Subject

Adoption of IACS CSR/BC RCP3

ClassNK

Technical Information

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To whom it may concern

IACS CSR/BC RCP3 (Rule Change Proposal 3) has been adopted by IACS Council on 12 September 2008 as shown in the attached document which has been disclosed at IACS website.

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Attachment:

1. Common Structural Rules for Bulk Carriers, January 2006, Rule Change Proposal 3

Common Structural Rules for Bulk Carriers, January 2006

Rule Change Proposal 3
(Ch 8 Sec 2, 2.3 Equivalent notch stress range)

Notes: (1) These Rule Changes enter into force on 12 September 2008.

For technical background for Rule Changes in this present document, reference is made to separate document Technical Background for Rule Change Proposal 3

Chapter 8 Fatigue Check of Structural Details

Section 2 – FATIGUE STRENGTH ASSESSMENT

2. Equivalent notch stress range

2.3 Equivalent notch stress range

2.3.1 Equivalent notch stress range

The equivalent notch stress range, in N/mm^2, for each loading condition is to be calculated with the following formula:

$$\Delta\sigma_{eq,\,j} = K_f \Delta\sigma_{equiv,\,j}$$

where:

$\Delta\sigma_{equiv,j}$: Equivalent hot spot stress range, in N/mm^2, in loading condition "*j*" obtained by [2.3.2].

K_f : Fatigue notch factor defined in Tab 1.

Table 1: Fatigue notch factors K_f

Subject	~~KfNot Grinding~~ **Without weld grinding**	~~Grinding~~ **With weld grinding** (not applicable for ordinary stiffeners and boxing fillet welding*1)
Butt welded joint	1.25	1.10
Fillet welded joint	1.30	1.15 *2
Non welded part	1.00	-

Note:
*1 Boxing fillet welding is defined as a fillet weld around a corner of a member as an extension of the principal weld.
*2 This is applicable for deep penetration welding, or full penetration welding only.

In case where grinding is performed, full details regarding grinding standards including the extent, smoothness particulars, final welding profiles, and grinding workmanship as well as quality acceptance criteria are to be submitted to the Society for approval.
It is preferred that any grinding is carried out by rotary burrs, is to extend below plate surfaces in order to remove any toe defects and ground areas are to have sufficient corrosion protection.
Such treatments are to procedure smooth concave profiles at weld toes with the depth of these depressions penetrating into plate surfaces to at least 0.5mm below the bottom of any visible undercuts.
The depth of any grooves produced is to be kept to a minimum and, in general, kept to a maximum of 1mm.
Under no circumstances is grinding depth to exceed 2mm or 7 % of plate gross thickness, whichever is smaller.
Grinding has to extend to 0.5 longitudinal spacing or 0.5 frame spacing at the each side of hot spot locations.

2.3.2 Equivalent hot spot stress range

The equivalent hot spot stress range, in N/mm², is to be calculated for each loading condition with the following formula:

$$\Delta\sigma_{equiv,\,j} = f_{mean,\,j} \cdot \Delta\sigma_{W,\,j}$$

where:

$f_{mean\,,\,j}$: Correction factor for mean stress :

- for hatch corners $f_{mean\,,\,j} = 0.77$
- for primary members and longitudinal stiffeners connections, $f_{mean\,,\,j}$ corresponding to the condition "*j*" taken equal to:

$$f_{mean,\,j} = \max\left\{0.4,\ \left[\max\left(0,\ \frac{1}{2} + \frac{-\ln\left(10^{-4}\right)}{4}\,\frac{\sigma_{m,\,j}}{\Delta\sigma_{W,\,j}}\right)\right]^{0.25}\right\}$$

$\sigma_{m\,,1}$: Local hot spot mean stress, in N/mm², in the condition "1", obtained from the following formulae:

- If $0.6\Delta\sigma_{W,1} \geq 2.5R_{eH}$:

$$0.6\Delta\sigma_{m,1} = -0.18\Delta\sigma_{W,1}$$

- If $0.6\Delta\sigma_{W,1} < 2.5R_{eH}$:

$$\sigma_{m,1} = R_{eH} - 0.6\Delta\sigma_{W,1} \quad \text{for} \quad 0.6\Delta\sigma_{W,1} > R_{eH} - \sigma_{res} - \sigma_{mean,1}$$

$$\sigma_{m,1} = \sigma_{mean,1} + \sigma_{res} \quad \text{for} \quad 0.6\Delta\sigma_{W,1} \leq R_{eH} - \sigma_{res} - \sigma_{mean,1}$$

$\sigma_{m\,,\,j}$: Local hot spot mean stress, in N/mm², in the condition "*j*", obtained from the following formulae:

- If $0.24\sigma_{W,\,j} \geq R_{eH}$:

$$\sigma_{m,\,j(\,j\neq 1)} = -0.18\Delta\sigma_{W,\,j}$$

- If $0.24\sigma_{W,\,j} < R_{eH}$:

$$\sigma_{m,\,j(\,j\neq 1)} = -R_{eH} + 0.24\Delta\sigma_{W,\,j} \quad \text{for} \quad 0.24\Delta\sigma_{W,\,j} > R_{eH} + \sigma_{m,1} - \sigma_{mean,1} +_{mean,\,j}$$

$$\sigma_{m,\,j(\,j\neq 1)} = \sigma_{m,1} - \sigma_{mean,1} + \sigma_{mean,\,j} \quad \text{for} \quad 0.24\Delta\sigma_{W,\,j} \leq R_{eH} + \sigma_{m,1} - \sigma_{mean,1} + \sigma_{mean,\,j}$$

$\sigma_{mean\,,\,j}$: Structural hot spot mean stress, in N/mm², corresponding to the condition "*j*"

σ_{res} : Residual stress, in N/mm², taken equal to: ~~obtained from the following formulae:~~

~~$\sigma_{res} = \max\{\sigma_{res,\,j}\ ,\quad j = 1,2,3,4\}$~~

$\sigma_{res} = 0.25R_{eH}$ for stiffener end connection

$\sigma_{res} = 0$ for non welded part and primary members(cruciform joint or butt weld)

$$\sigma_{res,\,j} = \begin{cases} \max\left[-R_{eH}\,,\min\left\{R_{eH}\,,\sigma_{res0} + \sigma_{mean,\,j} + 0.6\Delta\sigma_{W,\,j}\right\} - \sigma_{mean,\,j} - 0.6\Delta\sigma_{W,\,j}\right] & \text{for } \sigma_{mean,\,j} \geq 0 \\ \min\left[R_{eH}\,,\max\left\{-R_{eH}\,,\sigma_{res0} + \sigma_{mean,\,j} - 0.24\Delta\sigma_{W,\,j}\right\} - \sigma_{mean,\,j} + 0.24\Delta\sigma_{W,\,j}\right] & \text{for } \sigma_{mean,\,j} < 0 \end{cases}$$

$$\sigma_{res0} = \begin{cases} 0.25R_{eH} & \text{for welded joint} \\ 0 & \text{for non welded part} \end{cases}$$

Common Structural Rules for Bulk Carriers, January 2006

Technical Background for Rule Changes 3 (Ch 8 Sec 2, 2.3 Equivalent notch stress range)

Technical Background for the Changes Regarding Equivalent notch stress range:

1. Reason for the Rule Change in Ch 8 Sec 2 2.3:

The fatigue assessment according to the current rule gives the result which is far from our experiences for the primary members (bilge knuckle and lower stool) in empty and loaded holds in the case that (1) the excessive compressive mean stress is calculated and (2) the mean stresses in four loading conditions are negative. The reasons of obtaining such result are due to the assumptions that (1) the tensional residual stress is generated after the excessive compressive load is removed and (2) the existence of initial weld residual stress of $0.25R_{eH}$.

As specified in Appendix 1, almost all damages are occurred in ballast hold.

The reasons that the majority of damage caused by cracks occurs in ballast holds are as follows. Structural members in ballast holds are subject to high internal pressure due to ballast water. However, since they are subject to relatively low external pressure, high tensile stresses (both the mean stress and stress range are large) are placed on those structural members susceptible to low fatigue life such as lower stool connections and bilge knuckle connections as shown in Fig. 3.1, while, the stresses placed on structural members in cargo holds that are other than ballast holds are relatively small or compressive even in cases where their value is large.

Therefore, the majority of damage caused by cracks occurs in ballast holds. In the case of bilge knuckle connections in ballast holds under heavy ballast conditions, since the sum of the tensile mean stress and 0.6 times stress range are greater than R_{eH}, the term σ_{res0} does not affect any formula specified in CH 8 Sec 2 [2.3.2] of the current CSR (See the background for the treatment of residual stress specified in Appendix 2.

This means that any fatigue assessment results for structural members such as those bilge knuckle connections in which damage occurs are not affected by the value of residual stress.

On the other hand, with respect to those structural members in empty and loaded holds that are other than ballast holds, excessive compressive mean stresses or the mean stresses in four loading conditions are compressive or relatively low.

Therefore, any fatigue assessments performed according to current rules give results which are far from our experience that less damage caused by cracks of primary members (bilge knuckles and lower stools) in empty and loaded holds other than ballast holds occur

The reasons for obtaining such results are due to the assumptions that (1) the tensile residual stresses are generated after any excessive compressive loads are removed, and (2) the existence of initial weld residual stresses of 0.25 R_{eH}.

In some cases, the weld residual stress is released due to certain reasons for the primary members. The factors which are the cause of stress release are (i) assembly process (ii) tank test (iii) internal and external loads etc. And we obtained the remark that the weld residual stress is released even if the large compressive load is applied

Based on the above knowledge, the calculation formula of the equivalent hot spot stress range is corrected to make weld residual stress zero except the case for ordinary stiffener. Moreover, it is also known that when excessive compression loads are imposed on the welded structure and then removed, it does not lead to production of tensional residual stress. This knowledge has been reflected in the formula.

However, the assumption of initial weld residual stress is kept for longitudinal stiffeners, because longitudinal stiffeners penetrate transverse webs at so many locations that the estimation should be left on the safer side.

Furthermore, the stress concentration at the hot spots subjected to fatigue strength assessment can be mitigated by grinding as can the stress concentration in primary members. As the CSR for tankers reflects this information, the effects of stress mitigation by grinding have been included in the assessment of primary members except the connection of side frames which the boxing fillet welds are adopted, considering the actual and practical construction procedure.

2. Summary of the Rule Change

2.1 Improvement of the calculation of the equivalent hot spot stress range of primary members to include weld residual stress and excessive compressive stress

(1) The current assumption of the initial weld residual stress is to be applied to the fatigue strength assessment for longitudinal stiffeners.

$\sigma_{res} = 0.25 R_{eH}$ for ordinary stiffener

(2) As the effects of weld residual stress do not need to be considered for primary members, the assumption of the initial weld residual stress is to be added in a similar way to the current assumption for non welded parts in which the residual stress does not exist.

$\sigma_{res} = 0$, (for non welded part and primary members (cruciform and butt weld)

2.2 Consideration of the effects of grinding

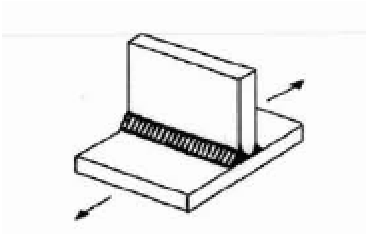
In the calculation of hot spot stress, the coefficient for the grinding effect is to be defined with reference to the 'International Institute of Welding (IIW) Recommendation of IIW "Fatigue design welded joint and component"' and added to Ch8 Sec2 Table1.

According to the post welds improvements specified in "IIW Recommendations on Post Weld Improvements of Steel and Aluminum Structures, XIII-1965-00, 2004", grinder finishing for the purpose of removing any undercut and /or smoothing any welding beads is recommended to be carried out.

The recommended practice for grinder finishing is to the plate surface to a depth of at least 0.5mm from the bottom of the visible undercut but not to exceed 1.0mm.

According to the results of experiments specified in several technical papers, the grinder effect on fatigue life is estimated to have a value of 1.3. If a value of 1.0 is used for those surfaces that are not subjected to grinder finishing then this is an improvement.

According to "IIW Recommendations for Fatigue Design of Welded Joints and Components, 2004, IIW Document XIII-1965-03/XV-1127-03" the grinder effect value is to be taken as 1.25 in order to be on the safe side. For example, (extract of IIW Rec.) No. 511



Two-sided fillets, toe ground: 100MPa
Fillet weld(s) as welded : 80MPa
(100/80=1.25)

The recommended value is based on the results of experiments that used specimens in well controlled conditions.

Considering that any actual grinding work on structures is not so well controlled, we feel that, to be even more on the safe side, the grinder effect value should be even further lowered to 1.15 as proposed in RCP3.

Table 1 Fatigue notch factors K_f

Subject	~~KfNot Grinding~~ Without weld grinding	~~Grinding~~ With weld grinding (not applicable and boxing fillet welding*1)
Butt welded joint	1.25	1.10
Fillet welded joint	1.30	1.15*2
Non welded part	1.00	-

Note:
*1 Boxing fillet welding is defined as a fillet weld around a corner of a member as an extension of the principal weld.
*2 This is applicable for deep penetration welding, or full penetration welding only.

However, to avoid any risk of root cracking, the application of this technique is limited to deep penetration welding or full penetration welding.
Furthermore, in order to ensure the effects of the grinding, procedures specified by the International Institute of Welding have been added to the Rules.

3. Effects due to this change

To see the effects of the change to the calculation formulae of the equivalent hot spot stress range for primary members, the fatigue strength assessment of the connections of the inner bottom plate with the bilge hopper sloping plate and the lower stool side plate was carried out. For reference, all the lower stool side plates have slanted configuration.

Table 3.1 Considerable ships and cargo holds

	Type of ship	Type of cargo holds		
A	Cape (DSS) 170K	Ballast hold	Empty hold	Loaded hold
B	Cape (SSS) 180K	Ballast hold	Loaded hold	
C	Panamax (SSS) 82K	Ballast hold	Empty hold	
D	Panamax (SSS) 110K	Ballast hold	Loaded hold	
E	Handymax (SSS) 57K	Ballast hold	Empty hold	

The equivalent hot spot stress range and mean stress obtained by FEA are shown in Figure 3.1
The following cumulative fatigue damage was calculated from the above equivalent hot spot stress range and mean stress.
(1) The cumulative fatigue damage according to the current CSR
(2)(a) The cumulative fatigue damage according to the corrected formulae in 2.1 (“mod_1” in Figure 3.2)
(b) The cumulative fatigue damage according to the corrected formulae in 2.1 with the effect of grinding in 2.2 (“mod_1(G) in Figure 3.2)

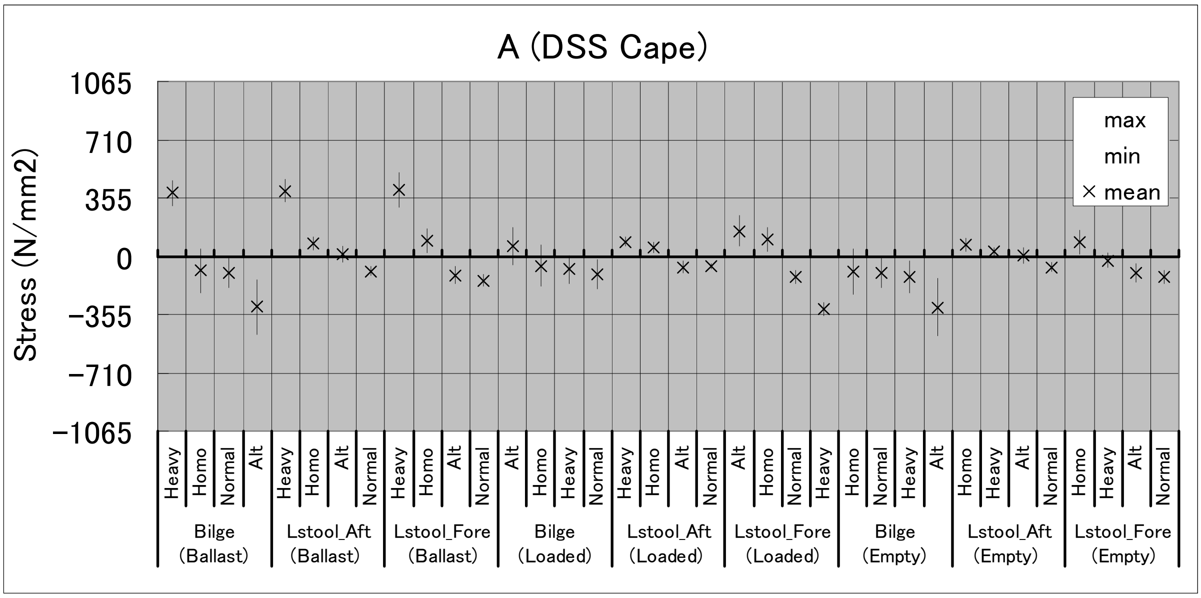
The results of the cumulative fatigue damage are shown in Figure 3.2.

From the results in Figure 3.2, the following can be said about the corrected formulae in 2.1.
(1) There is no effect on the cumulative fatigue damage at the fatigue assessment points in ballast holds where there was high tensional mean stress.
(2) In cargo holds other than ballast holds, the cumulative fatigue damage at the fatigue assessment points was less than that of the current CSR, when there was compressive or low tensional mean stress and the hot spot stress range was large.
(3) The relative tendency of the cumulative fatigue damage at the fatigue assessment points in ballast holds and other holds was consistent with the damage record specified in the Appendix.
(4) The cumulative fatigue damage with grinding was about 60% of that without grinding.

4. Impact on scantlings

Since the results of the fatigue strength assessment depend on various countermeasures such as grinding, additional reinforcement, inset plate or local thickness increase, and other fabrication improvements, the scantling impact due to this change cannot be estimated directly. However, the correction of the calculation formulae mitigates the excessive result on fatigue damage in cargo holds other than ballast holds, where less fatigue cracks have been found in the damage record.

Fig. 3.1 Hot spot stress range and hot spot mean stress



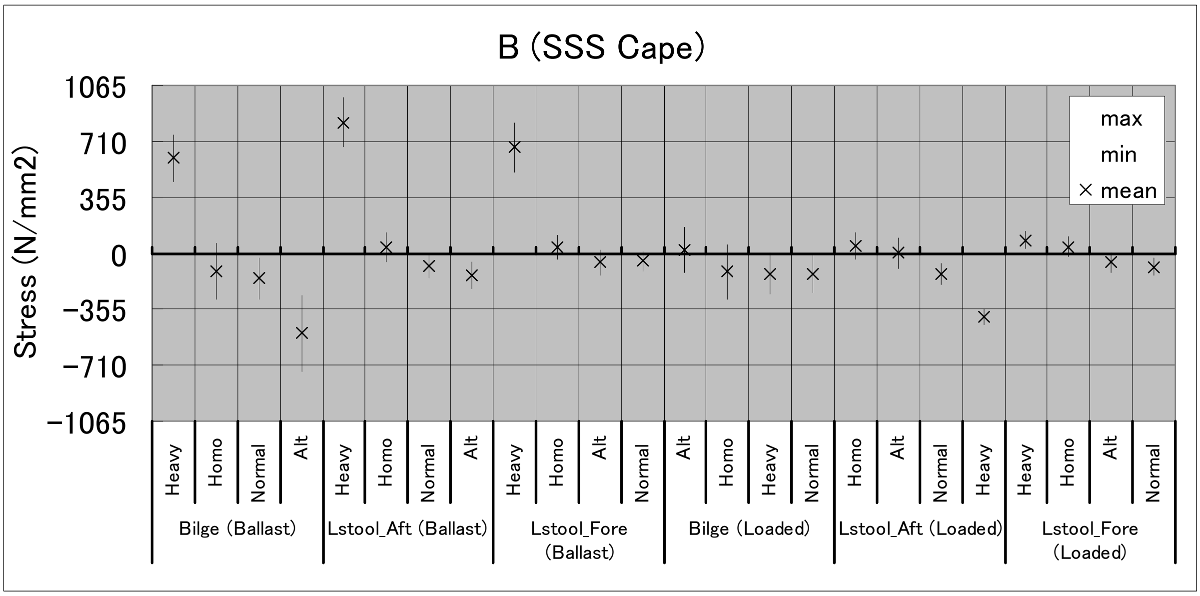
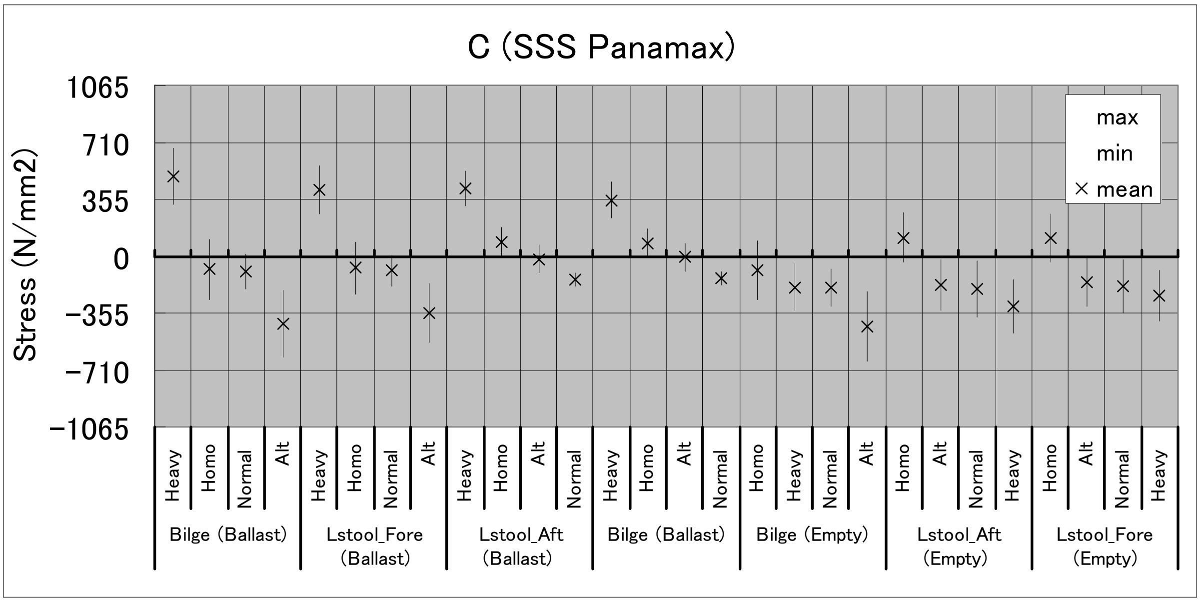
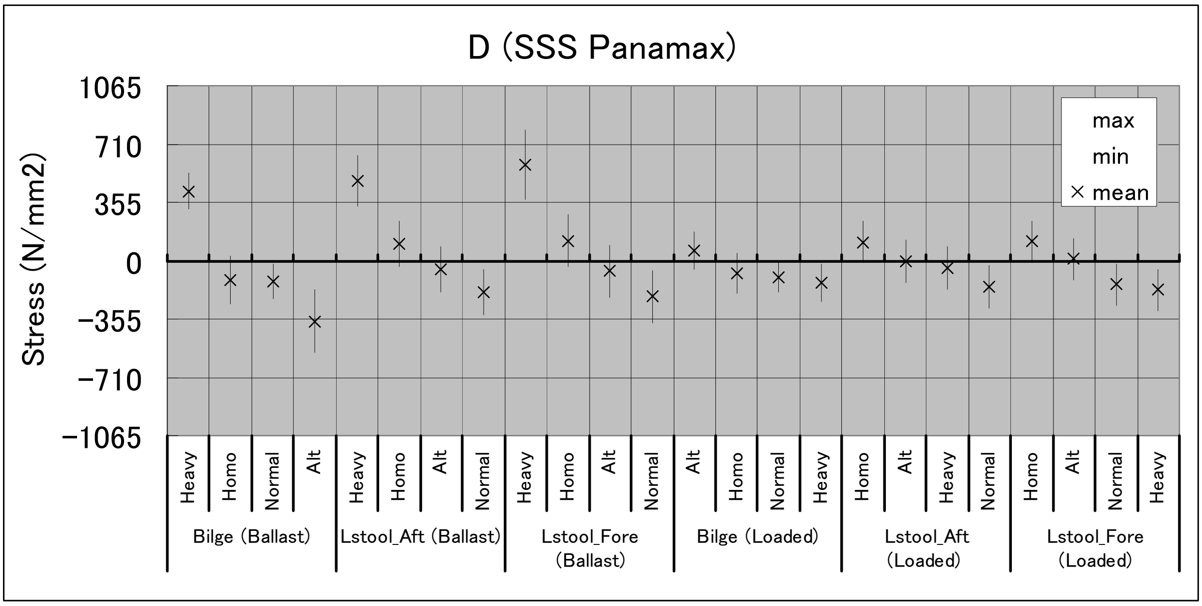
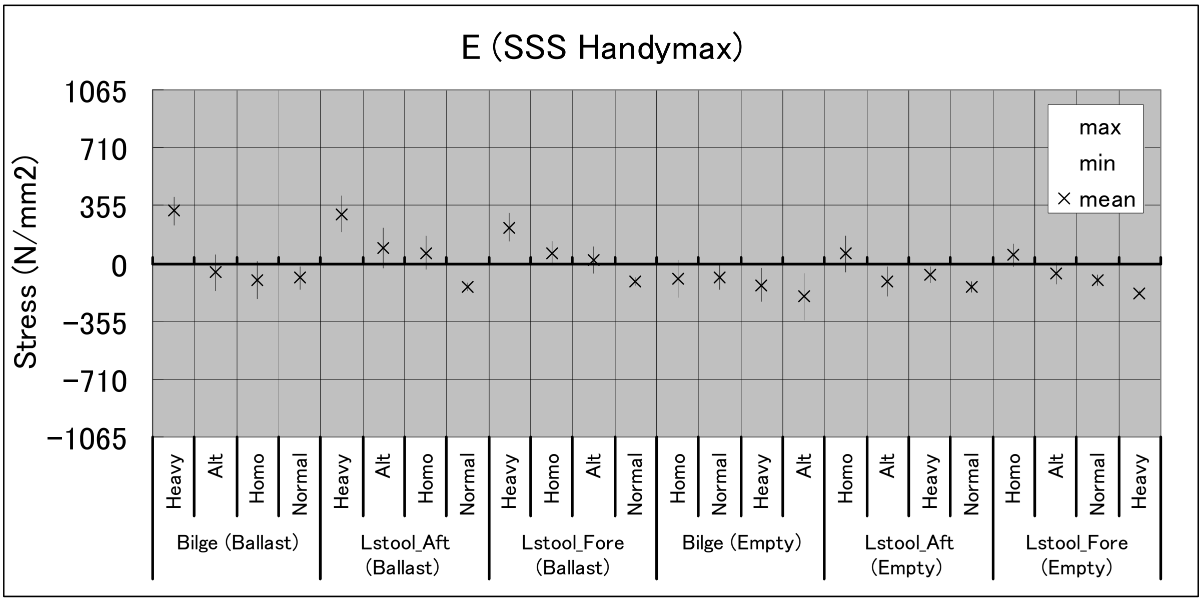


Fig. 3.1 Hot spot stress range and hot spot mean stress (continued)

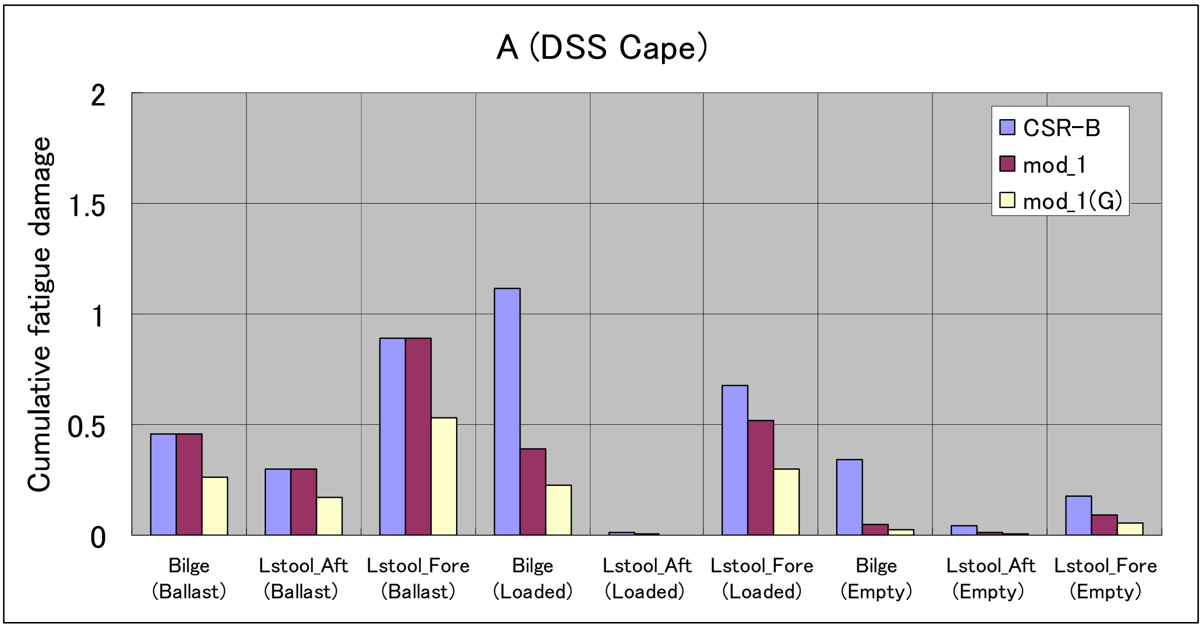


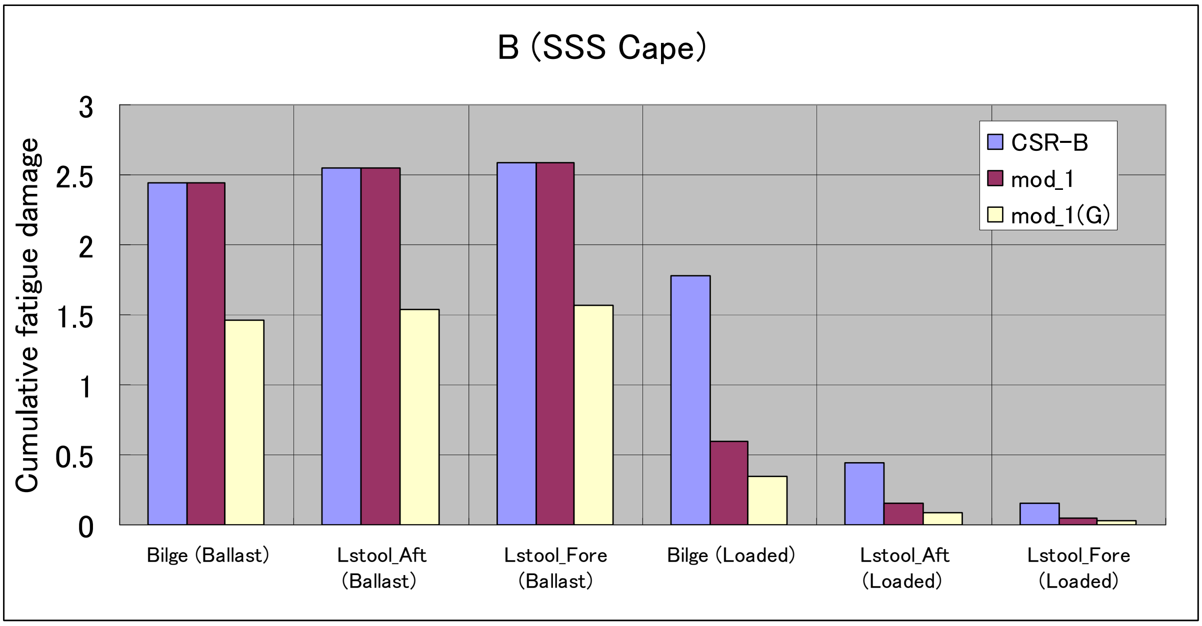




*"Lstool_Aft" and "Lstool_Fore" mean the lower stool of the aft end and fore end of the cargo hold.

Fig. 3.2 Cumulative fatigue damage





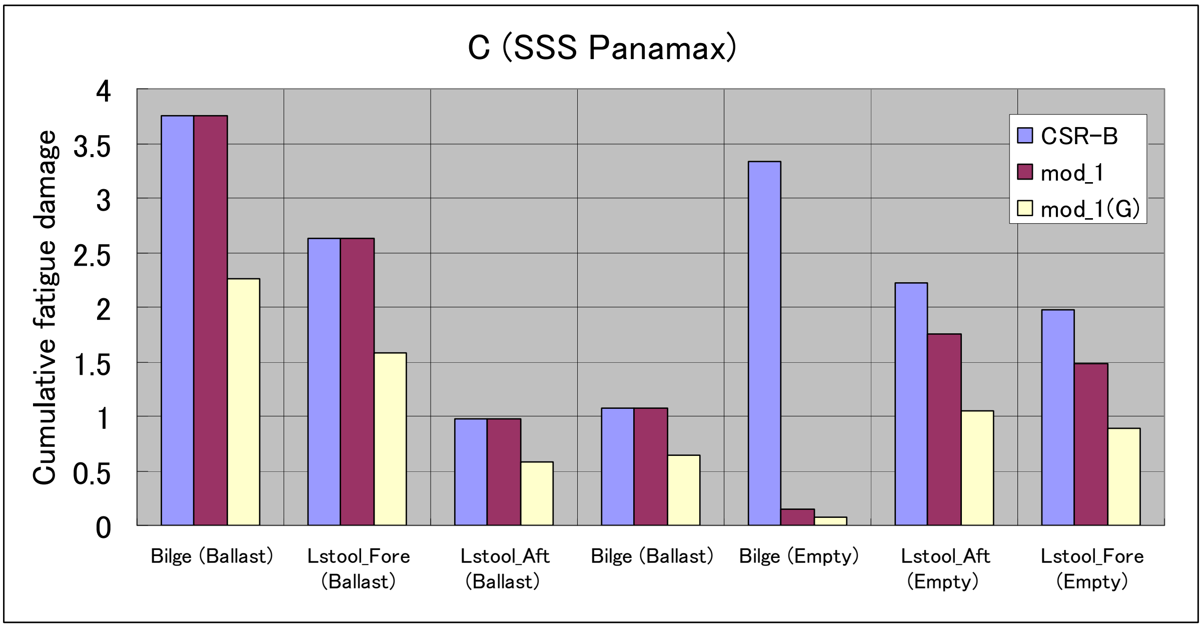
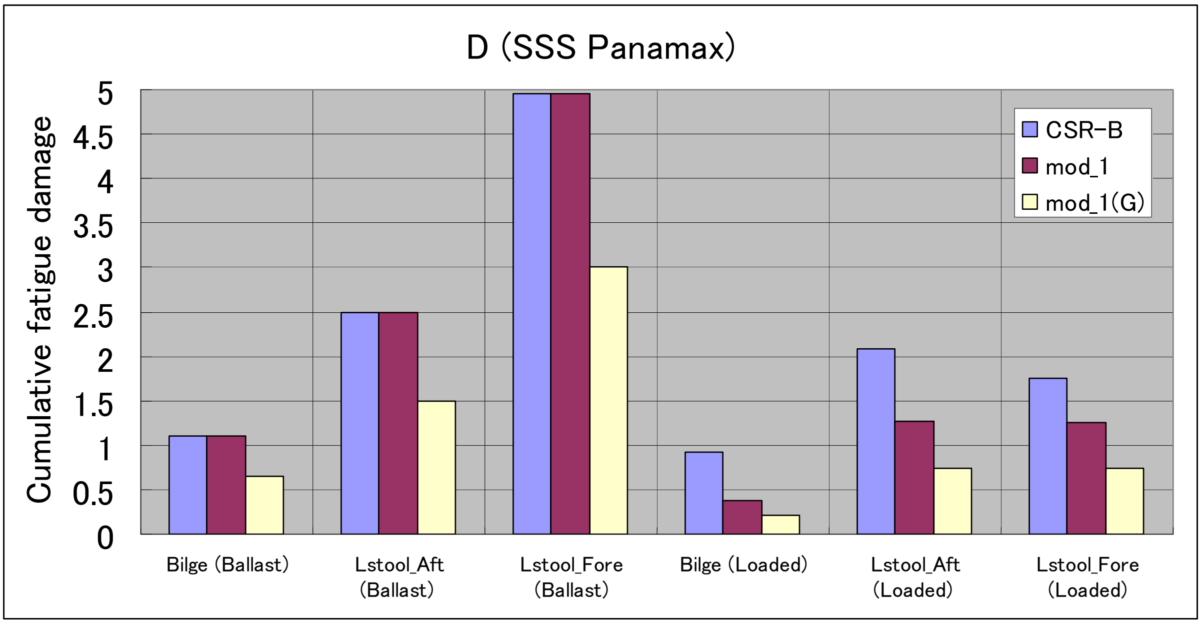
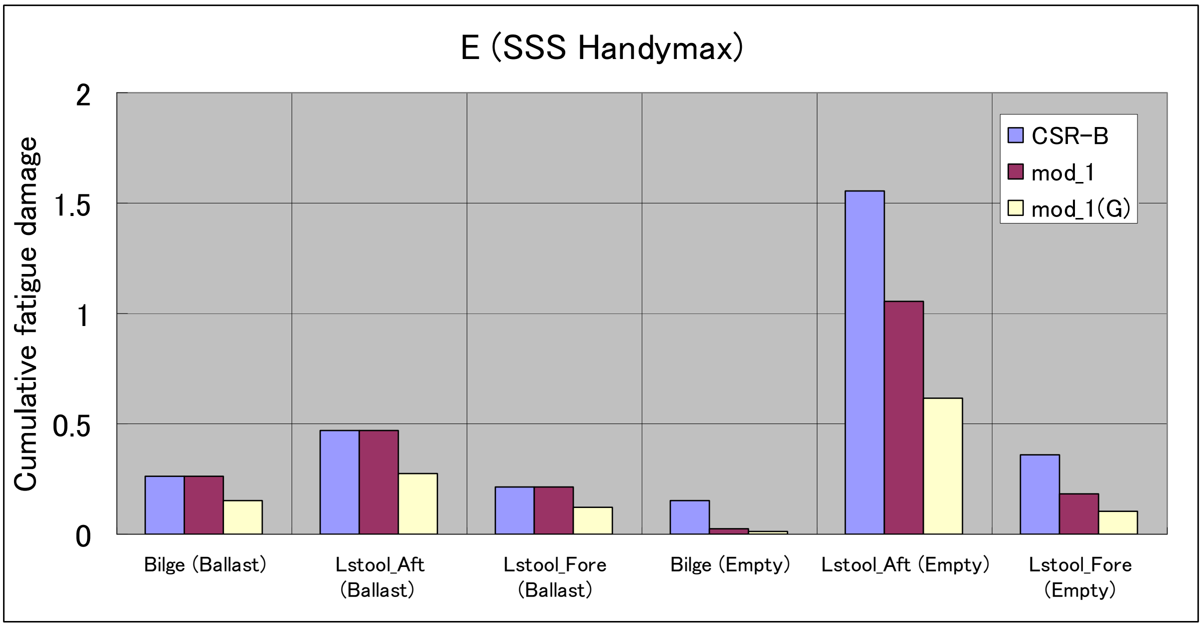


Fig. 3.2 Cumulative fatigue damage (Continued)





*"Lstool_Aft" and "Lstool_Fore" mean the lower stool of the aft end and fore end of the cargo hold.

Appendix 1 Damage record

The members and locations specified in Ch 8 Sec 1 of CSR for Bulk Carriers are those that have a potential risk of fatigue damage regardless of the type of hold or damage frequency.
We surveyed damage data of the primary members listed below that require fatigue strength assessment in order to comprehend the exact risk of fatigue damage:

- Connections between inner bottom plating and sloping and/or vertical plate of lower stool (IB/slant of LS)
- Connections between inner bottom plating and sloping plate of hopper tank (IB/sloping of BH)
- Connections between inner hull plating and sloping plate of hopper tank (IS/sloping of BH)
- Connections between transverse bulkhead and sloping plate of lower stool (TB/LS)
- Connections between transverse bulkhead and sloping plate of upper stool (TB/US)
- Connections between hold frames and sloping plate of lower wing tank (HF/BH)
- Connections between hold frames and sloping plate of upper wing tank (HF/TST)

The survey was carried out according to the following conditions.

(1) Crack damage data reported between 1996 and 2007 in the 3015 ships constructed between 1958 and 2007
(2) Damage that occurred due to design, fatigue, or unknown causes
(3) For hold frames, damage of ships complying with IACS S12 (1992)

~~The~~ Damage data is ~~was~~ classified by the type of hold (ballast hold and cargo hold) and~~then~~ the number of cases of damage is~~was~~ normalized by the number of classified holds per a ship.
The results are~~is~~ given in Table A1.

Table A1 Number of cases of damage *

	Ballast hold	Cargo hold (No. of cases of damage / No. of cargo ~~cases of~~ holds)
IB/slant of LS	365	0
IB/sloping of BH	173	0.4
IS/sloping of BH	9	0
TB/LS	92	0.2
TB/US	63	0.5
HF/BH	15	0
HF/TST	31	0
Total	748	1.1

Note
* The number of cases of damage per cargo hold is the quotients of number of cargo damage divided by number of cargo holds.

As given in Table A1, the damage to members in ballast hold is 99.8% of the total number of the case of damage for primary members and the damage to holds other than ballast hold is 0.2%. About 72% of damage occurred at the connection between inner bottom plating and the sloping plate of the hopper tank and between inner bottom plating and the sloping and/or the vertical plate of the lower stool.

Appendix 2 Technical Background for the treatment of mean stress and residual stress

1. It is well and widely known that any initial residual stresses (σ_{res}), which are tensile and have magnitudes that are normally close to the yield stresses of materials, exist in welded joints (hot spots) or their periphery thereof.

In cases where loads are imposed onto hot spots and stresses at such hot spots reach locally yield stresses, any initial residual stresses are relaxed after the removal of such loads. This phenomenon is called the shake-down effect. This shake-down effect occurs in those perfectly elasto plastic models introduced in the Rules.

Furthermore, it is also known that static mean stresses (structural mean stresses) influence the fatigue strengths.

The effect of any mean stresses influencing the fatigue strengths can be evaluated by the sum of any residual stresses and structural mean stresses.

Since the S-N curves with slopes equal to 3, as given by UK-HSE standards, express fatigue strengths of welded structures in those cases where residual welds close to the yield stresses of materials exists, it cannot be used to evaluate the effects of mean stresses.

2. The relaxation of any initial residual stresses at hot spots can be evaluated by using shake-down models based on the assumptions of perfectly elasto plastic models. Those loads to be considered are hydrostatic loads (structural mean stresses) and hydrodynamic loads induced by waves.

Since those stress ranges due to hydrodynamic loads induced by waves are random variables in which wave heights are subject to the Gaussian process, any stresses contributing to shake-down effects depend on the periods of duration in navigating under specific loading conditions.

Assuming that ships are imposed upon by significant hydrodynamic pressure only in cases where such ships are at sea, these periods of duration for one loading condition can be set to about 10 days (10^5 cycles).

In this case, the magnitude of any stress ranges σ_S dominating mean stress conditions during this period can be expressed by $0.96\Delta\sigma_5$ (Ref. SNAJ 190, November 2001), where $\Delta\sigma_5$ is defined as the maximum stress range corresponding to these 10^5 cycles loads.

In those fatigue strength assessment procedures specified in the Rules, reference stresses correspond to 10^4 cycle loads. In cases where $\Delta\sigma_5$ is defined as the maximum stress range corresponding to 10^5 cycles loads, the relationship between $\Delta\sigma_5$ and $\Delta\sigma_4$ is:

$$\Delta\sigma_5 = 1.25\Delta\sigma_4$$

Then, we can get the following relationship :

$$\sigma_S = 0.96\Delta\sigma_5 = 1.2\Delta\sigma_4$$

The model regarding initial residual stresses σ_{res}, mean stresses σ_{mean} and σ_S can be illustrated as given in Fig. A1 and $\sigma_{\max}$ is used, in order to evaluate any shake-down effects.

From the relationship illustrated by the above figure, we can get the following equation:

$$\sigma_{\max} = \sigma_{res} + \sigma_{mean} + 0.5\sigma_S = \sigma_{res} + \sigma_{mean} + 0.6\Delta\sigma_4$$

3. As specified above, shake-down effects are to be considered in cases where the $\sigma_{\max}$ exceeds the yield stress of material (R_{eH}).

In such cases, any considered mean stresses can be expressed by the following equation:

$$\sigma_m = R_{eH} - 0.6\Delta\sigma_4$$

In those cases where $0.5\sigma_S + \sigma_{res} + \sigma_{mean}$ is less than R_{eH}:

$$\sigma_m = \sigma_{mean} + \sigma_{res}$$

The above cases are applicable to "Condition 1" which is defined the condition in which maximum stress is the largest on the tension side among the loading conditions "homogeneous", "alternate" "normal ballast" and "heavy ballast"

According to experience as well as some studies regarding fatigue damages of side longitudinals in single hull tankers, initial weld residual stresses for welded joints such as longitudinals are conservatively given the value of 0.25 R_{eH}.

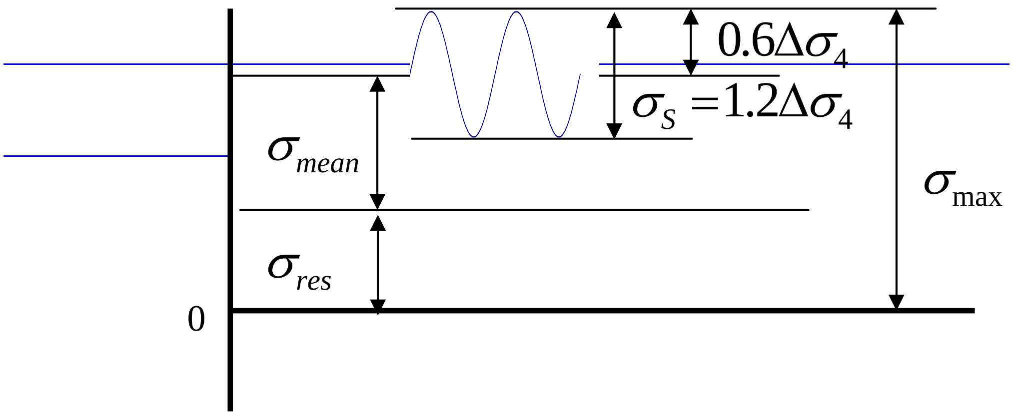


Fig. A1 Illustration of the relationship of σ_{res}, σ_{mean} and σ_S

4. However, in the cases of fatigue strengths of any of the welded joints of primary members, initial residual stress values of 0.25 R_{eH} are too conservative considering the tendency of fatigue damage, especially, in those cases where mean stresses of all loading conditions are compressions.

In the case of weld joints of primary members, any residual stresses after removal of applied loads can be still evaluated by the following equation in order to consider shake-down effects.

$$\sigma_{res}' = \sigma_{m1} - \sigma_{mean1}$$

Where,

σ_{m1} : the mean stress of the "Condition 1" considered the shake-down effect

σ_{mean1} : the structural mean stress in the "Condition 1".

However, in cases where σ_{mean1} is a compression, σ_{res}' should be taken to equal 0 considering the damage tendencies of the welded joints of primary members.

5. In conclusion, the treatment of residual stresses of primary members is to be changed as specified by the RCP.