GUIDANCE NOTES
GD006-2026

CHINA CLASSIFICATION SOCIETY

GUIDELINES FOR HULL MONITORING AND ASSISTANT DECISION-MAKING SYSTEM FOR OPERATIONS IN ICE

2026

Effective from 1 July 2026

Beijing

CONTENTS

Section 1 General

1.1 Purpose

1.1.1 The Guidelines are intended to provide technical guidance on the design, installation, usage and maintenance of hull monitoring and assistant decision-making system for ships engaged on voyages in ice regions (hereinafter referred to as monitoring and decision system).

1.1.2 The Guidelines include the conditions and operational procedures for the monitoring and decision system. The safety state of hull structures is monitored, assessed and recorded through measuring and recording the structural response during operation of ships in ice and ice loads.

1.1.3 The Guidelines provide technical guidance for users on selecting monitoring and decision system, setting data measurement and recording method, and determining safety threshold alarms. The Guidelines are not intended to replace the responsibilities of ship owners and equipment suppliers on the monitoring and decision system.

1.2 Application

1.2.1 Monitoring and decision system is to be provided with an independent start/close function. Prior to entry of a ship into ice, the monitoring and decision system is started, and after the ship is out of ice, the system is closed.

1.2.2 During operation of a ship in ice, the monitoring and decision system can provide real time measurement information on hull structural response under the effects of ice load conditions.

1.2.3 When the real time measurement information approaches/exceeds structural safety threshold, the monitoring and decision system is to provide safety warning/alarms to ships and provide corresponding suggestions on decision making.

1.2.4 The monitoring and decision system is to be capable of predicting subsequent trend of data change based on the available measurement information. When such trend is likely to approaches safety threshold, a safety reminder is to be given to the ship.

1.2.5 When the ship navigates in the first time in ice, the newly installed monitoring and decision system is to be used in comparison with other polar risk index systems (e.g. POLARIS).

1.2.6 For accumulation of ice load data, an ice load inversion function can be added in the monitoring and decision system according to the requirements of Section 4.

1.3 Definitions

1.3.1 The definitions in CCS Rules for Classification of Sea-going Steel Ships (hereinafter referred to as CCS Steel Ship Rules), International Code for Ships Operating in Polar Waters by IMO (Polar Code), CCS Guidelines for Polar Ships and CCS Polar Water Operation Manual are applicable to the Guidelines.

1.3.2 **Monitoring and decision system** means a system that is capable of monitoring relevant parameters, judging the safety level of structural spaces through comparison with safety thresholds and providing the supplementary recommendations.

1.3.3 **Monitoring parameters** mean the data that can describe hull structural response and/or ship motion. For the monitoring and decision system, local stress in ice belt area under the impact of ice load is the most important parameter.

1.3.4 **Safety threshold** means the permissible stress value of a monitored node that is provided according to the rule strength criteria and the structural formation of a monitored structural member. This value is determined by the designer and can serve as the reference for decision support during operations in ice; however, it cannot replace the decision and responsibilities of the Master during operations in ice.

1.3.5 **Assessment index** means the ratio of the measured stress, after data processing, of a structural member to the safety threshold.

1.3.6 **Early warning** means an information on danger forecasting released by the monitoring and decision system when the assessment index of the monitored hull position of a ship operates in ice equals or is more than 0.8

1.3.7 **Alarm** means the information on danger released by the monitoring and decision system when the assessment index of the monitored hull position of a ship operates in ice equals or is more than 1.0.

1.3.8 **Safety reminder** means that the information reminding safety is to be released when the monitoring and decision system predicts that the assessment index of the monitored hull position of a ship operates in ice approaches 1.0.

1.3.9 **Ice class rules** mean Chapter 13 Additional Requirements for Polar Class Ships of PART EIGHT, and Chapter 4 Strengthening for Navigation in Ice of PART TWO in CCS Steel Ship Rules.

1.3.10 **Standard ice operation mode** means an operation scenario that is assumed in the ice class rules, including operation methods, ice conditions and ship speed, etc.

1.3.11 **Non-standard ice operation mode** means an operation scenario other than the standard ice operation mode.

1.3.12 **Real time** means the actual time during ice operation.

1.3.13 **Short-term forecast** means the prediction of change within a short period.

1.4 Class notations

1.4.1 Ships that are installed with monitoring and decision system according to the requirements of the Guidelines and relevant rules can apply for the class notation related to the monitoring and decision system: HMS-ICE, and characters for extended operations as appropriate, such as HMS-ICE(Turn, Glancing).

1.4.2 According to the requirements of Section 2 of the Guidelines, the class notation for monitoring and decision system can be assigned to a ship with ice class which is capable of monitoring stress of structure members in ice belt area during operations in ice and can send a safety alarm when the monitored value and forecasted value approach or exceed safety value, and will provide a suggestion on modification of operation to the Master.

1.4.3 According to the relevant requirements of Section 3 and Section 4 of the Guidelines, ships with ice class which comply with the requirements for monitoring of non-standard ice operation mode and ice loads can be assigned with characters for extended operations as appropriate.

Table 1.4.3

Character	Description
Turn	The monitoring and decision system that can meet the need for monitoring of structural response in ice belt area during turning of ships in ice
Glancing	The monitoring and decision system that can meet the need for monitoring of hull girder bending and shear during glancing operation of ships in ice
Oblique	The monitoring and decision system that can meet the need for monitoring of structural response in ice belt area during oblique operation of ships in ice
Stern-Ahead	The monitoring and decision system that can meet the need for monitoring of structural response in ice belt area during stern-ahead

	operation of ships in ice
Shallow-Water	The monitoring and decision system that can meet the need for monitoring of structural response of ship bottom during shallow-water operations of ships in ice
Drift	The monitoring and decision system that can meet the need for monitoring of structural response of ship side and bottom during long-term stay in ice
Ice Load Identification	The monitoring and decision system that can meet the need for monitoring of ice loads

1.4.4 Class notations as indicated in 1.4.2 and 1.4.3 are to be assigned according to the approved plans, equipment certificates and ship surveys.

1.4.5 The monitoring and decision system (including sensors) are to be provided with CCS type approval certificate.

1.5 Plans and documents

1.5.1 The following documents are to be submitted for approval:

(1) Sensor arrangement (including information on each sensor, safety threshold of monitored nodes);

(2) Electric system diagram of the monitoring and decision system.

1.5.2 The following documents are to be submitted for information:

(1) Description of related software (including data processing unit);

(2) User's manual for monitoring and decision system.

1.6 Survey and test

1.6.1 An initial survey is to at least include the following items:

(1) to confirm that related plans and documents have been reviewed;

(2) to confirm that the monitoring and decision system has been reflected in the polar water operational manual (PWOM);

(3) to confirm that the system and hardware products (including sensors) are provided with appropriate certificates;

(4) after installation of the equipment, to carry out survey and test according to the test procedure and calibration procedure of the monitoring device, so as to verify system function.

1.6.2 During annual survey/intermediate survey/special survey, the following items are to be inspected, so as to confirm the monitoring and decision system is in normal function:

(1) Record of maintenance of the monitoring and decision system;

(2) General performance of the monitoring and decision system;

(3) Details and cause analysis of system malfunction/failure;

(4) Repair record and replacement of spare parts;

(5) Inspection and confirmation that the apparatus and instruments in relation to the monitoring and decision system are calibrated according to the specified procedures and plans;

(6) Actual verification of monitoring data under typical working conditions if deemed necessary by the surveyor.

1.6.3 In case of malfunction of the monitoring and decision system, or damage, repair and replacement of equipment, or substantial change of the means of monitoring, shipowners or ship management companies are to apply for an occasional survey.

1.7 Documents maintained onboard

1.7.1 The user's manual is to be kept on board, and is at least to describe the following:

(1) operation;

(2) setting and calibration of sensors and the system;

(3) failure identification;

(4) repair;

(5) system maintenance and functional tests (indicating test methods for the components and system and what is to be observed during test);

(7) explanations of test result.

1.7.2 The log on maintenance and calibration of the monitoring and decision system is to be kept on board.

Section 2 Hull Monitoring and Assistant Decision-Making System for Operations in Ice

2.1 General provisions

2.1.1 This section provides basic requirements for the monitoring and decision system installed on ships using standard ice operational mode.

2.1.2 The monitoring and decision system is to be able to monitor the stresses of structural members in ice belt area during operations in ice and can send a safety alarm when the monitored value and forecasted value approach or exceed safety value, and will provide a suggestion on modification of operation to the Master.

2.1.3 The measurement frequency for the monitoring and decision system is to meet the requirements for measuring impact load, recommended as not to be less than 150Hz. Zero drift during the measurement is to be eliminated, and operational measures such as temperature compensation, regular calibration, timely cleaning and balancing, etc. are to be adopted.

2.1.4 The wheelhouse is to indicate in real time the hull monitoring information during operations in ice, including early warning, alarming, safety reminder and decision support, etc., so as to provide decision support for the Master.

2.1.5 The flowchart of the monitoring and decision system is shown in Figure 2.1.5.

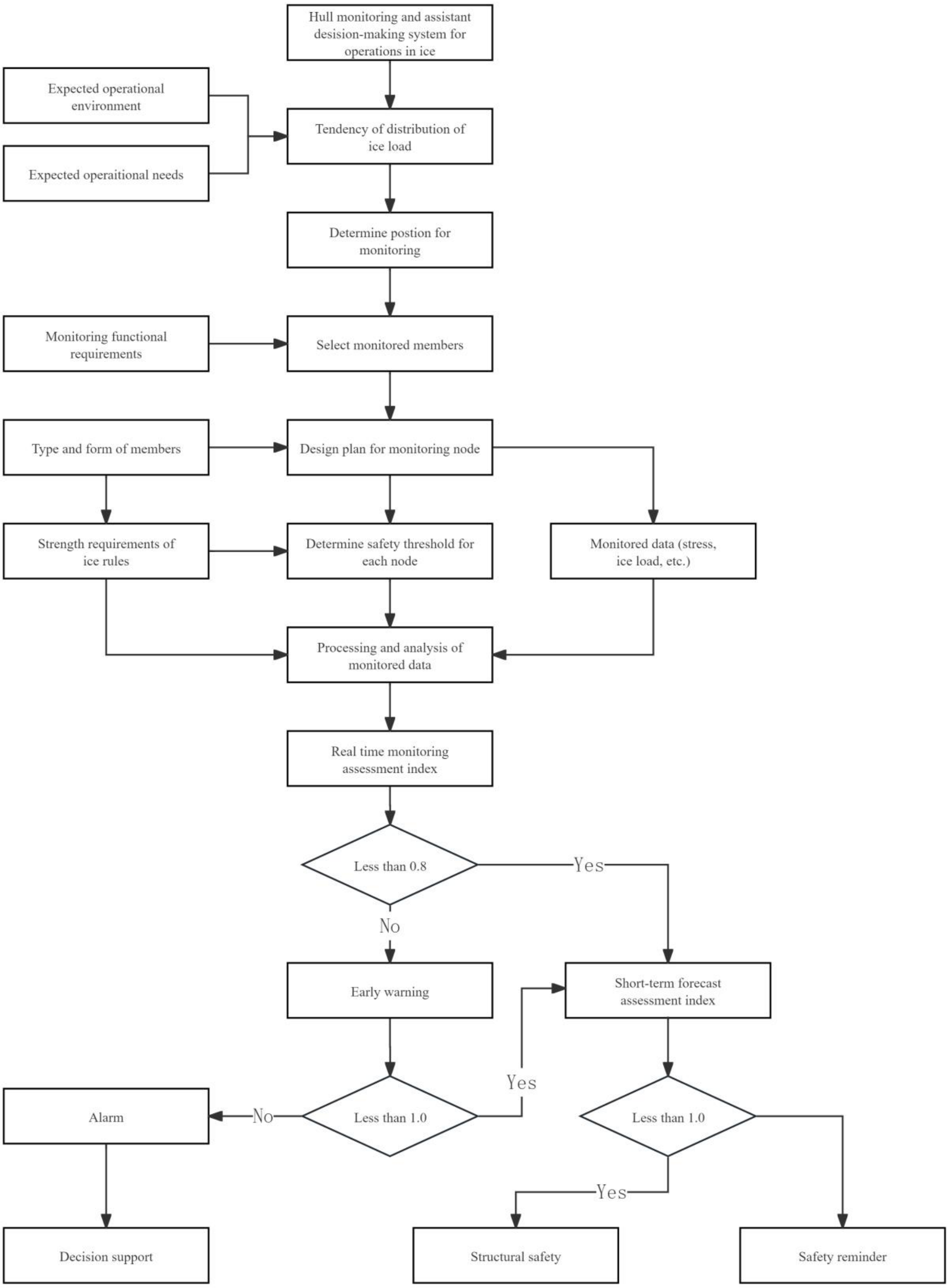


Figure 2.1.5 Flowchart of the monitoring and decision system

2.2 External information

2.2.1 The monitoring and decision system is to have the function of identifying or obtaining and displaying the ice environmental information, .e.g. air temperature, sea water temperature, sea ice type[1] and thickness, intensity, etc..

[1] See sea ice type and thickness as defined by the World Meteorological Organization (WMO).

2.2.2 The monitoring and decision system is to be able to obtain information on the ship's conditions (such as floating condition, speed, acceleration, heading, etc.), navigation trajectory, etc..

2.3 Data storage

2.3.1 The data of monitoring and decision system are to be so stored to meet the relevant requirements of Section 3, Chapter 21 of PART EIGHT in CCS Steel Ship Rules.

2.4 Hull monitoring positions for operations in ice

2.4.1 The monitoring and decision system monitors hull structural responses primarily through strain sensors arranged on hull members near the waterline.

2.4.2 The arrangement positions for sensors of the monitoring and decision system are to be selected based on distribution tendency of ice load. See Figure 2.4.2 and Table 2.4.2.

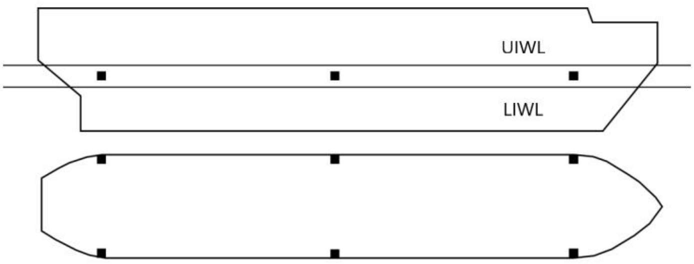


Figure 2.4.2 Schematic diagram of arrangement position of monitoring sensors

Table 2.4.2

Arrangement areas	The arrangement areas are to be selected according to the requirements of the Rules for Ice Class between Upper Ice Water Line (UIWL) and Lower Ice Water Line (LIWL). The arrangement positions can be determined according to ice load value forecast, ice load model test, FE analysis of structural stress, etc.
Arrangement means	Arrangement means for sensors are to be selected according to different members to be monitored: (1) 45^{o} bidirectional strain sensors or three-directional strain sensors are arranged on webs; (2) unidirectional strain sensors are arranged on face plates or flanges; (3) three-directional strain sensors are arranged on shell platings.
Types of sensors	Fiber grating sensor or resistance strain sensor

2.4.3 When arranging sensors, short strain sensors are generally used to measure local structural stress caused by ice excitation, and they are to be arranged at the position with the maximum strain.

2.4.4 Proper sensor installation means are to be selected according to different functional requirements for measuring tensile/compressive/bending normal strain or shearing strain, and the influence of temperature change on the measurement is to be taken into account.

2.5 Design of typical structural monitoring details

2.5.1 The devices for monitoring strain (stress) of typical structural details of hull for operations in ice are to be designed according to the following principals:

(1) unidirectional strain sensors are provided on face plates or flanges of transverse/longitudinal members to measure tensile/compressive strain (stress) of members during bending;

(2) bidirectional strain sensors are provided on webs of transverse/longitudinal members to measure shearing strain (stress) of webs;

(3) three-directional strain sensors are provided on shell platings to measure maximum main strain (stress) of shell platings;

(4) strain sensors are to be arranged as far away as possible from toe ends of brackets.

2.5.2 Web frames

(1) In general web frames subject to ice impact in the arrangement areas are to be selected. Unidirectional tensile/compressive strain sensors are to be arranged on face plates/flanges at midspan of web frames; bidirectional shearing strain sensors are generally to be arranged at upper and lower ends of span of transverse frames. The design of strain monitoring points is illustrated in Figure 2.5.2.

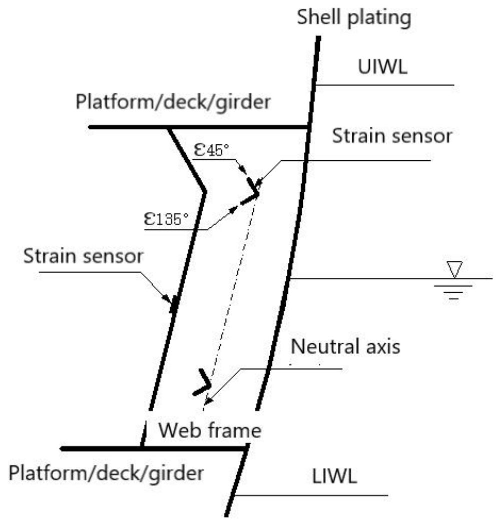


Figure 2.5.2 Schematic diagram of monitoring arrangement of web frame strain

(2) For face plates of web frames, tensile/compressive strain sensors can be used to measure tensile/compressive strain and monitor tensile/compressive strain (stress) on face plates of web frames.

(3) For transverse web frames, bidirectional shearing strain sensors can be used to monitor shearing strain (stress) of webs of transverses.

2.5.3 Girders

(1) In general girders subject to ice impact in the arrangement areas are to be selected. Unidirectional tensile/compressive strain sensors are to be arranged on face plates at midspan of girders; bidirectional shearing strain sensors are generally to be arranged at longitudinal members near the transverse ring. The design of strain monitoring points is illustrated in Figure 2.5.3.

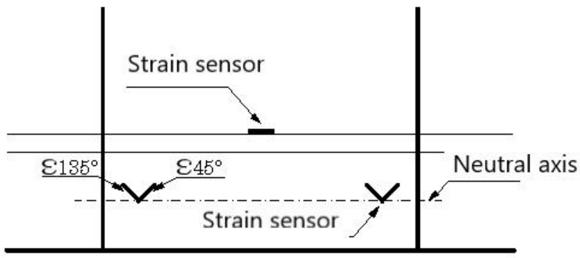


Figure 2.5.3 Schematic diagram of monitoring arrangement of girder strain

(2) For face plates of girders, tensile/compressive strain sensors can be used to measure tensile/compressive strain and monitor tensile/compressive strain (stress) on face plates of girders.

(3) For webs of girders, bidirectional shearing strain sensors can be used to monitor shearing strain (stress) of girders.

2.5.4 Longitudinals

(1) In general longitudinals subject to ice impact in the arrangement areas are to be selected. Unidirectional tensile/compressive strain sensors are to be arranged on face plates at midspan of longitudinals. The design of strain monitoring points is illustrated in Figure 2.5.4.

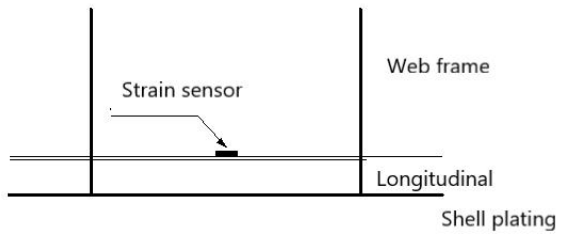


Figure 2.5.4 Schematic diagram of monitoring arrangement of longitudinal strain

(2) For face plates of longitudinals, tensile/compressive strain sensors can be used to measure tensile/compressive strain and monitor tensile/compressive strain (stress) on face plates of longitudinals.

2.5.5 Frames

(1) In general frames subject to ice impact in the arrangement areas are to be selected. Unidirectional tensile/compressive strain sensors are to be arranged on face plates at midspan of frames. The design of strain monitoring points is illustrated in Figure 2.5.5.

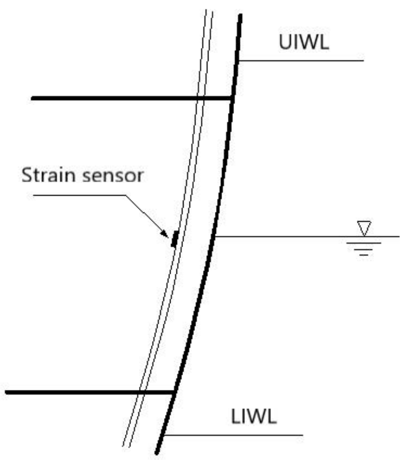


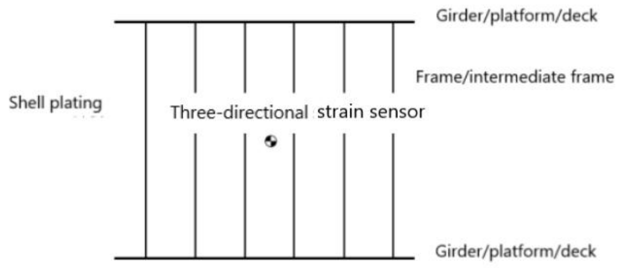
Figure 2.5.5 Schematic diagram of monitoring arrangement of frame strain

(2) For face plates of frames, tensile/compressive strain sensors can be used to measure tensile/compressive strain and monitor tensile/compressive strain (stress) on face plates of frames.

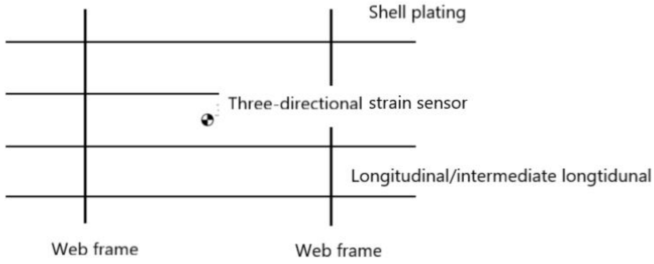
2.5.6 Shell platings

(1) In general side shell platings subject to ice impact in the arrangement areas are to be selected. Three-directional strain sensors are to be arranged at the center of shell plating panel. The design

of strain monitoring points is illustrated in Figure 2.5.6.



(Transversely framed)



(Longitudinally framed)

Figure 2.5.6 Schematic diagram of monitoring arrangement of shell plating strain

(2) For shell platings, three-directional strain sensors can be used to measure panel strain and monitor maximum main strain (stress) of shell platings.

2.6 Data processing

2.6.1 The data collected are to be processed by low-pass filter to filter measurement errors introduced by high frequency noise.

2.6.2 Due to the randomness of ice load distribution and the harsh ice area environment, the probability of abnormal values in the collected data is increased, and the abnormal values which are far from the values of other data samples are to be eliminated during data processing.

2.6.3 Collected hull monitoring data for a ship operating in ice can be used as input for assessment index after being processed such as low-pass filtering and removing abnormal values.

2.6.4 Necessary measures are to be taken to eliminate the influence of environmental temperature on monitoring data, such as setting up temperature compensation devices or using algorithms that take into account changes in environmental temperature.

2.6.5 When the sensor fails, the system is to provide a prompt and eliminate the influence of the failed measuring point, while display the location of the fault.

2.7 Determination of safety threshold

2.7.1 The monitoring and decision system is specifically used to monitor the response of hull structure under ice load. When the system is started, the initial value for a hull monitoring position is automatically set to zero.

2.7.2 In the monitoring and decision system, the safety threshold is determined by factors such as the location of measurement points, attributes of structural members, and permissible stress. Such threshold is used to evaluate the safety state of members.

2.7.3 For permissible stress of a monitored member under ice load impact deduced according to the requirements of the Rules for Ice Class, see relevant provisions of Chapter 4, PART TWO, or Section 2, Chapter 13, PART EIGHT of CCS Rules for Classification of Sea-going Steel Ships or other equivalent methods.

2.7.4 For ships with PC notations, see Table 2.6.4 for permissible stress of the monitored member under ice load impact.

Table 2.7.4

Member			Permissible stress
Shell plating	Transversely framed $\Omega \geq 70°$		$\dfrac{1}{2(1+\dfrac{s}{2b})^2} R_{\mathrm{eH}}$
	Longitudinally framed $\Omega \geq 20°$		$\dfrac{1}{2(1+\dfrac{s}{2l})^2} R_{\mathrm{eH}}$
	Longitudinally framed $\Omega < 20°$		$\dfrac{2\dfrac{b}{s}-(\dfrac{b}{s})^2}{2(1+\dfrac{s}{2l})^2} R_{\mathrm{eH}}$
Framing	Longitudinal	Bending stress	$A_4 R_{eH}$
		Shear stress	$\dfrac{R_{\mathrm{eH}}}{2\sqrt{3}}$
	Frame	Bending stress	$YA_1 R_{eH}$
		Shear stress	$\dfrac{R_{\mathrm{eH}}}{2\sqrt{3}}$
Bay	Web frames		Determined by direct analysis
	Girder		Determined by direct analysis
Longitudinal strength	Yield/bending		$\sigma_a - \dfrac{\bar{M}_{\mathrm{s}}}{W_{\mathrm{c}}} \times 10^3$
	shearing		τ_a

Note: For definitions of Ω, PPF_p, s, b, Y, A_1, A_4, R_{eH}, σ_a, τ_a in the table, see Section 2, Chapter 13 of PART EIGHT in CCS Steel Ship Rules; for definitions of $\bar{M}_{\mathrm{s}}$ and W_{c}, see Section 2, Chapter 2 of PART TWO in CCS Steel Ship Rules.

2.7.5 For ships with B3~B1* notations, see Table 2.6.5 for permissible stress of the monitored member under ice load impact.

Table 2.7.5

Member			Permissible stress
Shell plating	Longitudinally framed		$\dfrac{0.889}{f_2} R_{\mathrm{eH}}$
	Transversely framed		$0.667 f_1 R_{\mathrm{eH}}$
Longitudinals & framing	Longitudinal	bending stress	$\dfrac{8 f_4}{m} R_{\mathrm{eH}}$

		Shear stress	$\frac{f_4 f_5}{2\sqrt{3}} R_{\mathrm{eH}}$
	Frame	bending stress	$\frac{4}{m_t} R_{\mathrm{eH}}$
		Shear stress	$\frac{f_3}{2\sqrt{3}} R_{\mathrm{eH}}$
Strong member	Web frame		Determined by direct calculation
	Girder		Determined by direct calculation

Note: For definitions of f_2, f_1, f_3, f_4, f_5, R_{eH}, m_t, m, see Section 2, Chapter 4 of PART TWO in CCS Steel Ship Rules.

2.7.6 The ratio of maximum measured stress of members to the safety threshold is taken as the assessment index. When the assessment index is greater than or equal to 1.0, alarm is to be set; when it is greater than or equal to 0.8, early warning is to be set.

2.7.7 Where the system has the ice load monitoring function, the ratio of monitored ice load to the structural ultimate bearing capacity is taken as the assessment index. When the assessment index is greater than or equal to 1.0, alarm is to be set; when it is greater than or equal to 0.8, early warning is to be set.

2.8 Short-term monitoring forecast

2.8.1 The monitoring and decision system is to have the function of short-term monitoring forecast. Based on the existing monitoring data, it can reflect the variation trend of the monitoring data within next 1-2 hours (such as extreme value forecast, trend curve, etc.). When the forecasted assessment index reaches 1.0, a safety reminder is to be set.

2.9 Decision support

2.9.1 Assisted decisions are to be made to support the Master to select appropriate operation measures according to the ice area environment, ship state and early warning/alarm information.

2.9.2 When a ship operates in ice, appropriate operational measures corresponding to early warning/alarm from different locations are to be implemented. A general description is given in Table 2.9.2.

Table 2.9.2

Early warning/alarm location	Possible danger	Operational measure
Bow	Damage of bow structure; structural failure of girders and frames at bow	Reducing speed, changing course or stopping operation is recommended
Midship	Damage of side shell plating; failure of side girders and frames	Reducing speed or increasing turning radius is recommended
Stern	Damage of stern frames; structural failure of girders and floors at stern	Reducing speed is recommended

Section 3 Supplementary Requirements for Non-standard Ice Operation Mode

3.1 General provisions

3.1.1 When operating in ice, ship structural strength is affected. If there are functional requirements for non-standard ice operation mode, it is recommended to consider relevant requirements of this Section according to the characteristics of ice operation, based on Section 2.

3.1.2 According to selected non-standard ice operation mode, sensors are arranged on corresponding local hull structures and real-time monitoring and forecast are carried out on ice-induced hull structure response, so as to analyze the safety status of relevant structures.

3.1.3 Hull ice load distribution trend during non-standard ice operation and arrangement position of sensors can be determined by means of test, numerical analysis method.

3.1.4 For the design of structure monitoring nodes, see relevant requirements of 2.4, Section 2 of the Guidelines.

3.2 Turning operation in ice

3.2.1 For ships with higher ice operation performance (e.g. with high lifting rudder, with podded propulsion system), in order to meet the need of hull monitoring during turning operation in ice, it is recommended to set additional hull monitoring devices according to the requirements of 3.2.2.

3.2.2 During turning operation, the ice pressure was maximum at two positions: in front of the ship proceeding direction in adjacent to internal side of the shipping lane; and at rear of the ship proceeding direction in adjacent to the external side of the shipping lane. At the same time, ice pressure amidships is higher due to compression of large amount of sea ice. Therefore, based on Section 2 of the Guidelines, at least one hull monitoring position is to be additionally set in way of critical positions of shoulder and tail structures near molded line contraction respectively, on each side of the ship.

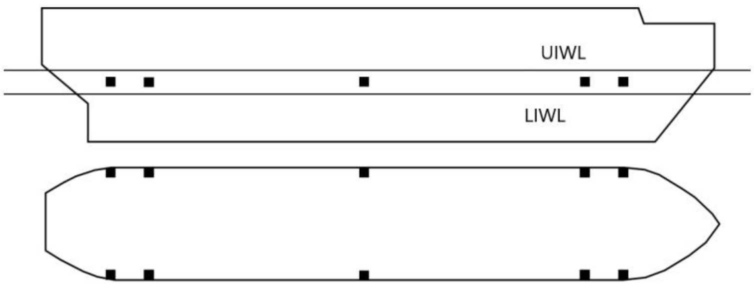


Figure 3.2.2 Schematic diagram of arrangement positions of monitoring sensors

3.2.3 When there is early warning or alarm, suggestions on correcting ship operation are to be given:

(1) When the ship is subject to turning operation, attention is to be paid to hull monitoring conditions at hull shoulder and stern positions. If early warning/alarm occurs, measures such as slowing down or increasing turning radius can be taken.

(2) For high ice class ships using azimuth thruster, in severe ice conditions, in order to avoid heavy ice load on hull, it is recommended to turn astern at low speed, so as to blow ice away from

hull through azimuth thruster and widen the lane, thus facilitating turning. If selecting turning ahead at high speed, it is recommended to control the angle of azimuth thruster within 30^{o}.

3.3 Glancing operation in ice

3.3.1 Considering that ships may adopt ice glancing operation mode (e.g. ice ridge glancing), in order to meet the need of hull monitoring during glancing operation, it is recommended to set additional hull monitoring devices according to the requirements of 3.3.2.

3.3.2 During glancing operation, there is heavy ice impact load in way of the position where the molded line contracts from bow to shoulder, and the bow may be subject to additional impact bending moment and shear force caused by heavy ice load, therefore, hull monitoring positions are to meet following requirements:

(1) At least one hull monitoring position is to be set on each side of the ship at critical position between the bow and the position where the moulded line contracts. And at least one hull monitoring position is to be set on each side of the ship at the position where the molded line contracts.

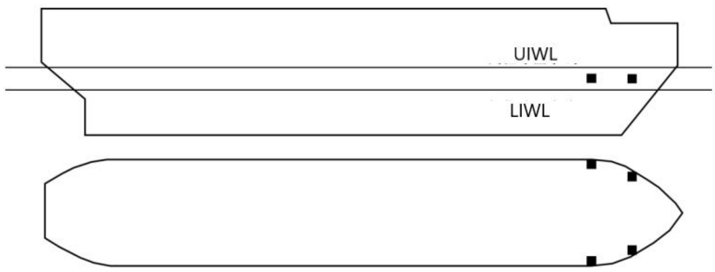


Figure 3.3.2(1) Schematic diagram of arrangement positions of monitoring sensors

(2) At least one hull girder shear strain (stress) monitoring position is to be set at critical position of bow shell plating, as shown in Figure 3.3.2(2), to obtain hull girder shear strain (stress) by installing bidirectional 45^{o} strain sensor.

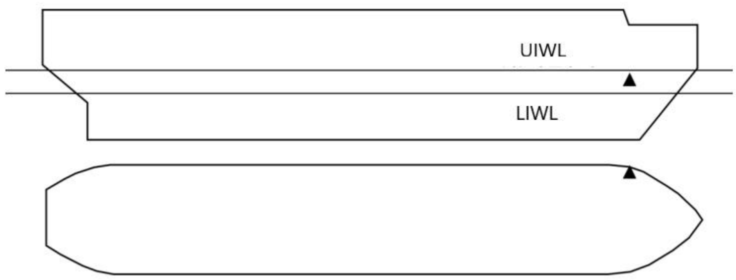


Figure 3.3.2(2) Schematic diagram of arrangement positions of monitoring sensors

(3) At least one hull girder bending moment monitoring position is to be set at critical position of typical transverse section 0.5L~0.7L away from the stern. In order to reduce measurement error and as far as practicable, several strain (stress) monitoring positions can be arranged at equal spacing along ship breadth and an average value is to be taken.

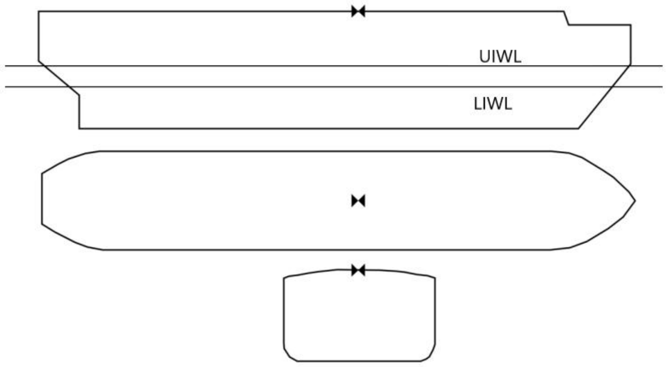


Figure 3.3.2(3) Schematic diagram of arrangement positions of monitoring sensors

(4) One three-directional strain (stress) monitoring position is to be set on bow hull plating to measure maximum strain (stress) of hull shell plating.

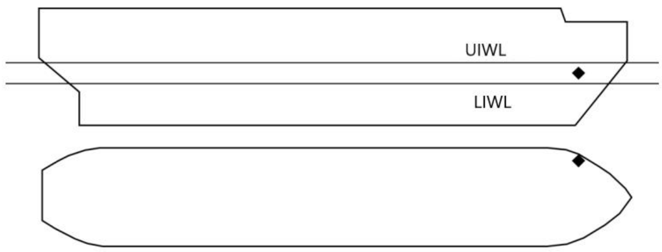


Figure 3.3.2(4) Schematic diagram of arrangement positions of monitoring sensors

3.3.3 When an early warning or alarm is released, suggestions on correcting ship operation are to be given:

(1) During first year ice glancing operation, if thickness of glancing ice is greater than that of design ice, speed of continuous glancing is to be lower than speed in design ice, and the maximum speed of single glancing is to be the speed in design ice.

(2) During multi-year ice glancing operation, bow glancing is to be used with low glancing speed.

(3) During ice ridge glancing, only bow glancing is allowed and glancing speed is not to be higher than design ice speed.

(4) There is risk of be trapped in ice when colliding with extreme ice barrier, so caution is to be taken when performing colliding operation.

(5) When hull monitoring data approaches or reaches safety threshold, glancing speed is to be reduced or glancing is to be stopped.

3.4 Stern-ahead operation in ice

3.4.1 Ships may adopt stern-ahead operation mode in ice region (e.g. ferryboats in ice region, bidirectional operational ships in ice region). In order to meet the need of hull monitoring during stern-ahead operation, it is recommended to set additional hull monitoring devices according to the requirements of 3.4.2.

3.4.2 During stern-ahead operation, there is heavy ice load on ship structure near stern waterline, and especially the positions where the molded line changes greatly withstand the greatest ice pressure, therefore, hull monitoring positions are to comply with following requirements:

(1) At least one hull monitoring position is to be set at critical positions of stern and stern transition zone respectively, on each side of the ship.

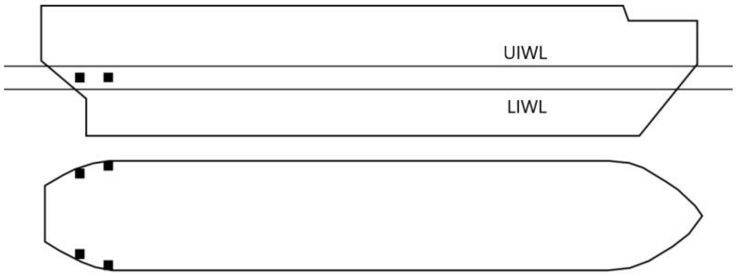


Figure 3.4.2(1) Schematic diagram of arrangement positions of monitoring sensors

(2) At least one three-directional strain (stress) monitoring position is to be set on stern shell plating to measure the maximum main strain (stress) of hull shell plating.

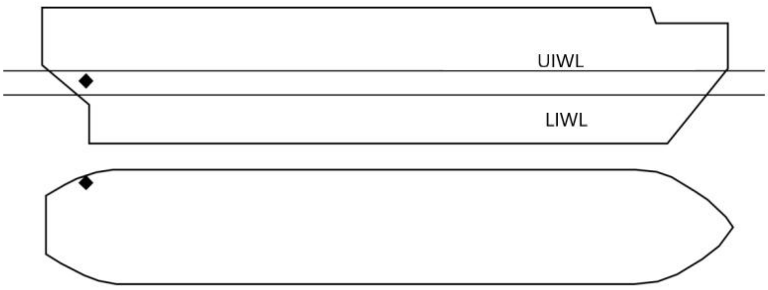


Figure 3.4.2(2) Schematic diagram of arrangement positions of monitoring sensors

3.4.3 When an early warning or alarm is released, suggestions on correcting ship operation are to be given:

(1) Appropriate propeller immersion at stern is to be maintained as far as possible to prevent damage due to direct ice collision by propeller blade.

(2) During stern-ahead operation in thicker ice region (ice ridge, thick brash ice), low speed and continuous rotation of pod can be adopted to increase efficiency of ice washing.

3.5 Shallow water operation in ice

3.5.1 Ships may carry out shallow water operation in ice (e.g. shallow water lane, port operation, etc.). In order to meet the need of hull monitoring during shallow water operation in ice, it is recommended to set additional hull monitoring devices according to the requirements of 3.5.2.

3.5.2 During shallow water operation in ice, bottom area is easy to subject to ice impact, therefore, the hull monitoring positions for operations in ice are to meet the following requirements:

(1) At least one hull monitoring position is to be set up at both port and starboard sides of the ship at critical positions of the bottom at the bow and stern respectively.

(2) The ice load/structural stress distribution of the ship during shallow water operations in ice is to be analyzed through test or numerical method to determine the specific hull monitoring positions and quantity.

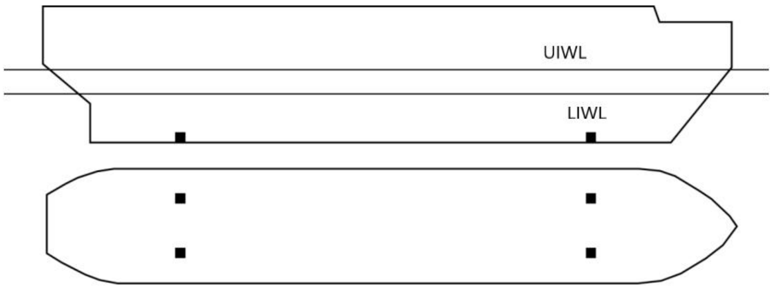


Figure 3.5.2 Schematic diagram of arrangement positions of monitoring sensors

3.5.3 When an early warning or alarm is released, suggestions on adjusting ship operation are to be given:

(1) Attention is to be paid to ship bottom monitoring state. If an early warning/alarm is released according to hull monitoring data, measures such as reducing speed and adjusting course are to be taken and proceeding is to be halted when necessary.

(2) When the ship is subject to severe ice condition, watch out is to be strengthened. Bypassing or slowly accessing from downwind edge of loose ice can be performed when necessary.

3.6 Oblique operation in ice

3.6.1 For dedicated icebreakers performing oblique operation in ice, in order to meet the need of hull monitoring during oblique operation in ice, it is recommended to set additional hull monitoring devices according to the requirements of 3.6.2.

3.6.2 During oblique operation in ice, there is large difference between ship-ice interaction and routine ice operation, and hull girder bending moment and shear force at ship side increase significantly, therefore, hull monitoring positions are to meet following requirements:

(1) At least two three-directional strain (stress) monitoring positions are to be set on hull shell plating at hull oblique icebreaking position to measure maximum main strain (stress) of hull shell plating.

(2) Hull ice load distribution during oblique operation is to be analyzed by means of test or numerical method, and sufficient quantity of hull monitoring positions are to be set in critical positions of hull structure in areas with heavy ice load.

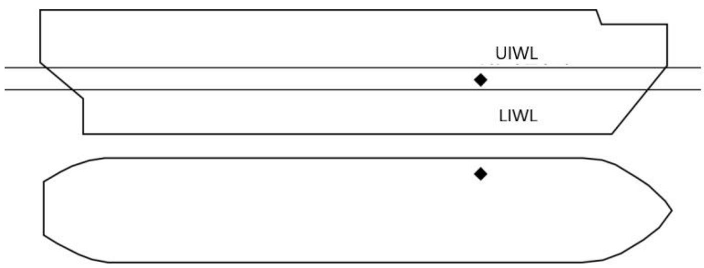


Figure 3.6.2 Schematic diagram of arrangement positions of monitoring sensors

3.6.3 When an early warning or alarm is released, suggestions on adjusting ship operation are to be given:

(1) Oblique operation can increase icebreaking breadth and improve icebreaking efficiency, but it can only be used in area with thinner ice layer. For thick ice layer or ice ridge, oblique operation

is to be stopped immediately.

(2) During oblique operation, draught is to be adjusted to near design waterline to advance at speed as low as possible.

3.7 Long-term drift operation in ice

3.7.1 For long-term drift operation in ice, in order to meet the need of hull monitoring during long-term drift operation in ice, it is recommended to set additional hull monitoring devices according to the requirements of 3.7.2.

3.7.2 During long-term drift operation in ice, both sides of the ship are compressed by sea ice, and the bottom is compressed by accumulated sea ice, therefore, hull monitoring positions are to meet the following requirements:

(1) At least four monitoring positions are to be set on both sides of the amidship area along the UIWL and LIWL respectively.

(2) At least one monitoring position is be set on both sides above UIWL, and at least three monitoring positions are to be set on both sides below LIWL on at least two cross-sections of amidship area.

(3) At least three monitoring positions are to be set on one side of the ship bottom on at least two cross sections of amidship area.

(4) The ice load/structural stress distribution on the hull during long-term stay operations in ice is to be analyzed through test or numerical method to determine the specific hull monitoring positions and quantity.

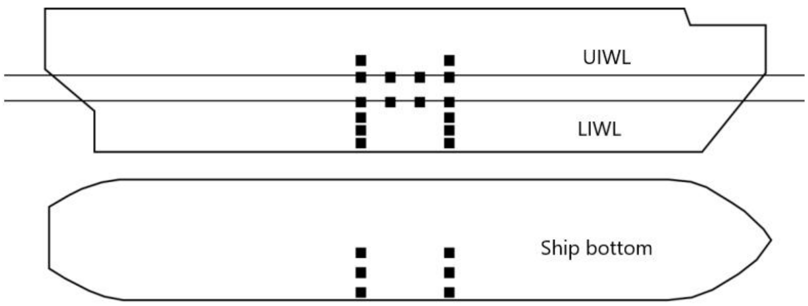


Figure 3.7.2 Schematic diagram of arrangement positions of monitoring sensors

Section 4　Hull Monitoring of Local Ice Load

4.1　General provisions

4.1.1 Ice load monitoring is an important technical means for identifying structural damage, safety assessment, and ice load research of ships operating in ice areas. Ice load monitoring is to meet the requirements of this Section.

4.1.2 Ice load can be obtained by measuring the hull structural response.

4.1.3 In the process of ice load monitoring, it can be assumed that the local strain response is only the deformation caused by the static effects of balanced external loads, ignoring the high-frequency strain response of the local area excited by the dynamic effect.

4.2　Sesnor arrangement for ice load monitoring

4.2.1 In order to meet the functional requirements of ice load monitoring, array strain sensors are to be arranged near the waterline to monitor the structural response required for identifying ice loads.

4.2.2 The array strain sensor is to be located between the UIWL and the LIWL, and cover sufficient monitored area. It is usually recommended to take a longitudinal range of not less than four times the spacing between frames or one time the spacing between web frames, which one is greater, and a vertical range of not less than four times the spacing between frames.

4.2.3 For array strain sensors at different locations of the hull, appropriate sensor arrnagement schemes are to be determined based on various ice load monitoring targets. Typical sensor arrangement scheme is shown in Table 4.2.3.

Table 4.2.3

Location	Ice load monitoring target	Arrangement position	Remark
Bow	Ice load on the bow or bow intermediate area during the heading ice breaking	Frame/longitudinal, web frame/girder web	Recommended
		Hull shell plating	Optional
Amidship	Compression load of sea ice on both sides during long-term drift in ice	Frame/longitudinal, web frame/girder web	Recommended
	Glancing load on ice edges during the navigation in ice	Hull shell plating	Optional
Stern	Ice load on the stern or intermediate area during the stern ice breaking	Frame/longitudinal, web frame/girder web	Recommended
		Hull shell plating	Optional

4.2.4 In order to achieve the monitoring accuracy of ice load, the array strain sensors are to have a sufficient quantity, and it is generally recommended to have a monitoring matrix of not less than 5 × 5 or an equivalent number of monitoring matrix.

4.3　Design of ice load monitoring details

4.3.1 Web frames

(1) In general web frames subject to ice impact in the arrangement areas are to be selected. Bidirectional strain sensors are to be arranged on the neutral axis to measure the shear strain of web frames. The design of strain monitoring details is shown in Figure 4.3.1 (1). According to the actual situation, unidirectional tensile/compressive strain sensors are also to be installed on the web frame near the shell plating. The design of strain monitoring details is shown in Figure 4.3.1

(2).

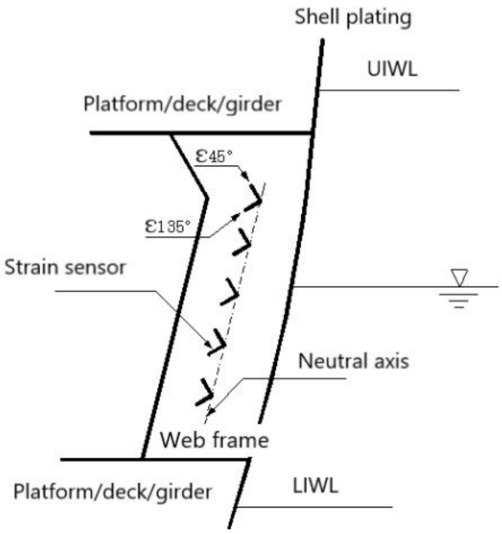


Figure 4.3.1(1) Schematic diagram of arrangement of bidirectional strain sensor on web frame for ice load monitoring

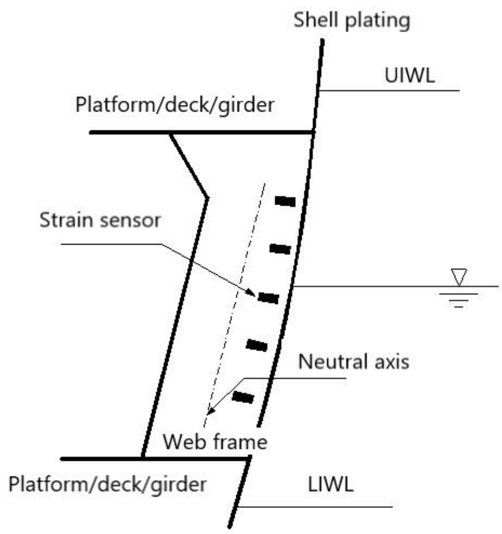


Figure 4.3.1(2) Schematic diagram of arrangement of unidirectional strain sensor on web frame for ice load monitoring

(2) Normal strain perpendicular to shell plating is obtained by directly measuring of unidirectional strain sensor. Where the bidirectional strain sensor is used, the normal strain ε_v and shear strain γ_{xy} on the structural member can be calculated by the following formulae:

$$\varepsilon_y = \varepsilon_{135^\circ} + \varepsilon_{45^\circ}$$

$$\gamma_{xy} = \varepsilon_{135^\circ} - \varepsilon_{45^\circ}$$

Where: ε_{45° — strain value measured by a 45 ° tensile/compressive strain sensor;

ε_{135° — strain value measured by a 135 ° tensile/compressive strain sensor.

4.3.2 Girders

(1) In general girders subject to ice impact in the arrangement areas are to be selected. Bidirectional strain sensor can be arranged on the neutral axis to measure the shear strain of girder. The design of strain monitoring details is shown in Figure 4.3.2 (1). According to the actual situation, unidirectional tensile/compressive strain sensor can also be installed on the girder web near the shell plating. The design of strain monitoring details is shown in Figure 4.3.2 (2).

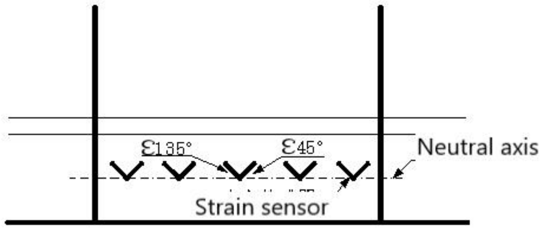


Figure 4.3.2(1) Schematic diagram of arrangement of bidirectional strain sensor on girder for ice load monitoring

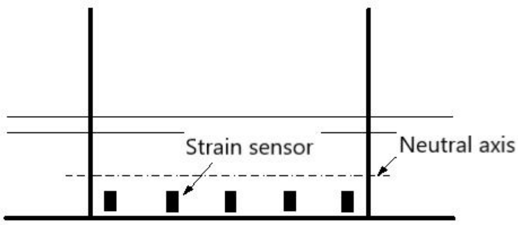


Figure 4.3.2(2) Schematic diagram of arrangement of unidirectional strain sensor on girder for ice load monitoring

(2) Normal strain perpendicular to shell plating is obtained by directly measuring using unidirectional strain sensor. Where the bidirectional strain sensor is used, the normal strain ε_v and shear strain γ_{xy} on the structural member can be calculated by the formulae in 4.3.1(2).

4.3.3 Frames

(1) In general, frames subject to ice impact in the arrangement areas are to be selected. Bidirectional strain sensor can be arranged on the neutral axis to measure the shear strain of frame. The design of strain monitoring details is shown in Figure 4.3.3(1). According to the actual situation, unidirectional tensile/compressive strain sensor can also be installed on the frame web near the shell plating. The design of strain monitoring details is shown in Figure 4.3.3 (2).

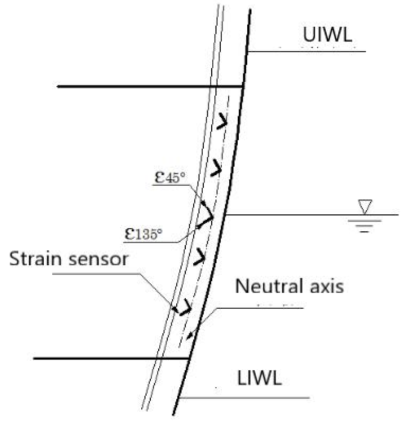


Figure 4.3.3(1) Schematic diagram of arrangement of bidirectional strain sensor on frame for ice load monitoring

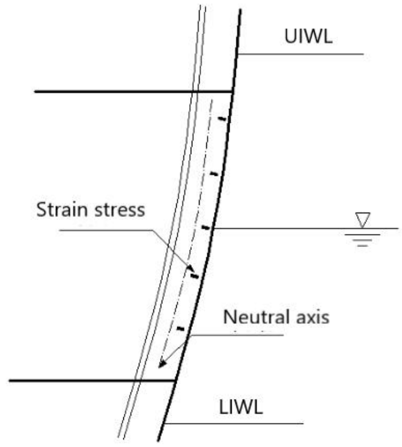


Figure 4.3.3(2) Schematic diagram of arrangement of unidirectional strain sensor on frame for ice load monitoring

(2) Normal strain perpendicular to shell plating is obtained by directly measuring using unidirectional strain sensor. Where the bidirectional strain sensor is used, the normal strain ε_v and shear strain γ_{xy} on the structural member can be calculated by the formulae in 4.3.1(2).

4.3.4 Longitudinals

(1) In general, longitudinals subject to ice impact in the arrangement areas are to be selected. Bidirectional strain sensor can be arranged on the neutral axis to measure the shear strain of longitudinal. The design of strain monitoring details is shown in Figure 4.3.4(1). According to the actual situation, unidirectional tensile/compressive strain sensor can also be installed on the longitudinal web near the shell plating. The design of strain monitoring details is shown in Figure 4.3.4 (2).

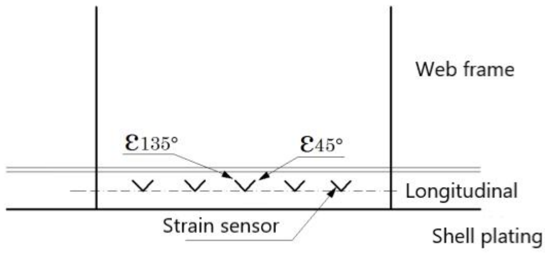


Figure 4.3.4(1) Schematic diagram of arrangement of bidirectional strain sensor on longitudinal for ice load monitoring

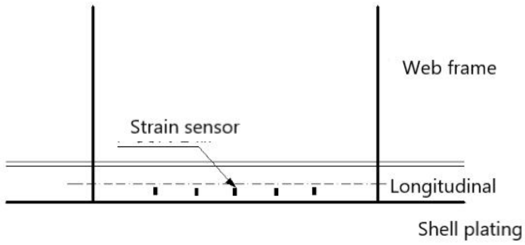
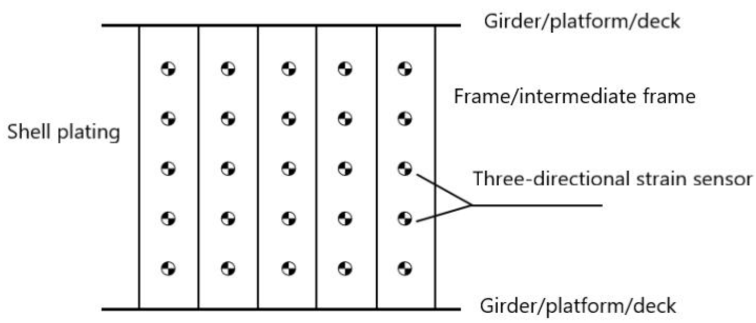


Figure 4.3.4(2) Schematic diagram of arrangement of unidirectional strain sensor on longitudinal for ice load monitoring

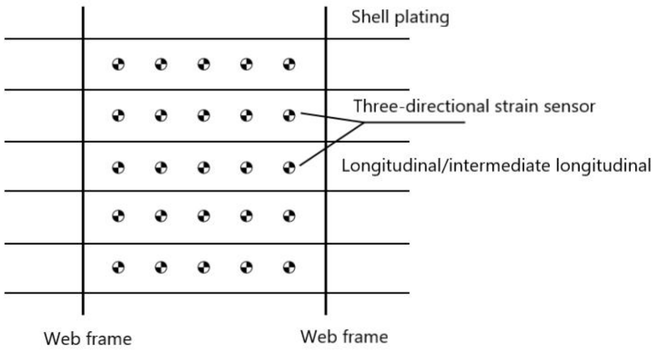
(2) Normal strain perpendicular to shell plating is obtained by directly measuring using unidirectional strain sensor. Where the bidirectional strain sensor is used, the normal strain ε_v and shear strain γ_{xy} on the structural member can be calculated by the formulae in 4.3.1(2).

4.3.5 Hull shell plating

(1) For the three-directional strain sensor set for hull shell plating, the design of strain monitoring detials is shown in Figure 4.3.5(1).



a. Transversely framed



b. Longitudinally framed

Figure 4.3.5(1) Schematic diagram of arrangement of strain sensor on hull shell plating for ice load monitoring

(2) The tensile and compressive strain is directly measured by strain sensors, and the maximum principal strain is calculated. One three-directional strain sensor is arranged as shown in Figure 4.3.5 (2), for determining the maximum principal strain.

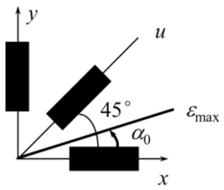


Figure 4.3.5(2) Schematic diagram of arrangement of a three-directional strain sesnor

$$\varepsilon_{\max} = \frac{1}{2}\left[(\varepsilon_x + \varepsilon_y) + \sqrt{2[\ (\varepsilon_x - \varepsilon_u)^2 + (\varepsilon_u - \varepsilon_y)^2\ ]}\right]$$

Where: ε_x, ε_y, ε_u — the linear strains in the x, y and u directions for the three-axis strain rosette on the xoy plane;

$\varepsilon_{\max}$ — the maximum principal strain.

Note: According to the actual situation, strain rosette with an angle of 60° or 120° between three strain sensors can also be installed.

4.4 Statistical calculation

4.4.1 The following statistical parameters are to be calculated for ice load monitoring:

(1) the maximum value;

(2) the minimum value;

(3) the average value;

(4) the standard deviation.

4.4.2 A bar chart of all peak values is to be established in chronological order for each stress response. The amplitude of each response is to be divided into pre-set time intervals (configurable in software), and the quantity of peaks is to be counted within each time interval.

4.4.3 Based on the assumption of statistical distribution of parameters obtained in 4.4.1 and 4.4.2, the probability curve of exceeding the specified value within a given time period is to be evaluated.

4.4.4 The probability of exceeding the predetermined threshold is to be determined based on the probability curve.

4.5 Ice load monitoring methods

4.5.1 Ice load monitoring can adopt the influence coefficient matrix method. If other methods are used, the effectiveness and accuracy of the methods are to be demonstrated.

4.5.2 At a certain moment under the action of ice load, the response of the local structure can be described by a static equation:

$$\underset{m\times m}{\left[K\right]}\underset{m\times 1}{\left\{\varepsilon(t)\right\}}=\underset{m\times 1}{\left\{p(t)\right\}}$$

Then its strain can be expressed as:

$$\underset{m\times 1}{\left\{\varepsilon(t)\right\}}=\underset{m\times m}{\left[K\right]^{-1}}\underset{m\times 1}{\left\{p(t)\right\}}=\underset{m\times m}{\left[\delta\right]}\underset{m\times 1}{\left\{p(t)\right\}}$$

Where: $\underset{m\times m}{\left[K\right]}$ — the strain stiffness matrix for the conversion between strain and ice load, i.e.: the influence coefficient matrix;

$\left\{\varepsilon(t)\right\}$ — the strain response vector of the structure at the moment;

$\left\{p(t)\right\}$— the ice load vector of at the moment;

$\underset{m\times m}{\left[\delta\right]}$ — the strain flexibility matrix, i.e.: inverse matrix of the influence coefficient matrix;

m — number of the measuring sensors.

4.5.3 The strain stiffness matrix $\left[K\right]$ of hull structure monitored during operating in ice can be determined through finite element or model testing methods. The calculation process is as follows: When a unit load is applied only at the nth measuring point, the corresponding strain response vector can be obtained through finite element analysis or model testing. According to equation in 4.5.2, it can be inferred that:

$$\begin{bmatrix} \delta_{11} & \delta_{12} & \cdots & \delta_{1n} & \cdots & \delta_{1m} \\ \delta_{21} & \delta_{22} & \cdots & \delta_{2n} & \cdots & \delta_{2m} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \delta_{n1} & \delta_{n2} & \cdots & \delta_{nn} & \cdots & \delta_{nm} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \delta_{m1} & \delta_{m2} & \cdots & \delta_{mn} & \cdots & \delta_{mm} \end{bmatrix} \begin{Bmatrix} 0 \\ 0 \\ \vdots \\ 1 \\ \vdots \\ 0 \end{Bmatrix} = \begin{Bmatrix} \delta_{1n} \\ \delta_{2n} \\ \vdots \\ \delta_{nn} \\ \vdots \\ \delta_{mn} \end{Bmatrix} = \begin{Bmatrix} \varepsilon_{1} \\ \varepsilon_{2} \\ \vdots \\ \varepsilon_{n} \\ \vdots \\ \varepsilon_{m} \end{Bmatrix}$$

The strain response vector at this moment is the nth column of the strain flexibility matrix. Similarly, after performing the same operation on each measuring point, a matrix $\left[\delta\right]$ can be obtained, and the strain stiffness matrix $\left[K\right]$ can be obtained by inverting the corresponding strain flexibility matrix.

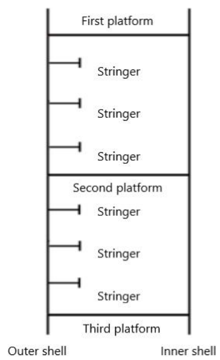
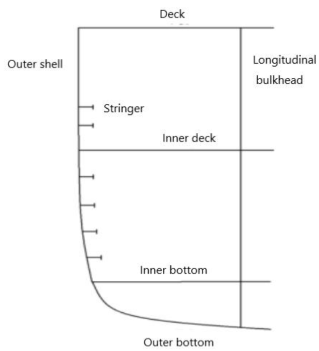
4.5.4 When determining the strain stiffness matrix through finite element method, the influences of boundary conditions and the load applied are to be eliminated as far as possible.

(1) The model range are to include the followings:

The longitudinal range can be taken as 1/2+3+1/2 web frame spacing, and not less than twice the length of the loaded plating w (see relevant provisions in Section 2, Chapter 13 of PART EIGHT in the CCS Steel Ship Rules;

The transverse and vertical ranges are shown in Table 4.5.4 (1).

Transverse and vertical ranges of local model Table 4.5.4(1)

<table>
<tr><th colspan="3">Type of structure</th><th>Transverse range</th><th>Vertical range</th></tr>
<tr><td rowspan="2">Double side structure</td><td rowspan="2">
</td><td>The ice stringer is located between the middle of two platforms</td><td>Spacing between inner shell and out shell</td><td>The vertical range is to be taken as the spacing between platforms</td></tr>
<tr><td>When the ice stringer is close to a certain platform</td><td>Spacing between inner shell and out shell</td><td>The vertical range is to extend upwards/downwards to the upper/lower platform</td></tr>
<tr><td rowspan="3">Single side structure</td><td rowspan="3">
</td><td>The ice stringer is located in the middle between the deck and inner deck</td><td>From outer shell to longitudinal bulkhead</td><td>The vertical range is to be taken as the spacing between deck and inner deck</td></tr>
<tr><td>The ice stringer is located in the middle between the deck and inner bottom</td><td>From outer shell to longitudinal bulkhead</td><td>The vertical range is to be taken as the spacing between inner deck and inner bottom</td></tr>
<tr><td>When the ice stringer approaches the inner deck</td><td>From outer shell to longitudinal bulkhead</td><td>The vertical range is to extend upwards/downwards to the deck/inner bottom</td></tr>
</table>

(2) The selection of finite element elements and mesh division are to be in compliance with the relevant requirements of Section 5, Chapter 1 of PART TWO in the CCS Steel Ship Rules.

(3) The structural mesh size for areas where measuring points are arranged is 50×50mm. A typical local model is shown in 4.5.4 (2).

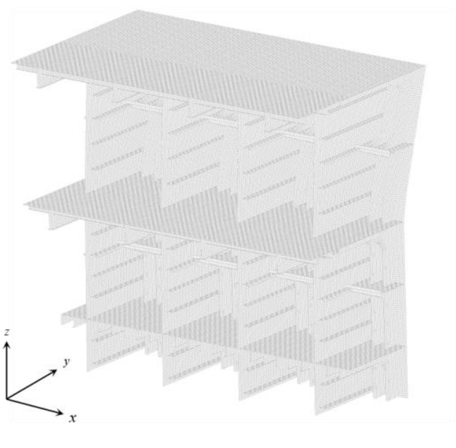


Figure 4.5.4(2) Finite Element Model of Local Structure

(3) The right-handed coordinate system is used for the finite element model, i.e.:

- X-axis measured in the length direction of the ship, positive toward the bow;
- Y-axis measured in the width direction of the ship, positive to the port from the centreline;
- Z-axis measured in the vertical direction of the ship, positive upwards from the baseline.

(4) Total construction thickness/actual thickness of the structure is used for the model.

(5) The boundary constraint conditions are to be able to simulate the deformation characteristics of local structures under ice loads, as shown in Table 4.5.4 (5) (a) and Table 4.5.4 (5) (b).

Boundary constraint conditions of double-side local model Table 4.5.4(a)

Location	Linear displacement constraint			Angular displacement constraint		
	δ_x	δ_y	δ_z	θ_x	θ_y	θ_z
Upper and lower ends	Fixed	Fixed	Fixed	—	Fixed	Fixed
Front and rear ends	Fixed	—	—	—	Fixed	Fixed

Boundary constraint conditions of single-side local model Table 4.5.4(b)

Location	Linear displacement constraint			Angular displacement constraint		
	δ_x	δ_y	δ_z	θ_x	θ_y	θ_z
Upper and lower ends	Fixed	Fixed	Fixed	—	Fixed	Fixed
Front and rear ends	Fixed	—	—	—	Fixed	Fixed
Inner deck edge	—	Fixed	—	—	—	—