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Effect of ship structure and size on grounding and collision damage distributions

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Abstract

It has been argued that a major shortcoming in the International Maritime Organization (IMO) Interim Guidelines for Approval of Alternative Methods of Design and Construction of Oil Tankers in Collision and Grounding is that grounding and collision damages normalized by the main dimensions of the ship have the same probability density distributions regardless of a particular structural design and ship size.

The present paper explores analytical methods for assessing the overall effect of structural design on the damage distributions in accidental grounding and collisions. The results are expressed in simple expressions involving structural dimensions and the building material of the ships. The study shows that the density distribution for collision and grounding damages normalized by the main dimensions of the ship depends on the size of the ship. A larger ship has a higher probability of a larger relative damage length than that of a smaller ship in grounding damage. On the other hand, the damages to the side structure caused by ship collisions are found to be relatively smaller for large ships.

The main conclusion is that the existing IMO damage distributions will severely underestimate the grounding damages to the bottom structure of larger vessels and to a lesser extent overestimate collision damages to the side structure of the hull.

Keywords: Collisions; Damage size; Grounding; Probabilistic distribution; Ship structure

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1. Introduction

In September 1995, the International Maritime Organization (1995) (IMO) adopted Interim Guidelines for Approval of Alternative Methods of Design and Construction of Oil Tankers under Regulation 13F(5) of Annex I of MARPOL 73/78. These guidelines give a probabilistic procedure for assessing the oil outflow performance of an oil tanker design in collision and grounding.

One of the important elements in the guidelines is the damage density distributions, which were derived from the actual damage data of 52 collisions and 63 grounding accidents of oil tankers, chemical tankers, Ore/Bulk/Oil carriers of 30 000 tons deadweight and above (Hysing, 1993). This data was collected in the period from 1980 to 1990 by the classification societies American Bureau of Shipping (1990) (ABS), Det Norske Veritas (1991) (DnV), Lloyd's Register of Shipping (1997) (LR), Nippon Kaiji Kyokai (1997) (Class NK), and the Registro Italiano Navale (RINa). Fig. 1 shows the probability density distributions for the longitudinal length, the vertical penetration and the transverse extent of expected grounding damages in the IMO Guidelines. It can be seen from Fig. 1 that the bottom grounding damages are assumed to scale linearly with the main dimensions of the ship. In a similar way, the side collision damage distributions are assumed to scale linearly with the main dimensions of the ship.

Since the publication of the IMO Interim Guidelines, many authors have used them to assess the environmental performance of oil tankers, see Bockenhauer and Jost (1995) and Michel et al. (1996). The Society of Naval Architect and Marine Engineers (SNAME) formed a special technical committee to make a further assessment of the performance of oil tankers from 1995 to 1997 (Sirkar et al., 1997).

As discussed by Sirkar et al. (1997) and Rawson et al. (1998), a major shortcoming of the IMO Guidelines is that they do not consider the effect of the local structural design or the crashworthiness on the damage extent and that all tankers have the same non-dimensional damage distributions. Sirkar et al. (1997), Rawson et al. (1998) and Simonsen (1998) performed theoretical grounding analyses and established damage density distributions given a grounding event for a specific ship. These calculations are based upon many assumptions, such as the distribution of grounding speeds and the distribution of rock shapes and rock elevations. Therefore, the validity of the damage density distributions obtained by such theoretical calculation needs further verification. One way to validate these assumed distributions of speeds, ground shapes etc. is to choose the speed and the rock shape distributions, so that the calculated grounding damage distributions for old and traditional single-hull tankers become identical to the damage distributions derived by Hysing (1993) and represented by Fig. 1. The idea is then to use the same ground and speed distributions to construct damage distributions for the new generations of tankers. It is evident that the result of such direct calculation procedures depends strongly on the validity of the IMO damage distributions given in Fig. 1 for grounding damages and similar non-dimensional damage distributions for collision damages.

Previous analyses of bottom damages due to grounding on plane, sloping sand or rock bottoms have shown that larger ships suffer considerably larger bottom damages

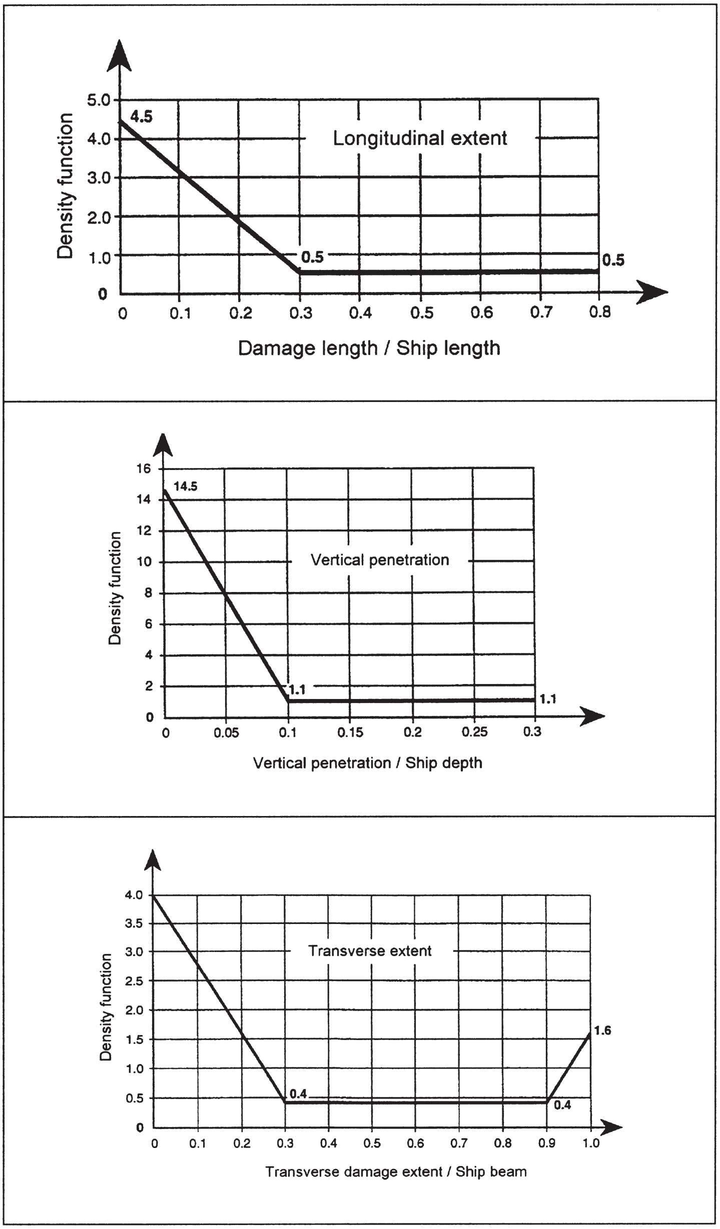

Fig. 1. Probabilistic density distributions for bottom grounding damages (International Maritime Organization, 1995).

than smaller ships. In addition, larger ships are exposed to larger hull girder sectional forces due to grounding (Pedersen, 1994).

In the present paper we shall first derive a procedure for analysis of the effect of ship size and building material on grounding on irregular rocks. That is grounding scenarios resulting in raking damage to the ship's bottom. Thereafter the results will be validated by a comparison with statistical grounding damage data. One purpose of this analysis is to investigate whether it is reasonable to assume that grounding damages scale linearly with ship dimensions, as assumed in the IMO Guidelines.

Similarly, an analytical procedure is derived for the prediction of damages due to ship-ship collisions, and compared to existing statistical results for side shell damages due to ship collisions and to previously published calculated collision damage distributions. Again the results of the collision analysis will be discussed in the light of the IMO representation of collision damage distributions.

2. Prediction procedures for the relative grounding damage

Recently, Pedersen and Zhang (1998) and Simonsen (1999) studied procedures for the analysis of the bottom raking damage distribution of high-speed craft. The main idea of these studies is to use the existing bottom damage distributions of conventional ships (such as IMO damage statistics) to predict the damage distributions of new high-speed craft. The studies show that high-speed craft have a significantly higher probability that the damage length normalized by the vessel length is larger than for conventional vessels. This procedure (Pedersen and Zhang, 1998) is further developed here to investigate the bottom damage distributions for oil tankers and conventional merchant vessels.

In grounding situations dominated by bottom raking, it may be assumed that the kinetic energy of a ship is totally dissipated by the destruction of the ship's bottom structures. Thus, we have

$$\frac{1}{2}M\cdot V^2=F\cdot L_{dam} \tag{1}$$

where M is the ship mass including the added mass effect, V is the grounding speed, F is the average horizontal grounding force, and L_{dam} is the damage length of the ship's bottom.

For two different ships, the ratio between the relative grounding damage length, i.e. the grounding damage length normalized by the ship length, (L_{dam}/L), can be expressed as

$$\frac{(L_{dam}/L)_1}{(L_{dam}/L)_2}=\frac{M_1}{M_2}\cdot\left(\frac{V_1}{V_2}\right)^2\cdot\frac{L_2}{L_1}\cdot\frac{F_2}{F_1} \tag{2}$$

where the subscripts represent the different ships. The major difficulty of this procedure is to determine the horizontal grounding forces F_1 and F_2. They depend on many factors, such as rock shape, rock elevation and the structural design.

Here we base the calculation of the grounding forces on a simple relationship between the dissipated energy and the destroyed material volume of the ship's bottom, previously applied by Pedersen and Zhang (1998):

$$E=3.21\left(\frac{t}{B_{dam}}\right)^{0.6}\sigma R_T \tag{3}$$

where t is the equivalent plate thickness of the bottom, including longitudinal webs and stiffeners in the tearing direction, B_{dam} is the width of the tearing object or damage width, σ is the flow stress of the material and R_T is the volume of damaged material.

The volume R_T of the destroyed material in bottom raking damage is approximately determined by

$$R_T=L_{dam}\cdot B_{dam}\cdot t_{eq}$$

where L_{dam} is the damage length, and t_{eq} is the equivalent material thickness of the whole bottom including transverse and longitudinal webs and stiffeners.

Therefore, the ratio, Eq. (2), between the relative damage for two different ships can be expressed as

$$\frac{(L_{dam}/L)_1}{(L_{dam}/L)_2}=\frac{M_1}{M_2}\cdot\left(\frac{V_1}{V_2}\right)^2\cdot\frac{L_2}{L_1}\cdot\left[\frac{\sigma_2}{\sigma_1}\cdot\frac{t_{eq2}}{t_{eq1}}\cdot\left(\frac{t_2}{t_1}\right)^{0.6}\cdot\left(\frac{B_{dam2}}{B_{dam1}}\right)^{0.4}\right] \tag{4}$$

From the right hand side of Eq. (4) it can be seen that all the parameters, except the damage width (B_{dam}), are known for two given ships. The damage width is related to ship size and the geometry of the grounding obstacle. It is assumed here that the vertical indentation of a rock into the ship's bottom is proportional to the draught of the ship. Obviously, the elevation of the rock above the baseline of a large ship is greater than that of a small ship, as shown in Fig. 2. This means that a ship with a larger draught suffers a larger vertical penetration. Therefore, a larger damage

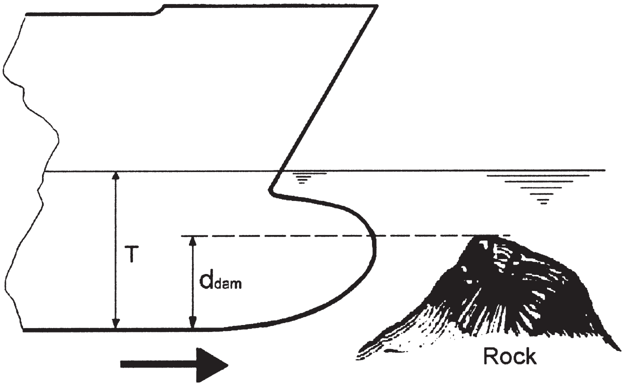

Fig. 2. The relationship between vertical penetration and ship draught in grounding.

width will also be created for a larger draught of a ship. Thus, the ratio between the damage width for two different ships is expressed as (T is the ship draught):

$$\frac{B_{dam2}}{B_{dam1}}=\frac{T_2}{T_1} \tag{5}$$

By comparison of Eqs. (2) and (4), it is found that the grounding force ratio (F_2/F_1) can be approximated as

$$\frac{F_2}{F_1}=\frac{\sigma_2}{\sigma_1}\cdot\frac{t_{eq2}}{t_{eq1}}\cdot\left(\frac{t_2}{t_1}\right)^{0.6}\cdot\left(\frac{T_2}{T_1}\right)^{0.4} \tag{6}$$

This formula has been verified against a large number of numerical and experimental results in Pedersen and Zhang (1998).

Based on rough statistics for existing ships and on the classification design rules, it is found that the equivalent thickness t and t_{eq} may be approximated by

$$\begin{cases} t=k_1\cdot L^{0.7}/\sqrt{f} \\ t_{eq}=k_2\cdot L^{0.7}/\sqrt{f} \end{cases} \tag{7}$$

where k_1 and k_2 are constants, L is the ship length in m, $f=\sigma/235$ is a material factor where σ is the flow stress (N/mm^2) of the material. The design draught of the ship is taken to be proportional to the length of the ship, that is

$$T=k_3\cdot L \tag{8}$$

where k_3 is a constant. By substitution of Eqs. (7) and (8) into Eq. (6), the ratio between the horizontal grounding forces for two different tankers is obtained as

$$\frac{F_2}{F_1}=\left(\frac{\sigma_2}{\sigma_1}\right)^{0.2}\cdot\left(\frac{L_2}{L_1}\right)^{1.52} \tag{9}$$

It can be seen from Eq. (9) that the grounding force increases with the length of the ship. Based on statistics and economic optimisation criteria, a ship's length can be related to the displacement of the ship by (Schneekluth, 1987):

$$L=C\cdot\nabla^{0.3}V_0^{0.3} \tag{10}$$

where ∇ is the ship's displacement in tonnes, V_0 is the design speed in knots, $C=3.2$ if the block coefficient has the approximate value of $C_B=0.145/F_n$ within the range of 0.48-0.85, and L is the length of the ship in meters. Substituting Eqs. (9) and (10) into Eq. (2) we get the relationship between the relative damage length for two different ships:

$$\frac{(L_{dam}/L)_1}{(L_{dam}/L)_2}=\left(\frac{\sigma_2}{\sigma_1}\right)^{0.2}\cdot\left(\frac{L_1}{L_2}\right)^{0.813}\cdot\left(\frac{V_1}{V_2}\right)^2\cdot\left(\frac{V_{02}}{V_{01}}\right) \tag{11}$$

For oil tankers, the design speed V_0 is normally around 12 to 15 knots. The difference is not large. Therefore, it is assumed that the design speed for all oil tankers is similar. It is also reasonable to assume that the distribution of the grounding speed is similar for all oil tankers. That is

$$\begin{cases}\dfrac{V_1}{V_2}=1\\ \dfrac{V_{01}}{V_{02}}=1\end{cases} \tag{12}$$

Thus, the approximation for the ratio between the relative damage length for two different tankers is

$$\frac{(L_{dam}/L)_1}{(L_{dam}/L)_2}=\left(\frac{\sigma_2}{\sigma_1}\right)^{0.2}\cdot\left(\frac{L_1}{L_2}\right)^{0.813} \tag{13}$$

For general cargo vessels, where the speed of the vessel is determined mainly by the Froude number F_n, this expression takes the form

$$\frac{(L_{dam}/L)_1}{(L_{dam}/L)_2}=\left(\frac{\sigma_2}{\sigma_1}\right)^{0.2}\cdot\left(\frac{F_{n1}}{F_{n2}}\right)\cdot\left(\frac{L_1}{L_2}\right)^{1.313} \tag{14}$$

From Eqs. (13) and (14) it can be seen that the relative damage length in grounding events depends upon the size of the ship. Larger ships suffer larger relative damage length. This reflects the influence of the structural design or ship size on the distribution of grounding damage length. It is also seen from Eqs. (13) and (14) that the flow stress of the material has a weak influence on the relative damage length.

3. Discussions and comparison with grounding damage data

Fig. 3 shows how the calculated relative damage length ratio varies with tanker ship lengths in the interval from 100 to 300 m. From the results it can be seen that for similar conditions the relative damage length of a 240 m tanker is two times that of a 100 m tanker. This shows that the tanker size has a significant influence on the relative damage length in accidental grounding. For conventional vessels, where the speed is mainly governed by the Froude number, the difference is even larger.

The damage density distributions in the IMO Guidelines were derived from the actual damage data of ships of 30 000 tons deadweight and above, as mentioned

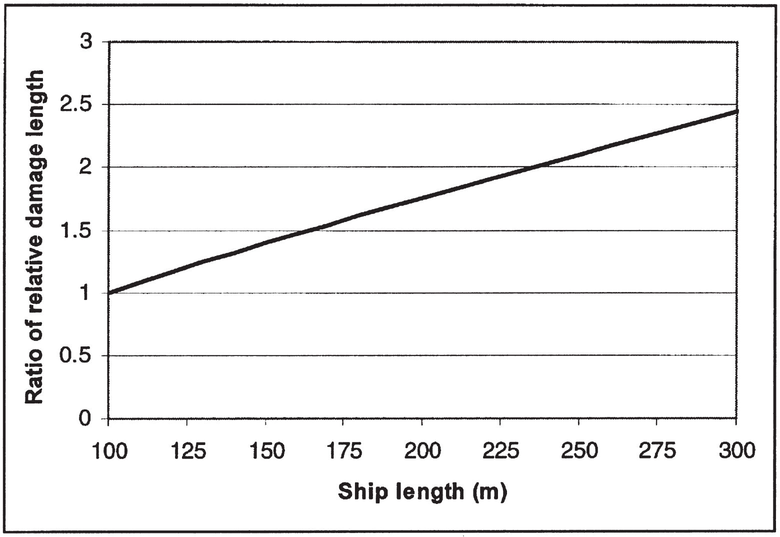

Fig. 3. The effect of ship size on the relative damage length in grounding.

previously. Here we shall assume that the mean value of the displacement is 50 000 tons in the IMO data for grounded ships. So the IMO bottom damage distribution is taken to be representative of a tanker with a length of about 185 m if the design speed of the tanker is assumed to be 15 knots. Then, by application of Eq. (13), the converted density distributions of the longitudinal extent of grounding damage for a 300 m tanker (250 000 tons displacement) are shown in Fig. 4. The corresponding cumulative probabilities are shown in Fig. 5.

In these transformations, we have assumed that in the IMO damage distribution for tankers the raking damage is represented by a constant density distribution equal to 0.5 for damage lengths between 0 and 80% of the length of the ship. The reason for this assumption is that the raking damage is only one part of several types of grounding damage to ships. Soft grounding, sideways stranding, etc. cause other grounding damage.

It can be seen from Figs. 4 and 5 that the larger tanker suffers a higher probability of large relative damage length than that of the smaller tanker. For damage lengths above 30% of a ship's length, the probability is 30% for the 300 m tanker and 25% for the 185 m tanker.

Unfortunately, the IMO tanker database for grounding damages is not large enough to give a statistical verification of calculated variations, Eq. (13), of expected grounding damages with ship size or building material. But for merchant ships the results, Eq. (14), obtained by the present method correlate well with statistical analysis of ship grounding accidents (Bjørneboe et al., 1999). These statistical results for bottom damage density functions of longitudinal extent are shown in Fig. 6, and the cumulative probabilities are shown in Fig. 7.

The results in Figs. 6 and 7 are based on 128 grounding accidents, which happened

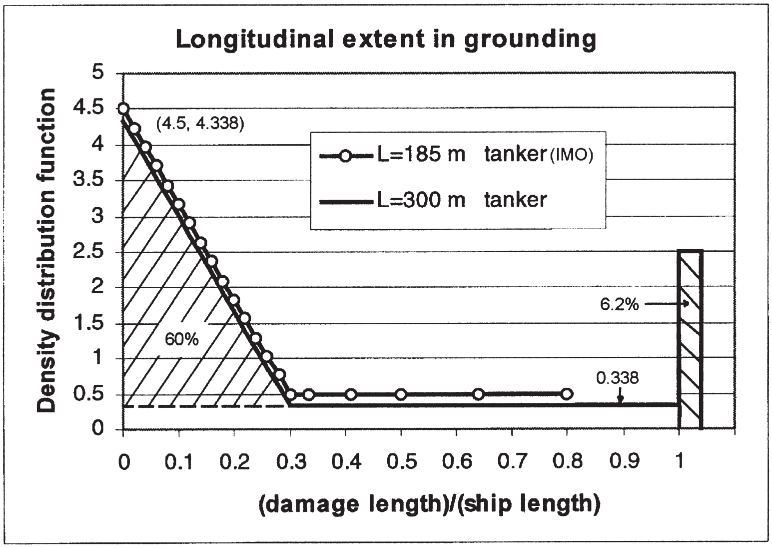

Fig. 4. The translated density distribution functions obtained by the present method for longitudinal extent with different ship sizes in grounding.

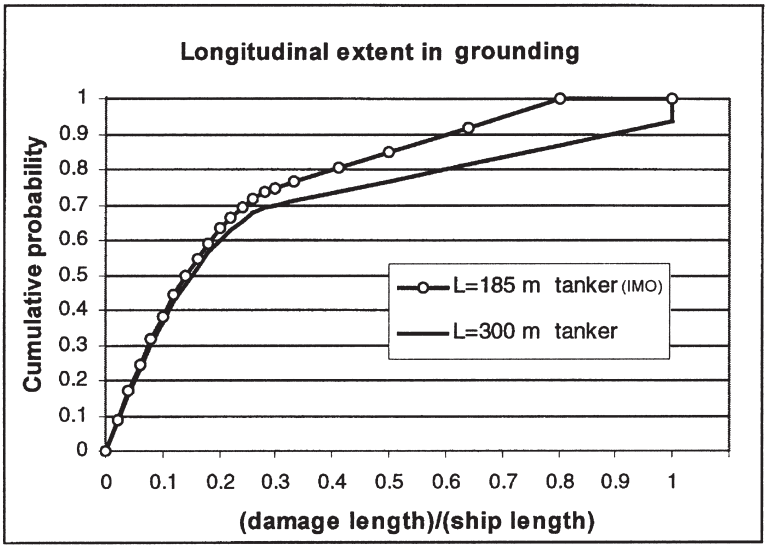

Fig. 5. The translated cumulative probabilities obtained by the present method for longitudinal extent with different ship sizes in grounding.

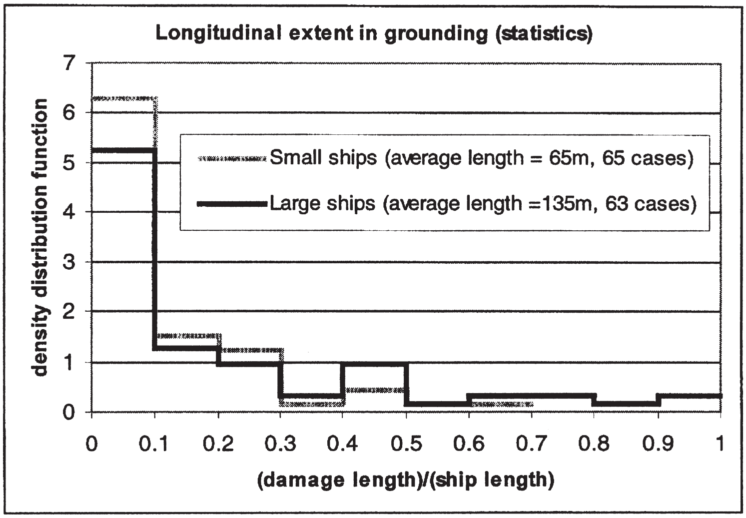

Fig. 6. Density functions for the longitudinal damage extent with different ship sizes in grounding obtained by statistical data in the period 1945 to 1965.

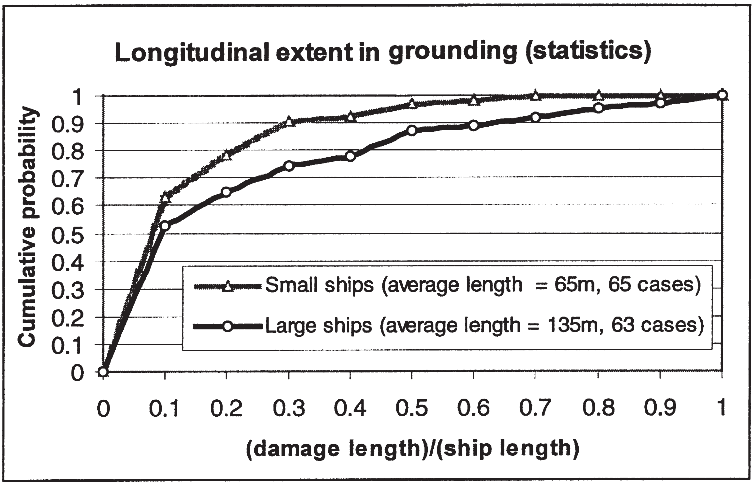

Fig. 7. Cumulative probabilities for the longitudinal damage extent with different ship sizes in grounding obtained by statistical data in the period 1945 to 1965.

during the period 1945 to 1965 and mainly involved various cargo ships. In order to investigate the effect of ship size on the damage distribution, the 128 grounding accidents are divided into two groups based on ship size. One group represents ship lengths below 100 m (the average length is 65 m), and the other group ship lengths above 100 m (the average length is 135 m). The small ship group contains 65 grounding cases, and the large ship group includes 63 cases.

The statistical results in Figs. 6 and 7 support the conclusions derived from the theory resulting in Eq. (14). It can clearly be seen from the statistical results that the group with the larger ships has a higher probability of relatively large damage length. For damage lengths above 30% of the ship's length, the probability is 25.4% for the large ship group, and 9.2% for the small ship group.

4. Prediction procedures for relative collision damage

In this section we shall perform a similar simple analysis of the influence of ship size and building material on the distribution of side damages due to ship-ship collisions.

To simplify the analysis procedure, it is assumed that the striking ship impacts the midship of the struck ship and that the struck ship is at a standstill before the collision. In this case, the energy loss is expressed as (Minorsky, 1959):

$$E = \frac{M}{M+0.6M_0} \cdot E_0 \tag{15}$$

where M is the mass of the struck ship, the added mass coefficient for sway motion is taken to be 0.66, and the kinetic energy of the striking ship is $E_0 = 0.5 M_0 U_0^2$, where M_0 is the mass of the striking ship and U_0 is the speed of the striking ship.

In side collisions, it is mainly crushing of the decks and stretching of the shell plating which absorbs the energy released for structural damage, see Fig. 8. For this case the absorbed energy can be estimated from (Pedersen and Zhang, 1998):

$$E = 0.77 \varepsilon_c \sigma R_1 + 3.50 \left(\frac{t}{d} \right)^{0.67} \sigma R_2 \tag{16}$$

where ε_c is the critical strain of the shell plating, R_1 is the volume of the damaged shell plating, t is the thickness of the crushed deck plate, d the plate width between stiffeners on the decks and R_2 the volume of the crushed decks. It can be seen from

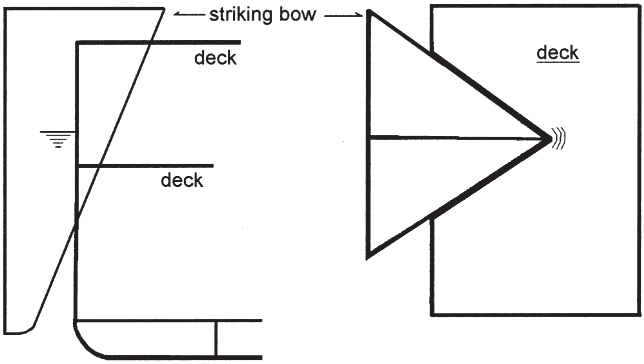

Fig. 8. A rigid bow penetrates into the side structure of a cargo ship.

Fig. 8 that the damage length and the damage height in the side shell are proportional to the damage depth δ. Therefore, the volume of the damaged shell plating can be approximated by

$$R_1=c_1\delta^2 t_1$$

where c_1 is a constant and t_1 is the equivalent thickness of the side shell. Similarly, the volume of the crushed decks is determined by

$$R_2=c_2\delta^2 t_2$$

where c_2 is a constant and t_2 is the equivalent thickness of the deck.

A study of the design rules of the classification societies shows that the equivalent thickness of the side shell t_1 and the equivalent thickness of the deck t_2 can be approximated by

$$t_1=k_1\cdot L^{0.7}/\sqrt{f}$$

$$t_2=k_2\cdot L^{0.7}/\sqrt{f}$$

where L is the ship length, $f=\sigma/235$ is a material factor, and k_1 and k_2 are constants. It is assumed that the ratio t/d between the deck plate thickness and the spacing of the transverse stiffeners on the decks is independent of the ship size for the same type of ships. Therefore, Eq. (15) can be further simplified to

$$E=C_3\sigma^{0.5}L^{0.7}L_{dam}^2$$

where C_3 is a constant, L_{dam} is the damage length, which is proportional to the damage depth δ. The non-dimensional damage length, defined as the ratio between the damage length and the ship length, is expressed as

$$\frac{L_{dam}}{L}=\frac{E^{0.5}}{\sqrt{C_3}\sigma^{0.25}L^{1.35}} \tag{17}$$

By the substitution of Eq. (15) into Eq. (17), the ratio of non-dimensional damage length between two struck ships can be determined from

$$\frac{(L_{dam}/L)_1}{(L_{dam}/L)_2}=\left(\frac{\sigma_2}{\sigma_1}\right)^{0.25}\cdot\left(\frac{L_2}{L_1}\right)^{1.35}\cdot\left(\frac{M_1}{M_2}\,\frac{M_2+0.6M_{0.2}}{M_1+0.6M_{01}}\right)^{0.5}\cdot\left(\frac{E_{01}}{E_{02}}\right)^{0.5} \tag{18}$$

By the use of Eq. (10) and on the assumption that all the ships have the similar design speed V_0, Eq. (18) becomes

$$\frac{(L_{dam}/L)_1}{(L_{dam}/L)_2}=\left(\frac{\sigma_2}{\sigma_1}\right)^{0.25}\cdot\left(\frac{L_1}{L_2}\right)^{0.317}\cdot\left(\frac{L_2^{3.33}+0.6L_{02}^{3.33}}{L_1^{3.33}+0.6L_{01}^{3.33}}\right)^{0.5}\cdot\left(\frac{E_{01}}{E_{02}}\right)^{0.5} \tag{19}$$

For cases where the same striking ship impacts two different struck ships, the ratio between the non-dimensional damage length for the two struck ships can be estimated from

$$\frac{(L_{dam}/L)_1}{(L_{dam}/L)_2}=\left(\frac{\sigma_2}{\sigma_1}\right)^{0.25}\cdot\left(\frac{L_1}{L_2}\right)^{0.317}\cdot\left(\frac{L_2^{3.33}+0.6L_0^{3.33}}{L_1^{3.33}+0.6L_0^{3.33}}\right)^{0.5} \tag{20}$$

From this equation it can be seen that the ratio between the non-dimensional damage length for two different struck ships not only depends on the two struck ships, but also on the size of the striking ship.

5. Calculated collision damages and discussions

Let us first consider a case where the same striking ship impacts two different struck ships. The length of struck ship no. 1 is L_1=135 m, and the length of struck ship no. 2 is L_2=65 m. The length of the striking ship varies from 60 to 140 m. The ratio of the non-dimensional damage length obtained by Eq. (20) is shown in Fig. 9.

It can be seen from Fig. 9 that the relative damage length ratio between the two struck ships depends on the length of the striking ship. When the striking ship is small, the difference between the relative damage length for the two struck ships is large. When the striking ship is large, the difference becomes smaller. In this example the ratio varies between 0.45 and 0.85.

As a second example we consider the case where a 110 m long striking ship

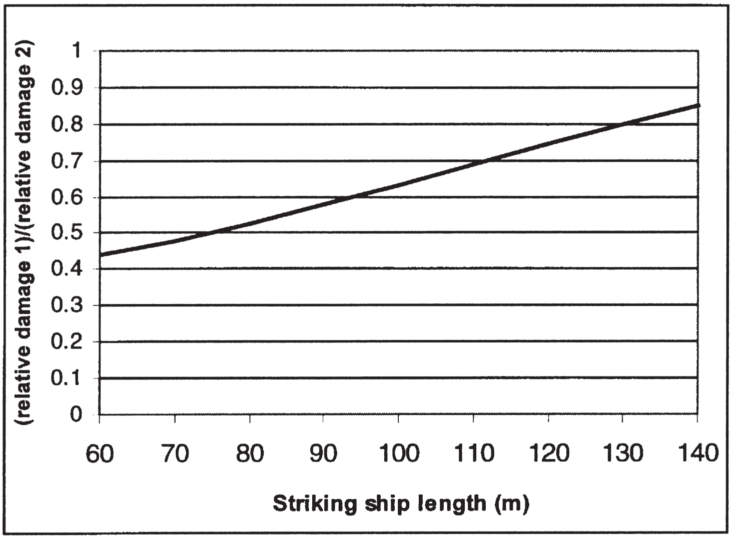

Fig. 9. The ratio of the relative damage length between struck ship no. 1 (L_1=135 m) and struck ship no. 2 (L_2=65 m), colliding with different striking ships.

impacts different struck ships with lengths between 60 and 140 m. For this case the ratio of the relative damage length as a function of the size of the struck ship is shown in Fig. 10. It can be seen that the relative damage to the larger struck ships are smaller than the damage to the smaller struck ships.

Therefore, from these examples we may conclude that it is to be expected that large struck ships suffer smaller relative collision damages than smaller struck ships.

Moreover this result correlates well with the IMO statistical analysis from 291 collision cases, which occurred during the period 1945 to 1965. The regression line for the non-dimensional damage length as a function of ship size is shown in Fig. 11. The statistical results show that the non-dimensional damage length of a large ship is smaller than that of a small ship. But the difference is not large. It should be noted that it is not possible to make a direct comparison of Figs. 10 and 11. The reason is that the IMO collision cases might be that small vessels meet mainly small vessels and large ships meet mainly large ships. The results in Fig. 10 represent the case where all vessels meet the same striking vessel.

To investigate further the effect of ship size on the damage distribution, the IMO database for ship collision damages is divided into two groups. One group represents larger ships where the length is above 100 m. The other group represents smaller ships where the length is below 100 m. The average length of the large ship group is 135 m (and includes 139 collision cases) and the average length of the small ship group is 65 m (and includes 131 collision cases). The statistical results for the probabilistic density distribution and the cumulative probabilities are shown in Figs. 12 and 13.

The statistical results show that the group of small ships has a higher probability of larger non-dimensional damage length than that of the group of large ships. For

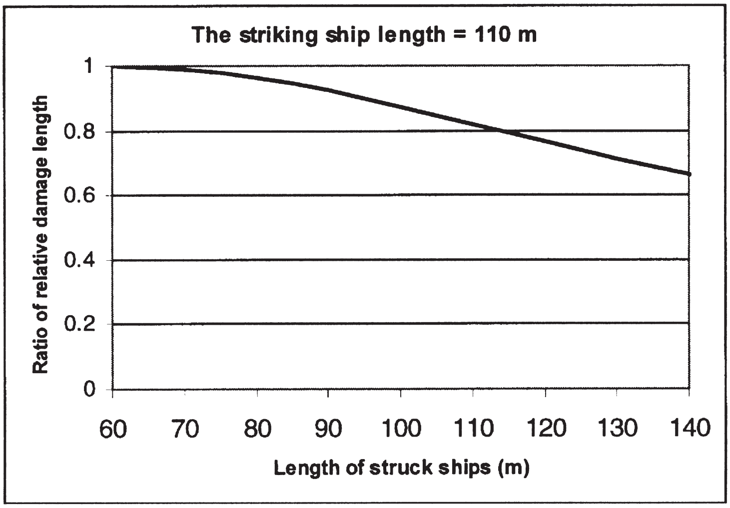

Fig. 10. The relative damage length between different struck ships where the striking ship length is 110 m.

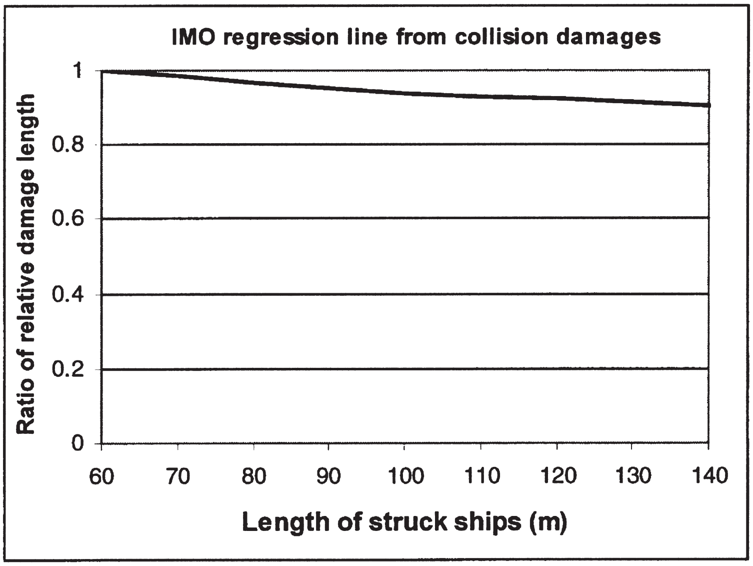

Fig. 11. The IMO statistical results of relative damage length between different struck ships obtained from collision damages in the period from 1945 to 1965.

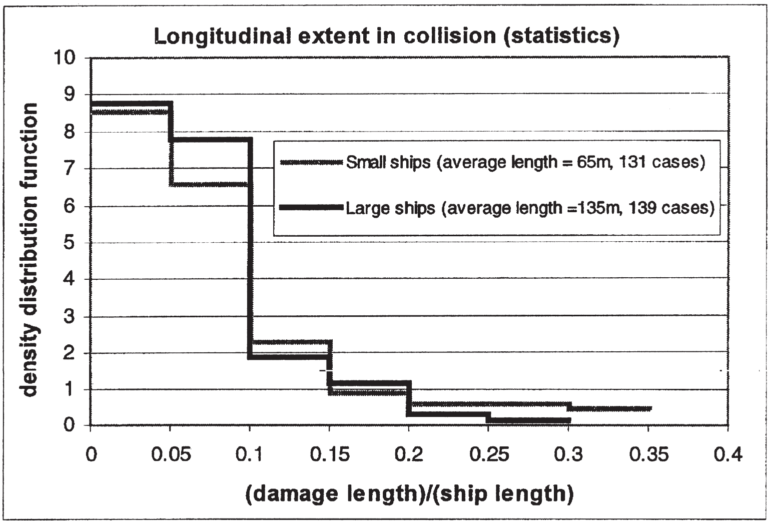

Fig. 12. Density function for damage length with different ship sizes in collisions found from statistical data in the period from 1945 to 1965.

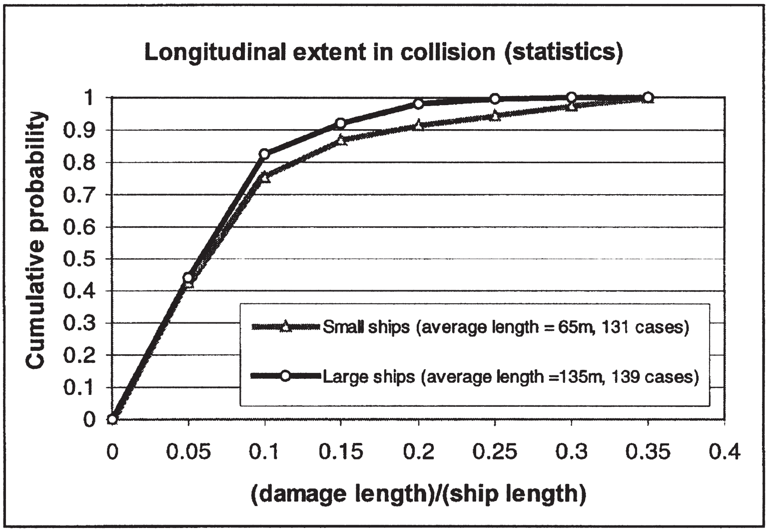

Fig. 13. Cumulative probabilities for damage length with different ship sizes in collisions found from statistical data in the period from 1945 to 1965.

the damage length above 15% of the length of the ship, the probability is 25% for the small ship group, and it is 17% for the large ship group.

Pedersen et al. (1996) carried out a probabilistic analysis of damage distributions for Ro-Ro ferry collisions. They established a procedure for calculating the probability of collisions and the damage distributions given a collision. The procedure was applied to various Ro-Ro vessels sailing on three different routes. The calculated cumulative probabilities of the non-dimensional damage length for a large ferry (ship length of 180 m) and a small ferry (ship length of 95 m) sailing on a Dover Calais route are shown in Fig. 14. Moreover, these analysis results show that the small ferry has a higher probability of large non-dimensional damage length than that of the large ferry. In the English Channel the average length of the striking ships is about 130 m. By the use of Eq. (20), the ratio of the relative damage length of these two ferries is determined as

$$\frac{(L_{dam}/L)_{95\ \mathrm{m}}}{(L_{dam}/L)_{180\ \mathrm{m}}}=1.58$$

The cumulative probability for the 95 m ship translated from the cumulative probability of the 180 m ship is also presented in Fig. 14. The correlation is reasonable taking into account the fact that the striking vessels are not just one ship with a length of 130 m but all the ships passing through the English Channel.

The conclusion of the present analysis is that the non-dimensional collision damages to larger ships can be expected to be smaller than those to smaller ships. This result has been verified by the IMO statistical results and previously published numerical results.

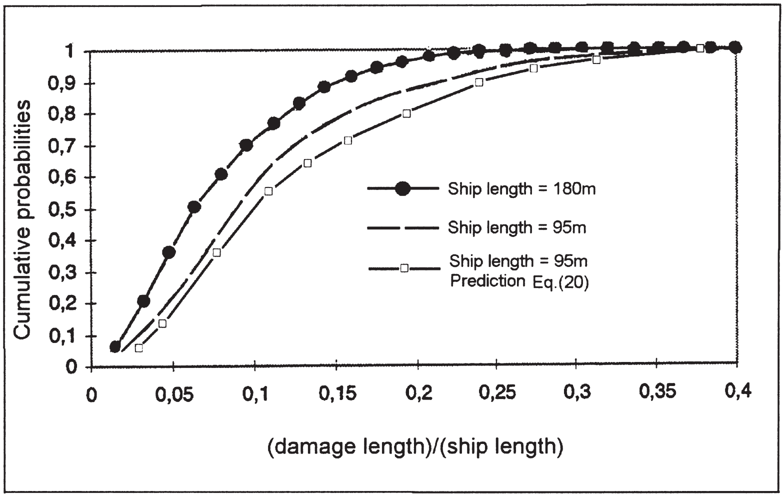

Fig. 14. Cumulative probabilities of non-dimensional damage length for a large ferry and a small ferry sailing on a Dover–Calais route (Pedersen et al., 1996).

It is noted that this prediction of the relative magnitude of collision damages is just opposite to the prediction concerning grounding damages.

6. Conclusions

In this paper simple analytical procedures have been developed for the analysis of the effect of ship size and building material on non-dimensional damage size in collisions and grounding.

Earlier analyses (Pedersen, 1994) have shown that for grounding on plane soft or hard grounds the ship bottom damage increases strongly with the size of the ship. It was also found that the grounding-induced hull sectional forces increase strongly with the size of the ship.

The analytical expressions derived in the present paper for raking damages caused by grounding on irregularly shaped rocks also show that larger ships will suffer relatively larger grounding damages. The analysis shows that the fundamental assumptions behind the IMO recommendations for grounding damage distributions for tankers do not hold. That is, the distributions for grounding damages do not scale linearly with the main dimensions of the ship. A comparison with existing statistical grounding damage data for cargo ships validates the derived analytical expressions and the main conclusions.

The derived analytical expressions also show that ships built with bottom plating made of high tensile steel must be expected to suffer less grounding damage than similar ships where the construction material is mild steel. But the difference is moderate.

For side shell damages due to ship-ship collisions, the present theory predicts that larger vessels can be expected to have somewhat smaller damages relative to the dimensions of the ship than smaller vessels. This result for ship-ship collisions is just the opposite to the conclusion concerning the damage distribution in ship grounding. The analytical results for side shell collision damages are also verified by existing statistical data and previously published analyses for specific ships.

Again the effect of using high tensile steel is to reduce slightly the expected side collision damages.

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