Revisions of “Guidelines for Container Stowage and Securing Arrangements (Edition 3.0)” and Future Outlook

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1. INTRODUCTION

Because cargoes loaded on container carriers are stowed not only in the holds but also on the deck, the container securing technology called lashing is necessary. Since the number of containers loaded on a vessel must be as large as possible to improve the economy of container carrier operation, container stacks exceeding 10 tiers are no longer rare. In addition to the self-weight of the containers, the loads caused by the rolling, pitching and heaving motions of a container carrier also act on these container stacks. Thus, as part of the container stacking and lashing method, it is necessary to calculate the strength of container stowage and securing arrangements so as to ensure that excess loads are not generated in the containers and lashing devices. Each classification society, including ClassNK (hereinafter, the Society), provides procedures for these calculations for the strength of securing arrangements in the form of rules or guidelines.

After the Society issued the first edition of “Guidelines for Container Stowage and Securing Arrangements” (hereinafter, Guidelines) in 2009, the second edition was released in 2014. However, the motion evaluation equations of a ship and procedures for calculating securing strength were unchanged from the first edition. Because upscaling of container carriers also continued in the meantime, and 24 000 TEU class Ultra Large Container Ships (ULCS) have now appeared, the applicability of the semiempirical motion evaluation equations adopted at the time of the 2009 Guidelines was a concern. Moreover, since the need to consider the nonlinear behavior of container stacks accompanying the introduction of fully automatic twist locks in recent years had also been pointed out, a revision of the Guidelines was carried out to contribute to achieving more rational container stowage by incorporating the results of Comprehensive Revision of Part C of the Society’s Rules for the Survey and Construction of Steel Ships, which was carried out until 2022, and the results of research in the Society’s Research Institute.

2. OVERVIEW AND COMPOSITION OF GUIDELINES AND MAIN POINTS OF REVISIONS

2.1 Overview and Composition of Guidelines

Table 1 shows the composition of the Guidelines by chapter. The composition of the Guidelines are unchanged from the second edition. Chapter 1 to Chapter 3 describe general items such as the overview of container stowage. Chapter 4 explains the basic concepts of the procedures for strength evaluation of container stowage and securing arrangements. Chapters 5 and 6 specify the design loads and strength evaluation methods used in strength evaluations of stowage and securing arrangements. The revisions this time targets mainly at Chapters 5 and 6. Chapters 7 and 8 are chapters that were newly established when the second edition of the Guidelines was released in 2014, and specify the class notations corresponding to the ship’s lashing calculation program (so-called lashing computer) and the character of classification corresponding to IMO CSS Code Annex 14.

Table 1 Chapter composition of Guidelines

Chapter 1	OVERVIEW OF CONTAINER STOWAGE AND SECURING ARRANGEMENTS
Chapter 2	STRENGTH OF CONTAINERS AND SECURING DEVICES
Chapter 3	PRECAUTIONS FOR HULL STRENGTH RELATED TO STOWAGE AND SECURING ARRANGEMENTS
Chapter 4	STRENGTH EVALUATION METHODS FOR STOWAGE AND SECURING ARRANGEMENTS
Chapter 5	DESIGN LOADS FOR STRENGTH EVALUATION OF CONTAINER STOWAGE AND SECURING ARRANGEMENTS
Chapter 6	STRENGTH EVALUATION OF CONTAINER STOWAGE AND SECURING ARRANGEMENTS
Chapter 7	LASHING CALCULATION PROGRAM
Chapter 8	SAFE DESIGN FOR CONTAINER LASHING

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2.2 Main Points of Revisions

Although various revisions were made in the third edition of Guidelines, the main revisions concerned the following three points. (The relevant chapters are shown in parentheses.)

i) Review of motion and load equations (Chapter 5)
ii) Updating of route correction factors (Chapter 5)
iii) Revision of methods of strength evaluation of stowage and securing arrangements (Chapter 6)

In addition to these revisions, the Society also plans to provide calculation tools and web applications corresponding to the content of the Guidelines to improve the convenience of the Guidelines and facilitate their use by a greater number of users. The provision of these digital tools is also described in the following chapter, together with the details of the respective revisions mentioned above.

3. OVERVIEW OF MAIN REVISIONS

3.1 Review of Motion and Load Formulae

In strength evaluations of container stowage and securing arrangements, the Guidelines consider the case of longitudinal waves (head seas and following seas) and the case of transverse waves (beam seas). In the former case (head/following seas), strength calculations of securing arrangements consider the loads acting on container stacks as a result of heave acceleration, the angular component of the acceleration of gravity due to the pitch angle and pitch angular acceleration, and in the latter case (beam seas), calculations consider the loads acting on container stacks as a result of the angular component of the acceleration of gravity due to the roll angle, roll angular acceleration and heave acceleration. In addition, the pressure due to wind loads acting on containers which are exposed to wind is also given. Fig. 1 shows a schematic diagram of the loads in a beam sea.

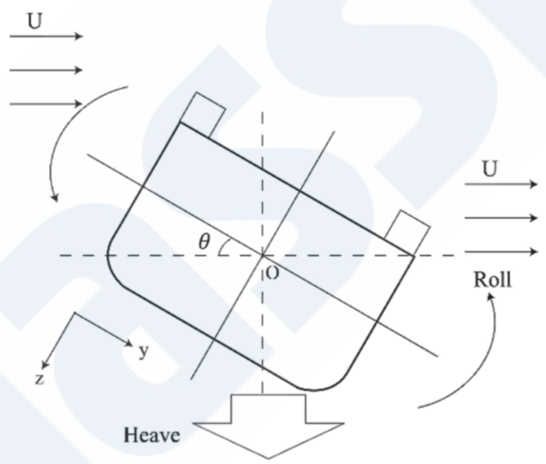

Fig. 1 Schematic diagram of loads in beam sea

Because ship hull motion and acceleration had been given as semiempirical formulae in the Guidelines until now, there were questions about their applicability to the ULCS of recent years. Therefore, in this revision, a decision was made to use equations that are physically meaningful and related to evaluations of structural strength, based on the results of the Comprehensive Revision of Part C of the Rules for the Survey and Construction of Steel Ships carried out from 2017 to 2022. A flowchart of the derivation of the motion and load equations in the Comprehensive Revision of Part C is shown in Fig. 2. The motion and load evaluation equations in the Rules and these Guidelines are obtained from the value of a simplified formula for the hull motion and acceleration for a unit wave amplitude, and applying nonlinearity effects and operational effects as coefficients to the maximum motion displacement and acceleration of the hull found by using the maximum wave height occurring once in 25 years obtained from a long-term forecast using direct load analysis (DLA) and wave scatter diagram for the North Atlantic Ocean. For the details of this flow, see paper No. 3 in this edition of ClassNK Technical Journal (Japanese ed.) [1].

The “operational effect” considered in the flowchart in Fig. 2 is obtained by an evaluation of the sea states that the ship actually encounters using AIS data and hindcast data. Although the details may be found at Miratsu *et al*. (2022) [2], the operational effect factor is derived by comparing the long-term prediction values found from the wave scatter diagram provided in IACS Rec. 34, and the long-term prediction values obtained from the wave scatter diagram for the actually-encountered sea states. A similar technique is also used in the review of the route correction factors described in the following.

In addition to the review of the load equations, this revision of the Guidelines also eliminated the previous provision setting the minimum value of 20° for the roll angle. Where this provision is concerned, conventionally, the roll angle had been set at a minimum of 20°to adequately secure an adequate safety margin, as the roll angle is the controlling factor in evaluations of container securing strength. However, it was deemed possible to eliminate this provision from the current revision, considering the facts that a quantitative evaluation of the sea states encountered by container carriers is possible by using AIS data and hindcast, it is now possible to construct physically meaningful motion equations in the above-mentioned Comprehensive Revision of Part C, and based on the results of an analysis of the measured data from actual ships to date, a roll angle of 20° is considered to be an unrealistic requirement, except in the case of parametric rolling. On the other hand, similar to the Comprehensive Revision of Part C, calculations for container securing strength are performed on the assumption that a certain roll angle occurs by applying a lower limit value of the metacentric height *GM* for calculation of the roll angle. Because the lower limit value of *GM* is given as a function of the ship’s breadth *B*, and not as a constant value, it takes a form that can respond to the upscaling of ships.

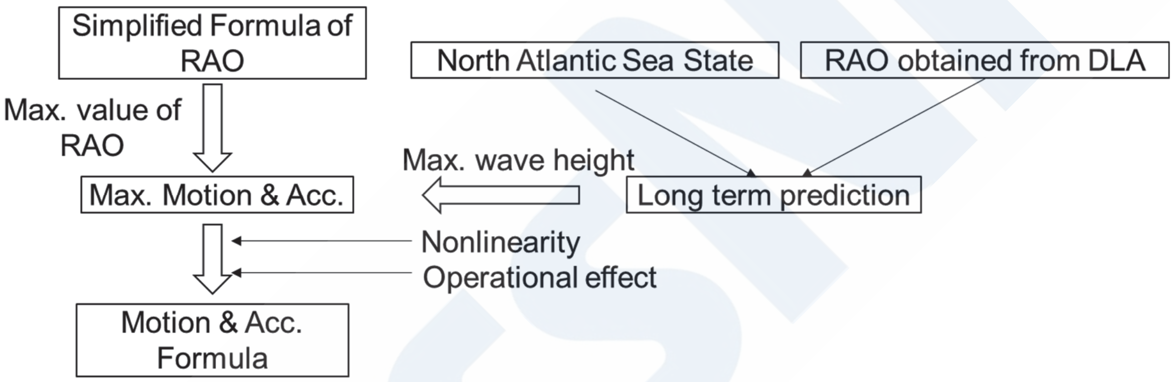

Fig. 2 Flowchart of the motion and load equation

Table 2 shows a comparison of the roll angles before and after the revision of the Guidelines. GM was set to 1.5 m for all ship sizes. Since the roll angle is influenced by various parameters such as C_w and *KG* in addition to *GM*, the author wishes to note that the calculations in Table 2 are only examples. For ship sizes of 8 000 TEU class or larger, the roll angle had been decided based on the limitation of a minimum roll angle of 20° in the second edition, but the roll angle has now decreased by about 2 to 5° because this limitation is no longer applied in the third edition of the Guidelines. Similarly, the roll angle for feeder container carriers (A, B) has also decreased by about 5°. From the influence evaluation in structural strength evaluations, it is considered that the roll angle evaluation equations obtained in the Comprehensive Revision of Part C do not conflict with the data for actual ships. Thus, it can be said that excessive safety factors for load evaluation equations could be eliminated as a result of this revision.

Table 2 Comparison of roll angles (*GM* = 1.5 m)

No.		A	B	C	D	E
Size(TEU)		2.5k	3k	8k	14k	24k
Roll angle (deg.)	2nd ed.	26	25.6	20	20	20
	3rd ed.	20.6	20.4	17.7	16.8	14.9

It is thought that many of the container stack collapse accidents of recent years were caused by parametric rolling due to the occurrence of large roll angles even in head or following seas. In addition to the fact that parametric rolling is an extremely strong nonlinear phenomenon, the maximum rolling angle also changes depending on the order of the waves that a ship encounters, even in sea states with the same significant wave height and mean wave period. For this reason, it is difficult to obtain the maximum response by the method used in the above-mentioned Comprehensive Revision of Part C. Therefore, in addition to assuming appropriate seamanship to avoid parametric rolling, techniques that support evasive navigation to avoid parametric rolling, such as the use of polar charts, etc., are also provided separately.

3.2 Updating of Route Correction Factors

The loads used in evaluations of hull structural strength are generally obtained assuming that the ship navigates for 25 years in the North Atlantic Ocean (IACS Rec.34), which is the sea area with the most severe sea states. The loads obtained in the Comprehensive Revision of Part C described in section 4.1 are also the same. This practice is adopted because the sea areas where ships will actually be used during their life, including vessels sold as used ships, are unknown. On the other hand, if the routes in short-term navigation are known in advance, there are no safety-related problems for securing strength evaluations using the motions and accelerations assumed in the sea states the ship will encounter when passing through those waters.

Therefore, in calculations of the strength of container stowage and securing arrangements, it is possible to use the loads obtained assuming the waters to be navigated which were determined in advance. Although Fig. 3 shows the significant wave height values for each sea area, it can be understood that there are large differences depending on the sea areas. The reduction factor for the load calculation formula for the sea area to be navigated described in Fig. 4.1 is called the route correction factor.

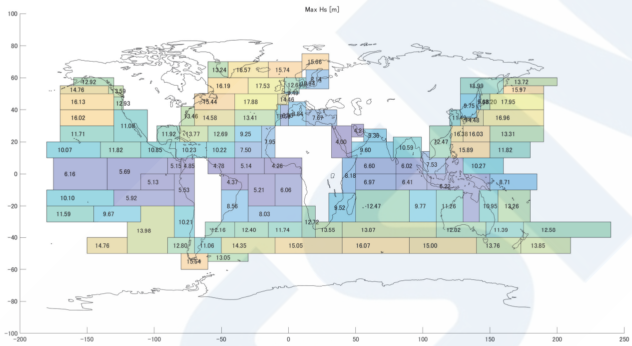

Fig. 3 Maximum significant wave heights of each sea area

While route correction factors were also provided in the Guidelines before revision, they were limited to the main routes and could not be used for any arbitrary route. As an additional problem, those factors were obtained empirically, and no technique for considering the ship sizes of individual ships was provided. Therefore, this revision provides a general technique for obtaining route correction factors, and the Society also plans to provide a web application for evaluating the route correction factors of arbitrary routes.

The sea states that occur on each route also differ depending on the season. Figs. 4, 5 and 6 show the significant wave height contours through the full year and in the summer and winter seasons, respectively, based on data acquired from the IOWAGA wave hindcasting database for the period from 1994 to 2018. Through the full year, high significant wave heights can be seen worldwide except around the equator. However, the significant wave height decreases during the summer and winter seasons, even in sea areas where high significant wave heights were seen through the year as whole. In calculating the route correction factors, this revision of the Guidelines provides a technique that makes it possible to obtain different factors not only for the route which a ship is navigating, but also for the season when it navigates that route.

One method for obtaining route correction factors, for example, is calculation using a ratio of the significant wave height. However, these Guidelines recommend making long-term predictions using the RAO (Response Amplitude Operator: response for a regular wave of a unit amplitude) of the individual ship after obtaining the target route and the seasonal wave scatter diagram for the encountered sea states. Although the RAO can also be obtained by a direct load analysis (DLA), a complicated procedure is required. Therefore, this revision uses the simplified formula proposed by Matsui *et al.* [3], which was also adopted in the Comprehensive Revision of Part C. The standard practice is to find the route correction factors by using this RAO as the numerator, and as the denominator, using the product obtained by multiplying the values of long-term predictions based on the wave scatter diagram for the North Atlantic Ocean for the full year by the operational influence factor [2]. This method was adopted because a systematic evaluation carried out by the Research Institute showed that use of evaluations using wave height ratios resulted in excessively conservative results. As an additional reason, more accurate route correction factors can be found by long-term predictions using the RAO of the individual ship because the synchronous period will differ depending on the actual ship, etc.

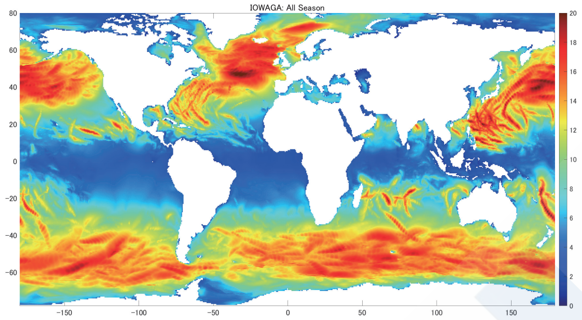

Fig. 4　Map of significant wave heights (full year)

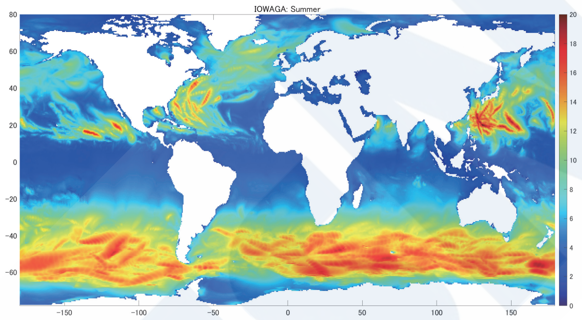

Fig. 5　Map of significant wave heights (summer)

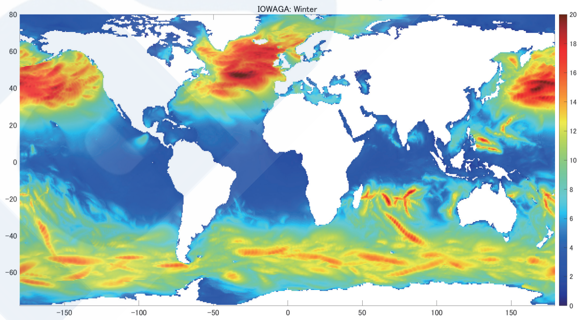

Fig. 6　Map of significant wave heights (winter)

As examples of the wave scatter diagrams used in making long-term predictions, in addition to the diagram for the North Atlantic Ocean given by IACS Rec. 34, the statistical wave database called Global Wave Statistics (GWS) is frequently used. However, since GWS uses sea-state information observed visually from ships during navigation, the influence of the ship operational effect (storm avoidance during bad weather) is implicitly included. Therefore, wave hindcast databases prepared with wave models are used as the natural sea states. The databases of this type are the above-mentioned IOWAGA database created by IFREMER (English name: French Research Institute for Exploitation of the Sea) in France, and ERA5, which was created by ECMWF (European Centre for Medium-Range Weather Forecasts). For more information regarding this type of wave model, please refer to paper No. 6 in this edition of ClassNK Technical Journal (Japanese ed.) [4].

Wave scatter diagrams of encountered sea states are prepared by obtaining the sea states encountered by container carriers by combining container carrier voyage data using AIS data with the natural sea-state data. In this process, appropriate statistical processing is important, since the AIS data only exist for limited periods. Although several statistical processing methods are available, Fig. 7 shows the result of using a generalized Pareto distribution as one example.

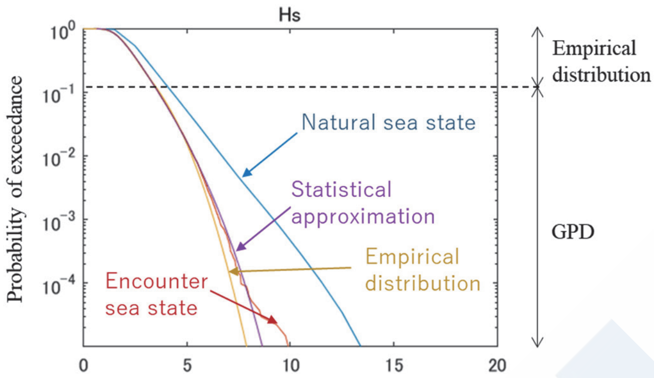

Fig. 7 Statistical processing of encountered sea states

Even on the same route, when seasonal factors are considered, a load decrease of about 30%, for example, can be expected for a feeder container carrier operating in the spring season on an Asian coastal route, in comparison with the load for the full year on the same route. In the case of a mega container carrier exceeding 10 000 TEU operating on an Asia-Europe route, load reductions of approximately 10% in spring and 20% in summer can be expected.

As a result of the updating of the route correction factors described above, it is now possible to set the optimum design loads for the strength of container stowage and securing arrangements for the sea areas where individual ships will operate based on the sea states in each season. We also plan to provide an application that enables easy calculation of route correction factors corresponding to the navigation route and season.

3.3 Revision of Methods of Strength Evaluation of Stowage and Securing Arrangements

Container stacks are generally subject to various types of deformation, namely, racking, floating of the corner castings, compression and shearing, as illustrated in Fig. 8. It is necessary to determine the container securing method, the weight of the containers to be stowed and the container stacking sequence so as not to exceed the allowable loads that occur during these types of deformation. (The Safe Working Load is generally used as the allowable value.) In cases where lashing rods are connected, as shown in Fig. 9, attention must also be paid to the allowable load of the lashing rods because tensile loads are generated in the lashing rods when racking deformation occurs in a container stack. If lashing is not performed, the forces that act on the various parts of the container lashing system can be obtained by regarding the container stack as a single beam. However, when lashing is performed, it is necessary to find the elongation of the lashing rods in order to evaluate the forces they are expected to absorb. At this time, if the container lashing system is linear, the racking displacement vector U can be found by solving the equilibrium equation for racking force shown in Eq. (1). Here, K is the racking stiffness tensor and $F_{racking}$ is the racking external force vector.

$$KU = F_{racking} \tag{1}$$

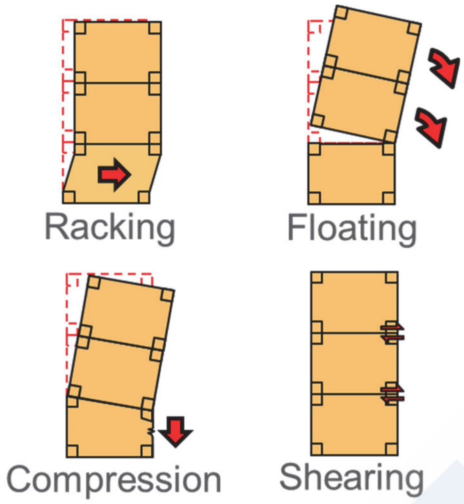

Fig. 8 Deformation behaviors of container stacks

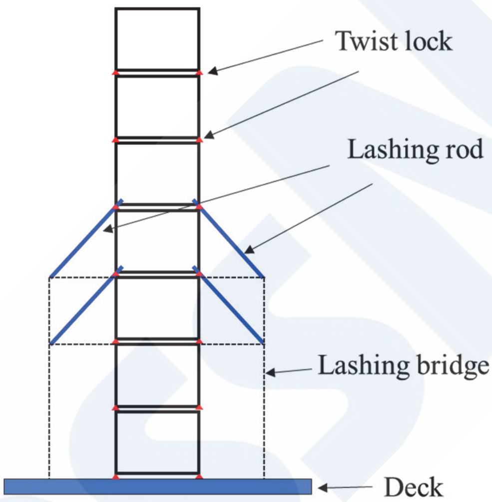

Fig. 9 Example of lashed container stack

For example, considering the case in Fig. 10, K in Eq. (1) comprises the racking stiffness $K_{container}$ of a container and the horizontal stiffness K_{rod} of lashing rods at the position where the lashing rods are connected (corresponding to displacement U_2) and lower positions. In linear problems, the amount of displacement can be obtained easily by solving Eq. (1), but this cannot be applied without modification to nonlinear problems. In calculating the strength of container stowing and securing arrangements considering nonlinearity, the forces acting on each part of the container lashing system can be evaluated directly by using finite element analysis, as in Ghesmi and Brindley (2021) [5] and Li *et al*. (2021) [6]. However, in using the finite element method as an evaluation technique for the Guidelines, there were problems in terms of the time and trouble required in modeling and convergence in nonlinear problems. Therefore, in the Guidelines, an equilibrium equation for nonlinear racking forces was created by expanding Eq. (1) to Eq. (2), where F_{rod_NL} is the nonlinear component of the lashing rod tensile force.

$$KU = F_{racking} - F_{rod\_NL} \tag{2}$$

The nonlinearity of a container lashing system originates from the clearance that exists between the twist lock and the corner casting, as illustrated in Fig. 11. When a corner casting floats, a clearance exists until it comes into contact with the twist lock, so it so free floating (separation) can occur in the meantime. This means the lashing rod connected to the upper corner casting can elongate in this case. The tension (nonlinear tensile force) of the lashing rod caused by this free floating of the corner casting corresponds to F_{rod_NL} in Eq. (2).

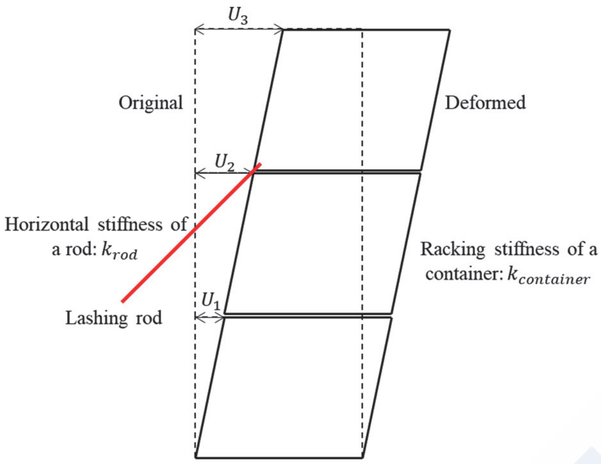

Fig. 10 Schematic diagram of lashed container stack

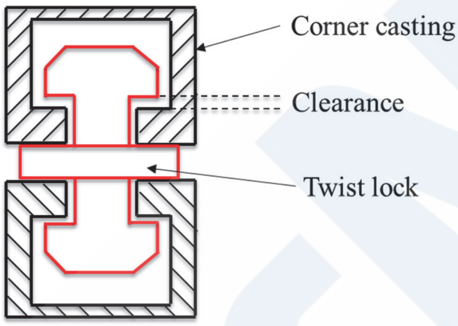

Fig. 11 Corner casting and twist lock

Although the nonlinear tensile force of a lashing rod is determined by the amount of floating of the twist lock, the amount of floating cannot be obtained without determining the tensile force of the twist lock, which is obtained as the result of Eq. (2). Accordingly, it is necessary to solve Eq. (2) by iterative calculation. This time, we developed an algorithm for obtaining the opening/closing and amount of floating of the twist locks by the bisection method, in order from the twist locks that exist at higher positions, for all twist locks positioned below the lashing rod connection, and verified its validity by comparison with the result of a nonlinear finite element analysis.

By considering nonlinearity, as described above, it is possible to evaluate the deformation behavior of container stacks in a more realistic form. The contribution of nonlinearity is particularly large in external lashing, as the lashing rods are connected to corner castings on the side where tension occurs, so the amount of vertical floating of the twist locks is reflected directly in elongation of the lashing rods. In internal lashing, on the other hand, only the increase in horizontal displacement accompanying rigid body rotation of the containers due to twist lock floating contributes to lashing rod tension, so the container stack deformation suppression effect of nonlinearity is small in comparison with external lashing.

In addition to introducing the above-mentioned nonlinearity, the new Guidelines also consider the stiffness of the lashing bridge, and the allowable loads for corner castings were also reviewed, reflecting recent trends.

4. RESULTS OF TRIAL CALCULATION

Assuming a mega container carrier of 14 000TEU class, a trial calculation was carried out considering the revisions described up to this point, and the results were compared with the results of an evaluation according to the second edition of the Guidelines. Here, the object was a 10-tier container stack with two external lashings, and wind loads were not considered. However, in the calculation according to the third edition, the stiffness of the lashing bridges was considered.

In addition, calculations were performed using the equations provided in the respective Guidelines for the roll angle, roll angular acceleration and heave acceleration. Figs. 12 and 13 show the evaluation results, targeting the compressive load on corner castings, which tends to be particularly severe. Figs. 12 and 13 show the cases of a container stack with a low center of gravity and a high center of gravity, respectively.

In the results in both Fig. 12 and Fig. 13, the usage factor (ratio of acting force to the allowable value) decreased in comparison with the former Guidelines. In particular, in the third edition calculation results for the container stack with a high center of gravity, the lashing rods work more because separation of the twist locks occurs, and the usage factor decreases greatly in comparison with the calculation results for the second edition. In the low center of gravity case, the load reduction and the review of allowable values resulted in a difference in the calculation results because separation did not occur. Although the same values were used for the stiffness of the lashing rods in the calculations according to the second edition and third edition, it should be noted that the stiffness of the lashing bridge is considered in calculations according to the third edition. Since this leads to a decrease in the stiffness of the lashing rods, care is necessary.

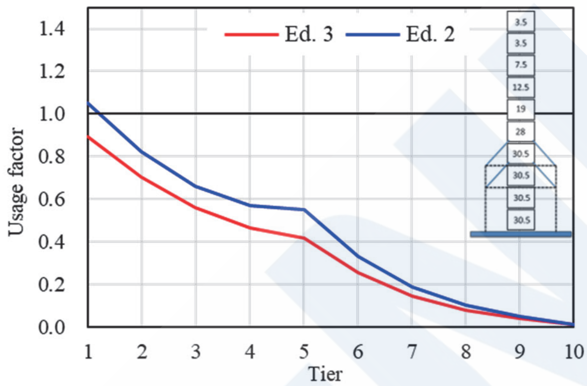

Fig. 12 Evaluation results of compressive load of corner castings (low center of gravity container stack)

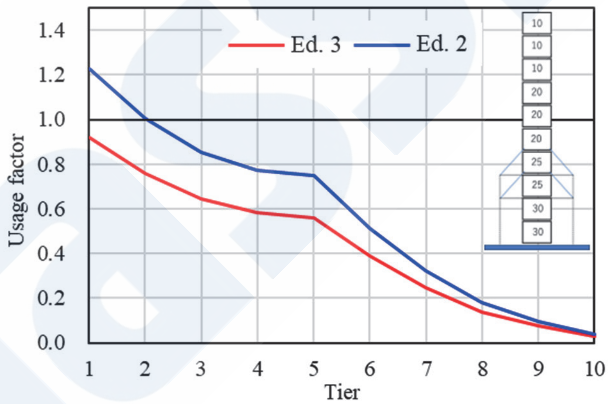

Fig. 13 Evaluation results of compressive load of corner castings (high center of gravity container stack)

5. SUMMARY AND FUTURE OUTLOOK

As explained up to this point, greater optimization and more realistic evaluations of the strength of container stowage and securing arrangements could be realized by incorporating the results of the Comprehensive Revision of Part C and the results of research by the Research Institute in the third edition of the Guidelines. In addition, the Society also plans to provide an application for calculation of route correction factors and calculation tools for use in strength evaluations of container stowage and securing arrangements to the related companies. Those with an interest in these items may contact the Research Institute.

On the other hand, in this revision work, we discovered several items which will require continuing study in the future. The first is integration with digital twin technology. In particular, by utilizing sea-state forecasting technologies, it is expected to become possible to conduct strength evaluations of container stowage and securing arrangements using the sea states which individual ships actually encounter during voyages. However, because the accuracy of sea-state forecasts decreases at dates further into the future, it will be necessary to verify the accuracy of forecast values and obtain a quantitative understanding of the limits of the technology. Because the devices used in container lashing (securing devices, lashing bridges, etc.) are exposed to sea winds, a certain amount of wear and tear is assumed. Since safer container shipping will be possible if we can grasp these conditions quantitatively and in real time, we plan to conduct continuing research on use of digital twin technology.

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