}$$

3.1 Wave Theory

Waves are the most important source of hydrodynamic loading affecting the structure, inducing maximum response. The selection of wave theories is also very important in obtaining reliable response in offshore structural analysis. This is due to the different pattern in water particle kinematics with respects to certain water depth and wave length ratio.

The selection of wave theories may be done by referring to Fig. 6 [4] while Norwegian Petroleum Directorate [9] suggested the selection as shown in Table 1.

3.2 Current

Currents that are associated with hydrodynamic loading on offshore structure may be categorised into three main groups [1]; (1) Tidal currents (associated with astronomical tides), (2) Circulational currents (associated with oceanic-scale circulation patterns), and (3) Storm-generated currents. The vector sum of these currents gives the total current magnitude and the current profile deduces the speed and direction at certain elevation of water depth.

Tidal currents are regular in nature and predictable since they are associated with the highest or lowest astronomical tide. The other components, circulational and storm-surge are irregular in nature and unpredictable.

Currents can affect the height and length of periodic surface waves, that is when currents travels in the same direction, wave length become longer and when it is thravels in opposite direction results in shorter wave length and higher wave amplitude. However, there are some uncertainties in the effects of current on the loading of offshore structures. They are among others; directional uncertainty corresponds to the direction of wave incident as well as sheilding effects that reduces the strength of current. experienced by structural member.

In offshore design and analysis, generally, currents are important loading component, especially in the case of fixed offshore structures where currents effect the total force exerted on the structure. It also affects the orientation of the structures concerning location and orientation of boat-landing bumper.

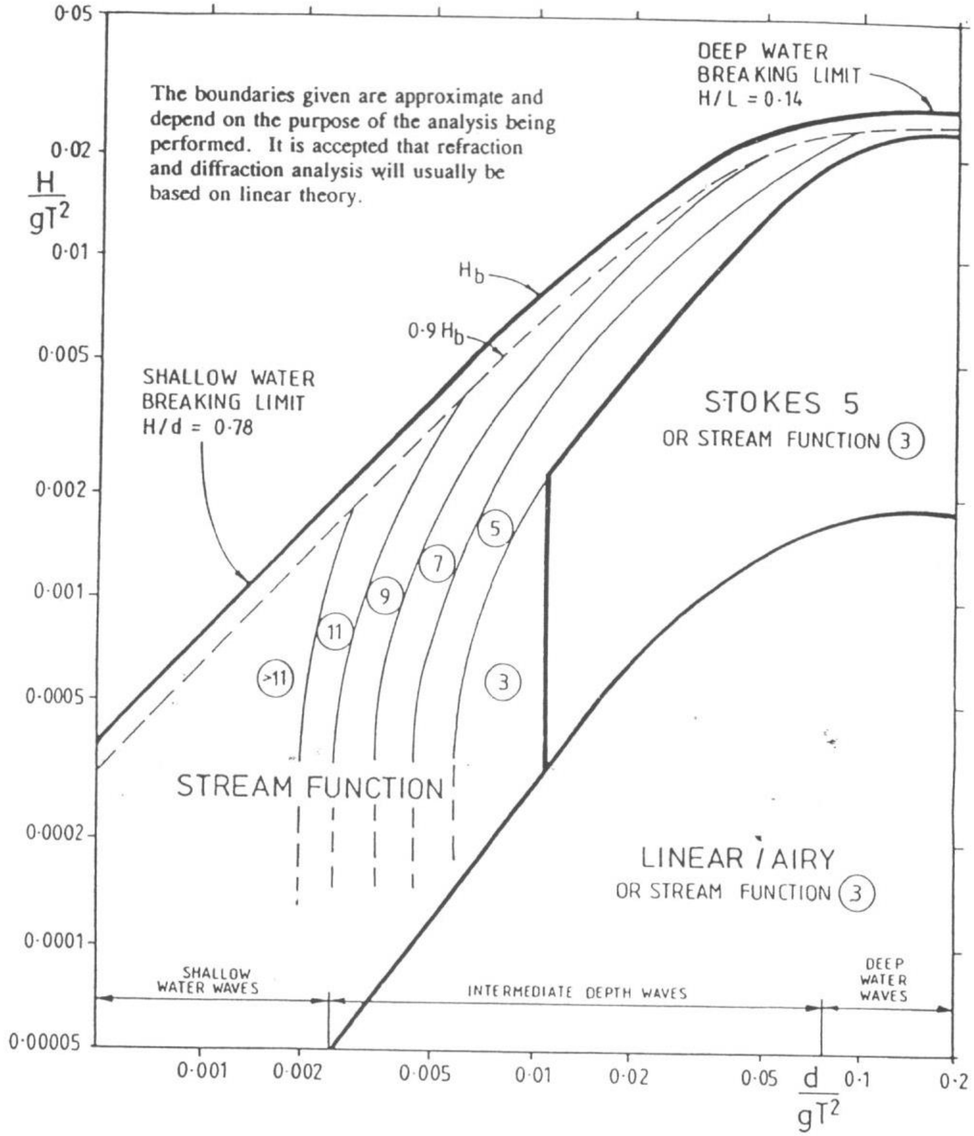
3.3 Estimation of Fluid Loading

Estimation of hydrodynamic loading on offshore structure may generally be done using Morison's equation to estimate the hydrodynamic force, F.

$$\begin{aligned} F &= \underset{Drag}{F_D} + \underset{Inertia}{F_I} \end{aligned}$$

$$F = \frac{1}{2}\,\rho\, C_D\, U|U| + \frac{1}{4}\,\rho\, C_M\, \pi\, D_e^2\, \dot{U} \qquad \text{per unit length} \qquad \text{Eqn. 1}$$

where; r is water density, C_D is drag coefficient, C_M is inertia coefficient, D_e is member's effective diameter (including marine growth), U is water particle velocity in direction of force and $\dot{U}$ is water particle acceleration in direction of force. Here will comprises the sum of the water particle velocity and the current velocity.



The boundaries given are approximate and depend on the purpose of the analysis being performed. It is accepted that refraction and diffraction analysis will usually be based on linear theory.

Nomenclature

H/gT^2 = Dimensionless wave steepness
d/gT^2 = Dimensionless relative depth
H = Wave height (crest to trough)
H_b = Breaking wave height
d = Mean water depth
T = Wave period
L = Wave length (distance between crests)
g = Acceleration due to gravity

Fig. 6 Regular Wave Theory Selection Diagram

Table 1 Limits for Wave Selections

Ratio Between Waterdepth and Wave Length	Wave Theory
0.1 - 0.3	Stokes 5th Order
> 0.3	Linear or Stokes 5th Order
Note: At shallow water depths outside the above limits, other wave theories should be used.	

On small diameter structure such as steel jacket structure having tubular members, the forces exerted by waves and current may basically be represented by simple vertical cylinder extending above the free surface as shown in Fig. 7. Steady flow parallel to x-direction passed the cylinder will results in in-line force and transverse (lift) force. The in-line force, F_D, may be represented by the drag term in the above equation. The shedding of vortices at certain flow velocities, give rises to transverse or lift force (e.g. in the case of marine riser). The transverse force, F_L, may be expressed in a similar form as the drag force.

$$F_L = \frac{1}{2} \rho C_L D_e U|U| \qquad \text{Eqn. 2}$$

where: C_L is lift coefficient, and r, D_e, and U as previously defined.

Lift coefficient, C_L, is significantly vary with a function of Reynolds number as shown in Figure 8 [3], (where: $C_L(rms) \approx 0.4C_L$). The broken line on Fig. 8 corresponds to the average of the values and recommended for design purposes [6].

However, current practice in offshore industry is not to consider tranverse forces in the loading assessment of jacket and other nominally rigid tubular structures. Whilst it is true that the absence of coherence of these force between members means they will have negligible effect on the overall structural loading the same may not be true for individual member loads in the presence of marine roughness. There is evidence that roughness not only increase tranverse forces but also increases their spanwise coherence on vertical cylinders in oscillatory and regular wave flows. This may significantly affect the loading [10].

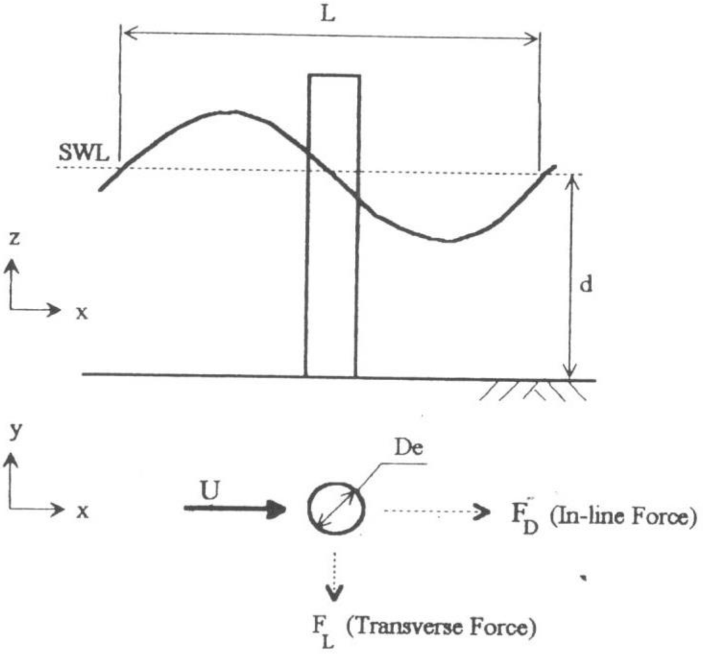


Fig. 7 Forces on Vertical Cylinder

4.0 EFFECTS OF MARINE GROWTH ON LOADING

Marine growth has number of effects on loading of offshore structure that may among others be listed as the following: (a) increase in structural diameter and displace volume, (b) increase in force coefficients, (c) increase in structural weight, (d) increase in mass and hydrodynamic added mass, (e) increase flow instability, (f) conceal the member's outer surface and (g) cause physical obstruction. These effects are described below.

Generally, these effects cannot be overlooked if accurate estimation of the response of the structure is required.

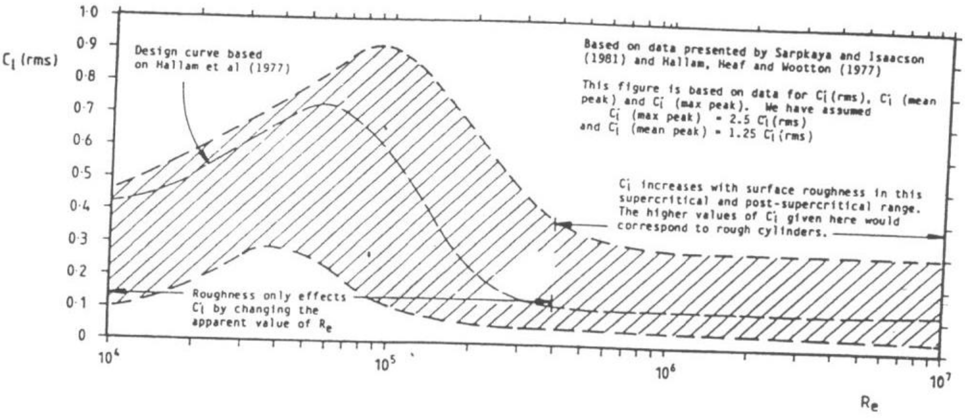


Fig. 8 Range of Measured Values of C_L (rms) Vs R_e for a Smooth Circular Cylinder Which does not Oscillate

4.1 Structural Diameter and Displace Volume

The present of marine growth on the outer surface of a submerged member will increase its effective diameter hence displaced volume of the structure. This change at certain levels will increase the overall loading substantially, reference the inertia term in Eqn. 1, especially if the growth is abundant on a relatively small structure.

4.2 Increase in Force Coefficients

A member's surface will become roughened with the attachment of the fouling organism. The increase in surface roughness gives rise to changes in both the drag and inertia coefficients in Morison's equation. In general the drag coefficient increases with the increase of surface roughness and the inertia coefficient decreases with increasing surface roughness. Fig. 9 clearly show the relationship between surface roughness and drag coefficients where at high KC value C_D increase with surface roughness [2].

4.3 Increase in Structural Weight

Marine growth will also increase the total weight of the structure. However, the increase is found to be insignificant compared to the total weight of the structure and the variable deck loading. This is due to the low specific gravity of marine growth.

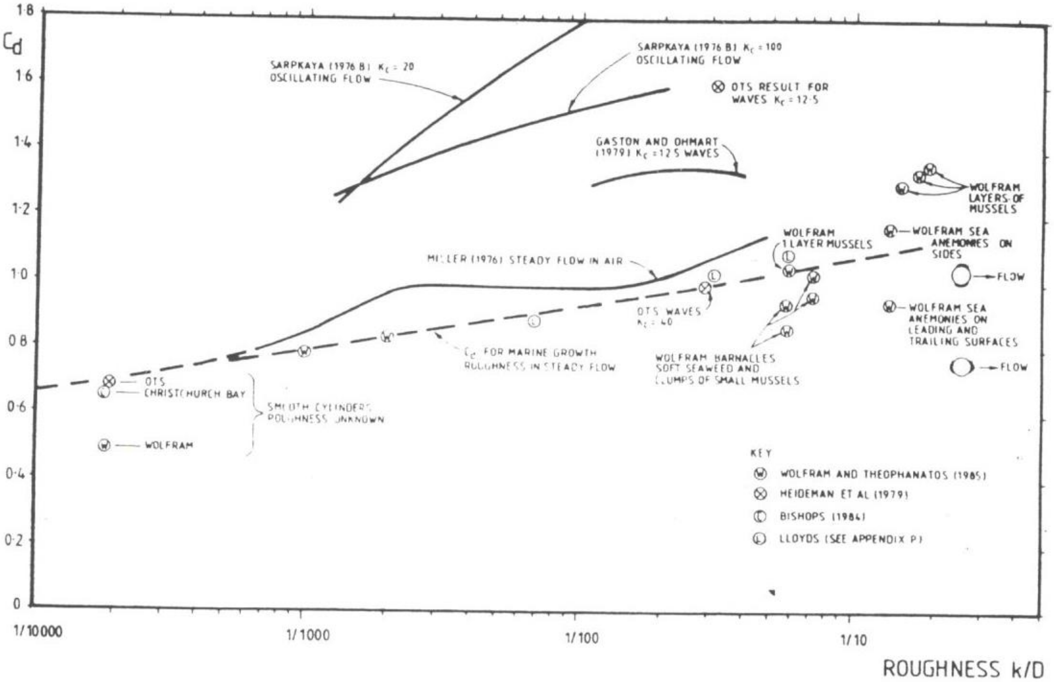


Fig. 9 Effects of Surface Roughness on C_D

4.4 Increase in Mass

The increase in displaced volume due to the present of marine growth will increase the mass, m_r, and hydrodynamic added mass, m_a, of the structure. These increment in mass will in turn decrease the natural frequency of the structure as represented by Eqn. 2.

$$\omega_n = \sqrt{\frac{k}{m_r + m_a}} \qquad \text{Eqn. 3}$$

where k is stiffness.

This can be significant for small diameter members and may move the structural response closer to resonance.

4.5 Increase Flow Instability

The accumulations of marine growth cause the surface profile become irregular. Marine growth also increases the size of member's diameter to an effective diameter, D_e. This change will affect the formation of vortex shedding that usually occurs at Strouhall number, S_n, of 0.2.

$$S_n = \frac{D_e f}{v} \qquad \text{Eqn. 4}$$

where D_e is effective diameter, f is vortex shedding frequency and v is flow velocity.

This will increase the strength of vortices and their spanwise coherence [10] thus increasing the cyclic lift forces that may significantly reduce the estimated fatigue life, particularly of a small diameter member [11].

4.6 Conceal the Member's Outer Surface

The structure in its life time will undergo a routine inspection to ensure the integrity of structural members particularly at the welded joints. The natures of marine growth attaching themselves on the structure and spreading, tend to cover the member's outer surface. This coverage has to be removed before inspection can be carried out.

4.7 Cause Physical Obstruction

The size and accumulation of marine growth can physically block or restricting the function of some system on the structure. For example the seawater inlet manifold may be covered by fouling thus to some extent reduce the overall performance of the structure.

5.0 CONSIDERATION OF MARINE GROWTH IN DESIGN

The presence of marine growth will change the value of hydrodynamic coefficients, and used in Morison's equation. The UK's Department of Energy [4], gives that the values of C_D and C_M used in the estimation of hydrodynamic loading should not normally less than the following;

$C_D = 0.6$	(no marine growth)
$C_D = 0.7$	(with marine growth)
$C_M = 1.7$	(extreme conditions)
$C_M = 2.0$	(fatigue conditions)

Norwegian Petroleum Directorate [9], suggested that thickness of marine growth refers to levels below mean water level (MWL) for the North Sea water as shown in Table 2. This value applicable in absent of more accurate data.

In practice C_D values significantly lower than those predicted by research finding has been used in design (however, it should not lower than the above values). This happened because in the analysis the following assumptions may be made [4]; (1) Wave are long (i.e. unidirectional), (2) Water particle motions are calculated by regular wave theories, (3) no shielding effects on the structures are included and (4) independent extreme values and current are combined (extreme loading only). These assumptions tend to overestimate the water particle kinematics. The are offset by assuming low C_D values.

Table 2 Thickness of Marine Growth for the North Sea

Water Depth	Latitude 56° - 59° N	Latitude 56° - 72° N
Above +2 m	0	0
+2m to -40m	100 mm	100 mm
Under -40m	50 mm	20 mm

incorporated into a porous silicon rubber matrix coating forming a slippery surface to settling marine organisms, and (2) Anti-fouling hoops and brushes which function by the action of passing water current resulting a spiral motion of the hoop thus removing marine organisms along the protected tubular member.

6.2 Removal of Marine Fouling

Several methods usually employ in removing marine growth from the surface of structural members [8]. These methods include; (1) Manual cleaning, (2) Water jets, (3) Hydraulic powered cutters or brushes, and (4) Clean and paint machines.

Manual cleaning employed hand tools such as wire brush and scrapper and this method have a low cleaning rate and usually use to clean small area of the surface. Water jets technique uses the impact force of water (through high pressure hose) to remove marine organisms from the surface. This technique can achieve cleaning rates between 8 and 30 m^2/h using pump pressures up to 20 000 lbf/in^2 (1400 bar) [8]. The third technique relies upon the rotating action of cutters or steel/nylon brushes. Cutter would shear the basal attachments of fouling organisms while brushes abrade through the fouling layer. The clean and paint machines are an automatic system designed for the on tubular members. It is clamped onto the member and travels along it during cleaning. The system carries nozzles for high-pressure water jetting.

7.0 MARINE GROWTH DATA

Data on the thickness and distribution of each type of marine growth were obtained for 11 fixed offshore structures representing four sectors of the North Sea, i.e. the northern, central inshore, central offshore and southern North Sea. The data are presented as mean values and standard deviation for each type of marine growth in each range of water depth. Tables 3 and 4 gives information on variation of marine growth thickness between platforms (referred to as "global") and within platform (referred to as "local") respectively. Table 3 shows the variation between the average thickness for each of the eleven platforms. They would be used when estimating global loading. Table 4 represents variation in marine growth thickness between individual members on platforms in specified North Sea sector. Data presented shows all the type of marine growth that are most prolific.

Several points need to be noted. First, layers of marine growth sometime overlay one another but the extent of this overlaying is not always clear from marine growth survey reports. Secondly, the sample of data presented here is relatively small and should not be view as definitive. Thirdly, it is important to remember that surveying marine growth is not an exact science and is subject to errors in measurement, location identification and marine growth classification.

When there are several marine growth layers it is the characteristics of the outermost layer which will have the greatest influence on the hydrodynamic force coefficients. The governing characteristics seem to be the type of marine growth and the size of the individual specimens.

These data are important for two reasons. First they allows the effective diameter D_e (= D + *(2* x *marine growth thickness)*) to be estimated for both individual tubular member ("local") and, as an average, for the whole structure ("global"). This necessary when using Morison's equation to estimate both individual member ("local") and global (base shear and overturning moment loads). Second the information also provides a guide to the dominant fouling species and hence the magnitude of an appropriate corresponding drag coefficient (see Figure 9 [2 and 13]).

8.0 DISCUSSION

Marine growth thickness data from eleven steel jacket platforms representing four sectors of the North Sea are postulated. The data corresponds to several types of marine growth that are found to be most prolific. There is, however, considerable uncertainty intrinsically incorporated in the data due to the variation in marine growth distribution, overlaying patterns, surveying technique and reporting, sampling and measurement error as well as classification of marine growth. Apart from that, the data can generally represent the growth pattern of marine organisms for the respective sector of the North Sea.

Table 3 Global Variation of Marine Growth Thickness

Depth Range (m)	Mussel			Tubeworm			Seaweed			Anemone			Soft Coral			Hydroid			Kelp		
	Mean (mm)	Std.Dev	Sample	Mean (mm)	Std.Dev	Sample	Mean (mm)	Std.Dev	Sample	Mean (mm)	Std.Dev	Sample	Mean (mm)	Std.Dev	Sample	Mean (mm)	Std.Dev	Sample	Mean (mm)	Std.Dev	Sample
0 - 10	56.22	19.52	10	8.08	4.62	9	126.31	44.74	10	62.91	27.61	8	81.45	33.09	8	35.12	16.31	10	683.65	229.99	6
11 - 20	51.79	12.16	6	8.76	5.38	10	109.22	105.27	5	85.16	52.71	9	116.72	45.42	10	39.51	19.58	10	-	-	-
21 - 30	23.75	-	1	13.54	9.42	8	50.00	-	1	80.05	44.71	5	110.11	34.96	8	37.09	14.51	8	-	-	-
31 - 40	30.00	-	1	10.55	5.40	7	-	-	-	107.81	23.24	5	102.14	37.70	7	34.00	19.01	7	-	-	-
41 - 50	30.00	-	1	10.99	5.51	6	-	-	-	98.44	31.01	3	40.80	47.08	5	44.46	20.03	6	-	-	-
51 - 70	-	-	-	7.95	2.07	3	-	-	-	94.53	27.96	3	85.13	20.49	3	29.71	14.97	3	-	-	-
71 - 100	-	-	-	8.92	2.71	3	-	-	-	84.90	27.08	3	81.10	28.68	3	27.28	13.79	3	-	-	-
101 - 160	-	-	-	15.57	7.24	2	-	-	-	65.85	25.15	2	63.44	8.44	2	18.26	12.34	2	-	-	-

Table 4 Local Variation of Marine Growth Thickness

Depth Range (m)	Mussel			Tubeworm			Seaweed			Anemone			Soft Coral			Hydroid			Kelp		
	Mean (mm)	Std.Dev	Sample	Mean (mm)	Std.Dev	Sample	Mean (mm)	Std.Dev	Sample	Mean (mm)	Std.Dev	Sample	Mean (mm)	Std.Dev	Sample	Mean (mm)	Std.Dev	Sample	Mean (mm)	Std.Dev	Sample
Southern North Sea																					
0 - 10	69.89	24.51	88	4.85	0.68	85	157.32	43.23	40	88.28	35.63	87	95.83	41.64	84	51.78	10.75	101	550	-	1
11 - 20	49.23	17.30	13	4.61	0.99	86	80.00	-	1	140.45	44.36	88	148.95	59.14	86	58.66	5.58	82	-	-	-
21 - 30	23.75	9.60	4	4.92	0.38	26	-	-	-	125.00	30.03	26	132.62	36.04	21	56.32	7.41	19	-	-	-
31 - 40	30.00	-	1	4.71	1.74	17	-	-	-	129.29	39.18	14	143.75	46.35	16	52.50	10.31	16	-	-	-
41 - 50	30.00	10.00	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Northern North Sea																					
0 - 10	35.71	12.94	7	5.00	0.00	8	165.30	115.30	15	-	-	-	25.00	5.00	4	29.29	20.60	14	900	-	1
11 - 20	47.50	8.29	4	6.00	2.00	5	316.67	23.57	3	72.67	4.42	15	33.33	14.91	9	16.76	19.90	25	-	-	-
21 - 30	-	-	-	22.61	13.92	11	-	-	-	50.00	0.00	4	66.25	23.82	4	24.38	6.82	8	-	-	-
31 - 40	-	-	-	15.00	5.00	2	-	-	-	116.67	4.71	4	60.00	0.00	2	6.25	2.17	4	-	-	-
41 - 50	-	-	-	10.00	0.00	3	-	-	-	85.00	30.41	8	22.50	3.54	2	24.00	7.35	5	-	-	-
51 - 70	-	-	-	9.55	9.88	11	-	-	-	94.17	28.12	12	68.00	29.93	10	22.69	9.53	13	-	-	-
71 - 100	-	-	-	11.09	12.06	23	-	-	-	70.00	23.09	24	62.65	44.13	17	19.79	9.63	24	-	-	-
101 - 160	-	-	-	18.57	34.30	35	-	-	-	61.67	27.64	24	66.25	25.59	12	20.38	13.45	29	-	-	-
Central Offshore																					
0 - 10	50.00	13.38	36	5.00	0.00	17	57.63	7.32	19	35.97	8.48	36	36.67	8.16	9	36.94	3.96	36	1000	-	2
11 - 20	40.00	10.00	2	5.11	0.91	36	64.44	10.97	18	40.00	33.38	14	128.33	52.29	24	36.93	4.29	44	-	-	-
21 - 30	-	-	-	5.00	0.00	7	-	-	-	91.43	8.33	7	126.74	19.48	23	47.14	4.52	7	-	-	-
31 - 40	-	-	-	5.22	0.96	27	-	-	-	111.54	13.43	26	116.67	12.47	3	52.08	4.06	24	-	-	-
41 - 50	-	-	-	5.13	0.88	15	-	-	-	125.33	14.54	15	134.50	31.34	10	52.67	5.73	15	-	-	-
51 - 70	-	-	-	5.11	0.47	18	-	-	-	114.84	14.84	31	112.37	17.42	19	48.62	5.07	29	-	-	-
71 - 100	-	-	-	5.19	0.53	16	-	-	-	114.69	14.63	16	115.83	22.53	12	43.75	5.99	16	-	-	-
Central Inshore																					
0 - 10	70.91	27.45	33	14.27	8.54	140	89.26	53.80	102	43.50	20.86	10	103.32	53.47	101	20.98	13.28	82	617	388.51	22
11 - 20	60.00	40.00	2	15.81	8.43	68	55.63	22.56	8	20.00	7.07	4	119.23	52.17	52	29.77	22.69	42	-	-	-
21 - 30	23.75	6.24	4	15.44	4.52	125	-	-	-	10.00	0.00	1	127.54	51.14	116	29.40	20.86	108	-	-	-
31 - 40	30.00	-	1	14.88	2.31	42	-	-	-	90.00	0.00	1	100.30	68.15	50	37.75	17.50	40	-	-	-
41 - 50	-	-	-	17.89	5.46	19	-	-	-	-	-	-	18.75	12.44	8	57.29	24.40	31	-	-	-

Estimation of marine growth thickness for structure design for certain location may be made using data from Table 4. The effects of marine growth can be estimated on overall loading of the structure in which thickness of marine growth averaged on structural members at certain range of water depth.

Prevention of accumulation of marine growth on structure demands the application of anti-fouling and maintenance of the structure requires systematic cleaning or removals of marine growth. There are certain limitation on the effectiveness of the cleaning systems among others; the size of the systems that may prevent it from negotiating small areas, cleaning method devised for it (either manual or automatic) and operator-dependent fatigue.

9.0 CONCLUSION

The present of marine growths has significant effects on the hydrodynamic loading of offshore structures and should be taken into consideration in the design and analysis of the structure.

Data presented in this paper enable a first estimation of marine growth thickness to be made globally for the North Sea as well as locally for specific sectors.

Based on this study it is found to be essential to prevent and remove marine organisms from the structure to allow for inspection as well as to relieve the loading on fouled individual members.

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