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BIOLOGICAL AND ENGINEERING PARAMETERS FOR MACROFOULING GROWTH ON PLATFORMS OFFSHORE LOUISIANA

by

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Abstract

Climax marine growth on several oil and gas platforms offshore Louisiana has been assessed. Dominant fouling species in different depth zones have been identified. Profiles of average growth thickness and roughness height needed for offshore structure design have been estimated from measurements and photographs.

Introduction

Marine growth affects the hydrodynamic loads on offshore structures subjected to waves and currents by increasing the member diameters and surface roughness. Marine growth also increases the mass of the structure, thereby affecting its dynamic response to both wave loading and earthquake loading. Therefore, marine growth should be considered in designing both fixed and floating offshore structures.

North Sea structures accumulate considerable marine growth. The impact of that growth on both the ultimate strength and fatigue resistance requirements of North Sea structures has spawned research efforts to quantify the rate of growth and climax size of marine growth in different sectors of the North Sea (Refs. 2, 5, 6, 8, 9). By contrast, Gulf of Mexico platforms experience less pronounced marine growth and fewer efforts have been made to quantify the climax growth. George and Thomas (Ref. 1) have studied the biofouling communities on shallow-water Gulf of Mexico structures. However, our knowledge of deep-water biofouling growth in the Gulf of Mexico has thus far been meager below 150 ft depth, below which diving is limited. In this paper we present new data to a depth of 310 ft based on a study of the Test Guyed Tower, which stood for 3-1/2 years in Grand Isle Block 86 offshore Louisiana.

In subsequent sections, we describe the dominant biofouling organisms at various depths offshore Louisiana; we compare offshore Louisiana fouling with North Sea fouling; we discuss the effect of marine growth on the response of offshore structures to waves and currents; and we present estimates of marine growth profiles based on inspections of 19 structures on the Louisiana continental shelf. This information may not be applicable to the eastern Gulf of Mexico, which is affected by the presence of the Loop Current.

Biofouling Organisms

Biofouling organisms on platforms offshore Louisiana are discussed in this section, first with emphasis on the major fouling species in different depth zones, and then in comparison with biofouling in the North Sea.

Dominant Species at Various Depths. We have carefully examined climax fouling growth on two Exxon platforms, GI 18-A and GI 22-L, in 50-60 ft water depths on the basis of *in situ* underwater photography and scrapings of marine growth from platform members. We have also thoroughly surveyed marine growth from the surface to the bottom of the Test Guyed Tower after it was removed from 310 ft water depth (Grand Isle Block 86) and towed to a dock. Finally, we have obtained information on settlement and recruitment of fouling species on the basis of *in situ* test panels suspended for a period of three months from two Chevron platforms, "Delta" and "Delta-Delta", in 35 and 60 ft water depths in the Timbalier area. These data have enabled us to arrive at the zonation pattern for the biofouling community. The most important fouling species and their depths of occurrence and quantitative abundance are given in Table 1. An assemblage of *in situ* photographs of growth at various depths on the Test Guyed Tower is shown in Fig. 1.

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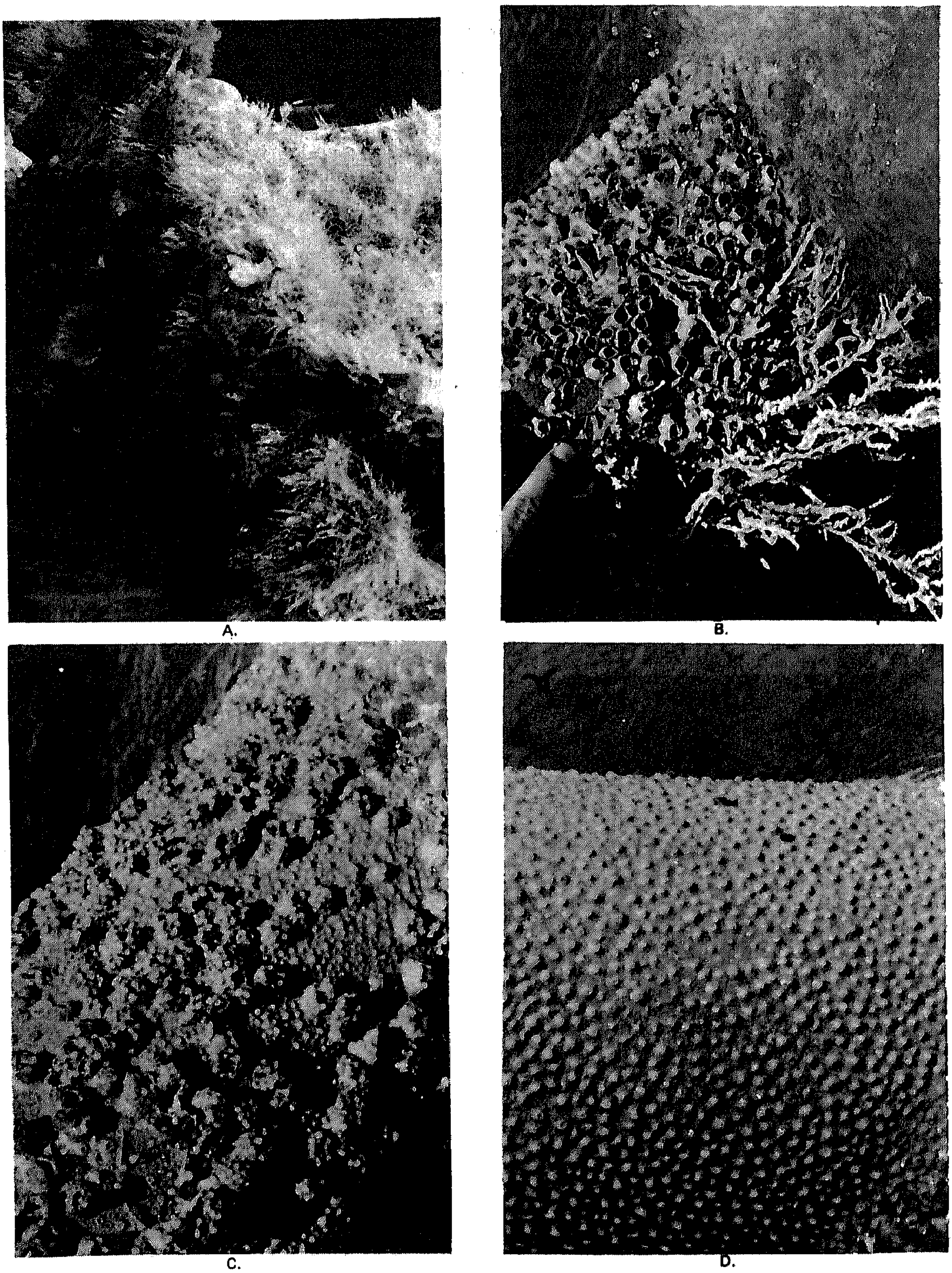

FIG. 1. IN SITU PHOTOGRAPHS OF MARINE GROWTH ON THE TEST GUYED TOWER AT VARIOUS DEPTHS. A. SPLASH ZONE, 5 FT, EXHIBITING A DENSE GROWTH OF HYDROIDS. B. SUBMERGED ZONE, 80 FT, SHOWING A THICK PATCH OF BARNACLES. C. DEEP ZONE, 120 FT, SHOWING BARNACLES COVERED WITH COLONIAL TUNICATE. D. DEEP SINGLE STRATUM FOULING ZONE OF THE COLONIAL TUNICATE MAT AT 260 FT.

Table 1

Dominant Fouling Species Offshore Louisiana

	Group	Species	Depth Range (ft)	Biomass (gm/m^2)
1.	Algae	Polysiphonia sp.	0-15	30
		Enteromorpha sp.	0-10	40
2.	Hydroids	Syncoryne sp.	10-30	90
3.	Bryozoa	Bougainvillia tennella	20-50	150
		Bugula nevitina	20-40	25
4.	Anemones	Alptasia pallida	30-40	110
		Astrangia astriformis	20-50	110
5.	Cirripedia	Balanus improvisus	0-20	4500
		Balanus reticulatus	50-90	5300
		Balanus eburneus	20-100	5000
6.	Tunicates	Hypleurochillus geminatus	30-50	400
		Diademnum albidum	100-310	30
7.	Sponges	unidentified	40-60	220
8.	Bivalves	Crassostrea virginica	20-30	1800

The splash zone, from sea level to 20 ft, is dominated by the barnacle Balanus improvisus (Fig. 2), which exhibits peak reproduction and settlement in the summer months. This zone also contains a dense growth of the soft fouling hydroid Syncoryne in the fall and winter months. The green algae Enteromorpha occupy the upper 10 ft.

The subtidal zone, 20 to 50 ft, is predominantly represented by the bryozoan Bougainvillia tennella along with patchy clumps of oysters, clams, gastropods and tunicates. The large barnacle Balanus tintinnabulum is found in this zone here-and-there as clusters. The soft sea anemones Alptasia pallida and Astrangia astriformis are commonly encountered in this depth zone.

The submerged zone, 50 to 90 ft, exhibits somewhat uniform development of the barnacle Balanus reticulatus. This zone contains at the upper levels yellow and orange sponges and colonial tunicates as soft fouling growth. In the inner Louisiana shelf, where this zone is at the water and sediment interface, a dense growth of hydroids and sessile serpulid worms prevails.

The most homogeneous fouling growth is seen in the deep single-stratum fouling zone. A thin macrofouling film was found to encompass the entire surface area from 100 to 310 ft on the Test Guyed Tower after an immersion period of 3-1/2 yrs. This macrofouling film is a colonial soft tunicate Didemnum albidum. Its ability to spread evenly to cover a vast submerged surface area is attributed to its extraordinary asexual reproductive capabilities.

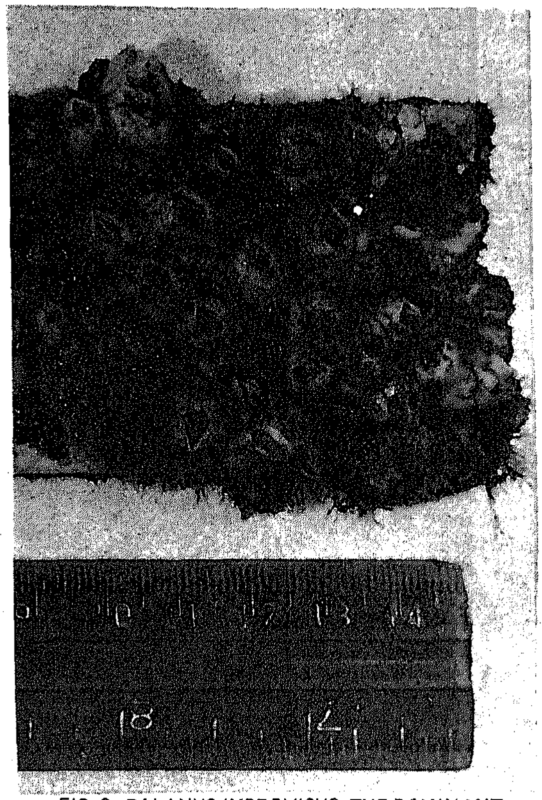

FIG. 2. BALANUS IMPROVISUS, THE DOMINANT BARNACLE SPECIES OFFSHORE LOUISIANA.

Comparison between Offshore Louisiana and North Sea Biofouling. Compared with other oceanic regions, the Louisiana continental shelf supports a relatively low level of marine growth. Contributing factors are the pronounced seasonal oscillations in near-surface temperature, the dilution of shelf waters by Mississippi River runoff, the high sediment load in the turbid layers, and the somewhat low nutrient availability. By contrast, the North Sea has nutrient-rich water and supports marine growth four-fold greater than offshore Louisiana. Climax marine growth is attained within 3 to 4 years offshore Louisiana, whereas 10 to 12 years are required in the North Sea.

Kelp and the mussel Mytilus edulis, characteristic foulers of North Sea structures, do not occur on structures offshore Louisiana. There is no prevailing current system there to transport a rich pool of mussel larvae for recruitment, settlement, and growth on offshore structures. The dominant barnacles offshore Louisiana, Balanus reticulatus and Balanus improvisus, are smaller in diameter and height than the large deep-water barnacle Balanus hameri prevalent on North Sea structures. In addition to barnacles, there are calcareous tube worms Filograna implexa, ascidians Ascidiella scabra, and sea anemones Metridium senile at depths between 100 ft and 350 ft on North Sea structures. By contrast, this depth zone offshore Louisiana appears to be populated almost solely by the thin film-like coating of the colonial tunicate Didemnum albidum seen on the Test Guyed Tower. Growth in this depth range on other deep-water platforms offshore Louisiana has not been inspected, so we cannot say that Didemnum albidum universally dominates this depth range.

Engineering Parameters

In this section, we first describe the effects of marine growth on platform response to waves and currents and define engineering parameters for marine growth. Then we estimate values for those engineering parameters offshore Louisiana.

Parameter Definitions. Hydrodynamic loads on offshore structures are customarily divided into two categories: drag load, proportional to the square of the relative fluid velocity, and inertia load, proportional to the relative fluid acceleration. In terms of parameters affected by marine growth, these two categories of hydrodynamic loads can be expressed as

$$\text{Drag} \sim C_d\, D$$
$$\text{Inertia} \sim C_m\, D^2$$

Marine growth thickness increases the effective member diameter D and thus increases both drag and inertia loads. Also, marine growth increases the surface roughness, which leads to a larger region of separated flow downstream of the member; the effect of this is to increase the drag coefficient C_d and decrease the inertia coefficient C_m. On some members, a third category of hydrodynamic loads is important: lift forces due to alternate vortex shedding. These forces have a similar functional form to drag forces. They generally increase both with increases in diameter and surface roughness.

For structures that are dynamically excited, marine growth has another effect. It increases the mass, particularly near the water surface, thereby increasing the structure's natural period and likely its dynamic response to wave loads. Since marine growth is negatively buoyant (density in water of 1.0 to 1.3 gm/ml) it also increases the dead load on the structure.

The effect of hard, rigid foulers such as barnacles and bivalve molluscs on member diameters and drag coefficients can be determined if one knows their average thickness and roughness height, as defined in Fig. 3. While both thickness and roughness height vary locally, the values needed in engineering design are respectively the average increase in cylinder radius and the average of peak-to-valley elevations around the member circumference. In Ref. 4, C_d is plotted versus relative roughness, the ratio of average roughness height to effective member diameter, based on empirical data from both field and laboratory experiments. The correlation has some scatter, which indicates that the shape and spacing of the roughness elements, as well as their relative roughness, may affect the drag coefficient. Nevertheless, one may accept the correlation of C_d with relative roughness alone as sufficient for engineering purposes. This correlation shows that only a small relative roughness of 0.3% causes a dramatic increase in C_d to about 1.0, compared with $C_d \cong 0.6$ for a perfectly smooth cylinder. There is a plateau in the correlation, where $C_d \cong 1.0$ for relative roughness in the range 0.3% to 2%, above which C_d increases. Most platform members in the marine growth zone have relative roughness in the range 0.07% to 4% with C_d in the range 0.8 to 1.2.

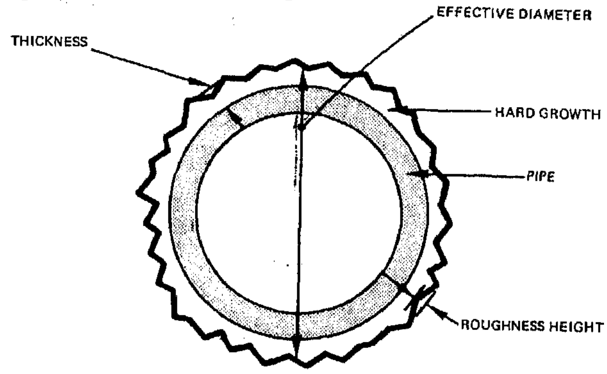

FIG. 3. SCHEMATIC DEFINING ROUGHNESS HEIGHT, THICKNESS, AND EFFECTIVE DIAMETER FOR A CYLINDER WITH MARINE GROWTH.

The effect of surface roughness on C_m is less pronounced than the effect on C_d. For example, in the field data in Ref. 4, C_m decreased from 1.5 to 1.25, only 17%, while C_d increased from 0.7 to 1.0, or 43%, as the cylinder surface changed from bare steel (relative roughness of about 0.01%) to barnacles (relative roughness of about 2%).

The effect of soft, flexible foulers such as hydroids on structural mass, cylinder diameter, and drag coefficient is not known but is being investigated (Ref. 7). Soft, flexible foulers increase the mass and diameter but not necessarily in proportion to their length. There is some unsubstantiated speculation that cylinders having both hard, rigid foulers and soft, flexible foulers will have a lower drag coefficient than cylinders having only hard rigid foulers. The argument is that the soft, flexible foulers give the cylinder a more streamlined shape.

Parameter Values. Thickness and roughness heights at various depths estimated from 19 Exxon structures in the Gulf of Mexico are shown in Figs. 4 and 5. Table 2 lists the location, water depth, installation date, inspection date and inspection depths for each structure. Estimates of marine growth thickness and roughness height for the Ocean Test Structure and GI 16-L conductor were obtained by direct measurement soon after they were removed from the Gulf. Thickness measurements were made by wrapping a flexible tape measure around members and computing the thickness as $1/2\pi$ times the increase in circumference of the member above clean steel. Roughness heights were measured at random spots with a small ruler. Estimates of marine growth thickness and roughness height for the Test Guyed Tower are strictly visual estimates based on photographs taken after the structure was removed from the Gulf and towed in a horizontal position to a dock. Estimates for the 16 other Exxon platforms are visual estimates made from underwater inspection photographs. In most of these photographs there was some reference object of known dimen-

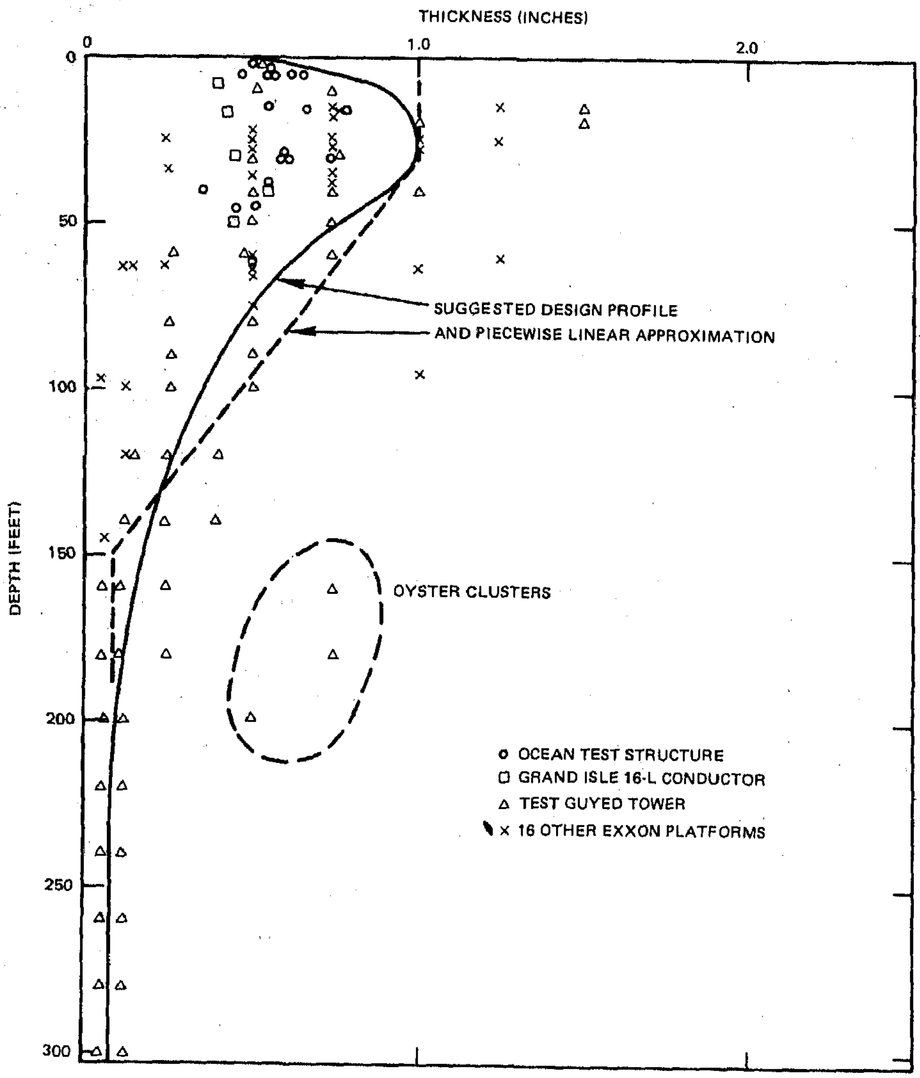

FIG. 4. AVERAGE MARINE GROWTH THICKNESS vs. DEPTH ESTIMATED FROM PLATFORMS OFFSHORE LOUISIANA.

Table 2

Offshore Louisiana Structures Inspected

STRUCTURE	LOCATION	WATER DEPTH (ft)	INSTALLATION DATE	INSPECTION DATE	INSPECTION DEPTHS (ft)
1. OCEAN TEST STRUCTURE	SOUTH TIM-BALIER BLOCK 67	66	11/1976	6/1978	0-45
2. GI 16-L CONDUCTOR	GRAND ISLE BLOCK 16	55	MID 1967	6/1978	0-55
3. TEST GUYED TOWER	GRAND ISLE BLOCK 86	310	LATE 1975	MAY 1979	0-310
4. GI 16-L	GRAND ISLE BLOCK 16	55	MID 1967	EARLY 1975	25
5. GI 16-T	GRAND ISLE BLOCK 16	48	LATE 1962	EARLY 1975	16
6. GI 16-P	GRAND ISLE BLOCK 16	55	MID 1957	EARLY 1975	17
7. WD 73-A	WEST DELTA BLOCK 73	168	EARLY 1964	1975	28,60,98
8. WD 73-F	WEST DELTA BLOCK 73	170	LATE 1965	1975	26,63
9. WD 30-E	WEST DELTA BLOCK 30	52	MID 1954	1972	18,34
10. SMI 6-A	SOUTH MARSH ISLAND BLOCK 6	63	MID 1963	4/1976	14,38
11. SMI 6-B	SOUTH MARSH ISLAND BLOCK 6	68	MID 1964	4/1976	26,63
12. SMI 73-A	SOUTH MARSH ISLAND BLOCK 73	136	MID 1963	4/1976	25,60,95
13. SMI 73-B	SOUTH MARSH ISLAND BLOCK 73	135	EARLY 1966	4/1976	26,63
14. SMI 73-C	SOUTH MARSH ISLAND BLOCK 73	137	LATE 1972	4/1976	27,64,101
15. EI 295-A	EUGENE ISLAND BLOCK 295	215	LATE 1971	MID 1974	33,145
16. ST 172-A (DRILL)	SOUTH TIMBA-LIER BLOCK 172	93	LATE 1969	MID 1974	23
17. ST 172-A (PROD)	SOUTH TIMBA-LIER BLOCK 172	93	LATE 1969	MID 1974	23,64
18. ST 172-A (LIVING)	SOUTH TIMBA-LIER BLOCK 172	93	MID 1971	MID 1974	64
19. VER 265-A	VERMILION BLOCK 265	165	LATE 1971	MID 1974	32,77,121

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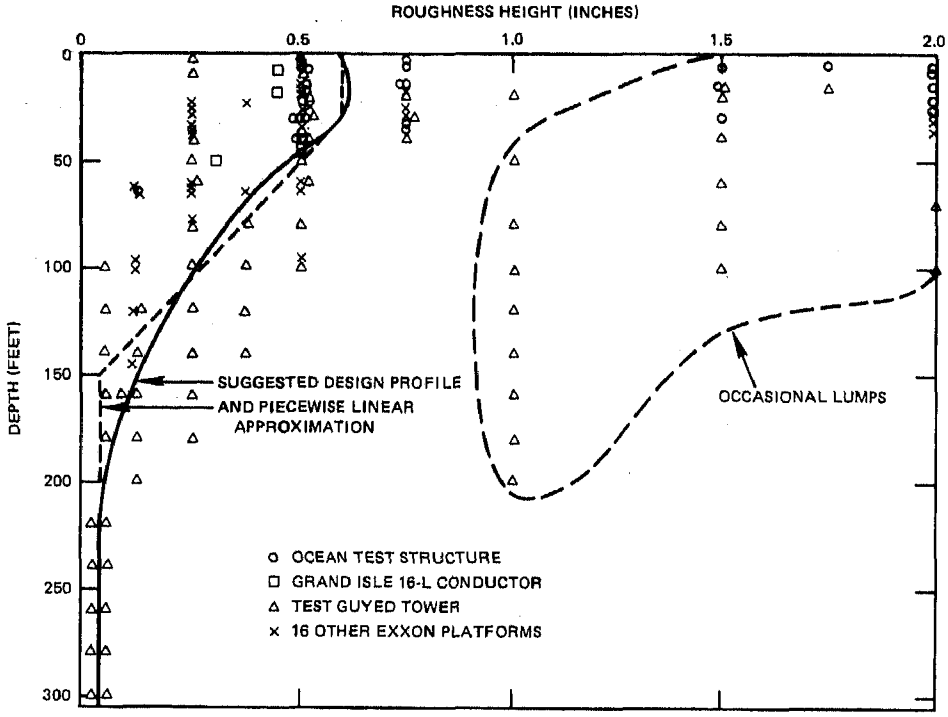

FIG. 5. AVERAGE MARINE GROWTH ROUGHNESS HEIGHT vs. DEPTH ESTIMATED FROM PLATFORMS OFFSHORE LOUISIANA.

sions. All of these structures were in place long enough to attain climax growth (3 to 4 years) except the Ocean Test Structure.

Only hard, rigid growth is shown in Figs. 4 and 5. All of these structures had some soft, flexible hydroids and bryozoans at shallow depths. These were most pronounced on the Test Guyed Tower in the depth range of 10-30 ft, where they attained lengths up to 5 in.

There is considerable scatter in the thickness and roughness height estimates in Figs. 4 and 5, reflecting the different locations and ages of the structures and inaccuracies of the different estimation techniques. Nevertheless, there is a clear trend of greatest growth near the surface. Suggested design profiles and their piecewise-linear approximations have been drawn through the data. These curves were drawn subjectively to be "reasonably conservative". At most depths the curves exceed the median of the data points. In the depth range of 80 to 150 ft an attempt was made not to give undue weight to the Test Guyed Tower data points. For the other Exxon platforms in this depth range, only one data point, representing the average estimate for that inspection depth, is shown; for the Test Guyed Tower, multiple data points at each inspection depth are shown. The oyster clusters seen between 160 and 200 ft depth on the Test Guyed Tower were neglected in drawing the suggested design thickness profile in Fig. 4, since only a few segments of some members were covered with oysters. At all depths down to 200 ft there were occasional isolated lumps of hard growth, sometimes the large barnacle Balanus tintinnabulum, sometimes oysters, and sometimes clams. These isolated clumps were neglected in drawing the suggested design roughness height profile because they are so widely spaced as to have only local effects on flow separation and hydrodynamic drag.

The suggested design thickness and roughness height profiles in Figs. 4 and 5 are appropriate for computing the total integrated hydrodynamic load on multi-membered permanent structures, since some members may have more growth and some less growth than the suggested design profiles. However, since one cannot predict a priori which members will have more growth and which will have less growth, it may be prudent to calculate the local hydrodynamic loads on individual members near the surface (where stresses due to local loads may be predominant over stresses due to loads transferred from other members) using more conservative thickness and roughness height estimates.

Conclusions and Recommendations

1. The relatively low level of marine growth on structures offshore Louisiana can be attributed to the low nutrient availability and hydrographic conditions.

2. Marine growth profiles suitable for platform design have thicknesses and roughness

heights of about 1.0 and 0.6 in, respectively, near the surface and decrease asymptotically to very small values below 200 ft depth.

3. Two questions not addressed in this paper deserve further investigation: (a) the question of differences in marine growth on diagonal and horizontal members compared with vertical members, and (b) the question of the effect of soft, flexible foulers on hydrodynamic loads.

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