A Proposed Design S-N Curve for Steels with Improved Fatigue Resistance (FCA steels)

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Abstract

Around 2001, a new steel material was developed that showed improved fatigue initiation life as well as improved crack growth life in welded structures, and a new alternative for fatigue life improvement was introduced. This steel was denoted FCA (Fatigue Crack Arrester) steel. In order to establish a design S-N curve that can be used for the FCA steel it was agreed 3 years ago to initiate a joint industry project between Kawasaki Shipbuilding Corporation, Sumitomo Metal Industries and Det Norske Veritas. This project is now finished and a design S-N curve has been proposed based on 66 small scale test data from small scale testing of specimens made from FCA steel and 18 tests from test specimens made from conventional steel.

The results from this joint industry project including a proposed design S-N curve for FCA steel are presented in this paper.

Keywords

Fatigue; testing; S-N data; improved crack growth properties; design.

Introduction

For many years fatigue design has been based on the fundamental principle that the fatigue capacity of welded structures is independent of the steel material and strength. For improvement of fatigue lives the designers have been advised to improve the geometry of the details, to reduce the general stress level or to use some post weld improvement method like toe grinding, TIG dressing or some type of hammer peening or ultrasonic peening, (DNV-RP-C203, 2008).

Around 2001, a new steel material was developed that showed improved fatigue initiation life as well as improved crack growth life in welded structures, ref. Katsuboto et al. (2005), and a new alternative for fatigue life improvement was introduced. This steel was denoted FCA (Fatigue Crack Arrester) steel. The improved fatigue resistance and crack arrest in the new material is explained by two mechanisms: One is increased fatigue initiation resistance at weld HAZ by suitable micro structures. The other is decreased crack growth rate in base material when a fatigue crack passes a grain boundary from a soft phase (ferritte) to a hard phase (bainite) that is present in these new dual phase steels.

The new steel material (FCA steel) has now been used in a number of new built ships in details where good fatigue properties are required. In order to establish a general design S-N curve that can be used for fatigue assessment using FCA steel it was agreed 3 years ago to initiate a joint industry project between Kawasaki Shipbuilding Corporation, Sumitomo Metal Industries and Det Norske Veritas. This project is now being finished and a design S-N curve has been proposed based on 66 small scale test data from small scale testing of specimens made from FCA steel and 18 tests from test specimens made from conventional steel. The test data have been compared with S-N curves used for fatigue design of ships and offshore structures such as IACS Common rules (2008) and DNV-RP-C203 (2008). The test data has also been supplemented by some large scale tests of relevant ship details.

The results from this joint industry project including a proposed design S-N curve for FCA steel are presented in the following.

The proposed design S-N curve is considered to be applicable for similar details as fatigue tested. It is also proposed to be extended to be used for design of other
welded details with FCA steel showing similar crack growth characteristics as that of the tested specimens.

Fatigue testing

Tested steel plates

The chemical compositions of the FCA steel plate are shown in Table 1. The mechanical properties of the plates tested are shown in Table 2. Low carbon content is one of the main characteristic of FCA steel plates. The microstructure of FCA is fine ferrite-bainite dual phase. As the result of dual phase structure, the yielding ratio is relatively small.

Table 1: Chemical composition of FCA steel plate (wt%)

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>others</th>
<th>Pcm</th>
<th>Ceqnw</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.04</td>
<td>0.42</td>
<td>1.50</td>
<td>0.009</td>
<td>0.002</td>
<td>Cr, Nb, Al, Ti</td>
<td>0.139</td>
<td>0.325</td>
</tr>
</tbody>
</table>

Pcm = C + Si/30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + 5B (%)

Ceqnw = C + Mn/6 + Cu/15 + Ni/15 + Cr/5 + Mo/5 + V/5 (%)

Table 2: Mechanical properties of steel plates tested

<table>
<thead>
<tr>
<th>Steel plate</th>
<th>Yield strength (MPa)</th>
<th>Tensile strength (MPa)</th>
<th>Yield/Tensile strength ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCA</td>
<td>419</td>
<td>578</td>
<td>0.725</td>
</tr>
<tr>
<td>Conventional</td>
<td>391</td>
<td>511</td>
<td>0.765</td>
</tr>
</tbody>
</table>

Welding of plates

The steel plates with attachment plate thickness equal 20 mm were welded together at three different sites. The welding conditions used at the different sites are listed in Table 3. This resulted in test specimens as listed in Table 4 at each site. A photo of a welded plate is shown in Fig. 1.

Table 3: Welding conditions

<table>
<thead>
<tr>
<th>Site A</th>
<th>Site B</th>
<th>Site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 100%</td>
<td>30L/min</td>
<td>CO2 100%</td>
</tr>
<tr>
<td>20L/min</td>
<td>DW-100</td>
<td>20L/min</td>
</tr>
<tr>
<td>(φ1.2mm)</td>
<td>(φ1.2mm)</td>
<td>(φ1.2mm)</td>
</tr>
<tr>
<td>190~200A</td>
<td>280A</td>
<td>CO2 100%</td>
</tr>
<tr>
<td>30~31V</td>
<td>26V</td>
<td>20L/min</td>
</tr>
<tr>
<td>27cm/min</td>
<td>26cm/min</td>
<td>DW-100</td>
</tr>
<tr>
<td>1.3~1.4kJ/mm</td>
<td>1.5kJ/mm</td>
<td>(φ1.2mm)</td>
</tr>
</tbody>
</table>

Hardness distribution of weldments

One of the mechanisms in FCA to improve fatigue strength of welded joints is avoidance of material notch effect by homogeneous hardness distribution. Material notch may occur at steep change in hardness. Hardness distribution of welded joints tested in this project was measured. Hardness distribution is relatively homoge-
that contains a higher residual stress than that in the small scale test specimens, (DNV-RP-C203(2008)). This is achieved by performing fatigue testing with maximum stress equal 350 MPa as indicated in Fig. 5. The stress range at the weld toe where failure occurred was reported as stress range to be used in derivation of S-N data. The actual thickness of each test specimen was measured and was used in calculation of stress range.

For assessment of test data also test specimens made of conventional steel and FCA steel were prepared and fatigue tested. This makes it possible to perform a relative assessment of the fatigue capacities which improves the basis for derivation of S-N curve keeping in mind all uncertainties that might be introduced during fabrication and fatigue testing.

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**Fig. 2:** Hardness distribution of welded joints

**Fig. 3:** Shape and size of welded specimen

**Fig. 4:** Location of gages for strain measurement

**Fig. 5:** Schematic illustration of cycling loading used in testing

The S-N curve is assumed to be on the form

\[
\log N = \log a - m \log \left( \frac{t}{t_{ref}} \right)^k
\]

(1)

where

- \( N \) = number of cycles to failure
- \( \log a \) = intercept of the S-N curve with the log N axis
- \( m \) = negative inverse slope of the S-N curve
- \( t_{ref} \) = reference thickness
- \( t \) = actual thickness at the considered hot spot
- \( k \) = thickness exponent

The thickness effect is included in the design procedure at end of this assessment as the test plates were made with \( t = 20 \) mm and in design standards such as IIW
(2009) and DNV-RP-C203 (2008) a reference thickness equal 25 mm is used.

8 test specimens of conventional steel with thickness of attachment plates $t = 20$ mm were fatigue tested as shown in Fig. 6.

10 test specimens of conventional steel with thickness of attachment plates $t = 11.57$ mm were fatigue tested as shown in Table 5. One of these test specimen resulted in one run out.

45 test specimens of FCA steel with thickness of attachment plates $t = 20$ mm were fatigue tested. Of these 8 test data were reported as run outs as shown in Fig. 7. Thus 37 data points were used for regression analysis. The fatigue testing of these specimens were performed at three different test laboratories as shown in Table 4. Based on a low standard deviation in the test data it is assessed that the testing laboratories have achieved consistent test results.

21 test specimens of FCA steel with thickness of attachment plates $t = 11.57$ mm were fatigue tested. 3 of these test data were reported as run outs as shown in Fig. 8.

### Table 5: Regression analysis of test data

<table>
<thead>
<tr>
<th>Type specimen</th>
<th>m</th>
<th>log a</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 conventional</td>
<td>2.700</td>
<td>11.580</td>
<td>0.052</td>
</tr>
<tr>
<td>$t_{att.} = 20$ mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 conventional</td>
<td>3.212</td>
<td>12.766</td>
<td>0.149</td>
</tr>
<tr>
<td>$t_{att.} = 11.57$ mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45 FCA</td>
<td>3.557</td>
<td>13.777</td>
<td>0.128</td>
</tr>
<tr>
<td>$t_{att.} = 20$ mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 FCA</td>
<td>3.979</td>
<td>14.466</td>
<td>0.114</td>
</tr>
<tr>
<td>$t_{att.} = 11.57$ mm</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Run outs were not included in regression analysis.

**Fatigue testing and test results of large scale test specimens**

FCA steel was applied to the face plate of longitudinal and the header (vertical stiffener) on the webs in a large structural model corresponding to the bottom longitudinal structure. The test specimen is shown in Fig. 9. The test specimens were subjected to four-point bending loading. Fatigue testing for this model was carried out under a storm model loading. The fatigue test results were compared with those for conventional steels under the same load patterns given by Takaoka, et al. (2009). The equivalent fatigue loading was rather high in order to finish the fatigue testing within a reasonable time. The fatigue life enhancement ratio using FCA steel as compared with conventional steel is approximately 1.37 times from typical S-N curves at this high load level, see e.g Figs. 10 and 11. The crack initiation ratio from the tests, FCA/Conventional is 1.40 times, whereas, the crack through ratio is 1.27 times. Thus, these values agree with that from the small scale fatigue tests.
Derivation of design S-N curve

Some engineering judgment is always required when assessing derivation of design S-N curves. Theoretically one may perform a regression analysis that provides a design S-N defined as 97.5 % probability of survival as function of number of test data that are available. However, the actual probability of failure depends on a number of parameters such as correspondence between fabrication of actual structures as compared with that of fabrication of test specimens, and residual stress and mean stress used during testing as compared with that of the actual structure. For ship structures also the material yield strength may be of significance for the fatigue life when shake down of residual stresses are considered, ref. Lotsberg (2006).

From Table 6 it is observed that the thinnest attachment show the largest m-value both for FCA steel and conventional steel. In order to derive a proposed design S-N curve for FCA steel that is conservative, the data set with attachment thickness t = 20 mm is considered for FCA steel and conventional steel. Use of attachment thickness equal 20 mm, which is similar to the base plate, also simplifies assessment of the thickness effect that is considered later in this paper.

The test data for conventional steel are shown in Fig. 6. Due to a limited number of test data the mean S-N curve is compared with mean S-N curves from design standards. A few test data is required for derivation of mean S-N curve as compared with a design S-N curve if the standard deviation in the test data is considered as unknown, (Lotsberg, 2010).

It is observed from Fig. 6 that the mean curve from test data is close to the mean F curve from DNV-RP-C203 (2008). This F-curve is approximately the same as referred to by IACS for tanker structures and in BS 7908 (1993). This curve also corresponds to the FAT71 curve referred to by IIW (2009). The negative inverse slope of this S-N curve is m = 3.0. The test data for conventional steel tested according to the procedure used with a high σmax value shows m = 2.7. This curve is shown in Fig. 10 together with the corresponding test data from FCA steel tested using the same test procedure. However, as the F-curve is a well established curve, it is proposed to make further comparisons with this curve. This becomes a conservative approach when going from Fig. 10 to that of Fig. 11 (with m = 3.0) that shows a somewhat smaller difference between the mean S-N curves. The slope of the S-N curve for FCA is rounded to m = 3.5. The corresponding log a = 13.653. The difference in plotted S-N curves (m = 3.5 as compared with m = 3.557) in Fig. 11 is hardly visible.

A standard deviation in the F-curve equal 0.20 is assumed, ref. DNV-RP-C203 (2008). The derived standard deviation for FCA steel is 0.128. However, to derive a similar robustness in a design S-N curve using FCA steel as using conventional steel, it is proposed to use a similar standard deviation also for FCA steel as for conventional welded steel connections. This gives a (log a) value for design equal 13.253 (derived as mean minus 2 standard deviations). A reason for using a larger standard deviation than derived from the present test data is also that the proposed design S-N curve for FCA steel is recommended for general use also for other geometries than that the test data are derived for. From experience with fatigue testing of other details it is observed that more complex details may show larger standard deviations, ref. e. g. Lotsberg and Sigurdsson (2006).

Then a (log a) value for a reference thickness equal 25 mm is derived by assuming a similar thickness exponent for the FCA steel as for conventional steel for this type of detail (DNV-RP-C203, 2008)

\[
\log a = 13.253 - 3.5 \log \left( \frac{25}{20} \right) = 13.168 - 3.5 \log S
\]
For welded structures subjected to variable amplitude loading it is normally assumed that there is a transition in slope in air environment at $10^7$ cycles. This is also supported by Maddox (2008). The slope of the right part of the S-N curve may be debated. Some design codes use the Haibach corrected slope equal 2m-1 while other simply assume a slope equal 5.0 (which corresponds to a Haibach correction of the basic S-N curve with a slope $m = 3.0$). It is difficult to achieve relevant test data to substantiate a conclusion on this (as variable amplitude loading would be required). Here it is suggested to use the more conservative approach by assuming a slope $m = 5.0$ to the right of $N = 10^7$ cycles.

It is possible that the transition in slope for the FCA steel is to the left from that of the conventional steel. Here it can be added that the transition of slope in the S-N curve may be considered to depend on notch effect and geometric stress concentration in the curve. Thus for a detail with a small notch effect and low geometric stress concentration factor the transition in slope is expected to be further to the left than that for the less good details. However, in fatigue design codes for welded structures it is not a normal procedure to distinguish between different details in this respect. In practice a conservative assumption about transition in slope is thus recommended for derivation of general design S-N curves.

Based on the present available test data the following design S-N curve for FCA steel is derived for the considered detail:

\[
\log N = 13.168 - 3.5 \log S \quad \text{for} \quad N \leq 10^7
\]

\[
\log N = 15.812 - 5.0 \log S \quad \text{for} \quad N > 10^7
\]

This design S-N curve is shown in Fig. 12. This S-N curve applies to cruciform joints with a similar geometry as for the details that have been tested.

In order to establish an expression for more general S-N curves for welded details made with FCA steel one may compare fatigue lives in the S-N curves for the FCA steel and the conventional steel at a stress range level corresponding to e. g. 2 mill cycles with the S-N curve for the conventional steel as reference (i. e. $N_{\text{conv}} = 2 \times 10^6$ cycles by definition). A reason for selecting the stress range at 2 mill cycles for reference is that this stress range is frequently referred to by IWW in their S-N classification and notation by FAT values. For example a detail classified as FAT71 denotes a stress range of 71 MPa at 2 mill cycles. (It might be added that the results of the following derivation are independent of this selection of position in the S-N curve and that another selection of reference point would provide the same final results). The design curves to the left of 10 mill cycles can be expressed for conventional steel and FCA steel respectively as

\[
\log N_{\text{conv}} = \log a_{\text{conv}}^{\text{log}S} - m_{\text{conv}} \log S
\]

\[
\log N_{\text{FCA}} = \log a_{\text{FCA}}^{\text{log}S} - m_{\text{FCA}} \log S
\]

Here $m_{\text{conv}} = 3.0$ and $m_{\text{FCA}} = 3.5$. Then from eq. (4) and the log a values from Table 6 an improvement factor at 2 mill cycles can be calculated as $I_{\text{FCA}} = N_{\text{FCA}}/N_{\text{conv}} = 2.44$. Reference is made to Fig. 13 for illustration of derivation of a general design S-N curve for FCA steel.

Then it is assumed that the form of eq. (4) can be used also for other details made of FCA steels with a similar improvement factor $I_{\text{FCA}}$ in the S-N curve from that of conventional steel. From eq. (4) and definition of $I_{\text{FCA}}$ given above the following characteristic value for the S-N curve for the detail made with FCA steel is derived

\[
\log N_{\text{FCA}} = \log I_{\text{FCA}} - \log N_{\text{conv}} \left( \frac{m_{\text{FCA}}}{m_{\text{conv}}} - 1 \right) + m_{\text{FCA}} \log a_{\text{conv}}
\]

By inserting numbers into eq. (5) the following expression is derived for a design S-N curve for number of cycles less than $10^7$

\[
\log a_{\text{FCA}}^{\text{log}S} = -0.6628 + 1.1667 \log a_{\text{conv}}^{\text{log}S}
\]

Then the S-N curve for cycles larger than $10^7$ can be derived by requiring continuity in the two curves. This gives

\[
\log a_{\text{FCA}}^{\text{log}S} = 1.4286 \log a_{\text{conv}}^{\text{log}S} - 3.0
\]

Here a superscript with $m = 5.0$ is inserted to show that this log a value should be used together with $m = 5.0$ and the log a value from eq. (6) should be used together with $m = 3.5$ to establish a general S-N curve for FCA steel details. Then the complete general design S-N curve reads

\[
\log N = \log a_{\text{FCA}}^{\text{log}S} - 3.5 \log S \quad \text{for} \quad N \leq 10^7
\]

\[
\log N = \log a_{\text{FCA}}^{\text{log}S} - 5.0 \log S \quad \text{for} \quad N > 10^7
\]

By inserting design values for a cruciform joint made of conventional steel into these equations it is checked that the corresponding design equation (3) for FCA steel is derived. From DNV-RP-C203 (2008) $\log a_{\text{conv}}^{\text{log}S} = 11.855$ for cruciform joint classified as F. And inserting this value into eq. (6) gives $\log a_{\text{FCA}}^{\text{log}S} = 13.168$ which is the same value as presented by eq. (3) for N less than $10^7$ cycles. Then by inserting this value into eq. (7) $\log a_{\text{FCA}}^{\text{log}S} = 15.812$ is derived which corresponds to eq. (3) for N larger than $10^7$ cycles. Thus, it is shown that the proposed format of a general design S-N curve is in line with the test data derived from fatigue testing of FCA steels. The presented format can be used to derive design S-N curves for other structural details made with FCA steel showing similar crack growth characteristics.

Derivation of a hot spot design S-N curve for details made from FCA steel is shown as an example in the following. From the FPSO Fatigue Capacity JIP (Bergan and Lotseberg, 2006) it was shown that the FAT90 curve (IWW, 2009) or the D-curve (DNV-RP-C203, 2008) can be recommended used as a hot spot design S-N curve for conventional steel (Maddox, 2001, Fricke, 2001, Lotsberg and Sigurdsson, 2006). The D-curve for details in air environment can be described by $\log a_{\text{conv}}^{\text{log}S} = 12.164$ for N less than $10^7$ cycles (DNV-RP-C203, 2008). Inserting this value into eq. (6) and eq. (7) gives the following hot spot stress design S-N curve for FCA steel

\[
\log N = 13.528 - 3.5 \log S \quad \text{for} \quad N \leq 10^7
\]

\[
\log N = 16.325 - 5.0 \log S \quad \text{for} \quad N > 10^7
\]
It is stressed that the hot spot stress to be used together with this curve should be derived in the same way as that used for details made of conventional steels in terms of finite element modeling and read out of hot spot stress in order to achieve consistent fatigue analysis results, ref. e. g. DNV-RP-C203 (2008) that can be downloaded for free from the internet (ref. link in reference list).

**Fig. 12:** Design S-N curve F conventional and FCA steel

**Fig. 13:** Illustration of derivation of general design S-N curve

**Comparison of calculated fatigue life using FCA steel as compared with conventional steel**

The fatigue test data from FCA steel specimens are compared with the fatigue test data from the conventional steel specimens in Fig. 10.

The difference in slope in the S-N curves is noted. Thus, FCA steels will show significantly longer fatigue life for typical wave loading than from that using conventional steel when looking at the high cycle region of the S-N diagram in Fig. 10.

For structures subjected to wave loading it is the region from $10^6$ – $10^8$ cycles that gives the largest contribution to fatigue damage. This is exemplified in Fig. 14 where fatigue damage for a structural detail classified as F subjected to a long term Weibull stress range distribution with shape parameter equal 1.0 and calculated damage equal 1.0 for 20 years, the calculated fatigue damage for FCA steel would be approximately 0.3 or a fatigue life of approximately 3.35 times longer for FCA steel than that of conventional steel as listed in Table 6. For longer fatigue lives the improvement factor using FCA steel becomes larger as the damage accumulation in the S-N curve is shifted to the right.

It is observed from Fig. 12 that the differences between the FCA steel and the conventional steel are insignificant for the left part of the S-N diagram when approaching that of the low cycle region (high stress range). This indicates that FCA steels should mainly be considered for details subjected to wave type dynamics and are of less interest in areas subjected to low cycle fatigue such as resulting from loading and unloading.

**Table 6: Calculated fatigue lives for different S-N curves**

<table>
<thead>
<tr>
<th>S-N curve (design)</th>
<th>F (Conventional)</th>
<th>FCA Steel</th>
<th>Factor on life</th>
</tr>
</thead>
<tbody>
<tr>
<td>log a m = 3.0</td>
<td>11.855</td>
<td>13.168</td>
<td></td>
</tr>
<tr>
<td>log a m = 3.5</td>
<td>15.091</td>
<td>15.812</td>
<td></td>
</tr>
<tr>
<td>Calculated fatigue life for n = $10^8$</td>
<td></td>
<td></td>
<td>3.35</td>
</tr>
<tr>
<td>Calculated fatigue life for n = $2*10^8$</td>
<td></td>
<td></td>
<td>3.75</td>
</tr>
</tbody>
</table>

**Fig. 14:** Accumulated fatigue damage in F-curve

**Conclusions**

Fatigue test data from FCA steel specimens have been compared with fatigue test data from conventional steel specimens. The test specimens used would be classified as FA171 (IIW, 2009) or F according to DNV-RP-C203 (2008). (This is also approximately the same as the F-curve in IACS rules for tankers (2008) and BS 7608:1993).

It is observed that the design S-N curve for conventional steel is in good agreement with that of the F-curve. This gives confidence in the test data derived for conventional steel; and as the FCA steel specimens are tested in the same manner, it is reasonable to associate a similar
confidence with the test data from these test specimens. The difference in slope of the S-N curves for FCA steel and conventional steel is noted. Thus, FCA steels will show significantly longer fatigue life for details subjected to a typical stress ranges from wave loading than using conventional steel when looking at the high cycle region of the S-N diagram.

The calculated fatigue life is more than 3 times longer for FCA steels than for that using conventional steel for a typical long term stress range distribution from wave actions for a ship structure.

The differences between the FCA steel and the conventional steel are insignificant for the left part of the S-N diagram when approaching that of the low cycle region. This indicates that FCA steels should mainly be considered for details subjected to wave type dynamics and are of less interest in areas subjected to low cycle fatigue (high stress range) such as resulting from loading and unloading.

A proposed design S-N curve for welded cruciform joints made with FCA steel has been presented. The derivation of this design S-N curve is based on test data with fatigue crack growth initiating at the weld toe and growing into the base material away from the heat affected zone. A basis for derivation of more general design S-N curves for other welded joints with similar crack growth behavior into the base material has also been presented in the present paper.

The proposed design S-N curve makes it easy already at a structural design stage to consider FCA steel as an alternative to conventional steel in areas of a hull structure with high stress concentrations as use of FCA steels can be applied without any scantling increase or structural reinforcements resulting in steel weight increase. Thus, long target fatigue lives (e.g. North Atlantic 25-years to North Atlantic 40-years) may be documented without requirements to post weld improvements like weld toe grinding.

Acknowledgement

The authors would like to acknowledge the contributions made by LRS for giving valuable opinions and comments on these activities and by both Mitsu Engineering & Shipbuilding Co., Ltd. and IHI Marine United Inc., especially for fabricating weld joints for fatigue test specimens and also partly conducting fatigue testing during this JIP.

References


IACS Common Rules for Bulk Carriers, 2005, International Association of Classification Societies.

IACS Common Structural Rules for Double Hull Oil Tankers, 2008, International Association of Classification Societies.


