CHARTING THE FUTURE

# ClassNK

## Guidelines for Direct Load Analysis and Strength Assessment (Edition 4.1)

[ English ]

# Introduction

Ships need to be capable of ensuring and maintaining their structural functions whenever they are in service, and today's ships are more diversified and larger than ever before. This means that ClassNK is always in search of new technical knowledge, either from recent research or from organisations such as IACS (the International Association of Classification Societies), to incorporate into its technical rules. Our goal is to constantly being reviewing our requirements related to structural strength assessment so as to develop safer and more rational requirements that continuously ensure ship structural integrity, even under the harshest sea and weather conditions.

Structural strength assessment methods using finite element analysis of classification society requirements such as the ClassNK Rules for the Survey and Construction of Steel Ships (hereinafter referred to as "the Rules") and the IACS CSRs (Common Structural Rules) are one type of structural strength assessment criteria. In such requirements, dominant loads for structural strength are specified as simplified formulae, which vary depending on ship type, to be evaluated, and strength assessments are specified to be carried out based upon structural responses to these loads. Since these simplified formulae for loads were developed to comprehensively cover the typical load conditions encountered by ships and are estimated based on from existing ships, their application to ships of new structural configurations or of sizes lacking sufficient records of service is, therefore, limited. For such ships, evaluations may need to be on individual ship basis taking the evaluated ship's particular characteristics into account.

One of the structural strength assessment methods that require advanced technology is called "Direct Load and Structural Analysis" and it employs direct load analysis and finite element analysis. This method directly simulates the wave-induced loads acting upon ships and uses structural strength assessments carried out by finite element analysis to reproduce these loads. This method makes it possible to reproduce actual ship states to a high degree of accuracy and thus evaluate the details of each ship characteristic correctly.

Hence, ClassNK clarifies the basic concepts related to the strength assessment based upon direct load analysis and finite element analysis and specifies necessary requirements for structural strength assessments in this Guidelines (Edition 1.0) in 2018.

In Part C of the Rules publicly released on July 2022, ClassNK fine-tuned the concept of structural strength evaluation, and the same was done in this Guidelines. In addition, the latest technical knowledge has revealed that the statistical prediction of nonlinear response quantities (such as Von-mises stress), which was previously considered impossible, is now actually possible, and requirements for strength evaluation using such statistical prediction methods have been added in this Guidelines.

In order to make further use of direct load structural analysis, ClassNK publishes benchmark test data as the base data of the analysis program, and at the same time, issues the fourth edition of this Guidelines which specifies the requirements related to the benchmark data.

December 2025

Revision History

| Version | Date | Part | Contents |
| --- | --- | --- | --- |
| 1.0 | March 2018 | — | — |
| 2.0 | August 2022 | All | Completely revised based on Part C of the Rules for the Survey and Construction of Steel Ships released in July 2022 |
| 3.0 | June 2023 | Appendix 7 | Added Appendix 7 |
| 4.0 | February 2025 | 5.2<br>A.3.2<br>Appenedix7 | Corrected 5.2 and A.3.2<br>Deleted Appendix 7 |
| 4.1 | December 2025 | A.5.4<br>A.6.4 | Corrected A.5.4 and A.6.4 |

# Guidelines for Direct Load Analysis and Strength Assessment (Edition 4.1)

## Contents

# 1 General

## 1.1 Application

-1. This Guidelines is applicable to mono hull type steel ships.

-2. The concepts contained in this Guidelines may be applied correspondingly to floating structures with shapes other than mono hull types (e.g. catamarans, high-speed craft, offshore structures) as long as the structure's particular characteristics are considered.

-3. Regarding the application of this Guidelines, evaluation areas, target members and target strength requirements applicable to the evaluation and scope of application for the Society's Rules and Guidelines for the Survey and Construction of Steel Ships are to be approved by the Society beforehand. As for ships subject to Part C of the Rules for the Survey and Construction of Steel Ships, see Annex 1.

-4. The application of relevant rules and other guidelines may be requested in accordance with ship type, evaluation area, target member and target strength requirements when deemed necessary by the Society.

## 1.2 General

-1. This Guidelines specifies procedures for structural strength assessments based upon direct load analysis and finite element analysis.

-2. The assessments of -1 above include yield strength assessments, buckling strength assessments and fatigue strength assessments, or any combination thereof.

-3. This Guidelines specifies a strength evaluation method based upon equivalent design waves that reproduces dominant loads for strength evaluations of hull structures. Where other methods are used, they are to be in accordance with Annex 2.

-4. Where loads based upon direct load analysis are applied to strength evaluations that neither use finite element analysis nor equivalent design waves (e.g. evaluation of local strength), the requirements for the finite element analysis and equivalent design waves in this Guidelines may not be applied.

-5. Anticipated periods of ship service are to be selected; such periods, however, are not to be less than 25 years.

-6. The anticipated sea state for structural strength assessments is to be the North Atlantic (all seasons), and the wave scatter diagrams of IACS Recommendation No.34 (Rev.1, 2001) are to be taken as the standard diagram. Other sea states and wave scatter diagrams, however, may be used when deemed appropriate by the Society.

## 1.3 Submission of Documents

For application of this Guidelines, the following documents are to be submitted to the Society. Additional document submissions may be requested when deemed necessary by the Society.

(1) Trim for design loading conditions and stability calculation sheets, which include information about the draught at AP and FP, mean draught, weight distribution, centre of gravity and metacentric height.

(2) Offset data

(3) Documents with regard to direct load analysis and statistical predictions, which include the following (a) to (h).

(a) Outlines of computer programs for direct load analysis, which include how to consider fluid force, bilge keel and roll damping, etc.

(b) Loading conditions to be considered, which include information regarding the draught, still water vertical bending moment, etc.

(c) Dominant ship motions and loads parameters for structural strength assessments (hereinafter referred to as "DLP")

(d) Calculation conditions for direct load analysis (wave heights, incident wave frequencies or periods, wave angles, ship speeds, etc.)

(e) Outlines of short-term and long-term predictions

(f) RAO as well as short-term and long-term prediction results for each DLP

(g) Wave angles/periods/heights of equivalent design waves

(h) Ship motions, accelerations, hydrodynamic pressure and hull girder moments at the time when each DLP becomes maximum or minimum.

(4) Documents regarding finite element analysis and strength assessments, which include the following (a) and (b).

(a) Documents describing the analysis procedures, as in the following (i) to (vi):

(i) Detailed description of the structural modelling, including all modelling assumptions

(ii) Any deviations in actual structural geometry and arrangement in comparison to designed structural geometry and arrangement

(iii) Name and version of the analysis system used, such as a finite element analysis program

(iv) Boundary condition details

(v) Distributions of shearing force, bending moment, and torsional moment and the details of the load conditions used of their calculation

(vi) Documents showing details of applied loads and confirmation of their correctness

(b) Documents containing the analysis results, as in the following (i) to (v):

(i) Plots and results that demonstrate the correct behaviour of the structural model under the applied loads

(ii) Summaries and plots of global and local deflections

(iii) Summaries and sufficient plots of stresses to demonstrate that the strength criteria are not being exceeded by any member

(iv) Summaries and sufficient plots to demonstrate that the buckling criteria are not being exceeded by any plating and stiffened members

(v) Summaries and sufficient plots to demonstrate that the fatigue criteria are not being exceeded in any discontinuous structure

# 2 Definitions

## 2.1 Definitions of terms

Definitions of the terms used in this Guidelines are as in Table 2.1. Definitions of terms other than those in the table are in accordance with Part C of the Rules for the Survey and Construction of Steel Ships.

Table 2.1 Definitions

| Term | Definition |
|---|---|
| Direct Load Analysis | Method for evaluating ship motions and wave-induced loads acting upon ships.<br>Direct load analysis as linear analysis is chosen as the analysis method so as to estimate responses for small wave heights. |
| DLP | Dominant Loads Parameter (i.e. dominant ship motions and loads used for structural strength assessments) |
| RAO | Response Amplitude Operator (i.e. function showing response amplitude values for regular waves with heights of 2 meters) |
| Regular Waves | Waves with constant heights and periods |
| Irregular Waves | Waves without constant heights and periods |
| Short-Term Prediction | Statistical method for predicting response in short-term sea states, superimposing responses in regular waves using wave spectrums which express the short-term sea state to be considered.<br>In general, this method is based upon linear superimposing. |
| Long-Term Prediction | Statistical method for predicting maximum and long-term distribution of responses in anticipated periods using the response statistics of short-term sea states and the occurrence frequencies of short-term sea states in the sea area to be considered.<br>In general, this method is based upon linear superimposing as well as short-term prediction. |
| Short-term Sea State | Sea state which can be taken as being constant. It is said to last from one to three hours. |
| Wave Scatter Diagram | Table which shows the frequency of short-term sea states in a given sea area |
| Equivalent Design Wave | As for selected DLP, equivalent regular wave which reproduces the same response as design values (i.e. maximum expected value at given probability level obtained from long-term prediction) |
| Full Spectrum Analysis | Analysis method which can calculate the RAO of structural response (stress) applying loads to finite element models reproducing entire ships (full ship model) under various wave conditions with all wave directions and wide ranges of wave periods |

## 2.2 Other

For the definitions of positive and negative of loads in the documents to be submitted in accordance with 1.3, it is recommended to follow Part C of the Rules.

## 3 Evaluation Procedures

-1. Procedures for structural strength assessments by direct load analysis and finite element analysis are to be in accordance with the following (1) to (5) (see Fig. 3.1).

(1) Evaluation areas and target members are to be selected and the DLP for each area and target member for structural strength assessments is to be selected.

(2) Direct load analysis in regular waves is to be carried out and a RAO is to be calculated for each DLP selected in (1) above.

(3) Statistical predictions for DLPs are to be carried out through short-term and long-term predictions. For yield strength assessments and buckling strength assessments, maximum and minimum values of DLPs within the anticipated periods during which the ship is in service are to be calculated. For fatigue strength assessments, response values of DLPs at the dominant level for fatigue strength are to be calculated.

(4) Equivalent design waves reproducing responses equivalent to (3) above are to be created for each DLP.

(5) Loads are to be created based upon the equivalent design waves of (4) above, and finite element analysis and structural strength assessments are to be carried out.

-2. Notwithstanding -1 above, structural strength assessments based upon either full-spectrum analysis or the worst short-term sea states may be carried out. Refer to Annex 2 for details.

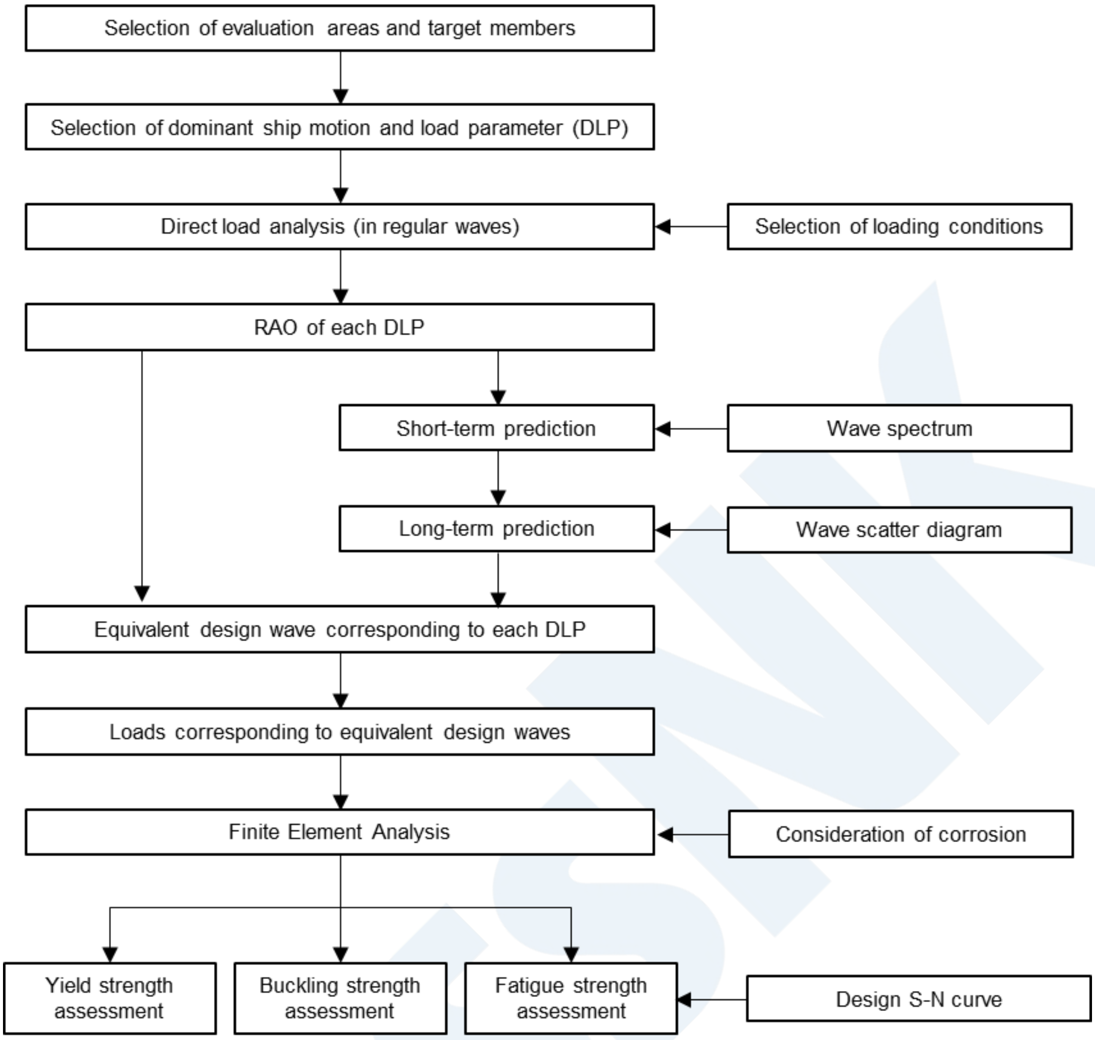


Fig. 3.1 Flow chart for structural strength assessments based upon direct load analysis and finite element analysis

# 4 Dominant Ship Motions and Load Parameters (DLP) for Structural Strength Assessments

-1. DLPs are to be selected for each evaluation target and approved by the Society. The following (1) to (6) DLPs are common to all ship types. Refer to Annex 3 for details.

(1) Vertical wave induced bending moment (x/L=0.5)

(2) Vertical wave induced shear force (x/L=0.25, 0.75)

(3) Hydrodynamic pressure at the intersection of bottom shell plating and the centreline for the cross section under consideration

(4) Hydrodynamic pressure at bilge parts for the cross section under consideration

(5) Hydrodynamic pressure at the intersection of side shell plating and waterline for the cross section under consideration

(6) Ship motions (roll, heave and pitch) and the corresponding accelerations invoked by these motions

-2. Any of the DLPs listed in -1 above which are expected to only have a slight impact on the structural strength of the evaluation target may not be considered; in such cases, however, relevant documentation related to the decrease in the number of DLPs is to be submitted to the Society beforehand for approval.

# 5 Direct Load Analysis and RAO Calculations

## 5.1 General

Direct load analysis is to be carried out in regular waves and a RAO is to be calculated for each DLP. In principle, direct load analysis is to be linear analysis, and any application of non-linear programs is to be approved beforehand by the Society.

## 5.2 Computer Program Verification

-1. Outlines of direct load analysis are to be approved beforehand by the Society.

-2. The documents in 1.3(1) and 1.3(2) and 1.3(3)(a) are to be submitted beforehand and the analysis program to be used for the direct load analysis is to be verified by the Society. Where deemed necessary, the Society may request the submission regarding the accuracy verification of the analysis program to be used. Refer to Annex 3 for details.

## 5.3 Loading Condition Selection

The loading conditions to be considered during direct load analysis are to be determined and approved by the Society. Refer to Annex 4 for details.

## 5.4 RAO Calculations

-1. Direct load analysis in regular waves is to be carried out and a RAO for each DLP is to be calculated.

-2. The analysis is to be carried out in regular waves with multiple angles and periods to select the dominant regular waves for each DLP. Refer to Annex 3 for details.

# 6 Statistical Predictions of Ship Response in Irregular Waves (Short-Term and Long-Term)

## 6.1 Short-Term Predictions

-1. Short-term predictions are to be carried out for each DLP based upon the RAO calculated in accordance with 5.4.

-2. The wave spectrum and relative spreading around the main wave heading to be considered are to be approved beforehand by the Society.

-3. Refer to Annex 5 for details on short-term predictions.

## 6.2 Long-Term Predictions

-1. Long-term predictions are to be carried out for each DLP based upon the results of the short-term predictions calculated in accordance with 6.1.

-2. Refer to Annex 5 regarding the details of long-term prediction.

# 7 Equivalent Design Waves and Associated Loads

## 7.1 General

Loads used for the finite element analysis of Chapter 8 are to be created based upon the equivalent design waves of this chapter and the results of direct load analysis corresponding to such waves. Equivalent design waves and loads are to be created for each DLP.

## 7.2 Determination of Wave Periods and Wave Directions

Dominant wave directions and wave periods with respect to response in regular waves are to be taken as the wave period and wave direction of the equivalent design wave. Consideration of more than one equivalent design wave may be requested for a DLP when deemed necessary by the Society.

## 7.3 Determination of Wave Heights

-1. Wave heights of the equivalent design waves used in yield strength assessments and buckling strength assessments are to reproduce the maximum and minimum responses of the target DLP for in the periods when the ship is in service.

-2. Wave heights of equivalent design waves used in fatigue strength assessments are to reproduce the response of the DLP corresponding to the occurrence probability which significantly affects the fatigue strength assessment.

-3. For the application of -1 and -2 above, the times when the target DLP reaches a maximum and minimum during a single wave period are to be considered.

## 7.4 Associated Loads

-1. Loads are to be created based upon responses (e.g. hydrodynamic pressure, ship motions, acceleration due to ship motions, hull girder moments) in the equivalent design waves determined in 7.2 and 7.3.

-2. Where loads are created, static sea pressures, hydrodynamic pressures, loads generated by cargoes or ballast water, inertial forces acting on loaded cargoes, the weights of the ship hull and each cargo tank as well as the inertial forces acting on the ship's hull and cargo tanks are all to be considered together with the loading conditions of 8.3-2.

-3. Loads are to be applied according to their respective type.

-4. Where analysis based upon partial structural models is carried out, hull girder loads acting upon the model are also to be considered in addition to lateral loads. In principle, hull girder loads are to be applied using the direct method.

-5. Notwithstanding any loading conditions under consideration, the permissible maximum and minimum vertical still water bending moments described in the loading manual are, in principle, to be used. However, the maximum and minimum moments (which are generated in consideration of all physically possible loading combinations such as each consumable tank being full, empty, etc.) for loading conditions under consideration may be considered.

-6. For fatigue strength assessments, the still water vertical bending moment at departure for the loading condition to be considered is, in principle, to be used.

-7. Where hydrodynamic pressures are to be applied to structural models, the hydrodynamic pressure above the waterline is to be considered in cases where the hydrodynamic pressure at the waterline is positive. Furthermore, any negative pressure below the waterline is not to be applied when static pressure is considered in cases where the hydrodynamic pressure at the waterline is negative.

Hydrodynamic pressure may not be considered for locations other than the outer shell (e.g. exposed decks).

# 8 Finite Element Analysis

## 8.1 Verification of Calculation Method and Analysis Accuracy

-1. Calculation of structural responses, such as stress, is to be carried out using the finite element method (FEM).

-2. Verification of the accuracy of analysis programs may be requested when deemed necessary by the Society.

## 8.2 FE Models

-1. Modelling is to be carried out to reproduce the stress conditions of evaluation areas.

-2. Members to be modelled are to be selected according to evaluation area and target member, and they are to be approved beforehand by the Society. In general, longitudinal members, primary supporting structures (bottom structures, side structures, deck structures, bulkhead structures, etc.), longitudinal stiffeners, stiffeners attached to transverse stiffened structures, and stiffeners attached to bulkheads and girders are to be modelled.

-3. Each member is to be modelled using an appropriate element type.

-4. Meshing is to be carried out so that structural response can be reproduced accurately in the evaluation areas. In principle, the aspect ratio of mesh is to be close to 1.0 and a triangle mesh is to be avoided as possible. Where fatigue strength assessments are carried out, target locations are to be modelled using very fine mesh to ensure adequate evaluations of local stresses.

-5. Young's modulus, Poisson's ratio and density are to be considered for materials used for hull structures.

-6. Corrosion effects are to be considered by strength evaluations based upon scantlings deducted from the scantlings described in relevant drawings (i.e. gross scantlings). The corrosion additions and corrosion models to be considered are to be as deemed appropriate by the Society. A corrosion model appropriate for the relevant strength requirements is to be selected.

## 8.3 Load and Boundary Conditions

-1. Boundary conditions taking the model area into account are to be applied to adequately reproduce structural model behaviour. Depending on the analysis program and analysis method adopted, nodes of structural models that are not constrained may be used.

-2. Loading conditions for structural analysis are to be selected and approved beforehand by the Society. Refer to Annex 4 for details.

-3. Where fatigue strength is assessed using local finite element models which are modelled around target locations, the load and boundary conditions applied to the local models are to be approved by the Society beforehand.

## 9 Structural Strength Assessments

-1. For yield strength assessments, the stress for each element in evaluation areas is to be confirmed to not be greater than its permissible stress. Relevant permissible stresses are to be as deemed appropriate by the Society.

-2. All plating and girders in evaluation areas are to be modelled as stiffened panels or plate panels separated by stiffeners, girders or some other means. Buckling strength assessments are to be carried out for each panel and stiffener, with the methods used for such assessments being as deemed appropriate by the Society.

-3. Locations subjected to fatigue strength assessments are to be discussed with the Society before being selected. The methods used for fatigue strength assessments are to be as deemed appropriate by the Society.

-4. Refer to Annex 6 for additional details.

## Annex 1 Relevant Requirements of Part C of the Rules

Where this Guidelines is used to decide the structural arrangements and scantlings of each member, the relevant requirements of the Rules are to be satisfied separately. Table A.1.1 summarises, for reference, the relevant requirements in cases where this Guidelines is applied to ships subject to Part C of the Rules for the Survey and Construction of Steel Ships.

Table A.1.1 Relevant requirements regarding hull structures of Part C of the Rules for the Survey and Construction of Steel Ships

| Item | Relevant requirement |
|---|---|
| Application of steels | 3.2 of Part 1 and relevant requirements of Part 2 |
| Corrosion addition and corrosion model | 3.3 of Part 1 and relevant requirements of Part 2 |
| Longitudinal strength | Chapter 5 of Part 1 and relevant requirements of Part 2(1) |
| Local strength | Chapter 6 of Part 1 and relevant requirements of Part 2(2) |
| Strength of primary supporting structures under maximum load conditions<br>(Strength assessment by cargo hold analysis) | This Guidelines<br>Assessment criteria: Chapter 8 of Part 1 and relevant requirements of Part 2 (includes Annex 8.6 and Annex 8.6A) |
| Fatigue strength assessment for cyclic load condition<br>(Finite element analysis) | This Guidelines<br>Fatigue strength assessment details (e.g. assessment criteria): Chapter 9 of Part 1 and relevant requirements of Part 2 |
| Strength of primary supporting structures for harbour condition, testing condition and flooded condition | Chapter 4 of Part 1, relevant requirements of Part 2 and relevant requirements of Chapters 7 or 8 of Part 1 |
| Fatigue strength assessment of longitudinals | Chapter 9 of Part 1 (simplified stress analysis) and relevant requirements of Part 2(2) |
| Arrangement | Chapter 2, Part 1 and relevant requirements of Part 2 |
| Other<br>(Minimum requirement, additional structural requirements, requirements for structures outside cargo regions) | Chapters 3, 10 and 11 of Part 1 and relevant requirements of Part 2 |

Notes:
(1) The Guidelines may be applied for torsional strength assessments. As for requirements of longitudinal strength other than torsional strength, this Guidelines is not to be applied.
(2) As for the wave-induced loads of these requirements, loads obtained according to this Guidelines related to direct load analysis may be considered instead of said requirements.

## Annex 2 Structural Strength Assessments Based Upon Full-Spectrum Analysis and Structural Strength Assessments Based Upon Worst Short-Term Sea States

### A.2.1 General

This annex states procedures for structural strength assessments based upon full-spectrum analysis or worst short-term sea states. A structural strength assessment based upon full-spectrum analysis means a method in which statistical prediction is carried out based upon the stress RAOs obtained from said analysis. There are two methods: one is an assessment method based upon equivalent design waves of A.2.2, and the other is an assessment method through non-linear statistical prediction not using equivalent design waves of A.2.3.

### A.2.2 Procedures for structural strength assessments based upon stress RAOs and equivalent design waves

The procedure for structural strength assessments based on stress RAOs, obtained from full-spectrum analysis is as given in the following (1) to (5) (see Fig. A.2.1). Stress RAOs means RAOs of component stress, but the index combining multiple component stresses such as Von-mises stress cannot be a stress RAO.

(1) Evaluation areas and target members are to be selected.

(2) Direct load analysis is to be carried out in regular waves and then loads corresponding to each regular wave are to be applied to a finite element model. The stress RAOs for target members are to be calculated through finite element analysis.

(3) Short-term and long-term statistical predictions based upon linear theory are to be carried out for each stress component generated in target members. For yield strength assessments and buckling strength assessments, the maximum and minimum stresses for anticipated service periods are to be calculated. For fatigue strength assessments, stresses at probability levels expected to be dominant to fatigue strength are to be calculated.

(4) Equivalent design waves which reproduce responses equivalent to (3) above and loads based upon such waves are to be created and finite element analysis is to be carried out.

(5) Yield strength assessments, buckling strength assessments and fatigue strength assessments are to be carried out based upon the stress obtained from the analysis of (4) above.

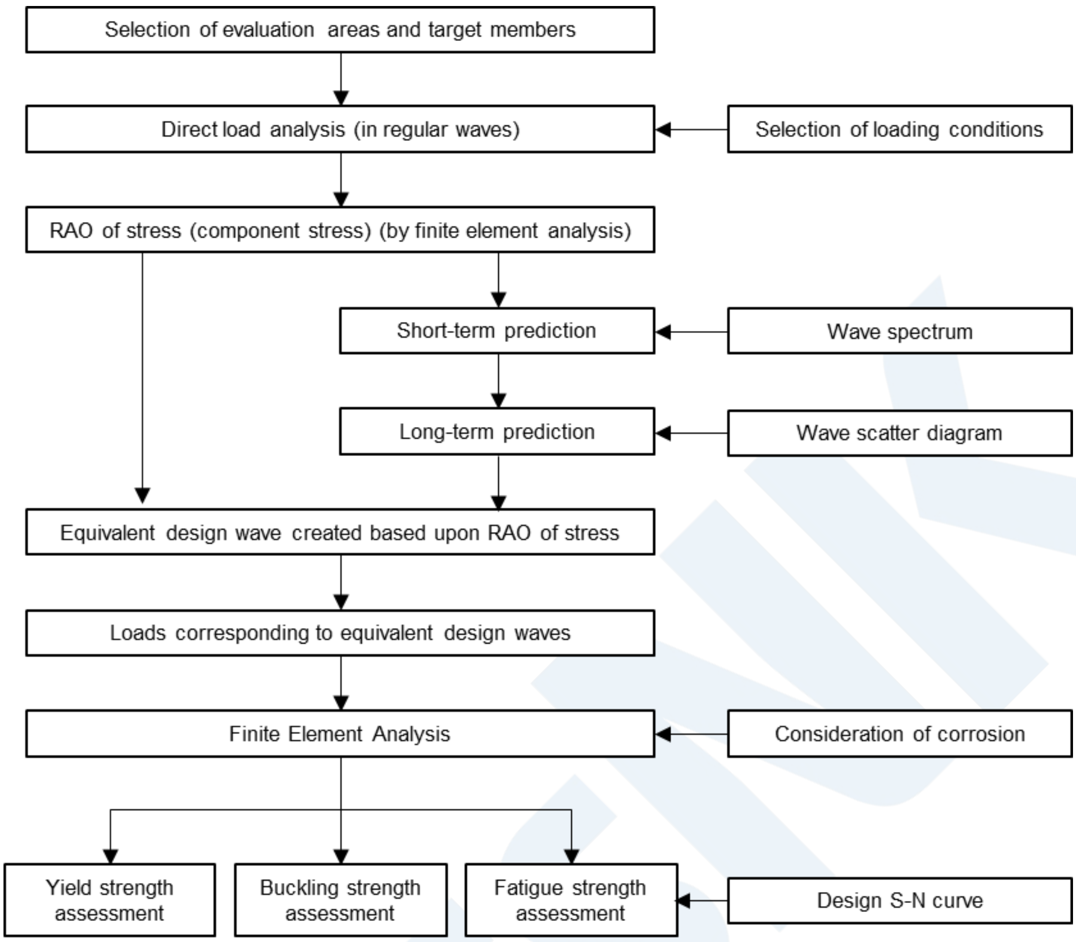


Fig. A.2.1Flow chart for structural strength assessments based upon stress RAOs and equivalent design waves

### A.2.3 Procedures for structural strength assessments based upon statistical prediction method for non-linear response values

-1. Extreme values of non-linear response values (such as Von-mises stresses used for yield strength assessments, combinations of stresses considered for buckling strength assessments and resultant stresses considered for fatigue strength assessments) cannot be estimated where a statistical prediction method based upon linear superimposing is applied. However, there are statistical methods that can derive the extreme values of such stresses directly. The procedures for structural strength assessments using such statistical prediction methods is as given in the following (1) to (4) (see Fig. A.2.2).

(1) Evaluation areas and target members are to be selected.

(2) Direct load analysis is to be carried out in regular waves and then loads corresponding to each regular wave are to be applied to a finite element model (i.e. full-spectrum analysis is carried out). The amplitudes of component stresses (i.e. stress RAOs), and the phase between these component stresses for target members are to be calculated through finite element analysis.

(3) Statistical prediction of target non-linear responses (e.g. Von-mises stress) is to be carried out based upon the amplitude and phase of component stresses obtained from (2) above. For yield strength assessments and buckling strength assessments, the maximum and minimum stresses for anticipated

service periods are to be calculated. For fatigue strength assessments, stresses at probability levels expected to be dominant to fatigue strength are to be calculated.

(4) Yield strength assessments, buckling strength assessments and fatigue strength assessments are to be carried out based upon the stresses obtained from (3) above.

-2. Attention is to be paid to the difference between stress amplitudes and stress ranges with respect to fatigue stress assessments in cases where -1 above is applied.

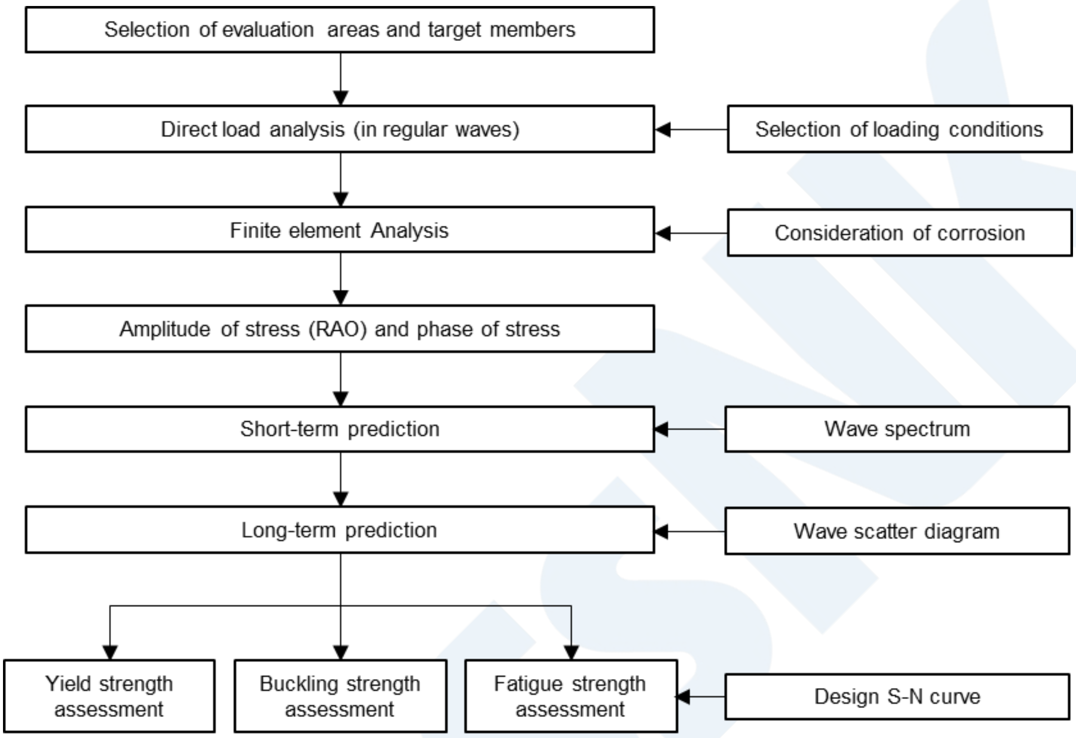


Fig. A.2.2Flow chart for structural strength assessments based upon statistical prediction methods for non-linear response values

## A.2.4 Procedures for structural strength assessments based upon worst short-term sea states

The procedure for structural strength assessments based upon worst short-term sea states is as given in the following (1) to (5). This assessment method may be applied to yield strength assessments and buckling strength assessments; however, fatigue strength assessments are to be in accordance with the procedures of Chapter 3, A.2.2 or A.2.3.

(1) Evaluation areas and target members are to be selected and then their respective DLPs are to be selected.

(2) Direct load analysis in regular waves is to be carried out and RAOs for the DLPs selected in (1) above are to be calculated.

(3) Short-term predictions are to be carried out for each DLP and the maximum expected value for 1000 waves of the DLP in the worst short-term sea state is to be calculated. Average wave period in which the result of the short-term prediction (i.e. the standard deviation of response) becomes the maximum is to be taken as the average wave period of the worst short-term sea state. Significant wave height of the worst short-term sea state is to be as deemed appropriate by the Society.

(4) Equivalent design waves reproducing responses equivalent to those in (3) above are to be created

for each DLP.

(5) Loads based upon the equivalent design waves obtained from (4) above are to be created and then finite element analysis and structural strength assessments are to be carried out.

### A.2.5 Other

For the applications of A.2.2, A.2.3. and A.2.4, this Guidelines may be modified accordingly and applied to each procedure.

## Annex 3 Terms and Conditions for DLP and Direct Load Analysis

### A.3.1 Additional DLPs

-1. In cases where the widths of hatchways amidships exceed 0.7B, torsional moments around shear centres at midship cross sections are to be considered as DLP in addition to Chapter 4. The moments at x/L=0.25, 0.5, 0.75 are, in principle, to be considered; however, where the moments at the cross sections near these locations (e.g. x/L=0.3) are larger, such sections are to be considered.

-2. For ships carrying liquefied gases in bulk, accelerations at the centres of gravity of cargo tanks are to be considered as DLPs in addition to Chapter 4.

-3. For assessments at locations far from midship such as foremost cargo holds, vertical wave induced bending moments at the middles of evaluation areas are to be considered as DLPs in addition to in Chapter 4. In cases where evaluation areas correspond to more than one cargo hold, vertical bending moments at the middle of each cargo hold are to be considered as the DLPs.

-3. Where locations far from midship such as foremost cargo holds are evaluated, consideration of yaw and acceleration invoked by yaw as DLPs may be requested in addition to Chapter 4.

### A.3.2 Direct Load Analysis

-1. The following (1) to (3) are to be taken as standard conditions for direct load analysis:

(1) Five knots is to be considered as ship speed where the loads for yield strength assessment and buckling strength assessment are calculated. Ship speed is 75% of maximum service speed where the loads for fatigue strength assessment are calculated.

(2) Analysis is to be carried out at intervals of wave headings of 30 *degrees* within the range of 0 to 330 *degrees*. In case where symmetry between port and starboard side is obvious, the range of degree may be 0 to 180 *degrees*.

(3) Analysis is to be carried out at intervals of 0.1 within the range of $\sqrt{L/\lambda} = 0.5{\sim}2.0$.

-2. RAOs are to be drawn with horizontal axis of $\lambda / L$ (or value related to wave period) and vertical axis of response amplitude corresponding to wave height of 2 *m* (equal to wave amplitude of 1 *m*).

-3. Peak values of responses are to be sufficiently obtained for each DLP. It is recommended that the range of $\sqrt{L/\lambda} = 0.5{\sim}2.0$ and the interval of the range of -1(3) above be adjusted if necessary.

-4. In general, definitions of coordinates, plus and minus of parameters, etc. differ between programs for direct load analysis and structural analysis. Thus, careful attention is to be paid when the design loads of 7.4 are created.

-5. Comparison and verification with the results of appropriate tank tests are, in principle, to be conducted in order to verify the accuracy of direct load analysis program. It is recommended to use the benchmark test data for a container carrier and an oil tanker published separately by the Society.

## Annex 4 Loading Conditions for Direct Load Analysis and Finite Element Analysis

For yield strength and buckling strength assessments, loading conditions which significantly affect the structural responses of each structure to be assessed are to be appropriately considered for all possible loading conditions. For fatigue strength assessments, loading conditions occurring for extended periods of time during ship service are to be considered.

Table A.4.1 and Table 4.2 are the standard concepts for loading conditions to be considered in direct load analysis and finite element analysis. The cases in which loads can be created when the loading conditions to be considered are different between both analyses are shown on the same line in Table A.4.1 and Table A.4.2.

Table A.4.1 Loading conditions to be considered in yield and buckling strength assessments
(Even in cases where loading conditions are different between direct load analysis and finite element analysis, loads for finite element analysis can be created based upon the results of direct load analysis under loading conditions shown in the left row on the same line.)

| Ship type | Loading conditions for direct load analysis | Loading conditions for finite element analysis |
|---|---|---|
| Container carriers | Full load condition | Full load condition (40' containers loading condition)<br>Light 40' containers loading condition<br>One bay empty condition |
| | The condition in which container cargo is loaded almost homogenously in each cargo hold and draught is obtained by multiplying the scantling draught by 0.9 or less than 0.9 | 20' containers loading condition |
| Box-shaped bulk carriers | Full load condition | Full load condition (homogenous)<br>Full load condition (alternate loading)<br>Full load condition (block loading) |
| | Ballast condition | Ballast condition |
| | Heavy ballast condition | Heavy ballast condition |
| | Condition loaded/unloaded in multiple ports | Condition loaded/unloaded in multiple ports |
| Ore carriers | Full load condition | Full load condition (low density cargo)<br>Full load condition (high density cargo) |
| | Ballast condition | Ballast condition |
| | Condition loaded/unloaded in multiple ports | Condition loaded/unloaded in multiple ports (low density cargo)<br>Condition loaded/unloaded in multiple ports (high density cargo) |

| | | |
|---|---|---|
| Wood chip carriers | Full load condition | Full load condition |
| | Ballast condition | Ballast condition |
| | Heavy ballast condition | Heavy ballast condition |
| | Condition loaded/unloaded in multiple ports | Condition loaded/unloaded in multiple ports |
| Vehicle carriers | Standard full load condition | Standard full load condition<br>The condition in which passenger cars are fully loaded |
| | Ballast condition | Ballast condition |
| Oil tankers / Dangerous chemical bulk carriers | Full load condition | Partial load condition<br>The condition in which draught is obtained by multiplying the scantling draught by 0.9 among the jumping load conditions |
| | Ballast condition | Ballast condition<br>The condition in which draught is obtained by multiplying the scantling draught by 0.6, among jumping load condition<br>The condition in which draught is obtained by multiplying the scantling draught by 0.6 among the zig-zag load conditions |
| | Emergency ballast condition | Emergency ballast condition |
| Ships carrying liquefied gases in bulk | Full load condition | Full load condition |
| | Condition loaded/unloaded in multiple ports (1 cargo tank empty) | Condition loaded/unloaded in multiple ports (1 cargo tank empty) |
| | Condition loaded/unloaded in multiple ports (2 cargo tanks empty) | Condition loaded/unloaded in multiple ports (2 cargo tanks empty) |
| | Condition loaded/unloaded in multiple ports (3 cargo tanks empty) | Condition loaded/unloaded in multiple ports (3 cargo tanks empty) |
| | Ballast condition | Ballast condition |
| Note:<br>Loading conditions for restricted service in loading manuals may not be considered in finite element analysis except for container carriers. | | |

Table A.4.2 Loading conditions to be considered in fatigue strength assessments
(Even in cases where loading conditions are different between direct load analysis and structural analysis, loads for finite element analysis can be created based upon the results of direct load analysis under loading conditions shown in the left row of the same line.)

| Ship type | Loading conditions for direct load analysis | Loading conditions for finite element analysis |
|---|---|---|
| Container carriers | The condition in which container cargo is loaded almost homogenously in each cargo hold and draught is obtained by multiplying the scantling draught by 0.82 or greater than 0.82 | The condition in which container cargo is loaded almost homogenously in each cargo hold and draught is obtained by multiplying the scantling draught by 0.82 or greater than 0.82 |
| Box-shaped bulk carriers | Full load condition | Full load condition (homogenous)<br>Full load condition (alternate loading) |
| | Ballast condition | Ballast condition |
| | Heavy ballast condition | Heavy ballast condition |
| Ore carriers | Full load condition | Full load condition (low density cargo)<br>Full load condition (high density cargo) |
| | Ballast condition | Ballast condition |
| Wood chip carriers | Full load condition | Full load condition |
| | Ballast condition | Ballast condition |
| | Heavy ballast condition | Heavy ballast condition |
| Vehicle carriers | The condition in which passenger cars are fully loaded | The condition in which passenger cars are fully loaded |
| | Ballast condition | Ballast condition |
| Oil tankers / Dangerous chemical bulk carriers | Full load condition | Full load condition<br>The condition in which draught is obtained by multiplying the scantling draught by 0.9 among the jumping load conditions |
| | Ballast condition | Ballast condition<br>The condition in which draught is obtained by multiplying the scantling draught by 0.6 among the jumping load conditions<br>The condition in which draught is obtained by multiplying the scantling draught by 0.6 among the zig-zag load conditions |

| | | |
|---|---|---|
| Ships carrying liquefied gases in bulk | Full load condition | Full load condition |
| | Ballast condition | Ballast condition |
| Note:<br>Loading conditions for restricted service in loading manuals may not be considered in finite element analysis except for container carriers. | | |

## Annex 5 Short-Term and Long-Term Predictions, and Equivalent Design Waves

### A.5.1 General

This annex specifies the standards for short-term and long-term predictions for estimating responses in irregular waves. It also specifies how to create equivalent design waves based upon such statistical predictions.

### A.5.2 Short-Term Predictions

-1. The standard wave spectrum is the wave spectrum of IACS Recommendation No. 34 (Rev.1, 2001).

-2. The standard relative spreading around the main wave heading is the relative spreading of IACS Recommendation No. 34 (Rev.1, 2001).

-3. Where a structure is registered for use in a restricted sea area, the wave spectrum and relative spreading for the concerned sea area can be applied.

-4. The results of short-term prediction are to be expressed on the horizontal axis as average wave periods and on the vertical axis as standard deviations of response to significant wave height of 1.0 *m* (unit significant wave height). It is standard to use short-term prediction results for short crested irregular waves in consideration of the relative spreading of such waves.

### A.5.3 Long-Term Prediction

-1. The standard wave scatter diagram is the diagram of IACS Recommendation No. 34 (Rev.1, 2001) (see Fig. A.5.1).

-2. Where a structure is registered for use in a restricted sea area, the wave scatter diagram for the concerned sea area can be applied. The wave scatter diagram is to be obtained from wave information under a period longer than the period during which said structure is in service.

-3. The standard wave heading acting upon a ship is considered to be uniform in all directions.

-4. The results of long-term prediction is to be expressed by showing the exceedance probability (in general the logarithmic notation) on the horizontal axis and maximum expected amplitude of response on the vertical axis.

### A.5.4 Equivalent Design Waves

-1. In general, the response corresponding to an exceedance probability of $10^{-8}$ is to be taken as the maximum response for a ship service period of 25 years. However, this value may be modified when taking into account operational effects in rough sea conditions, non-linearity of response generated under large wave heights, etc. when deemed appropriate by the Society.

-2. A wave height corresponding to an exceedance probability of $10^{-2}$ is to be taken as the standard wave height of equivalent design waves used for fatigue strength assessments.

-3. The height of an equivalent design wave ($H_{design}$) that reproduces the responses of -1 or -2 above is to be obtained from the following formula:

$$H_{design} = 2\frac{R_{\max}}{RAO} \quad (m)$$

$R_{\max}$: Response decided by -1 or -2 above

$RAO$: Amplitude value of response of equivalent design wave (wave height is 2 *m*) of Chapter 7.

-4. For application of -1 above, non-linearity of response can be estimated directly based upon direct load analysis that considers non-linearity. In addition, operational effects may be estimated through analyses based upon automatic identification system and hindcast weather data. In any case, the methods of investigation and analysis are to be discussed beforehand with the Society.

-5. In applying 7.4-4, it is recommended to apply nodal forces at the ends of the partial structural model to reproduce warping stresses when creating loads based on the equivalent design wave with torsional moment taken as the DLP. To determine these nodal forces, the stiffness and warping function of the ship's cross-section are to be calculated in advance, and using this information, a beam model analysis that additional degree of freedom is introduced by adding the first derivative of the rotation angle around the longitudinal axis to the six degrees of freedom can be carried out.

Table 1, Probability of sea-states in the North Atlantic described as occurrence per 100000 observations.
Derived from BMT's Global Wave Statistics

| Hs/Tz | 1.5 | 2.5 | 3.5 | 4.5 | 5.5 | 6.5 | 7.5 | 8.5 | 9.5 | 10.5 | 11.5 | 12.5 | 13.5 | 14.5 | 15.5 | 16.5 | 17.5 | 18.5 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.5 | 0.0 | 0.0 | 1.3 | 133.7 | 865.6 | 1186.0 | 634.2 | 186.3 | 36.9 | 5.6 | 0.7 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3050 |
| 1.5 | 0.0 | 0.0 | 0.0 | 29.3 | 986.0 | 4976.0 | 7738.0 | 5569.7 | 2375.7 | 703.5 | 160.7 | 30.5 | 5.1 | 0.8 | 0.1 | 0.0 | 0.0 | 0.0 | 22575 |
| 2.5 | 0.0 | 0.0 | 0.0 | 2.2 | 197.5 | 2158.8 | 6230.0 | 7449.5 | 4860.4 | 2066.0 | 644.5 | 160.2 | 33.7 | 6.3 | 1.1 | 0.2 | 0.0 | 0.0 | 23810 |
| 3.5 | 0.0 | 0.0 | 0.0 | 0.2 | 34.9 | 695.5 | 3226.5 | 5675.0 | 5099.1 | 2838.0 | 1114.1 | 337.7 | 84.3 | 18.2 | 3.5 | 0.6 | 0.1 | 0.0 | 19128 |
| 4.5 | 0.0 | 0.0 | 0.0 | 0.0 | 6.0 | 196.1 | 1354.3 | 3288.5 | 3857.5 | 2685.5 | 1275.2 | 455.1 | 130.9 | 31.9 | 6.9 | 1.3 | 0.2 | 0.0 | 13289 |
| 5.5 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 51.0 | 498.4 | 1602.9 | 2372.7 | 2008.3 | 1126.0 | 463.6 | 150.9 | 41.0 | 9.7 | 2.1 | 0.4 | 0.1 | 8328 |
| 6.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 12.6 | 167.0 | 690.3 | 1257.9 | 1268.6 | 825.9 | 386.8 | 140.8 | 42.2 | 10.9 | 2.5 | 0.5 | 0.1 | 4806 |
| 7.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.0 | 52.1 | 270.1 | 594.4 | 703.2 | 524.9 | 276.7 | 111.7 | 36.7 | 10.2 | 2.5 | 0.6 | 0.1 | 2586 |
| 8.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 15.4 | 97.9 | 255.9 | 350.6 | 296.9 | 174.6 | 77.6 | 27.7 | 8.4 | 2.2 | 0.5 | 0.1 | 1309 |
| 9.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 4.3 | 33.2 | 101.9 | 159.9 | 152.2 | 99.2 | 48.3 | 18.7 | 6.1 | 1.7 | 0.4 | 0.1 | 626 |
| 10.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 | 10.7 | 37.9 | 67.5 | 71.7 | 51.5 | 27.3 | 11.4 | 4.0 | 1.2 | 0.3 | 0.1 | 285 |
| 11.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 3.3 | 13.3 | 26.6 | 31.4 | 24.7 | 14.2 | 6.4 | 2.4 | 0.7 | 0.2 | 0.1 | 124 |
| 12.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 1.0 | 4.4 | 9.9 | 12.8 | 11.0 | 6.8 | 3.3 | 1.3 | 0.4 | 0.1 | 0.0 | 51 |
| 13.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 1.4 | 3.5 | 5.0 | 4.6 | 3.1 | 1.6 | 0.7 | 0.2 | 0.1 | 0.0 | 21 |
| 14.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.4 | 1.2 | 1.8 | 1.8 | 1.3 | 0.7 | 0.3 | 0.1 | 0.0 | 0.0 | 8 |
| 15.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.4 | 0.6 | 0.7 | 0.5 | 0.3 | 0.1 | 0.1 | 0.0 | 0.0 | 3 |
| 16.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 1 |
| SUM: | 0 | 0 | 1 | 165 | 2091 | 9280 | 19922 | 24879 | 20870 | 12898 | 6245 | 2479 | 837 | 247 | 66 | 16 | 3 | 1 | 100000 |

The Hs and Tz values are class midpoints.

Fig. A.5.1 Wave scatter diagram of IACS Rec. No. 34 (2001)

## Annex 6 Structural Strength Assessments

### A.6.1 General

For structural strength assessments, A.6.1, A.6.2 and A.6.3 are the standard methods to be followed. For ships subject to Part C of the Rules is applied, assessment criteria and other matters are to be in accordance with Annex 1 and the relevant requirements of Part C.

### A.6.2 Yield Strength Assessments

-1. Yield strength assessments are to be carried out using Von-mises stresses for the plating of structural members. Stress at the centre of thickness and at the centre of the concerned element are to be used for such assessments.

-2. For beam elements and rod elements, axial stresses at the middle of element length are to be used for such assessments.

### A.6.3 Buckling Strength Assessments

-1. Buckling strength assessments which consider ultimate strength after elastic buckling strength may be carried out for both panels and stiffeners. In such cases, panels are assessed as either stiffened panels or plate panels, and the stresses acting on said panels are to be confirmed to not be greater than relevant buckling capacity.

-2. Buckling strength assessments are to be carried out in consideration of tensile stresses, compression stresses, shear stresses and lateral pressures (e.g. water pressure) acting on the stiffened panels or the plate panels.

### A.6.4 Fatigue Strength Assessments

-1. Fatigue strength assessments are to be carried out using hot spot stresses in consideration of localised stress concentrations. In addition, the effect of mean stress is to be considered.

-2. Fatigue strength assessments are to be carried out based upon linear cumulative damage summations (i.e. Palmgren-Miner rules).

-3. Fatigue strength assessments are to be carried out for representative loading conditions according to the ship’s intended operation. Cumulative fatigue damage may be estimated in consideration of the periods for each loading condition during the service period of the ship.

-4. Design S-N curves are to be as deemed appropriate by the Society. A typical design S-N curve in air is shown in Fig. A.6.1.

-5. Long-term distributions of stresses are to be assumed to be Weibull distributions, and a Weibull coefficient of 1.0 is to be taken as standard. In cases where stress long-term distributions are calculated directly in accordance with Annex 2, said long-term distribution may be used.

-6. Regarding -5 above, long-term distributions of stresses based upon anticipated sea routes of ships and sea states related to such routes may be applied. For example, the requirements of 9.5.2.1, Part 1, Part C of the Rules for the Survey and Construction of Steel Ships may be applied.

-7. Regarding -5 above, long-term distributions of stresses may be calculated under the assumed condition that stress wave headings acting on ships are uniformly distributed in all directions.

-8. For ships for which it is deemed necessary by the Society, consideration of the effect of elastic vibration may be requested.

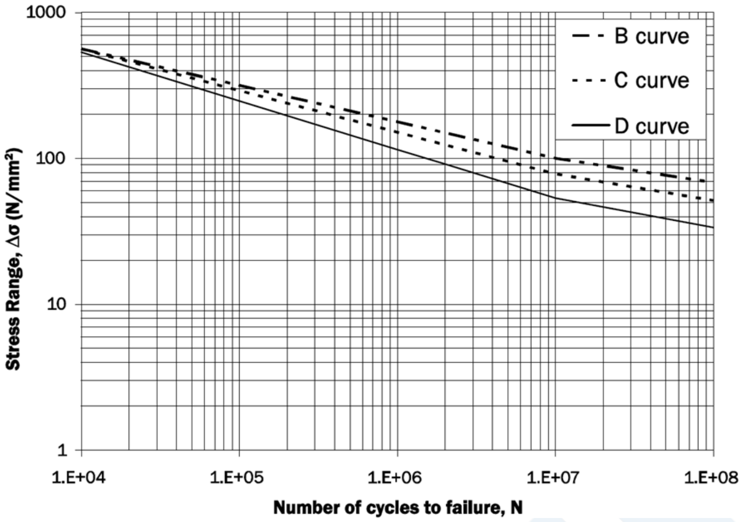


Fig. A.6.1 Typical design S-N curve

Guidelines for Direct Load Analysis and Strength Assessment (Edition 4.1)
[ English ]

NIPPON KAIJI KYOKAI
Research and Development Division
Research Institute
3-3 Kioi-cho, Chiyoda-ku, Tokyo 102-0094, JAPAN
Tel : +81-3-5226-2737
E-mail : ri@classnk.or.jp

www.classnk.com

December 2025