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LONG-TERM PREDICTION OF GLOBAL CORROSION WASTAGE OF OIL TANKERS

Summary

The paper describes investigation of global corrosion wastage of three oil tankers with single-hull structure built in eighties. Analysis of data is based on existing thickness measurements of hull elements reduction from Croatian Register of Shipping (CRS) file, gauged on periodic dry-docking and close-up surveys of ships in service after 10, 15 and 20 years. Hull girder section modulus (HGSM) is determined as function of time taking into account the lifetime of protective coatings. The obtained results are compared to the available theoretical non-linear corrosion models in order to predict the long-term corrosion wastage progression. The results of this study can be used when planning ship hull inspection of oil tankers in service.

Key words: *corrosion wastage, hull girder section modulus (HGSM), oil tanker*

DUGOROČNO PREDVIĐANJE GLOBALNIH ISTROŠENJA TRUPA TANKERA

Sažetak

Opisan je postupak analize korozijskih istrošenja tri tankera s jednostrukom oplatom izgrađenih osamdesetih godina. Obrada podataka temelji se na postojećim izmjerama debljina elemenata trupa iz baze Hrvatskog Registra Brodova (HRB) s periodičnih suhih dokovanja i pregleda brodova u službi nakon 10, 15 i 20 godina. S obzirom da su u model unesene vrijednosti korozijskih istrošenja u različitim fazama vijeka trajanja broda određen je gubitak momenta otpora poprečnog presjeka kao funkcija vremena, uzimajući u obzir vijek trajanja zaštitnog premaza. Za predviđanje napredovanja korzijskog istrošenja odnosno općenitog trenda smanjenja momenta otpora glavnog rebra na temelju rezultata dobivenih navedenom analizom, korišten je dostupni teorijski nelinearni korozijski model. Rezultati ove studije mogu se koristiti kod planiranja inspekcijskih pregleda brodskog trupa tankera u službi.

Ključne riječi: *korozijska istrošenja, moment otpora poprečnog presjeka, tanker.*

1. Introduction

Damages to ships due to corrosion are very likely and the possibility of accident increases with the aging of ships. Statistics reveal that corrosion is the number one cause for marine casualties in old ships. The consequences of corrosion wastage can be very serious in some circumstances. Severe corrosion can result in deck cracks across almost the entire ship width and also consequently result in the loss of ships. Figure 1 shows the underdeck area of 20-year-old tanker. The deck plates and longitudinals suffered various degrees of corrosion. In some locations, the web plate of deck longitudinal was totally wasted away. This caused loss of support of deck plates from longitudinals. The unsupported spans of the deck plate increased and effectively decrease in buckling strength. In heavy seas, buckling repeatedly occurred under the action of the cyclic wave loads. Plastic deformation accumulated and eventually cracks appeared.

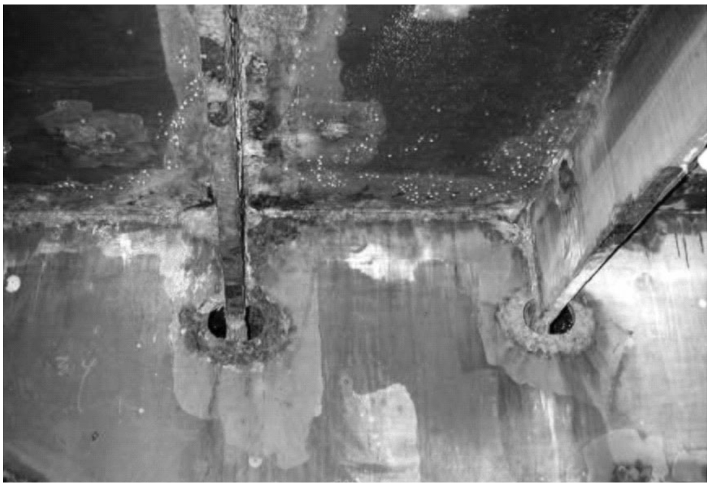

Fig. 1 Heavily corroded under-deck of 20 years old oil tanker

Slika 1. Uznapredovala korozija potpalublja 20 godina starog tankera

Hull girder section modulus (HGSM), as fundamental measure of the ship longitudinal strength deteriorate over time due to corrosion. Traditional engineering and analysis use simplified deterministic approaches to account for this time-variant random process. In most cases some nominal values are predefined for corrosion additions. Thus, ship classification rules, including newly developed Common Structural Rules (CSR) for Double-hull Oil Tankers assume constant loss of HGSM throughout the whole ship lifetime [1]. Structural assessment in the ship structural design phase is performed using such "net" HGSM. Although "rule" approach is practical, it is obviously not realistic, as HGSM loss is actually time-dependant non-linear function [2]. There is a clear tendency nowadays to adopt theoretical non-linear models in order to predict the long-term corrosion wastage progression and associated loss of HGSM. Such direct approach for corrosion progression could be useful tool for classification societies and ship owners in order to predict long-term behaviour of hull structure and to decide weather the renewal of the hull structure is necessary and when would be the optimal time for the repair [3]. Furthermore, such direct approach has potential to facilitate application of more accurate computational methods in design and analysis of oil tankers [5].

Practical applicability of the time-dependant HGSM concept is investigated in the present study. This is done in a way that HGSM losses of three ships in service are calculated based on measurements after 10, 15 and 20 years. HGSM losses are then compared to the non-linear functions that are recently proposed based on measurements on large number of single hull oil tankers [2]. Furthermore, new functions are developed based on HGSM losses from the present study measured after 10 and 15 years. The main expected result of this research is the development of the method capable to predict HGSM after 20 or 25 years of service based on measurements collected in the history of each ship.

2. Assessment of HGSM loss

Structural configuration of all three analysed ships is typical for single-hull oil tankers, where central tanks along cargo hold areas are cargo oil tanks, while wing tanks can serve as ballast or cargo oil tanks, see Fig. 2.

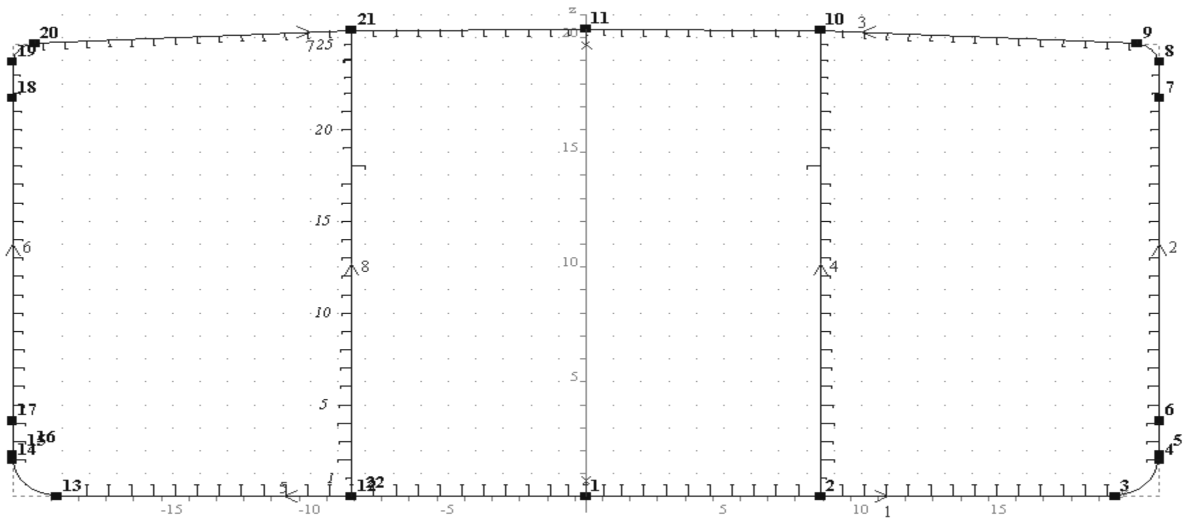

Fig. 2 Midship section of single-hull oil tankers

Slika 2. Glavno rebro tankera s jednostrukom oplatom

In the present study, HGSMs in cargo space are calculated with the program for the 2D sectional analysis MARS of classification society Bureau Veritas (BV) [8]. Firstly, the as-built HGSM is calculated. Then, thickness of structural elements (plates and longitudinals) contributing to the longitudinal strength are modified according to the results of thickness measurements from Croatian Register of Shipping (CRS) file. Gauging records were performed on periodic dry-dockings and close-up surveys of ships in service after 10, 15 and 20 years. Corrosion model of the ships was performed for the transverse sections with combination of central tanks as cargo oil tanks and wing tanks as ballast tanks.

Typical midship section of one of ships with corroded thickness of plate elements is presented in the Figure 3.

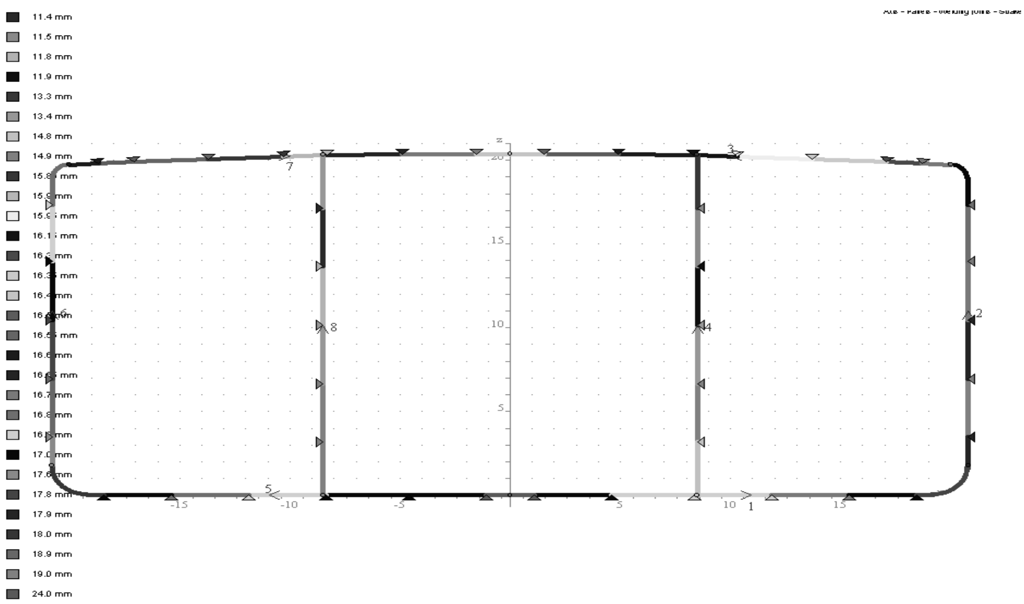

Fig. 3 Gauged plate's thickness of transverse section for 20 years old tankers.

Slika 3. Izmjerene debljine limova poprečnog presjeka 20 godina starog tankera

The aging effect is measured by the HGSM loss, which is the ratio of the as-gauged HGSM over the as built:

$$R(t) = 1\text{-}HGSM(\text{as-gauged at year } t)/HGSM(\text{as-built}) \quad (1)$$

Results for measured *R(t)* for three ships after 10, 15 and 20 years are presented in the Table 1.

Table 1 Measured R(t) for three ships

Tablica 1. Izmjereni R(t) za tri broda

Years of measured	R(t)-Ship 1	R(t)-Ship 2	R(t)-Ship 3
10	0.0151	0.0145	0.0161
15	0.0225	0.0290	0.0445
20	0.0410	0.0470	0.0592

3. Time-dependant HGSM

HGSM loss is determined as a function of time taking into account the lifetime of protective coatings. The following equation for the HGSM loss after *t* years of ship service is proposed based on the gauging results from all longitudinally-effective structural components on 2195 transverse sections of 211 single-hull oil tankers [2]:

$$R(t) = C(t-t_0)^I \quad (2)$$

where *R(t)* is the HGSM loss at age *t*, while t_0 is the year when HGSM starts to deviate from the as-built condition. *C* and index *I* are constants that can be determined according to the data set. Large data set is collected in ABS' Safe hull Condition Assessment Program (CAP) and results are presented as average parameters of the Equation (2) for four different levels of the corrosion severity, Table 2 and Figure 4 [2].

Table 2 Parameters of Equation (1) for different levels of corrosion severity

Tablica 2. Parametri jednadžbe (1) za različite razine oštrine korozije

Corrosion severity	C	t0, years	I
Slight	0.62	6.5	0.67
Moderate	0.80	5	0.75
Severe	0.84	3.5	0.83
Extreme	0.90	2	0.91

Results from the curves presented in Figure 4 indicate that corrosion loss of HGSM will be less than 10% during whole lifetime of the vessel, in cases of slight and moderate corrosion severities. For severe corrosion rate, HGSM will become less than 90% of its initial value after approximately 23 years while in extremely unfavourable corrosion conditions 10% loss limit will be exceeded after 18 years. This value of 10% of permissible loss of initial HGSM represents important industry standard that must be respected during whole lifetime of the ship.

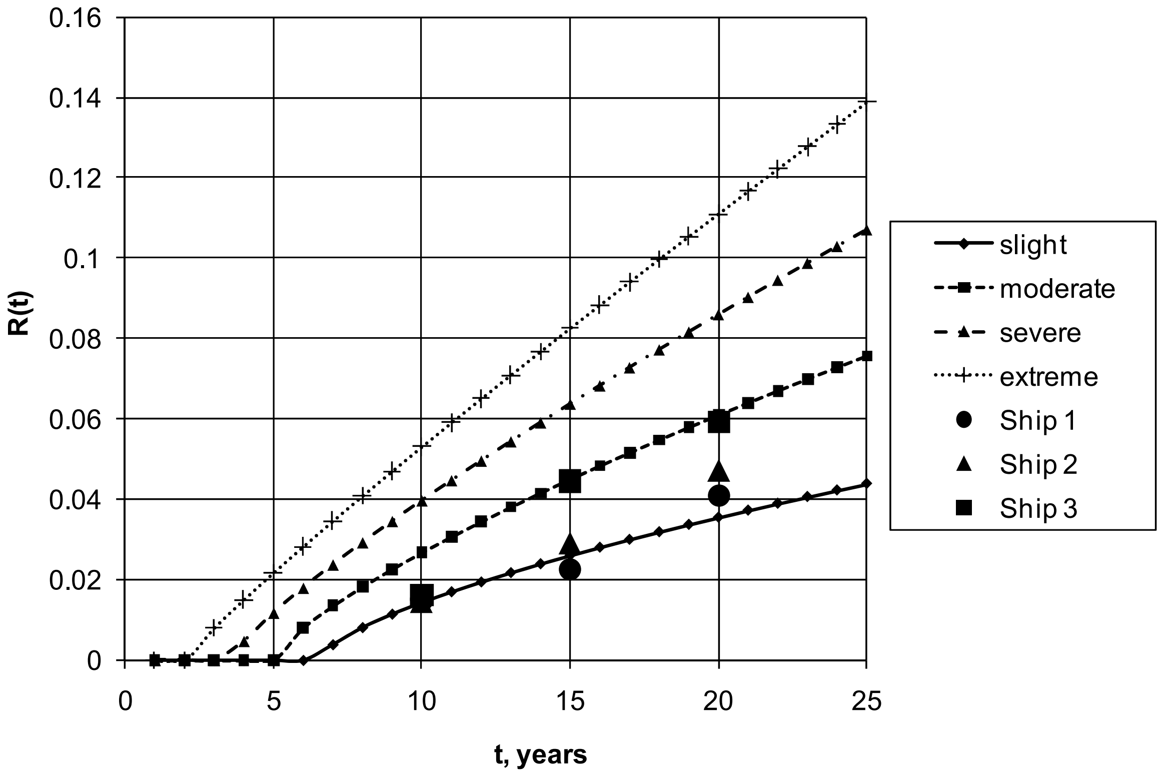

Fig. 4 HGSM loss for different levels of corrosion severity

Slika 4. Gubitak momenta otpora poprečnog presjeka za različite oštrine korozije

In the Figure 4, measured results obtained for three oil tankers considered in the present study are also shown. It may be seen that measured corrosion loss is always between prediction curves for slight and moderate corrosion levels.

Ship no. 1 in Figure 4 (circles) has slight corrosion wastage for all three measurement points (10, 15 and 20 years) and prediction curve represent approximately least square fit through these measurement points.

Measurement points for ship no. 2 (triangles) lie approximately on straight line and in long-term prediction it could be expected that the corrosion approaches curve for moderate corrosion.

Results obtained for ship no. 3 (squares) are very interesting. Measurements points seem to be placed on the curve that starts to grow from zero at approximately 8 years, that could represent coating lifetime in that particular case. After expiration of the coating lifetime, the corrosion is developed quite rapidly (until about 15 years) but then corrosion rate is reduced and corrosion loss approximately follows curve for moderate corrosion.

In order to investigate further improvement of predictions, curves similar to those from Figure 4 are fitted through measurement points of HGSM loss at 10 and 15 years. Results are presented in the Table 3 and Figure 5.

Table 3 Parameters of Equation (1) for different ships based on measurement after 10 and 15 years

Tablica 3. Parametri jednadžbe (1) za različite brodove prema mjerenjima nakon 10 i 15 godina službe

Corrosion severity	C	t0, years	I
Ship 1	0.60	5	0.58
Ship 2	0.44	6	0.86
Ship 3	0.92	8	0.81

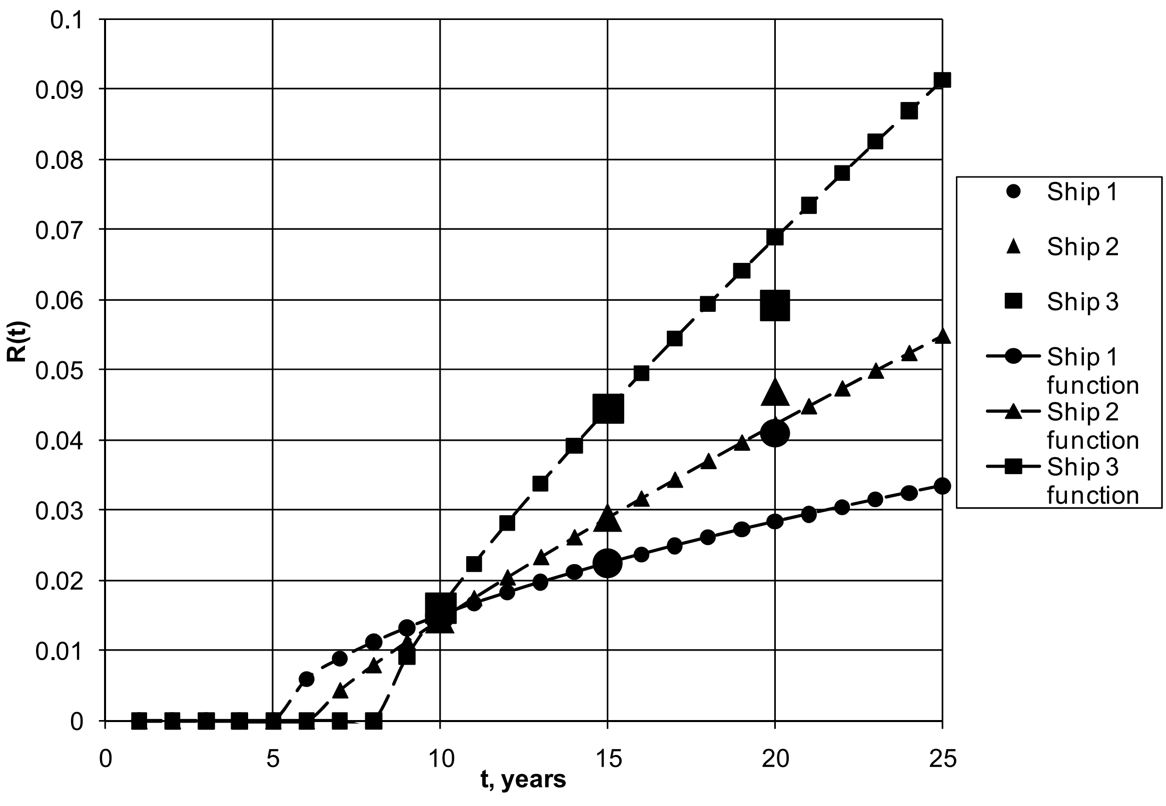

Fig. 5 Measured and predicted HGSM losses for different ships

Slika 5. Izmjereni i predviđeni gubitak momenta otpora poprečnog presjeka za različite brodove

It appears from Figure 5 that HGSM loss at 20 years for ship no. 1 is underestimated by prediction curve. Much better agreement is obtained by curve for slight corrosion from Figure 4.

Prediction of HGSM loss in 20 years for ship no. 2 is quite good. Curve is almost linear from time of coating breakdown (6 years).

Results for ship no. 3 indicate that the coating lifetime for that ship could be the longest, but after the breakdown of the coating corrosion progression is very fast. Prediction curve would overestimate actual HGSM loss.

It should be mentioned that there is a large uncertainty associated to HGSM loss as the corrosion loss is different for each transverse section of the ship hull. It may be assumed, however, that surveyors of analysed ships measured sections with representative (average) corrosion losses. More research is required to improve reliability of long-term predictions of corrosion losses.

4. Conclusion

Each individual oil tanker, particularly if it is an aged one of single side skin type, represents potential huge threat to the environment. Classification societies most seriously take into consideration the corrosion wastage as one of the very important degradation factors for ship structural strength [9][10]. Therefore, it is of interest to examine how the corrosion wastage of ship structural elements propagates through the years.

The present paper proposes the methodology how to efficiently anticipate long-term corrosion wastage using thickness measurement results from ship history. Long-term non-linear corrosion model is fitted through measured HGSM losses of three single hull tankers after 10 and 15 years of service and predictions are then compared to the measured HGSM losses after 20 years. This approach could lead to more refined and more rational inspection and repair planning of existing ships. The procedure represents an improvement compared to CSR, as the rules assume constant corrosion loss throughout whole ship's lifetime, being an unrealistic assumption.

It is shown in the paper that measured corrosion wastage generally agrees well with proposed curves for long-term HGSM loss. However, further researches are required since large uncertainties regarding the coating lifetime and rate of corrosion propagation are noticed.

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