IX International Conference on Computational Methods in Marine Engineering
MARINE 2021
I.M. Viola and F. Brennan (Eds)

A STUDY ON THE EFFECT OF HULL SURFACE TREATMENTS on SHIP PERFORMANCES

KEUNJAE KIM*, MICHAEL LEER-ANDERSEN* AND SOFIA WERNER*

*Research Department
SSPA Sweden AB
400 22 Gothenburg, Sweden
e-mail: keunjae.kim@sspa.se

Key words: Hull Surface Treatment, Ship-scale performance, Cleaning Efficiency Index (*CEI*), CFD

Abstract

This paper presents a numerical analysis on the induced relation between hull surface roughness and ship performance and discuss how to maintain hull-surface with cost and environmental impact in mind. The analysis is based on CFD simulation of the ship performance due to change of hull surface roughness condition before/after dry-docking and in-water hull cleaning. A typical tanker ship, KVLCC2 is investigated for 14 different partial cleaning cases. The attainable reduction of propulsive power by hull surface treatment is estimated as an index, Cleaning Efficiency Index (*CEI*).

A clear understanding is obtained how hull geometry has profound implication for the effect of roughness on the change of power. Partial hull cleaning of fore-end and stern-aft part of the hull was found to give higher relative *CEI* than entire hull cleaning. The present study provides guidelines which part of the hull to treat during dry-docking and hull cleaning process with better quality or higher priority if necessary.

1 INTRODUCTION

Hull surface condition plays an important role for ships performance, for new-built ships as well as ships in operation as the drag penalties are often substantially enhanced due to hull roughness. The importance of taking full scale roughness effects account in the design of ship hull and propulsion device has been addressed by the authors [1, 2]. However, many ship operators cannot directly assess the impact of hull surface condition on ship performance owing to the inherent limitation of performance monitoring systems. In reality, ship performances can be different in actual speed, draft (trim), water depth and wind and wave conditions in addition to hull roughness condition.

In recent years the capabilities for interpretation of added resistance due to waves have been improved significantly by model tests and numerical simulation. In ship performance monitoring systems, more precise measurements and reliable procedures are being established; measurement to be made for many ships (sister ships) operating on a fixed trade at a day with nice weather condition. Onboard measuring and monitoring systems now could produce more reliable data for ship performance, thereby contributing to analysis of roughness effect on ship performance.

A statistical study of the performance of the ships and of the effects of different hull and propeller treatment on the performance has been performed by Gunderman [3] and Munk [4] based on data monitored for more than one thousand maintenance events and several hundred vessels. According to Gunderman, most vessels have encountered increase of resistance due to surface roughness in the range between 10 ~ 40 percent with development rates between 0.3~1.5 per-cent per month. But the values range can be a few percent or up to 80 percent very much depending on how well the hull surface condition has been maintained. It is also reported that dry dockings in average reduce the level of added resistance by 2/3 of the pre dock level. Hull cleaning between dry-dockings may have a remarkable effect, especially if one of the less active types of antifouling paint has been used.

Dry docking of a ship is an integral part of the regular maintenance of underwater hull and usually accommodated on a regular basis within a five years interval. However, docking of ships is extremely costly to the ship owner and a major part of the cost is due to the time spent in the dock (the costs of lost profit) beyond the hull maintenance costs. The costs of hull maintenance may vary greatly depending on type of hull treatment (full grit blasting or spot blasting) and quality of coating systems (anti fouling, TBT free biocidal, silicone). Each ship owner has its own procedure in the selection of hull treatment and coating. Unfortunately, however, it is difficult for the owner/operator to secure confidence on whether the hull maintenance is invested in an optimum way.

In this paper, the possibility of optimum hull treatments is offered based on better understanding of the relation between the cost saving benefit and the cost of investment on surface treatment of different parts of the hull. It is a standard procedure of applying the same treatment, sometimes a full blast and expensive painting over the entire hull surface. Although it is not yet commonly accepted, but a new procedure of partial hull treatment is proposed; applying full blast/high quality coating for hull part with higher *CEI* and spot blast/standard coating for remaining part with lower *CEI*, which is estimated by CFD based roughness simulation.

2 CFD CODE USED

Numerical simulations has been performed with SHIPFLOW, a code that has been developed by FLOWTECH and has been routinely used at SSPA for daily consulting service [5, 6, 7]. The roughness modelling has been implemented in the wall boundary condition for ω and applying no slip boundary condition directly at the wall. Five alternatives are available in SHIPFLOW and they include the roughness model pro-posed by Hellsten, Knopp, modified Knopp, Aupoix-Nikurdse and Aupoix-Colebook. All these models were tested by Orych [8] in numerical uncertainty study for 2-D flate plate and KRISO containership.

Following this study, the Aupoix-Colebook's model with the first target y+=0.5 is selected for the present investigation for two selected test case, a flat plate and a tanker. The roughness is assumed to be uniformly distributed and is characterized by the equivalent sand roughness k_s.

3 TEST SHIP - KVLCC2

The test ship selected is KVLCC2 representing full block slow speed ship. The main dimensions are L_{pp}=320m, B=58m, T_d=20.8m and C_B=0.81, and the operation speed is V_s=15.0 Knots. The body plan and sectional area curves are shown in **Figure 1**.

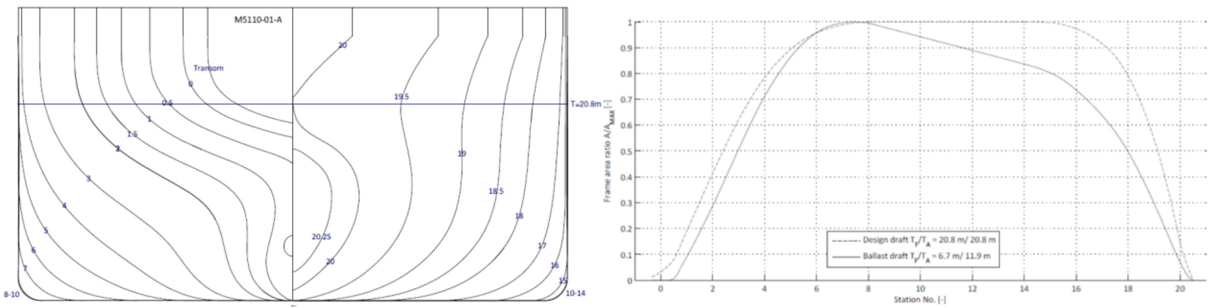


Figure 1: Body plan and sectional area curves for KVLCC2

4 HULL CLEANING CASE

The hull is divided into four parts by introducing the demarcation between fore and mid body at station 15, mid fore and aft part at the mid ship (station 10), and mid and aft body at station 5, respectively (see **Figure 2**). The fore body is a highly curved three dimensional structure including bulbous bow and the aft body is the most complex portion of ship having stern aperture end and transom. While the mid body of the ship is geometrically simpler than the other two but the biggest portion in terms of surface area as presented in sectional area curves (**Figure 1**) and cleaning surface area (**Table 1**). And thereafter, the following 14 test cases are designed in such a way that the cleaning of hull surface was performed based on artificial strategy with different combination of the four parts mentioned above. All test cases investigated are summarized in **Table 2**.

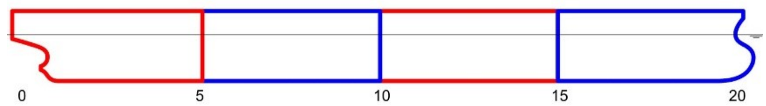


Figure 2: Hull cleaning area division designed

Table 1: Cleaning area

	Station 20-15	Station 15-10	Station 10-05	Station 5-0	Full hull
Cleaning area	6424 m^2/ 23.6%	8212 m^2/ 30.9%	8245 m^2/ 30.2%	4175 m^2/ 15.3%	27257m^2 /100%

Table 2: Hull surface cleaning cases investigated

Case no	code	Forebody		Aftbody		Remarks
		S20-15	S15-10	S10-05	S05-00	
1	*rrrr*					Fully rough hull surface
2	*rrrs*					Cleaning of a quarter of hull surface
3	*rsrr*					
4	*rrsr*					
5	*srrr*					
6	*rrss*					Cleaning of an half of hull surface
7	*rssr*					
8	*srrs*					
9	*ssrr*					
10	*rsss*					Cleaning of three quarter of hull surface
11	*ssrs*					
12	*srss*					
13	*sssr*					
14	*ssss*					Fully cleaned hull surface

Remark: Cleaned part of hull surface is denoted by green

5 HULL CLEANING EFFECT ON SHIP PERFORMANCES

A systematic roughness simulation was performed for the 14 cases to get an idea which is the best option of hull cleaning if part of hull surface to be cleaned from the fully rough hull with average roughness height k_s=500μm (case 1: rrrr). **Figure 3** presents an attainable reduction in percentage of skin friction resistance C_F, viscous pressure resistance C_{VP} and total resistance C_T.

First it should be noted that the reduction of skin friction resistance C_F seems depend mainly on cleaning area of the case; average 7% by cleaning of a quarter hull (case 2-5), 14% by cleaning of an half hull (case 6-9) and 21% by cleaning of three quarter of hull (case 10-13) as compared to 28% for the full hull surface cleaned case 14. This can be best explained by sectional ΔC_F distribution along the ship length as shown in **Figure 4**. A rather big difference can be seen from the integrated area of sectional area curves in **Table 1**. On the other hand, a quite different behaviour is noted for viscous pressure resistance C_{VP} which is more sensitive to hull geometry variation. The highest reduction being obtained for case 12 (srss), case 11 (ssrs) and case 8 (srrs), while marginal reduction for the case 3 (rsrr) and case 4 (rrsr). Cleaning of bow and stern part of the hull surface (station 20-15 and station 5-0) is more effective in reducing the viscous pressure resistance C_{VP}. This can be confirmed from comparison of sectional ΔC_{VP} distribution shown in **Figure 4** where a clear difference can be noted in bow and stern part of the ship. As the frictional resistance is a considerable part of the total resistance, similar but a slightly different trend can be seen in total resistance C_T as compared to C_F in **Figure 3**.

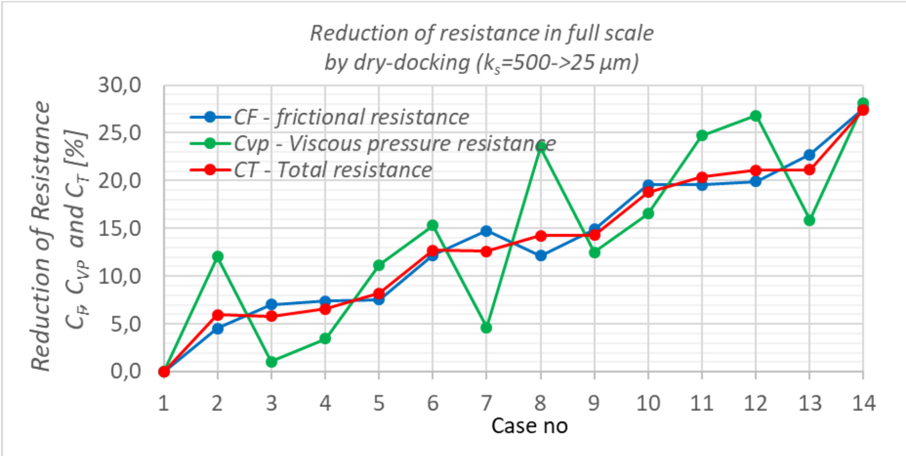
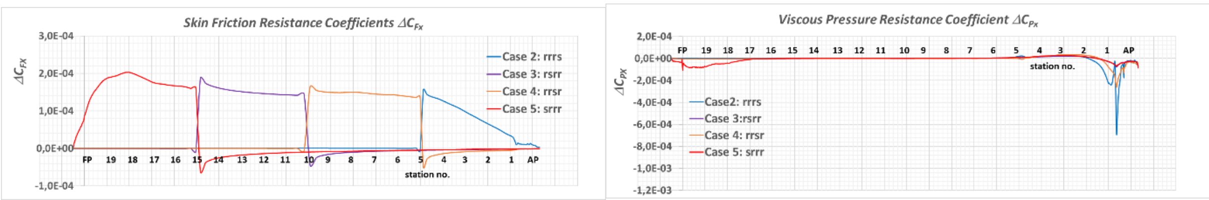
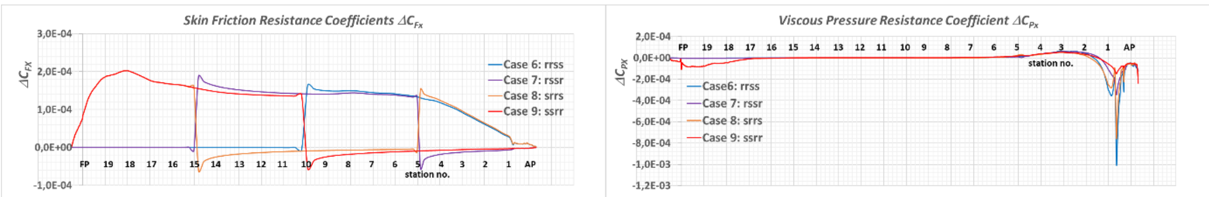


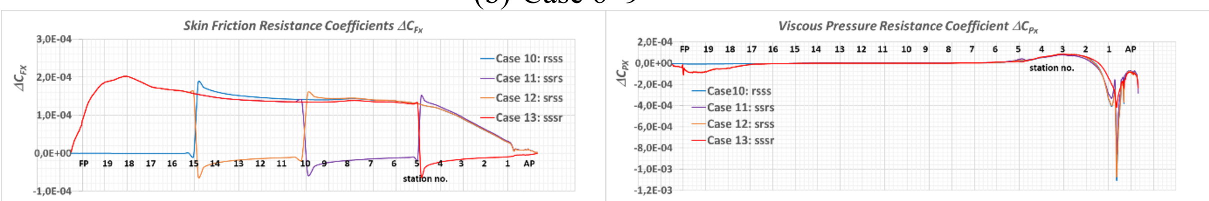
Figure 3: Attainable reduction of resistance coefficients by dry-docking (k_s=500 -> 25 μm) for case 10-13.



(a) Case 2~5



(b) Case 6~9



(c) Case 10~13

Figure 4: Sectional ΔC_F and ΔC_{VP} distribution along the ship length

The roughness affects not only integrated resistance but also the flow around the hull. The change in wake flow characteristics depending upon which part of hull to be cleaned is well predicted and fair comparison can be made with the fully rough (case 1) and smooth hull wake (case 14) in **Figure 5**. The major change is thickness of boundary layer; the thinner depending on how close the cleaned surface is placed toward the propeller wake position.

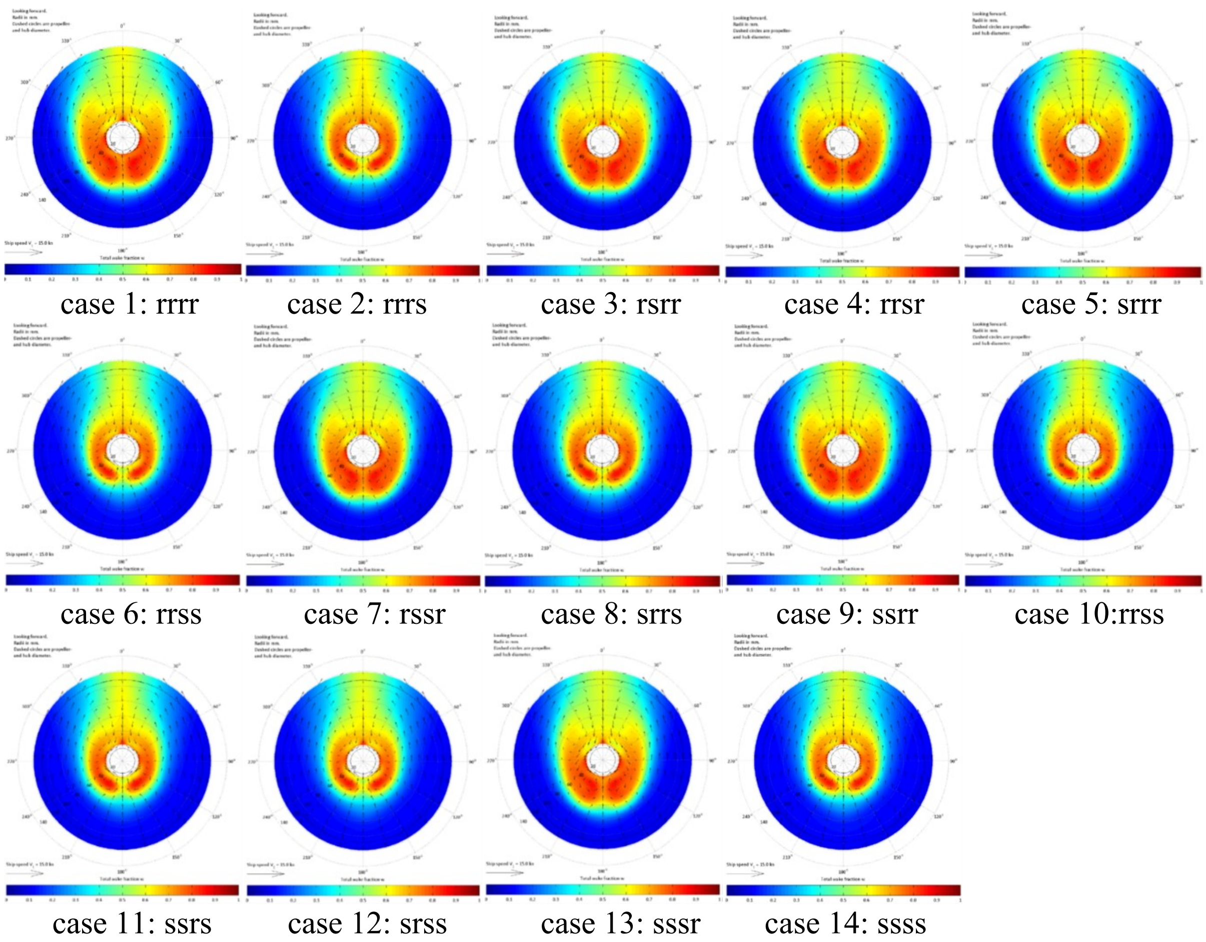


Figure 5: Wake predicted for all cleaning case at V_s=15.0 Knots and T_d=20.8m

A more detailed comparison of the circumferential wake distribution is made in **Figure 6**. It can be seen that the wake distributions are varying but within the envelope between full smooth hull (case 14: ssss, green line) and green line for full rough hull (case 1: rrrr, black line). The shift of the position of vortex core center and more stiff in wake slope can be observed depending on how close the cleaned surface is placed toward the propeller wake position.

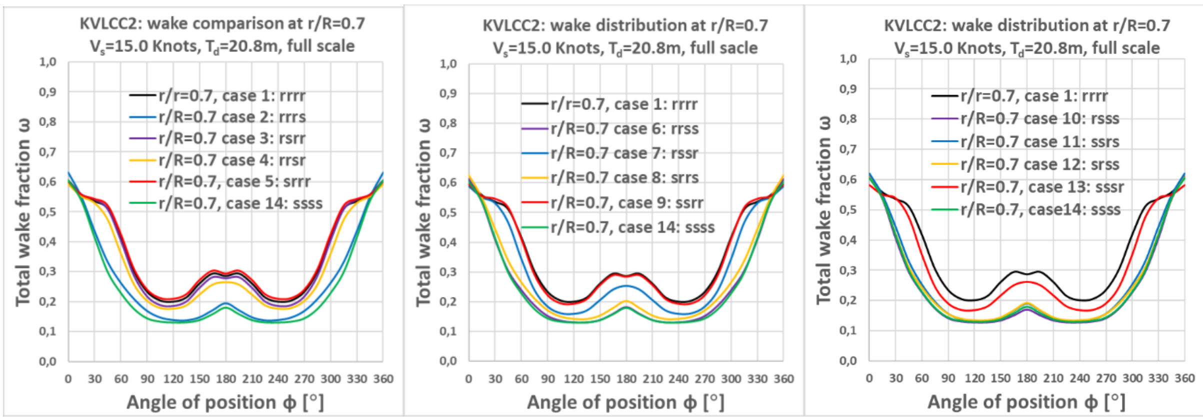


Figure 6: Propeller angle of attack predicted for all cleaning cases in comparison with the full rough hull (case 1: rrrr) and full smooth hull (case 14: ssss)

Similar trends can be observed again in the mean wake presented in **Figure 7**. A relatively higher mean wake is obtained for case 9 (ssrr), case 5 (srrr) and case 3 (rsrr) while lower mean wake for case 10 (rsss), case 6 (rrss) and case 8 (srrs) depending on whether stern end part of ship is cleaned or not.

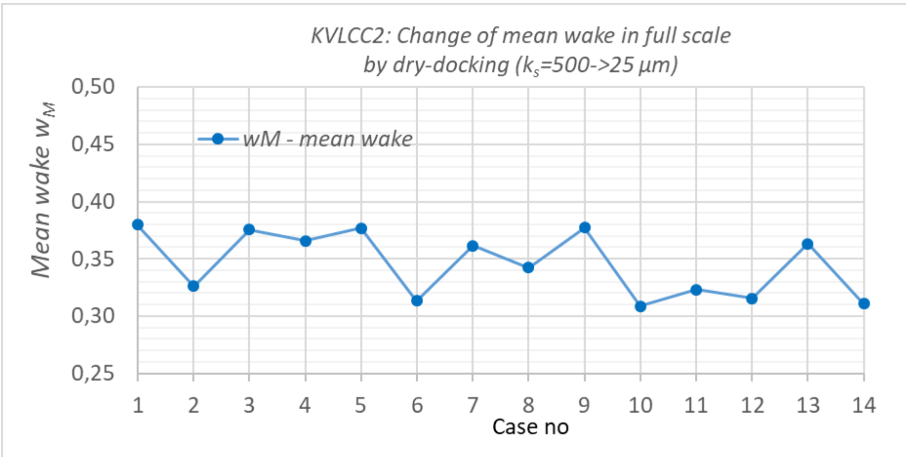


Figure 7: Mean wake predicted at the propeller disk for all cleaning cases in comparison with full smooth and rough hull

The decrease of flow speed into the propeller may affect the propeller hull wake interaction and results in noticeable difference in propeller angel of attack as predicted for the four cases in **Figure 8**. As can be seen in the figure, there are larger increase in angle of attack for case 2 and case 4 as compared to the full smooth hull (case 1).

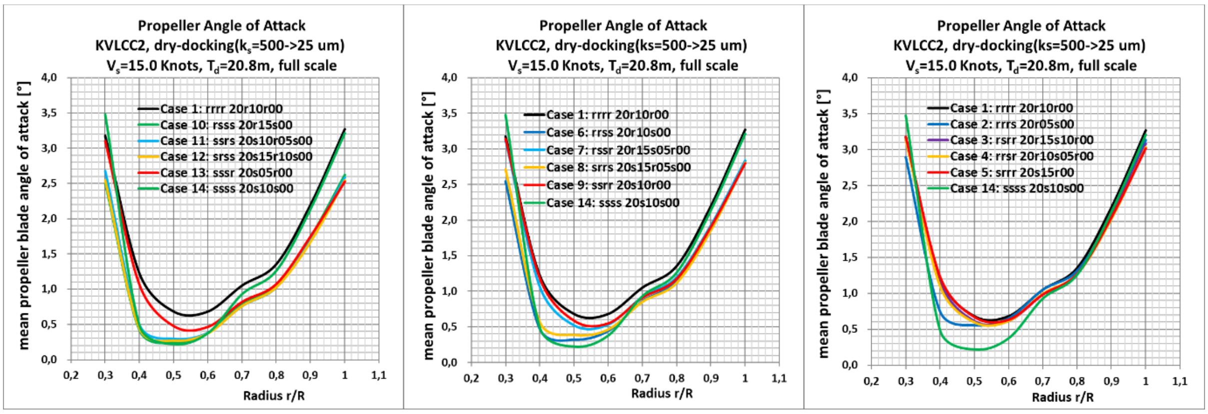


Figure 8: Propeller angle of attack predicted as compared to the full smooth hull (case 14) and full rough hull (case 1).

Change of boundary layer thickness and strength of bilge vortex because of hull cleaning directly resulted in the reduction of *EHP* and *DHP* as showin in **Figure 9**. Similar trends can be observed for propeller thrust (T), propeller torque (Q) and propeller revolution (n) in the figure. This is expected from the fact that the propeller should produce somewhat reduced thrust and torque with slow rotation in order to obtaine the balance between the resistance and thrust. The trends in the resistance, thrust, torque and rps due to hull roughness directlty result in reduction of *DHP*.

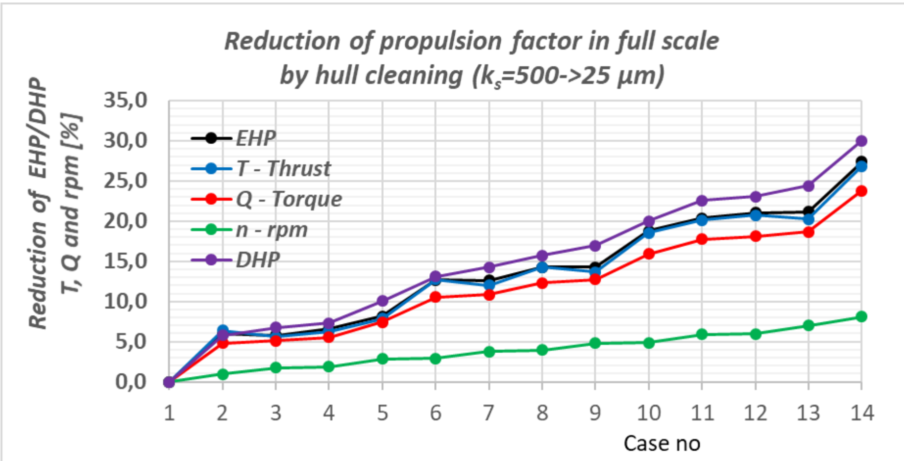
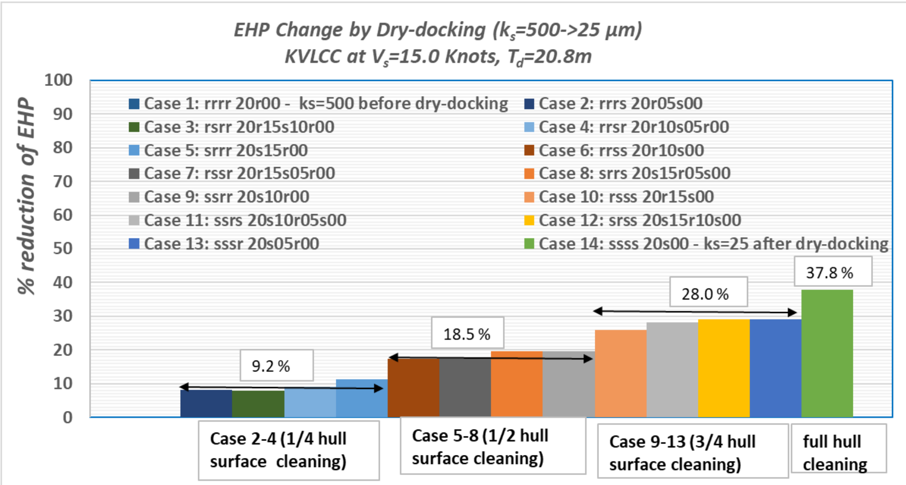


Figure 9: Relative decrease of T, Q and n of all cleaning cases as compared to full rough hull (case 1).

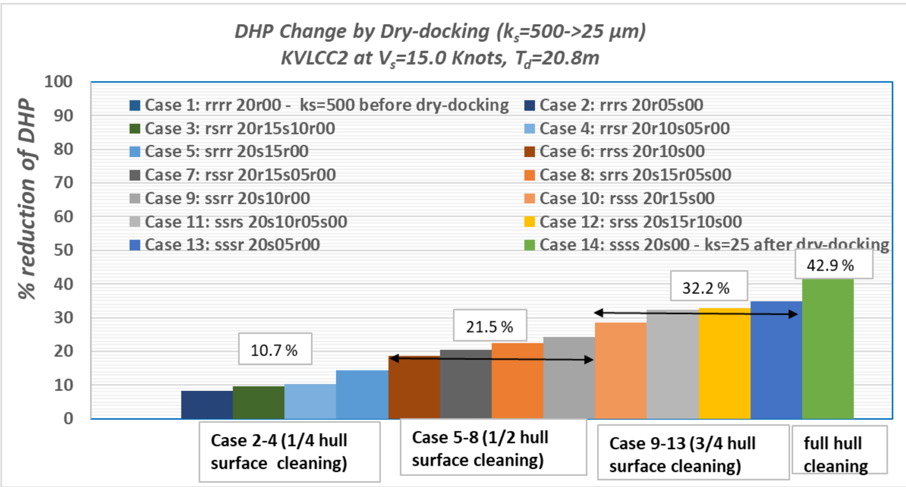
Figure 10 presents the predicted percentage reduction of *EHP* and *DHP* for 14 hull cleaning cases carried out during dry-docking (k_s=500 -> 25μm). The percentage figure indicates the predicted reduction of *EHP* and *DHP* relative to the fully cleaned hull surface condition (case 14: k_s=25μm) after dry-docking. It can be seen from the figure that 38%/43% reduction of

EHP/DHP can be attainable by full hull cleaning (case 14: k_s=25 μm). The 43% reduction of *DHP* is equivalent to a speed improvement of 2.0 Knots at the same engine power. In case of partial cleaning, the average attainable reduction of *EHP/DHP* varies as much as 9%/11% by ¼ part hull cleaning (cases 2-5), 19%/22% for half part hull cleaning (cases 6-9) and 28%/32% for ¾ part hull cleaning (cases 10-14).

To interpret the figures differently on a relative base with respect to full hull cleaning (case 14: k_s=25 μm), the *EHP/DHP* reduction is proportional to size of hull cleaning area: 25% for cleaning of a quarter hull (case 2-5), 50% by cleaning of an half hull (case 6-9) and 75% by cleaning of three quarter of hull (case 10-13).



(a) *EHP*



(b) *DHP*

Figure 10: *EHP* and *DHP* reduction by dry-docking (k_s=500->25μm)

It is quite interesting to note that a relative ranking based on *DHP* reduction is arranged in order of case 1 to 14. However, the ranking arranged in *DHP* is not necessarily identical in ranking based on *EHP* reduction. The reduction of *EHP* is surely the main cause of the reduction of *DHP*, but small variation of the relation between *EHP* and *DHP* reduction can be seen in the figure within the above three hull cleaning cases. This may be due to interaction effects of hull resistance on propulsion performance as discussed above.

6 ESTIMATION OF CLEANING EFFICIENCY INDEX (*CEI*)

An absolute figures for *DHP* reduction per unit cleaning area are given in **Figure 11**, as this relation is a ratio expressing the economical benefit of hull cleaning. It is seen that the largest reduction is achieved when bow and stern part of the hull are cleaned while smallest reduction is achieved when parallel middle body are cleaned. And thus a relative ranking can be arranged from the largest at top 3: case 5 (srrr) – case 8 (srrs) – case 2 (rrrs), and from the smallest at bottom 3: case 3 (rsrr) – case 7 (rssr) – case 4 (rrsr). Another point to be noted is the large difference in *DHP* reduction between the top and the bottom up to double. This information provides a useful guideline which part of hull to be treated with better quality or higher priority if necessary.

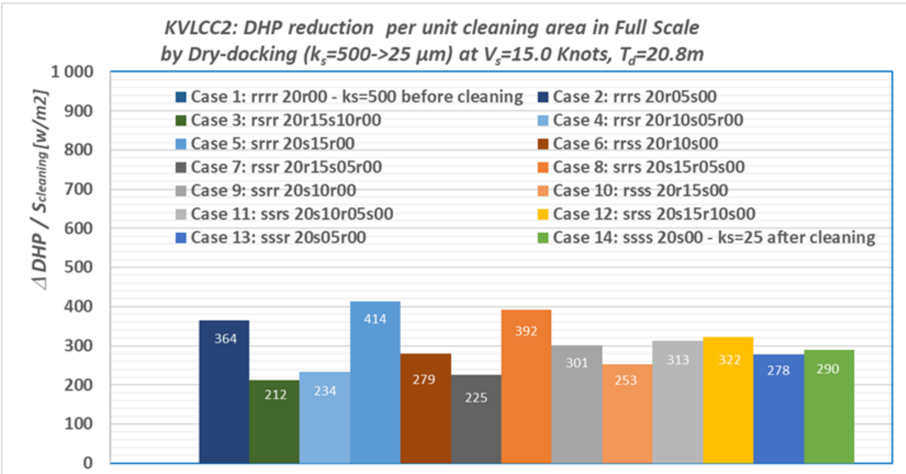


Figure 11: *DHP* reduction per unit cleaning area by hull cleaning (k_s=500->25 μm)

Figure 12 compares the cleaning efficiency index (*CEI*) defined in **Equation 1** below as the ratio between *DHP* reduction per unit cleaning area for the cases 1-13 and for full hull surface cleaning (case 14).

$$CEI = \{(DHP_{case1} - DHP)/ S_{cleaning}\}/ \{(DHP_{case1} - DHP_{case14})/WSA\} \quad (1)$$

where $S_{cleaning}$ is cleaning surface area and *WSA* is total wetted surface area including appendages.

It should be noted that the *CEI* 1.0 for case 14 is used as a reference and the absolute figures for *DHP* reduction per unit cleaning area are given in **Figure 12**. The cases with higher *CEI* are more attractive option for cleaning priority. It is seen that the higher cleaning efficiency is estimated when bow and stern of the hull are cleaned and thus the best three are case 5 (srrr) with average *CEI* of 1.43, case 8 (srrs) with 1.35 and case 2 (rrrs) with 1.25. On the other hand, the lower cleaning efficiency is arranged when bow and stern of the hull are NOT cleaned; average *CEI* 0.80 for case 3 (rsrr), case 4 (rrsr) and case 7 (rssr). The results of this study show only general tendencies, which may not necessarily apply to a feasible option, or the same conclusions for another types of hulls, but to provide an idea of which part of the hull to be treated and how.

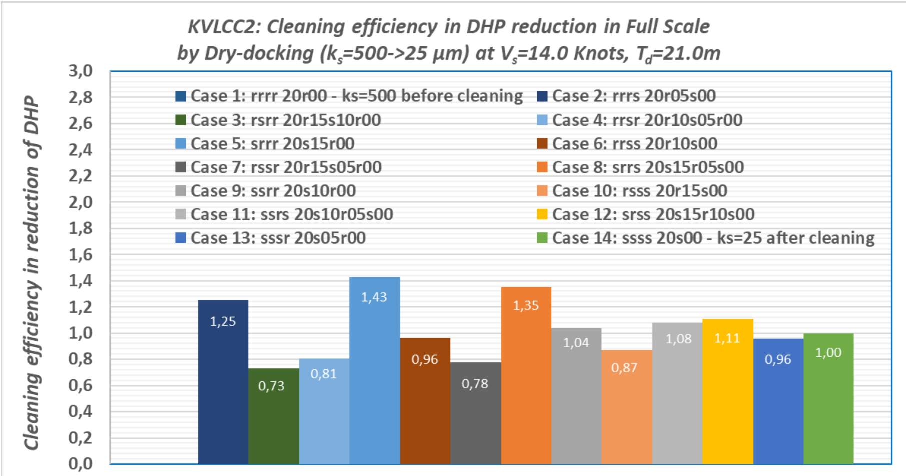


Figure 12: Cleaning efficiency index in *DHP* reduction by hull cleaning (k_s=500-> 25μm)

7 CONCLUSIONS

In the present paper, a numerical analysis on the induced relation between hull surface roughness and ship performance has been performed. The analysis is based on results of CFD simulation of the change of ship performance due to improvement of hull surface condition before/after dry-docking. KVLCC2 hull is investigated for 25 different partial cleaning cases. By compiling all the simulation results, the following three implementations have been made:

- The attainable reduction of propulsion power by hull surface treatment is estimated as an index (*CEI*), a measure representing cleaning efficiency and comparison study in relative sense between all cases has been made. A clear understanding is obtained how hull geometry has profound implication for the effect of roughness on the change of power. Partial hull cleaning of bow and stern part of the hull was found to give higher relative *CEI* than full hull cleaning.

- The present study could provide an idea which part of hull to be treated during dry-docking and hull cleaning process with better quality or higher priority if necessary. A new procedure of partial hull treatment is proposed based on cost benefit analysis; for example, applying full blast/high quality coating for hull part with higher *CEI* and spot blast/standard coating for remaining part with lower *CEI*.

The proposed method has the potential of economic justification, the process of deciding best optimized hull management strategy and demonstrated the feasibility of application to the example studies.

Although this paper show the economic viability of partial hull treatment, however only KVLCC2 was used as an example. Different ship types should be given the same procedure as described in this paper for optimum hull surface maintenance strategy.

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