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Basis of IACS Unified Longitudinal Strength Standard

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ABSTRACT

Classification societies of maritime states have established a variety of their own technical rules on ships' hull structures, installations and surveys under which a great number of classed ships are designed, built and operated during their whole life of service. On the other hand, the International Association of Classification Societies (IACS) requirements have been drawn up to unify the requirements of classification rule of the societies. Recently, the IACS Requirement S11 'Longitudinal Strength Standard' which forms the basic structural requirement for hull strength was established, and was agreed at the 22nd Session of the IACS Council Meeting to be introduced into the requirements of the rules of each classification society in April 1991. With the establishment of this unified requirement, a remarkable step forward has been taken in the international trend towards the long-wished-for unification of hull strength standards for ships. In this specific connection, IACS Requirement S11 and its technical background are outlined in this paper, followed by a brief discussion on the relationship between this Requirement and the relevant rule requirement of each classification society.

Key words: longitudinal strength, long-term prediction, wave-induced bending moment, wave-induced shear force, non-linear calculation of wave response, IACS Requirement, rules of classification society.

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1 LONGITUDINAL STRENGTH STANDARD

The draft Longitudinal Strength Standard for hull girders was approved at the IACS Council Meeting in May 1989, whereby it was determined that the standard was to be implemented as IACS Requirement S11.[1] The authors wish to briefly introduce the history behind the formation of S11 as well as the IACS Requirement S7[2] which is closely related to S11.

Unification of the classification societies' requirements for ship longitudinal strength, which should be taken as the basis of hull structural strength, has been the largest issue resting on the shoulders of the Working Party on Strength of Ships (WP/S) since the foundation of IACS. Needless to say, the longitudinal strength of a ship governs the basic scantlings of primary structural hull members such as decks, side shell plates, double bottom structures and longitudinal bulkheads, thereby having a significant influence upon hull weight, cargo deadweight capacity and ship price.

The importance of unification of the longitudinal strength standards has long been discussed in academic circles, shipbuilding and shipping communities. However, it was easily anticipated that considerable time and effort would be needed before the relevant requirements of classification societies would be amended to a unified standard considering the long record of existing classification society rules which have been formed through their own studies and experiences. It was first necessary to establish a sufficient technical basis for a unified standard, and then to reach a mutually agreed form on the understanding and with the cooperation of each IACS member society.

In 1973, IACS prepared for the first time a unified requirement UR No. 61 as the first step towards unification of the longitudinal strength standards of ships. Since then, this standard has been revised twice, in 1976 and 1978, and it is now implemented as IACS Requirement S7. IACS Requirement S7 was formulated on the basis of the records of scantlings of ships then in operation where the minimum required value of hull girder section modulus was specified in terms of the principal dimensions of ships without taking into consideration the stress criterion of the ships.

On the other hand, each classification society had already established its own requirements for the section modulus of hull girder that had been determined on the basis of the longitudinal bending stress caused by still water bending moments and wave-induced ones. It was thus necessary to unify these requirements but, as previously mentioned, the unification work of the existing rules of the societies was extremely difficult because the calculation formulae for wave-induced bending moment and shear force, as well as the allowable values of longitudinal bending and shearing stresses in hull girder, were to be reasonably determined by the common consent of the societies.

Regarding wave-induced bending moments, for example, each classification society had set out its own detailed requirements for them while, in studies, analytical approaches have been widely used based on the strip method for wave load calculations. It was also considered that a more logical standard formula could be derived by referring to the results of model experiments and theoretical analyses on the non-linear characteristics of wave-induced bending moments as has recently been pointed out by research groups. In these circumstances, the unification work has been carried out by also performing detailed analyses on the societies' existing wave load rules and corresponding theoretical studies.

There have been comparatively fewer specific studies on shear strength, however, and relatively large discrepancies were seen among the corresponding existing classification society rule requirements. What is more, there was the need for the shear strength requirement to be consistent with that for bending strength. These points were thus recognized as the major difficulties in this work of unification of classification society rules.

With substantial efforts made through discussions at the annual WP/S meetings and exchanges of documents during this long 10-year period, the final draft of IACS Requirement S11 was submitted to the IACS Council in May 1989, and was approved in one accord.

Since the problems of buckling strength and fatigue strength of longitudinal members of hull girders are an important part of the longitudinal strength of ships, extensive studies have been continuously carried out by WP/S following the establishment of the longitudinal strength standard, and relevant requirements relating to these items are expected to be prepared in the future.

2 IACS REQUIREMENT S11

The IACS Requirement S11 has been completed on the basis of a common consensus among classification societies to determine the maximum value of wave-induced load combined with still water load, and furthermore to determine allowable stress levels in hull girders by taking into account the scantlings of existing ships. The major contents of the standard are as follows.

2.1 Application

The scope of application of this standard is specified in S11.1. For ships having the following features ((i)–(vii)), special consideration should be taken in addition to the present unified requirement:

- (i) proportion: $L/B \leqslant 5$, $B/D \geqslant 2{\cdot}5$, where B is ship breadth, and D is depth,
- (ii) ship length: $L \geqslant 500$ m,
- (iii) block coefficient: $C_b < 0{\cdot}6$,
- (iv) large deck opening,
- (v) ships with large flare,
- (vi) carriage of heated cargoes,
- (vii) unusual type or design.

2.2 Still water bending moment and shear force

A standard loading condition to determine the still water bending moment and still water shear force is specified in S11.2.1. The sign conventions for these, to be superimposed on the wave-induced values, are defined in Fig. 1.

Because these definitions have not been unified in the conventional calculations for still water bending moment found by shipyards and those shown in the loading manual, care must be taken in the future.

2.3 Wave-induced bending moment

Wave-induced bending moment, WIBM, is specified in S11.2.2.1 as the maximum value predicted to occur during the life of a ship, where the probability level of exceedance on the long-term prediction of wave-induced load is assumed to be in the order of 10^{-8}. Further, by referring to the results of the non-linear calculations of hull girder wave response and the calculation formulae established by various classification societies (see Section 3.1), the following formula has been determined:

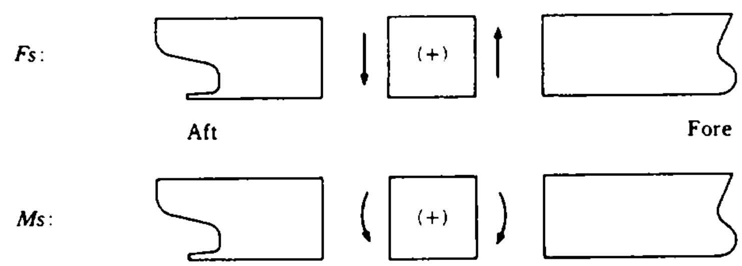

Fig. 1. Sign conventions for still water bending moment (*Ms*) and shear force (*Fs*).

$$Mw(+) = +0{\cdot}19MCL^2BC_b \quad \text{(kN-m)} \quad \text{hogging moment}$$
$$Mw(-) = -0{\cdot}11MCL^2B(C_b + 0{\cdot}7) \quad \text{(kN-m)} \quad \text{sagging moment} \tag{1}$$

where L and B are in metres; C_b should not be made smaller than 0·6.

$$C = 10{\cdot}75 - \left(\frac{300 - L}{100}\right)^{1{\cdot}5} \qquad 90 \leqslant L \leqslant 300$$
$$= 10{\cdot}75 \qquad 300 < L < 350$$
$$= 10{\cdot}75 - \left(\frac{L - 350}{150}\right)^{1{\cdot}5} \qquad 350 \leqslant L$$

M is the distribution factor for the wave-induced bending moment shown in Fig. 2.

2.4 Wave-induced shear force

As in the case of the wave-induced bending moment, the value of the wave-induced shear force, WISF, has been specified in S11.2.2.2 as the maximum value that would be encountered in the service life of a ship, and is expressed by the following formulae which takes into account the effects of non-linearity of the shear force due to the ship's hull form.

$$Fw(+) = +0{\cdot}3F_1CLB(C_b + 0{\cdot}7) \quad \text{(kN)}$$
$$Fw(-) = -0{\cdot}3F_2CLB(C_b + 0{\cdot}7) \quad \text{(kN)} \tag{2}$$

where L, B, C_b, C are as specified in Section 2.3, and F_1 and F_2 represent distribution factors of the wave-induced shear force shown in Figs 3 and 4.

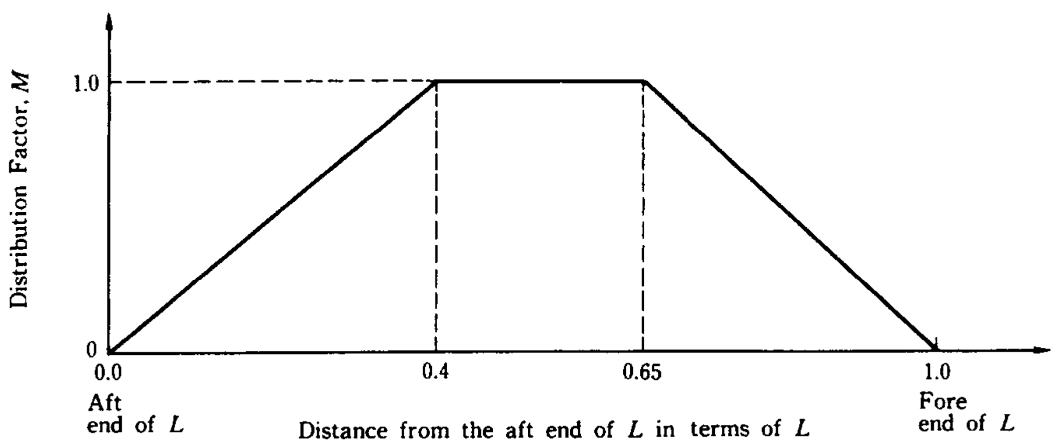

Fig. 2. Distribution factor of wave-induced bending moment, M.

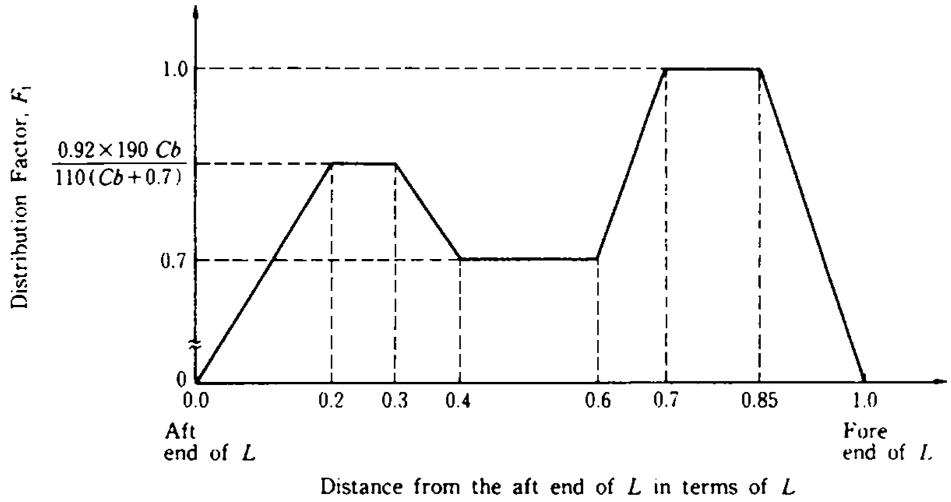

Fig. 3. Distribution factor of wave-induced shear force, F_1.

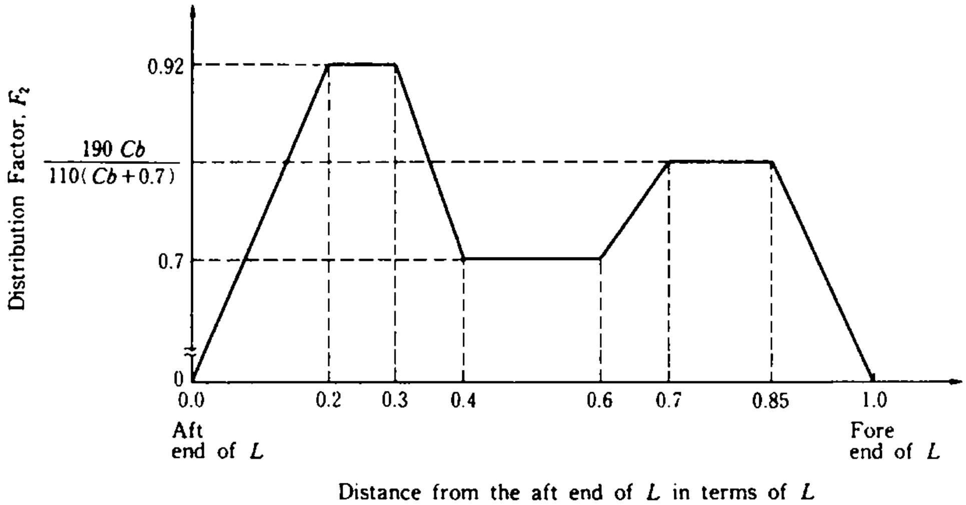

Fig. 4. Distribution factor of wave-induced shear force, F_2.

2.5 Bending strength

The requirement for longitudinal bending strength is established in S11.3 for the midship section of length 0·4*L*. Since the longitudinal bending strength at the forward and aft sections of the hull have less influence on determining the scantlings of structural members when compared with the midship section and also because the current practice of the various classification societies in handling these parts is not necessarily in accord, no unified requirement for the forward and aft sections has been established.

The ship midship bending strength is specified by section modulus and moment of inertia[3] of the hull girder. The section modulus is so determined that the stress caused by the total amount, namely the sum of the wave-induced bending moment specified in Section 2.3 and the still water bending moment as given in Section 2.2, does not exceed the allowable stress given below, and also that it conforms to the IACS Requirement S7 which specifies the minimum value of hull girder section modulus. The allowable stress level has been set at 175 N/mm^2 recognizing the proven fact that ships have been built for many years according to the rules of classification societies for determining ship longitudinal strength member scantlings.

In the IACS Requirement S7, the minimum value of the section modulus of hull girder, W_{min}, is specified as follows:

$$W_{min} = CL^2B(C_b + 0{\cdot}7) \qquad (cm^3) \qquad (3)$$

Although this requirement has been established on the basis of the records of existing ships in operation, the specific relation with the IACS Requirement S11 can be obtained as shown below from formulae (1) and (3).

$$W_{min} = \frac{|Mw(-)|}{110(N/mm^2)} \qquad (4)$$

Namely, the requirement has been interpreted so as 'to secure the section modulus of the hull girder so that the longitudinal bending stress due to wave-induced bending moments is to be maintained below 110 N/mm^2 at all times, even for a ship whose loading condition is such that the still water bending moment is negligible.'

2.6 Shearing strength

Requirements on shear strength are established in S11.4 so that the scantlings of ship side shell plating and longitudinal bulkhead plating are determined throughout the ship's length in accordance with the wave-induced shear force, still water shear force and allowable stress. As in the case of bending strength, the allowable stress for shear strength has been set at 110 N/mm^2, recognizing the proven records of ships in operation.

Besides the above, the following items have been established but their details are left to be specified at the discretion of each classification society:

(a) When the alternate loading system is employed for a bulk carrier, the value of the still water shear force acting on the side shell plating should be corrected by modifying the value obtained from Section 2.2, taking into account the fact that a part of the still water shear force is shared by structural members in the double bottom.

(b) Still water shear force should be corrected to take into account the effects of the local loads created in an oil tanker.

(c) The ratio of shear force shared by the side shell plating and that shared by longitudinal bulkhead plating should be taken into account.

3 DISCUSSION

3.1 Wave-induced bending moment

Calculation of the wave-induced bending moment formula in Section 2.3 has been determined by referring to the calculation formulae for the wave-induced bending moment specified in the present rules of the various classification societies.[4–14] It is, therefore, instructive to now conduct a comparison between them.

The calculation formulae for wave-induced bending moment specified by various classification societies have been established as corresponding to the values of the long-term prediction of wave-induced loads and the probability of exceedance levels determined by the respective societies. The interpretation of probability level differs from society to society within the range 10^{-4} to 10^{-8}.

If the calculation formula of each classification society is converted into one that corresponds to a 10^{-8} probability level by assuming that the long-term distribution of wave-induced bending moments is an exponential distribution, then the value of wave-induced bending moment obtained from the formula as specified in Section 2.3 can be compared with those obtained from the rules of each classification society at the 10^{-8} probability level. Table 1 presents the results of such a calculation on 12 existing ships with lengths varying from approximately 90 m to 320 m. The values given in the upper row in Table 1 show the mean values of wave-induced sagging moments for these ships divided by the values of $Mw(-)$ given by formula (1) while, the values given in the lower row, show the mean values of the wave-induced hogging moments obtained in the same manner. As can be seen from the table, $Mw(-)$ of S11 is close to the mean value of the wave-induced sagging moment used by each classification society whereas $Mw(+)$ is smaller by approximately 7% than the average value of the wave-induced hogging moments used by the societies.

The formulations of wave-induced bending moment (eqn (1)) can now be compared with the results of theoretical calculations on the long-term

TABLE 1
Comparison of Wave-Induced Bending Moment between IACS Requirement S11 and Rules of Classification Societies at 10^{-8} Probability Level (Average of 12 Ships)

Rules of Classification Societies		*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*Average*
WIBM (Rule of Classification Society)	Sag	0·89	0·95	0·97	0·93	1·04	0·91	1·04	1·16	1·06	1·07	1·00
WIBM (IACS Req. S11)	Hog	0·97	0·93	0·97	0·95	1·14	1·00	1·14	1·27	1·17	1·17	1·07

Note: Symbols *A–J* indicate the Rules of IACS member societies.

TABLE 2
Comparison of Wave-Induced Shear Force between IACS Requirement S11 and Rules of Classification Societies at 10^{-8} Probability Level (Average of 12 Ships)

Rules of Classification Societies		*A*	*B*	*C*	*D*	*E*	*F*	*G*	*I*	*J*	*Average*
WISF (Rule of Classification Society)	Sag	0·85	1·13	1·25	1·10	1·39	0·77	1·23	0·92	1·08	1·08
WISF (IACS Req. S11)	Hog	0·93	1·24	1·37	1·11	1·53	0·85	1·35	1·01	1·18	1·17

Note: Symbols *A–J* indicate the Rules of IACS member societies.

prediction of wave loads based on the linear analysis performed by IACS member societies using their own computer programs on wave response calculations.[15] The calculations were conducted on a container ship with principal dimensions of $L \times B \times D \times C_b$ = 158·48 m × 24·23 m × 14·07 m × 0·567, and the results are shown in Fig. 5. Since the calculations were performed by computer programs with different parameters of wave data, transfer function, and so on, a wide scatter of results is realised. However, the values obtained from formulae (1), for which the probability level is assumed to be 10^{-8}, are almost consistent with the theoretical calculation results of long-term prediction, varying from 10^{-6} to 10^{-9} for sagging moment and from 10^{-5} to 10^{-8} for hogging moment, respectively.

When the effects of non-linearity are considered in the hull response calculations, it is known that a difference exists between the calculated values of hogging and sagging moments; this has also been verified by test results. For example, Ohtsubo *et al.*[16] made an analysis of wave-induced bending moments imposed on a container ship of L = 200 m and C_b = 0·581, proceeding in irregular waves (significant wave

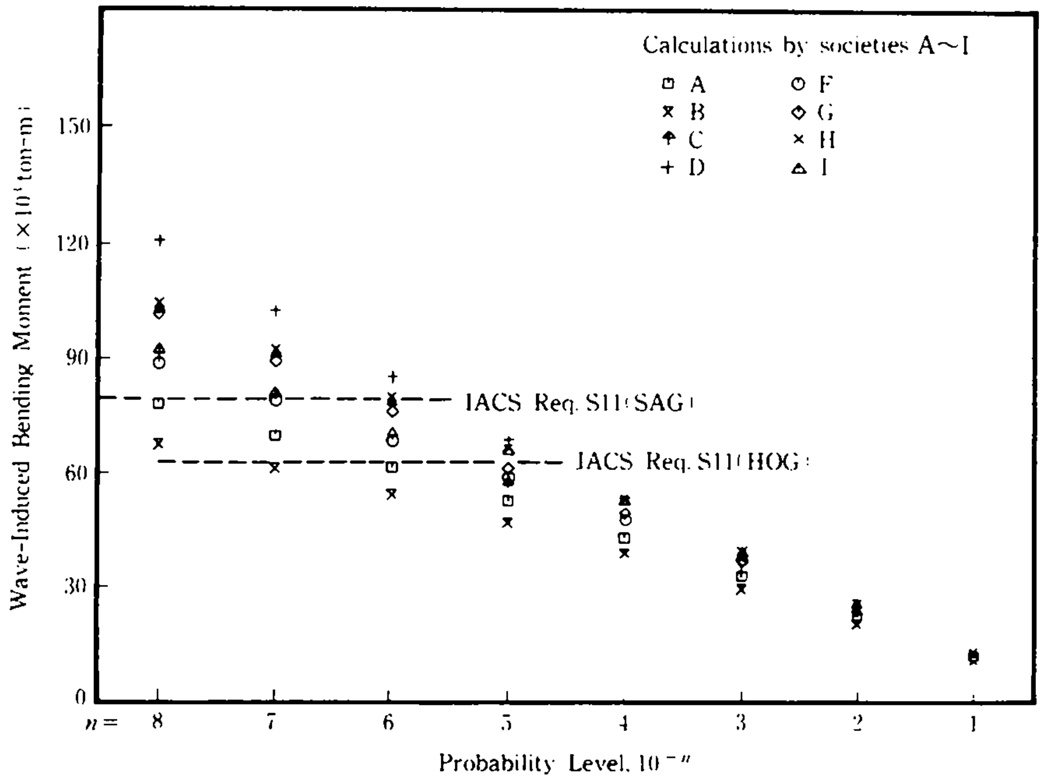

Fig. 5. Comparison of wave-induced bending moments between IACS Requirement S11 and the results of theoretical calculations of the long-term predictions performed by classification societies on a container ship with principal dimensions of $L \times B \times D \times C_b$ = 158·48 m × 24·23 m × 14·07 m × 0·567 and V = 0 knot.

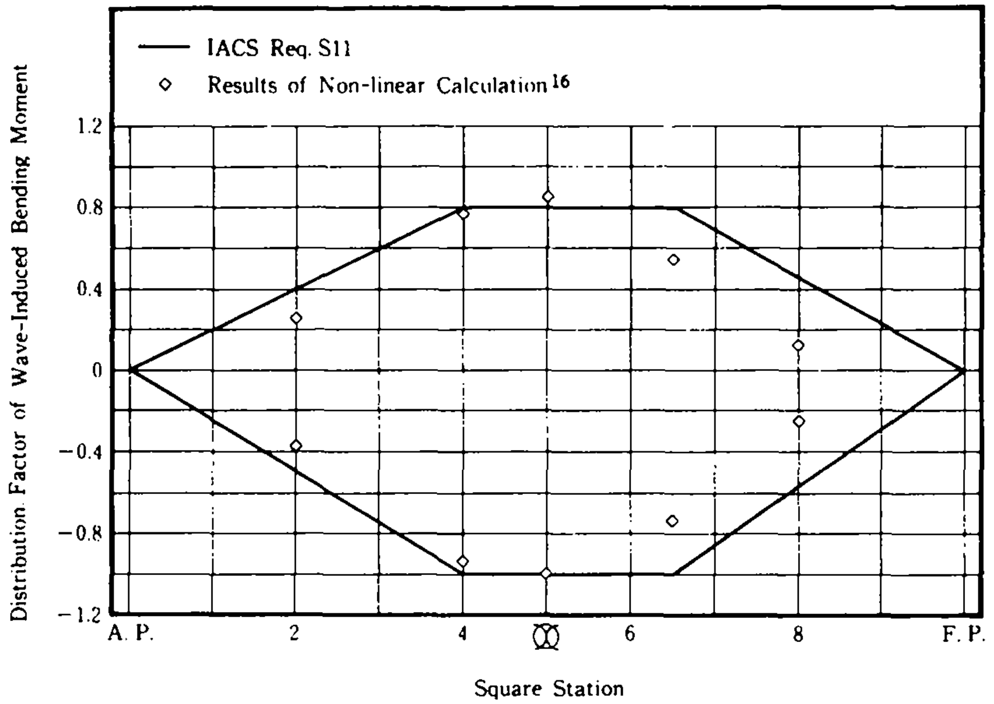

Fig. 6. Comparison of distribution factor of wave-induced bending moment between IACS Requirement S11 and the results of non-linear calculations.[16]

height = 8 m, against head waves with 90 crests having a mean wave period of 11·6 s). From these, the distribution factor of wave-induced bending moments (the values at various locations of a ship divided by the maximum value of sagging moment) were obtained and are as shown in Fig. 6. On the basis of the results of a number of non-linear calculations conducted so far, it has been noted that the differences between the maximum values of sagging and hogging moments increase as C_b becomes smaller, and that the hull locations where these maxima occur are different when the non-linearity due to hull forms is considered as well as those in the loads due to slamming and whipping.[17–24] In IACS Requirement S11, the difference between the values of sagging moments and hogging moments in particular was noted, and the distribution factor of wave-induced bending moments as shown by the solid lines in Fig. 6, which agrees well with the results of the presented calculations.

According to IACS Requirement S11 (see eqn (1)), the ratio of hogging to sagging moment can be expressed as follows:

$$\frac{|Mw(+)|}{|Mw(-)|} = \frac{1{\cdot}73C_b}{C_b + 0{\cdot}7} \qquad (5)$$

where C_b is to be taken equal to 0·6 when $C_b < 0{\cdot}6$.

The above relationship is depicted by the solid line in Fig. 7. Similar

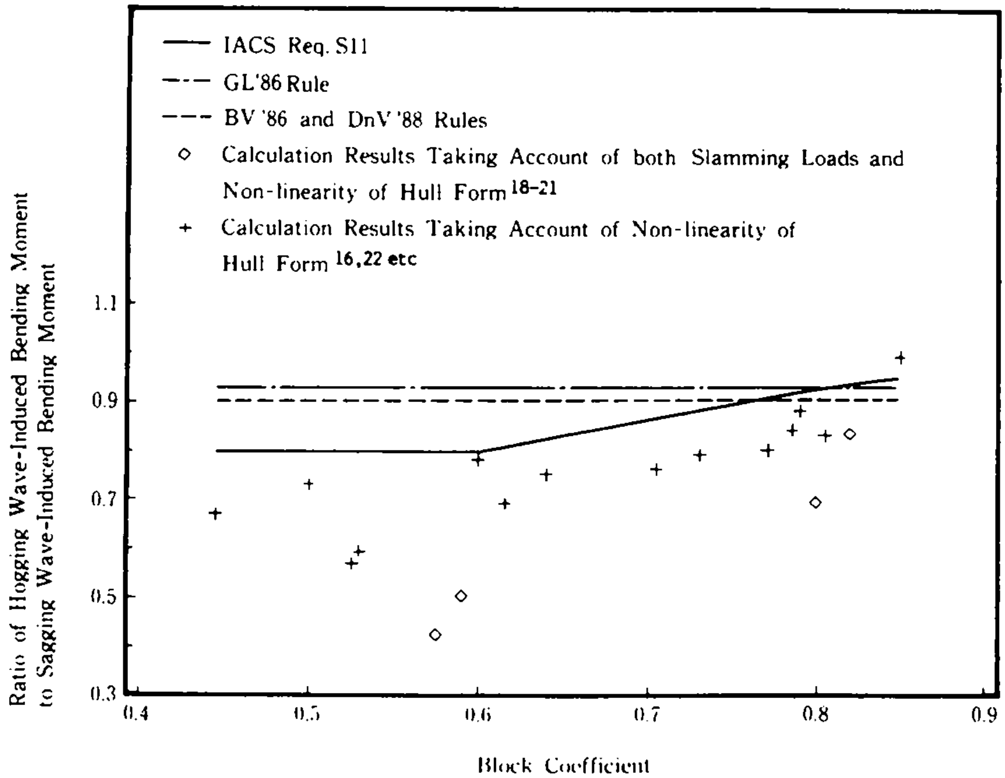

Fig. 7. Non-linearity in wave-induced bending moment.

ratios for the rule formulae of Germanischer Lloyd[7], Bureau Veritas[5] and Det norske Veritas[6] are also shown.

For comparison, the results of non-linear calculations given in the literature[16, 18-22] are also shown in Fig. 7. The results refer to the cases where non-linearity of hull form only is considered, and also where the effects of non-linear loads due to slamming and whipping also are considered in addition to that of the hull form. As can be seen from this figure, it may be interpreted that in IACS Requirement S11 the effect of the non-linearity of ship's hull form is considered in the main, while the load increment due to slamming and whipping is not taken into account since these effects can be avoided to a certain degree through manoeuvering efforts such as course changes and speed reductions of ships.

3.2 Wave-induced shear force

For the wave-induced shear forces introduced in Section 2.4, the positive values $Fw_2(+)$ and $Fw_7(+)$ and negative values $Fw_2(-)$ and $Fw_7(-)$ at locations $0{\cdot}2L$ and $0{\cdot}7L$ from the aft end of a ship, respectively, can be expressed as follows:

$$Fw_2(+) = 0{\cdot}476CLBC_b = -0{\cdot}92Fw_7(-)$$
$$Fw_2(-) = -0{\cdot}276CLB(C_b + 0{\cdot}7) = -0{\cdot}92Fw_7(+) \qquad (6a)$$

$$Fw_7(+) = 0{\cdot}30CLB(C_b + 0{\cdot}7) = -2{\cdot}7\frac{Mw_5(-)}{L}$$
$$Fw_7(-) = -0{\cdot}52CLBC_b = -2{\cdot}7\frac{Mw_5(+)}{L} \qquad (6b)$$

where $Mw_5(+)$ and $Mw_5(-)$ are the wave-induced hogging and sagging bending moments amidships.

As can be seen from the above formulae, $Fw_7(+)$ and $Fw_2(-)$ are directly proportional to the sagging moment $Mw_5(-)$ amidships. In other words, these correspond to the wave-induced shear force generated by sagging waves. Similarly, $Fw_7(-)$ and $Fw_2(+)$ are directly proportional to the hogging moment $Mw_5(+)$ amidships, thus corresponding to the wave-induced shear force generated by hogging waves. In this respect, it is to be noted that the wave-induced shear force given in IACS Requirement S11 clearly indicates correlation with the wave-induced bending moment.

From eqns (6a) and (6b), the effects of non-linearity upon wave-induced shear force can be expressed as follows:

$$\frac{|Fw_2(+)|}{|Fw_2(-)|} = \frac{|Fw_7(-)|}{|Fw_7(+)|} = \frac{|Mw_5(+)|}{|Mw_5(-)|} \qquad (7)$$

Equation (7) suggests that the effects of non-linearity in wave-induced shear force are similar to those in wave-induced bending moments. Furthermore, as can be seen from Fig. 8, the wave-induced shear force determined by the above formula agrees quite well with the results of the non-linear calculations by Ohtsubo *et al.*[16]

Next, a comparison is made between the required value of wave-induced shear force determined by the IACS Requirement S11 formula and those obtained from the rules of various classification societies after converting to the 10^{-8} probability level as in the case of wave-induced bending moments. Since the calculation formula for the wave-induced shear force specified in each classification society rule contains several different parameters relating to hull form, each shear force value calculated for the twelve ships demonstrates wide scatter from ship to ship. Therefore the comparison is conducted by taking an average value for the twelve ships and this is shown in Table 2. As can be seen from Tables 1 and 2, the values between societies of wave-induced shear force

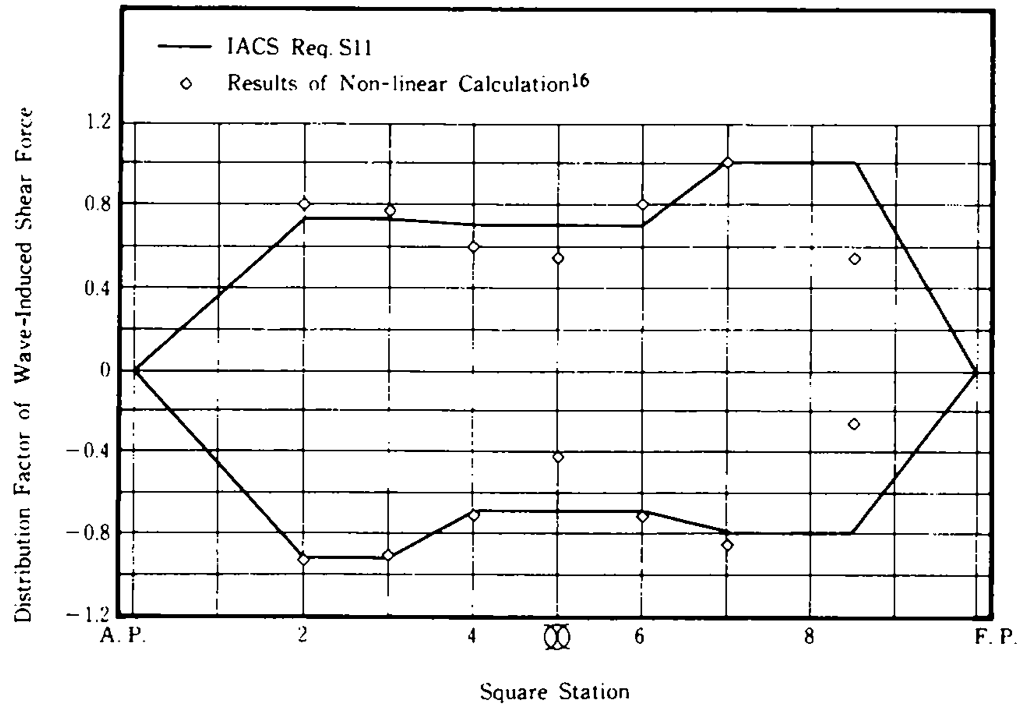

Fig. 8. Comparison of distribution factor of wave-induced shear force between IACS Requirement S11 and the results of non-linear calculations.

differ more than in the case of wave-induced bending moments. Also, the value of wave-induced shear force specified in IACS Requirement S11 is smaller than the average value of the requirements of the various classification societies, approximately 8% for the sagging condition, and approximately 17% for the hogging condition.

3.3 Required bending strength

Figure 9 shows the required values of section modulus determined from combined wave-induced and still water bending moments that cause the ships to sag among the loading conditions of the ships in operation. It can be seen from this figure that the values required by IACS Requirement S11 are nearly equal to the mean value of the requirements by the various classification society rules. In contrast, Fig. 10 shows the required values in the hogging condition where it is seen that the IACS Requirement S11 values are slightly smaller than the mean values required by the various classification society rules. It is therefore expected that in ships like container ships, in which the still water bending moment mainly assumes the hogging condition, the required value by IACS Requirement S11 would be slightly smaller than the conventional requirements by the rules of various classification societies.

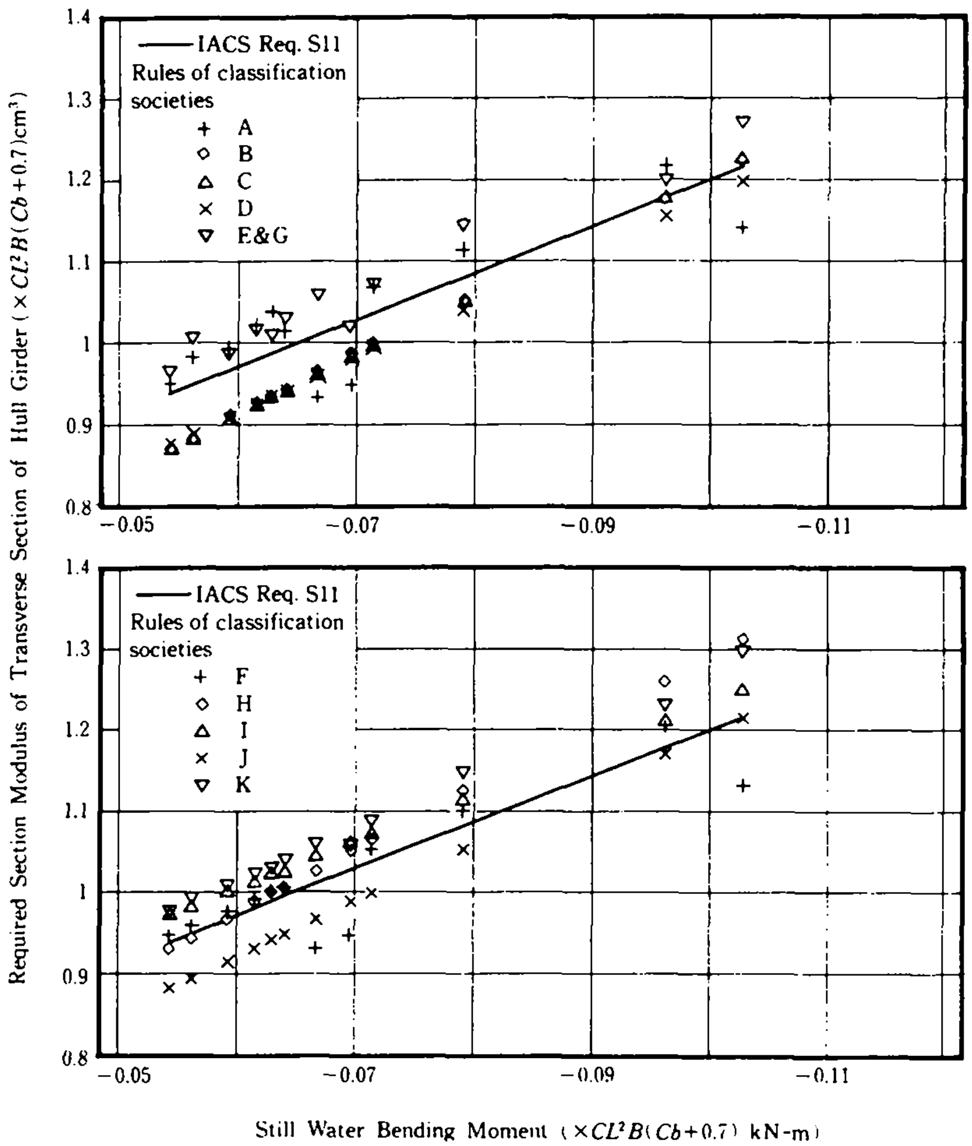

Fig. 9. Comparison of bending strength requirement between IACS Requirement S11 and Classification Society Rules for a sagging condition at midship section.

3.4 Required shear strength

On shear strength, the plate thickness requirements for side shell plating at the location $0{\cdot}7L$ from the aft end of a ship by both the IACS Requirement S11 and the various classification society rules are compared in Fig. 11. Here the plate thickness requirements are determined from combined wave-induced and still water shear forces that cause the ships to sag among the various loading conditions of the ship in operation.

On the other hand, Fig. 12 shows the required values for the hogging condition. From these figures, it can be seen that in both sagging and

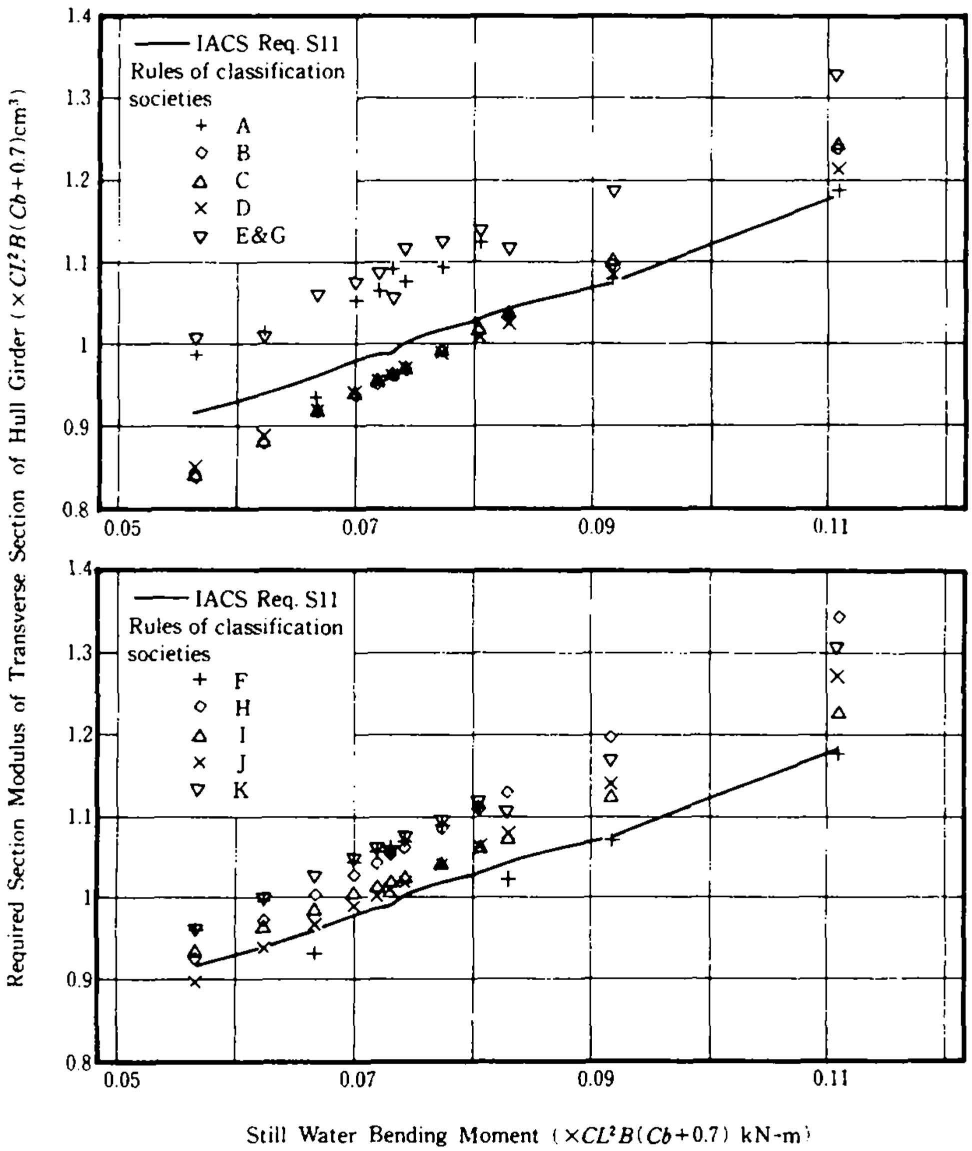

Fig. 10. Comparison of bending strength requirement between IACS Requirement S11 and Classification Society Rules for a hogging condition at midship section.

hogging conditions, the required values of the IACS Requirement S11 are slightly larger than the average values of the requirements by the rules of various classification societies.

4 REMARKS FOR FUTURE DEVELOPMENT

The IACS member societies have come to the conclusion that, at present, the proposed requirements for longitudinal strength of ships are a suitable standard as the unified rules of the IACS member societies to be implemented in the relevant parts of the technical rules. The unified

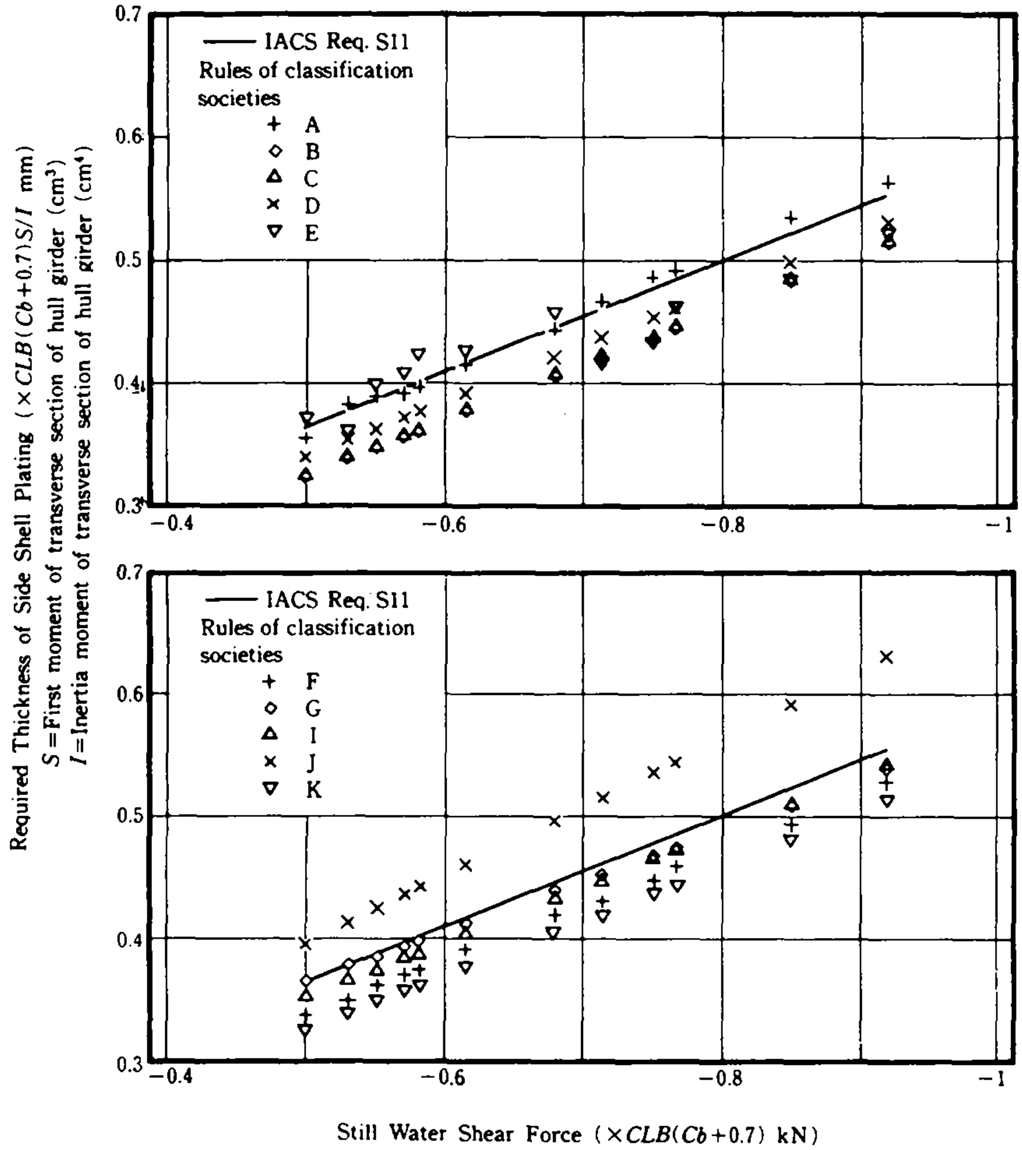

Fig. 11. Comparison of shearing strength requirement between IACS Requirement S11 and Classification Society Rules for a sagging condition at 0·7*L* from after end of ship.

rules should of course be applied in general to the ships of ordinary type for normal operation and unrestricted services as specified in Section 2.1, so that the majority of ships classed with the IACS member societies are of an equal quality at least in the structural design of the ship, fulfilling the minimum level of ship's hull longitudinal bending and shear strengths. For ships to be built of a special type of structural design or to be engaged in particularly specified services or duties, the classification societies are to independently consider the safety and economy of the ship in each case and give their own rational evaluation standard for the design procedure of such special purpose ships.

Since the IACS unified standards are of a nature to be perpetually

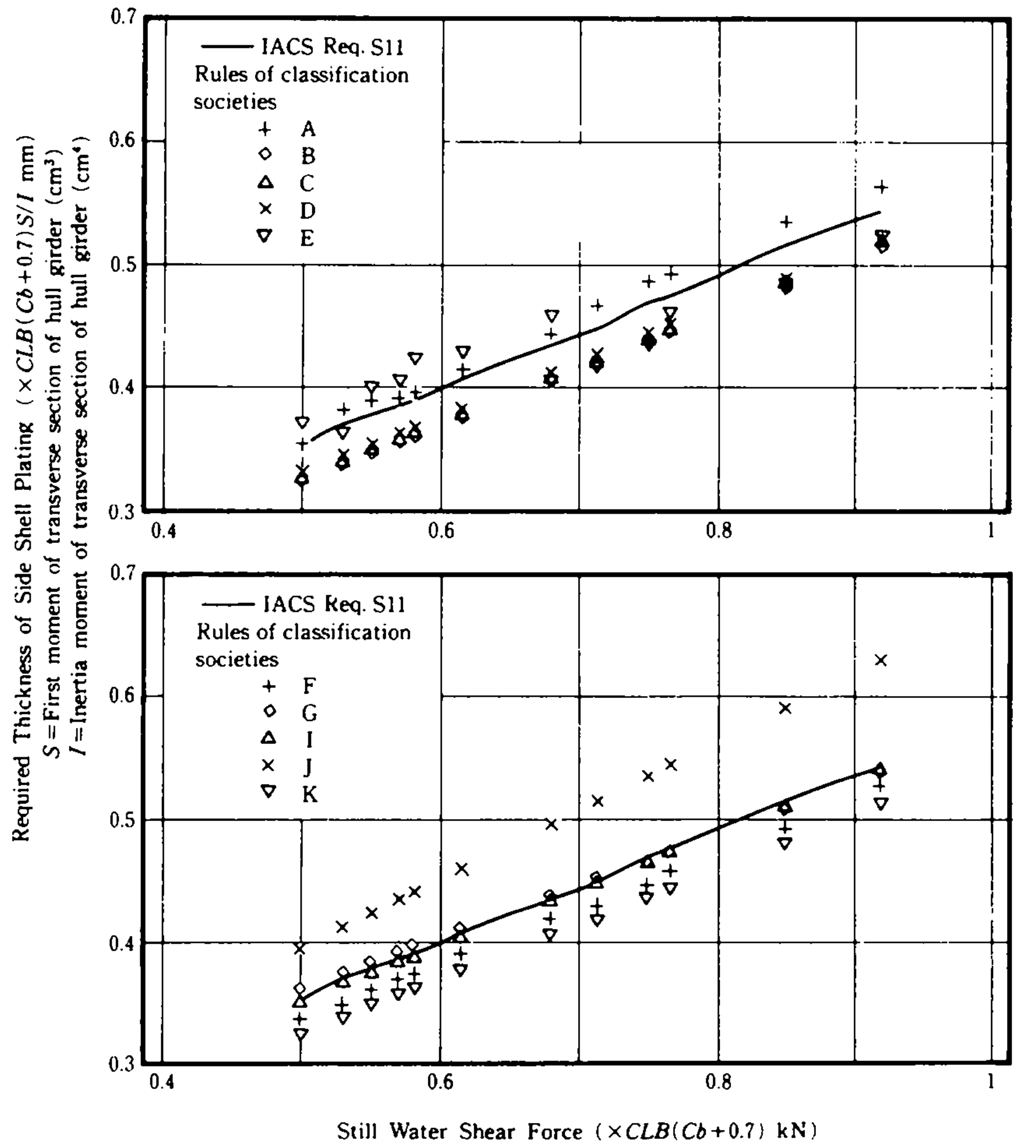

Fig. 12. Comparison of shearing strength requirement between IACS Requirement S11 and Classification Society Rules for a hogging condition at 0·7L from after end of ship.

checked and evaluated through the feedback from the actual records of ships in service, thorough investigations have to be carried out into the causes of any unreasonable problems encountered in the application of the unified standards. In this respect, it should be borne in mind that the longitudinal strength standard must have once been unified with the consent of the member societies so that IACS may easily cope with such unexpected matters for improving and revising the technical standards on the basis of the established rules.

During the course of the development of the IACS unified standards, consideration was also given to the possibility of the relevant application of so-called advanced reliability methods to the formulation of longitudinal strength criterion. The theoretical treatment based on reliability methods is well established at present and a large number of research works have already been reported on the results of application to the structural design procedure of ships. However, most of the papers are only concerned with a limited pattern or mode of structural failure under certain given conditions of ship operation, mainly due to lack of sufficiently relevant data related to the actual performance of ships in service. As has been pointed out from the results of reliability studies, appropriate evaluation of external loads is one of the most important and dominant tasks to be solved in the formulation of the strength criteria. A distinguished research work, for example, on wave data has recently been introduced by ISSC Committee I.2[25] which would certainly play a profitable role in the determination of wave loads.

It is thus the present authors' view that the IACS efforts are to be directed from now on towards further rationalization of the IACS unified standards through a comprehensive research activity which should concentrate on the evaluation of accumulated data and materials related to the future development of more reliable criteria on the longitudinal strength of ships.

5 CONCLUSIONS

The IACS Requirement S11 has been drawn up mainly on the basis of the existing rules of various classification societies, i.e. the proven records of class vessels. However, it is considered noteworthy that the calculation formula for wave-induced loads introduced under the new design concept takes into account the effects of the non-linearity of hull form, and that the wave-induced bending moment and shear force are specified as the maximum values in the service life of a ship. When the requirements of the various classification society rules are unified in accordance with the IACS Requirement S11, unprecedented benefits will be brought about in ship design and operation. *Inter alia*, freedom to choose a classification society without changing the basic design philosophy at the design stage of a sister ship, and the elimination of possible loading restrictions that might have been imposed at the time of a class change are considered to be of a considerable advantage for ship designers, owners and operators.

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During the course of study and discussions made by the IACS Working Party on Strength of Ships, a large number of documents were prepared by the member societies and valuable information and technical data were exchanged among the members for their review. In this paper, some of the data are referred to when analysing the wave loads as specified by the existing rules of the classification societies.

REFERENCES

1. IACS Requirement S11, Longitudinal Strength Standard.
2. IACS Requirement S7, Minimum Longitudinal Strength Standards.
3. IACS Requirement S4, Criteria for the Use of High Tensile Steel with Yield Points of 315 N/mm^2 and 355 N/mm^2 with respect to Longitudinal Strength.
4. American Bureau of Shipping. Rules for Building and Classing Steel Ships, 1988.
5. Bureau Veritas, Rules and Regulations for the Classification of Steel Ships of More than 45 m in Length, 1986.
6. Det Norske Veritas, Rules for Classification of Steel Ships, 1988.
7. Germanischer Lloyd, Rules for the Classification and Construction of Seagoing Steel Ships, 1986.
8. Korean Register of Shipping, Rules for the Classification of Steel Ships, 1986.
9. Lloyd's Register of Shipping, Rules and Regulations for the Classification of Ships, 1987.
10. Nippon Kaiji Kyokai, Rules and Regulations for the Construction and Classification of Ships, 1986.
11. Polski Register Statkow, Rules for the Classification and Construction of Sea-going Ships, 1982.
12. Registro Italiano Navale, Rules for the Construction and Classification of Ships, 1986.
13. USSR Register of Shipping, Rules for the Classification and Construction of Sea-going Ships, 1987.
14. Register of Shipping of the People's Republic of China, Rules and Regulations for the Construction and Classification of Seagoing Steel Ships, 1983.
15. IACS WP/S AHG/WRC, Report on Wave Response Calculation for IACS Ship. April 1982, Report on Additional Calculations, April 1987.
16. Ohtsubo, H. & Kuroiwa, T., Non-linearity in sagging moment and shear force of fine ships. *Technical Bulletin of Nippon Kaiji Kyokai*, 7 (1989) 1–10.

17. Jensen, J. J. & Pedersen, P. T., Bending moments and shear forces in ships sailing in irregular wave. *Journal of Ship Research*, **25**(4) (1981) 243–51.
18. Yamamoto, Y., Fujino, M. & Fukasawa, T., Motion and longitudinal strength of a ship in head sea and the effects of non-linearities. *Journal of SNAJ*, **143** (1978) 179–87.
19. Yamamoto, Y., Fujino, M. & Fukasawa, T., Motion and longitudinal strength of a ship in head sea and the effects of non-linearities (3rd report). *Journal of SNAJ*, **145** (1979) 63–70.
20. Watanabe, I., Miyamoto, T., Yoshino, T., Yamamoto, T., Ishida, S., Tanizaiva, K. & Sawada, H., Model experiments on slamming and hull girder responses of a bulk carrier in fully loaded condition using the elastic model technique. *Journal of SNAJ*, **154** (1983) 505–15.
21. Toki, N., Hatakenaka, K., Takahashi, T., & Fujii, H., Experimental and theoretical approach to the estimation of non-linear vertical loads. *Journal of SNAJ*, **154** (1983) 141–50.
22. Fujino, M., Fukasawa, T., Eguchi, S., Nakaro, M., Kose, K., Toki, N. & Hashimoto, K., Application of nonlinear simulations of wave loads to the design of ship structures. Research project grant-in-aid for scientific research (1), Project No. 63850095 (1989).
23. Dawkins, R. A., Practical prediction methods for short and long term sagging and hogging moments. CADMO 1986 Paper.
24. Børrensen, R. & Tellsgård, F., Time history simulation of vertical motions and loads on ships in regular, head waves with large amplitudes. *Norwegian Maritime Research*, **8**(2) (1980) 2–12.
25. 2.4.4 — Long-term response. In Report of Committee I.2, Proceedings of the 10th International Ship & Offshore Structures Congress, Vol. 1. Department of Ocean Engineering Technical University of Denmark, Lyngby, 1988, pp. 121–2.