GUIDANCE NOTES
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GUIDELINES ON DIRECT CALCULATION OF UNCONVENTIONAL STRUCTURES OF CRUISE SHIPS

2025

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CONTENTS

CHAPTER 1 GENERAL

1.1 General provisions

1.1.1 The Guidelines provides requirements for direct calculation assessment of unconventional structures. Unconventional structure refers to a novel structure different from the conventional ship structure form or arrangement, including but not limited to unconventional transversely-framed, longitudinally-framed and mixed-framed structures, or non-continuous, non-planar structures, such as steel space frame structures and aluminum alloy space frame structures (including space truss structure, latticed shell structures and spatial truss structures), as well as supporting structures for large recreational facilities.

1.1.2 The Guidelines apply to strength assessment of unconventional structures of cruise ships under local and/or global design loads.

1.1.3 Calculation methods and assessment criteria different from those required in the Guidelines may be used as alternative and equivalent methods if corresponding tests, theoretical basis, experience in use or recognized standards can be provided subject to ISC approval.

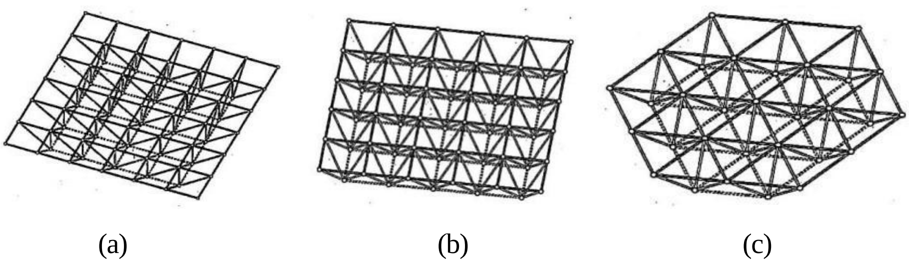
1.1.4 The finite element model in the Guidelines is based on the as-built dimensions of the structure.

1.2 Symbols and definitions

1.2.1 Unless expressly provided otherwise, the definitions of the symbols in the Guidelines are same as those in PART TWO of ISC Rules for Classification of Sea-going Steel Ships (hereinafter referred to as "the Rules").

1.2.2 Space frame structures refer to spatial structures composed of members(bars and components) arranged according to a certain rule through the joints, including space trusses, latticed shells and spatial trusses.

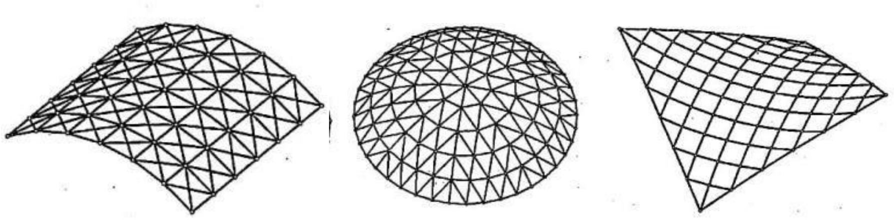
1.2.3 Space truss structures refer to flat or micro-curved space member structures formed by connecting the members arranged according to a certain rule through joints, which can be of double-layer or multi-layer form. Typical space truss structures are shown in Figures 1.2.3 (a) ~ (c) below.



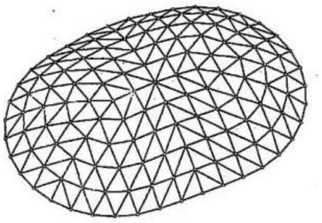
(a) (b) (c)

Figure 1.2.3 Diagram of Space Truss Structures

1.2.4 Latticed shell structures refer to curved space member system or beam system structures formed by connecting the members arranged according to a certain rule through joints, which can be of single or double layer form, or local double-layer form, including curved surface forms such as spherical surface, cylindrical surface, hyperbolic paraboloid surface, elliptic paraboloid surface or various combined surface forms. Typical latticed shell structures are shown in Figures 1.2.4(a) ~ (d) below.



(a) Cylindrical surface (b) Spherical surface (c) Hyperbolic paraboloid surface



(d) Elliptic paraboloid surface

Figure 1.2.4 Diagram of Latticed Shell Structures

1.2.5 Spatial truss structures refer to latticed trusses with a triangular or quadrilateral cross-section composed of top chords, web members, and bottom chords. The top and bottom chords refer to the upper and lower outer members of the truss, while the member connecting the top and bottom chords is called the web member. Spatial trusses can be of straight or curved form.

1.2.6 Equivalent stress (von Mises stress) σ_e is to be calculated as follows:

$$\sigma_e = \sqrt{{\sigma_x}^2 + {\sigma_y}^2 - \sigma_x\sigma_y + 3{\tau_{xy}}^2}$$

where: σ_x ——stress of the element in the *x-axis*, in N/mm^2;

σ_y ——stress of the element in the *y-axis*, in N/mm^2;

τ_{xy} ——shear stress of the element in *xy-plane* , in N/mm^2.

1.2.7 The bending efficiency of the superstructure may be defined as the ratio of the actual stress to the assumed linear stress of the superstructure. For details, refer to 1.2.4 of ISC Guidelines for Local Strength Assessment of Cruise Ships.

CHAPTER 2 DIRECT CALCULATION OF STRENGTH OF STEEL SPACE FRAME STRUCTUES

2.1 General requirements

2.1.1 This chapter gives the strength assessment requirements for steel space frame structures permanently attached to cruise ships as part of the hull structure, including yield strength calculation and global stability calculation.

2.1.2 The stress and displacement of the yield strength assessment of space frame structures can be calculated according to the theory of elastic mechanics, and the nonlinear influence of space frame structures is to be considered in the calculation of the global stability of latticed shells.

2.1.3 The space truss, double-layer lattice shell and spatial truss can be calculated by using the finite element method of spatial member system, while the single-layer lattice shell is to be calculated by using the finite element method of spatial beam system.

2.2 Finite Element (FE) modelling

2.2.1 When analyzing space truss structures and double-layer lattice shells, it can be assumed that the joints are hinged and the rods only bear axial forces. When analyzing spatial pipe trusses, it can also be assumed that the joints are hinged when the ratio of the length between the joints to the height (or diameter) of the section is not less than 12 (main pipe) and 24 (branch pipe). When analyzing single-layer lattice shells, it is to be assumed that the joints are rigid, and the rods bear not only axial forces, but also bending moments, torsional forces, shear forces, etc.

2.2.2 The modeled extent of the space frame structure may be determined according to the actual structural layout, including the entire space frame structure, as well as the deck structure on which the space frame structure is located and extending one deck height upper and below, transversely to the port and starboard sides, 1/2 length of the space frame structure area forward and aft, or to the adjacent transverse bulkhead.

2.2.3 The elements and finite element meshes are to comply with the following requirements:

(1) Hull plates and webs of primary supporting members are simulated by plate elements while stiffeners and face plates of primary supporting members are simulated by beam elements;

(2) Mesh size of longitudinal stiffener spacing can be used in the model;

(3) Normally, the aspect ratio of plate elements is not to exceed 3. Triangular plate elements are to be minimized in modeling as far as possible; the aspect ratio of plate elements is to be close to 1 as far as possible within the high stress area or area of high stress gradient, and triangular plate elements are to be avoided;

(4) In general, rod elements are used in space truss, double-layer lattice shell and spatial truss structures, and beam elements are used in single-layer lattice shell structures;

(5) The degree of freedom of the connection joints and their correlation between the space frame structure and the surrounding connection structure are to be reasonably simulated according to the

actual connection form and load-bearing characteristics.

2.3 Calculation conditions and loads

2.3.1 Design loads

(1) hull girder loads;

(2) local design loads.

2.3.2 Hull girder loads

(1) When hull girder loads are applied, the loading conditions listed in Table 2.3.2 are to be considered:

Loading Conditions Table 2.3.2

Conditions	Descriptions
1	Maximum vertical bending moment
2	Minimum vertical bending moment

(2) When the FE analysis for the whole ship is not carried out, the hull girder loads can be achieved by applying vertical bending moments on the intersection of the neutral axis of the model end surface and the center line of the section. The vertical bending moment is calculated as follows:

1) By calculating the longitudinal strength, the hull girder bending stress on each longitudinal member of the target model section is obtained under the combination of the permissible vertical hydrostatic bending moment and vertical wave bending moment. When the space frame structure is located in the superstructure, the bending efficiency of the superstructure is to be taken as 80%; when the space frame structure is located inside the main hull, the bending efficiency of the superstructure is to be taken as 50%;

2) The vertical bending moment of the transverse section is obtained by integrating the hull girder bending force on each longitudinal member (the hull girder bending force is the product of the longitudinal bending stress and the area of the corresponding member) to the moment of the neutral axis of the transverse section;

(3) When the FE analysis for the whole ship is carried out, sub-model method is used for the space frame structure and the hull girder load can be applied by forced displacement at the boundary joints.

2.3.3 Local design loads

(1) Permanent loads

1) Self-weight of the structure

The standard value of the structure's self-weight can be calculated according to the design size of the structural member and the self-weight per unit volume of the material;

2) Self-weight of the covering material on the space frame structure

The surface of the space frame structure is not involved in the FE modeling, but the glass or other materials covering the surface is to be calculated according to the actual material characteristics and to be loaded on the FE model.

(2) Variable loads

1) Moving load on the space frame surface

The space frame surface is generally not mounted, and the standard value of surface moving load is often taken as q=0.5 kN/m^2;

2) Wind load

The standard value of wind load perpendicular to the space frame surface is to be taken as:

$$w_k = \beta_z \mu_s \mu_z w_0 \quad \text{kN/m}^2$$

where: w_k ——standard value of wind load, in kN/m^2;

β_z ——wind vibration coefficient at height z;

μ_s ——wind load type coefficient;

μ_z ——wind pressure height variation coefficient;

w_0 ——reference wind pressure, in kN/m^2.

where β_z, μ_s, μ_z and w_0 are taken with reference to Rules for Load on Building Structures GB50009-2012. In the absence of wind load data of the ship route, the data of the port city of call with the largest design load is to be taken. Generally, large structures are to be simulated by wind tunnel test, and more flexible structures are to pay attention to wind vibration.

3) Snow load

The standard value of the snow load on the horizontal projection plane of the space frame structure is to be determined as follows:

$$s_k = \mu_r s_0 \quad \text{kN/m}^2$$

where: s_k ——standard value of snow load, in kN/m^2;

μ_r ——space frame structure snow distribution coefficient;

s_0 ——reference snow pressure, in kN/m^2.

where μ_r and s_0 are taken with reference to the Rules for Load on Building Structures GB50009-2012. In the absence of snow load data of the ship route, the data of the port city of call with the largest design load is to be taken;

4) Inertia loads due to ship motions

For space frame structures, inertia loads due to ship motions are to be considered. For the accelerations of ship motions, refer to 2.3.2(6), (7), (8) of ISC Guidelines for Local

Strength Assessment of Cruise Ships;

5) Other loads

Where the space frame structure also bears other loads, such loads are also to be taken into account. For example, when the space frame structure is located at a lower position in the bow, the green sea load is to be considered during navigation.

2.3.4 Calculation conditions

(1) Sailing conditions

The combination of hull girder load, permanent load, wind load, snow load and inertial load of the ship is be considered, and the load combination S_d is to be applied according to the following formula:

$$S_d = \gamma_G \sum_{j=1}^{2} G_j + \gamma_{Q_1}\gamma_{L1}Q_1 + \sum_{i=2}^{n} \gamma_{Q_i}\gamma_{Li}\psi_i Q_i$$

where: γ_G —partial coefficient of the permanent load, to be taken according to Table 2.3.4(1);

γ_{Q_i} —partial coefficient of the i^th^ variable load Q_i, where γ_{Q1} is the partial coefficient of the dominant variable load Q_1 in the condition, to be taken according to Table 2.3.4(1);

γ_{L_i} —adjustment coefficient of the i^th^ variable load considering the service life, to be taken as 1.0, where γ_{L1} is the adjustment coefficient of the dominant variable load Q_1 in the condition considering the service life;

ψ_i —combined coefficient of the i^th^ variable load Q_i, to be taken as 0.6 for wind load and 0.7 for other variable loads;

G_j —the j^th^ permanent load;

Q_i — the i^th^ variable load, i.e. other variable loads except for the moving load on the surface of the space truss;

Q_1 —the dominant variable load in the condition; each variable load may be taken as Q_1 in turn.

Partial Coefficients of Loads　　　　　　　　Table 2.3.4(1)

Load types	Partial coefficient
Hull girder load	1.0
Permanent load	1.3
Wind load	1.5
Snow load	1.5
Inertia load of the ship	1.0
Other loads	1.0 or 1.3（1）

(1) Note: For other loads, the partial coefficient is to be selected according to the degree of certainty of the load. If the loads are certain, the combined coefficient is to be taken as 1.0, otherwise it is to be taken as 1.3.

(2) Harbour conditions

The combination of permanent load, moving load, wind load and snow load is be considered, where the moving load and snow load do not occur simultaneously, and the load combination S_d is to be applied according to the following formula：

$$S_d = \gamma_G \sum_{j=1}^{2} G_j + \gamma_{Q_1}\gamma_{L1}Q_1 + \sum_{i=2}^{n} \gamma_{Q_i}\gamma_{Li}\psi_i Q_i$$

where: γ_G —partial coefficient of the permanent load, to be taken according to Table 2.3.4(2);

γ_{Q_i} —partial coefficient of the ith variable load Q_i, where γ_{Q1} is the partial coefficient of the dominant variable load Q_1 in the condition, to be taken according to Table 2.3.4(2);

γ_{L_i} —adjustment coefficient of the ith variable load considering the service life, to be taken as 1.0, where γ_{L1} is the adjustment coefficient of the dominant variable load Q_1 in the condition considering the service life;

ψ_i —combined coefficient of the ith variable load Q_i, to be taken as 0.6 for wind load and 0.7 for other variable loads;

G_j —the jth permanent load;

Q_i —the ith variable load;

Q_1 —the dominant variable load in the condition; each variable load may be taken as Q_1 in turn.

Partial Coefficients of Loads Table 2.3.4(2)

Load types	Combined coefficient
Hull girder load	1.0
Permanent load	1.3
Moving load	1.5
Wind load	1.5
Snow load	1.5
Other loads	1.0 or 1.3(1)

(1) Note: For other loads, the combined coefficient is to be selected according to the degree of certainty of the load. If the loads are certain, the combined coefficient is to be taken as 1.0, otherwise it is to be taken as 1.3.

2.4 Boundary conditions

2.4.1 The boundary conditions of the model are as follows:

(1) When the global FE analysis is not carried out, the connection between both ends of the typical structure model is shown in Table 2.4.1(1) and Table 2.4.1(2) when hull girder loads are applied. The nodes on the longitudinal members at both end sections are to be rigidly linked to independent points at neutral axis on the centreline as shown in Table 2.4.1(1). The independent points of both ends are to be fixed as shown in Table 2.4.1(2).

Rigid-link on Both Ends Table 2.4.1(1)

Nodes on longitudinal members at both ends of the model	Translational			Rotational		
	δ_x	δ_y	δ_z	θ_x	θ_y	θ_z
All longitudinal members	RL	RL	RL	-	-	-
RL means rigidly linked to the relevant degrees of freedom of the independent point						

Support Condition of the Independent Point Table 2.4.1(2)

Location of the independent point	Translational			Rotational		
	δ_x	δ_y	δ_z	θ_x	θ_y	θ_z
Independent points on the aft end model	Fix	-	-	-	-	-
Independent points on the fore end model	Fix	Fix	Fix	Fix	Fix	Fix

(2) When the global FE analysis is carried out, the corresponding node displacement of the global FE calculation is applied to the boundary node of the space frame structure model as the boundary condition of the space frame structure.

2.5 Strength criteria

2.5.1 Yield strength assessment is to be carried out for space frame structures and adjacent deck structures, side and longitudinal wall structures of superstructure as well as bulkhead structures.

2.5.2 The yield strength criteria for hull structure and space frame structure are shown in Tables

2.5.2(1) and 2.5.2(2) respectively.

Yield Strength Criteria for Hull Structure Table 2.5.2(1)

Hull structure	Load type	Permissible stress (N/mm^2)		
		Longitudinal stress	Shear stress	Equivalent stress
Web plating of deck transverses and deck girders	Local only	-	0.35R_{eH}	0.75 R_{eH}
Face plates of deck transverses and deck girders	Local only	0.52 R_{eH}	-	-
Deck girders	Local + Hull girder	200/K	-	220/K
Other members		-	110/K	220/K

Note: K is the material factor; R_{eH} is the yield stress of the material, in N/mm^2.

Yield Strength Criteria for Space Frame Structure Table 2.5.2(2)

Space frame structure	Permissible stress (N/mm^2)	
	Axial stress	Maximum combined stress ⑴
Space trusses, double-layer latticed shells, spatial trusses	R_{eH}/1.1	-
Single-layer latticed shells	-	R_{eH}/1.1

(1) Note: The maximum combined stress = axial stress of members + bending normal stress; R_{eH} is the yield stress of the material, in N/mm^2.

2.5.3 The maximum deflection values of space frame structures under the permanent loads and variable loads are not to exceed the permissible deflection values in Table 2.5.3.

Permissible Deflection Values of Space Frame Structures Table 2.5.3

Structure system	Deflection value
Space truss, double-layer latticed shell, spatial truss	$l/250$
Single-layer latticed shell	$l/400$

l: span of space frame structures.

2.6 Stability calculation of latticed shells

2.6.1 Stability calculation is to be carried out to single-layer latticed shells and double-layer latticed shells of which the thickness is less than 1/50 of the span.

2.6.2 When stability calculation for latticed shells is carried out, the corresponding node displacement in the global FE calculation results is to be applied to the model boundary.

2.6.3 The stability of the latticed shell may be calculated according to the FE method (i.e., the whole process of load-displacement analysis) considering geometric nonlinearity, in which the material can be assumed as elastic or elastoplastic. For large and complex latticed shell structures, the whole process analysis method considering material elastic-plasticity is preferred. The iterative equation of the whole process analysis may be as follows:

$$\mathrm{K}_t \Delta U^{(i)} = F_{t+\Delta t} - N_{t+\Delta t}^{(i-1)}$$

where: K_t —tangent stiffness matrix of t time structure;

$\Delta U^{(i)}$ —iterative increment of the current displacement;

$F_{t+\Delta t}$ —node load vector applied externally at t+Δt;

$N_{t+\Delta t}^{(i-1)}$ —internal force vector of member node corresponding to t+Δt.

2.6.4 The whole process analysis of spherical latticed shells may be carried out according to the full span uniform load; for cylindrical latticed shells and elliptic parabolic latticed shells, the analysis is to consider not only the full span uniform load, but also the half-span moving load distribution.

2.6.5 The influence of initial geometric defects (i.e. the installation deviation of the initial curved surface shape) is to be considered during the whole process analysis of the latticed shell. The initial geometric defect distribution can adopt the most unfavorable or most likely buckling mode of the structure, and the maximum calculated value of the defect can be taken as 1/300 of the span of the latticed shells.

2.6.6 The load value at the first critical point obtained from the whole process analysis of the latticed shell according to 2.6.3 to 2.6.5 of this Section can be used as the stable ultimate bearing capacity of the latticed shell. The allowable stability bearing capacity of the latticed shell Q_{UD} (the standard value for the load) is to be equal to the stable ultimate bearing capacity of the latticed shell divided by the safety factor K. When the whole process analysis is carried out according to elastic-plasticity, the safety factor may be taken as 2.0. When the whole elastic process is carried out according to elasticity and it is single-layer spherical latticed shell, cylindrical latticed shell and elliptic parabolic latticed shell, the safety factor K may be taken as 4.2.

2.6.7 For the ultimate state of bearing capacity, the following criteria are to be met according to the basic combination of loads and the most unfavorable condition selected from the following combination of loads:

$$\gamma_G \sum_{j=1}^{2} G_j + \gamma_{Q_1} \gamma_{L_1} Q_1 + \sum_{i=2}^{n} \gamma_{Q_i} \gamma_{L_i} \psi_i Q_i \le Q_{UD}$$

where: γ_G —partial coefficient of the permanent loads, to be taken according to Table 2.6.7;

γ_{Q_i} —partial coefficient of the i^th^ variable load Q_i, where γ_{Q1} is the partial coefficient of the dominant variable load Q_1 in the condition, to be taken according to Table 2.6.7;

γ_{L_i}—adjustment coefficient of the ith variable load considering the service life, to be taken as 1.0, where γ_{L1} is the adjustment coefficient of the dominant variable load Q_1 in the condition considering the service life;

ψ_i —combined coefficient of the ith variable load Q_i , to be taken as 0.6 for wind load and 0.7 for other variable loads;

G_j —the jth permanent load;

Q_i —the ith variable load, i.e. other variable loads except for the moving load on the surface of the space truss;

Q_1 —the dominant variable load in the condition, i.e. other variable loads except for the moving load on the surface of the space truss; each variable load may be taken as Q_1 in turn;

Q_{UD} —stable permissible bearing capacity of latticed shells, to be determined according to 2.6.6.

Partial Coefficients of Loads Table 2.6.7

Load types	Partial coefficient
Permanent load	1.3
Wind load	1.5
Snow load	1.5
Inertia load of the ship	1.0
Other loads	1.0 or 1.3(1)

(1) Note: For other loads, the partial coefficient is to be selected according to the degree of certainty of the load. If the loads are certain, the combined coefficient is to be taken as 1.0, otherwise it is to be taken as 1.3.

CHAPTER 3 DIRECT STRENGTH CALCULATION OF ALUMINUM ALLOY SPACE FRAME STRUCTURES

3.1 General requirements

3.1.1 This Chapter is applicable to strength assessment of aluminium alloy space frame structures fixed on cruise ships.

3.1.2 In addition to the requirements of this Chapter, the strength of aluminium alloy space frame structures is to comply with the relevant requirements of Chapter 2.

3.1.3 The yield strength and overall stability assessment is to be carried out for aluminum alloy space frame structures.

3.1.4 Aluminum alloy space frame structures are to be designed to prevent continuous collapse, and important structures can be calculated for preventing continuous collapse. The relevant provisions may be referred to Rules for Anti-collapse Design of Building Structures (CECS 392:2014).

3.2 Material performance

3.2.1 Aluminum alloy materials are to comply with the relevant requirements of ISC Rules for Materials and Welding.

3.2.2 The elastic-plastic stress-strain relationship of aluminum alloy materials is to be calculated as follows:

(1) The elastic-plastic stress-strain relationship of aluminum alloy is to be calculated according to the following formula:

$$\varepsilon = \frac{\sigma}{E} + \left(\frac{\sigma}{R_{p0.2}}\right)^n$$

where: ε — strain;

E — modulus of elasticity of aluminum alloy material, to be taken in accordance with 1.3.5, Chapter 1, PART TWO of CCS Rules for Classification of Sea-going Steel Ships;

σ — stress, in N/mm^2;

$R_{p0.2}$ — the minimum yield stress of aluminum alloy which can be guaranteed, in N/mm^2, to be taken in accordance with 1.3.5, Chapter 1, PART TWO of CCS Rules for Classification of Sea-going Steel Ships;

n — hardening coefficient, to be taken as 0.1 $R_{p0.2}$;

(2) For the force analysis, calculation is to be based on the stress-strain curve of commonly used materials (Figure 3.2.2).

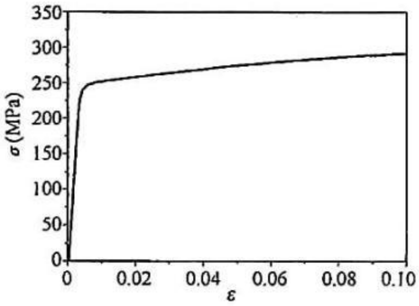


Figure 3.2.2 Diagram of material stress-strain curve

3.3 Strength criteria

3.3.1 Yield strength assessment is to be carried out for space frame structures and adjacent deck structures, side and longitudinal wall structures of superstructure as well as bulkhead structures.

3.3.2 The yield strength criteria for hull structure are shown in Table 2.5.2(1) of Section 2, and the yield strength criteria for space frame structure are shown in Table 3.3.2.

Yield strength criteria for aluminum alloy space frame structure Table 3.3.2

Space frame structure	Permissible stress (N/mm^2)	
	Axial stress	Maximum combined stress
Space truss, double-layer latticed shell, spatial truss	$_{w}/1.1^{(1)}$	-
Single-layer latticed shell	-	$_{w}/1.1^{(1)}$

Note: (1)σ_{sw} (N/mm^2): for aluminum, take $R_{\lim}^{'}$. Refer to 1.3.5, Chapter 1, PART TWO of ISC Rules for Classification of Sea-going Steel Ships.

3.3.3 The maximum deflection values of space frame structures under the permanent loads and variable loads are not to exceed the permissible deflection values in Table 3.3.3.

Permissible Deflection Values of Aluminum Alloy Space Frame Structure Table 3.3.3

Structure system	Deflection value
Space truss, double-layer latticed shell, spatial truss	$l/250$
Single-layer latticed shell	$l/400$

l : span of space frame structure

3.4 Stability calculation

3.4.1 Global stability calculation is to be carried out to single-layer or double-layer latticed shell structures.

3.4.2 In the stability analysis of latticed shell structure, the non-linear finite element method of material elastic geometry can be used.

3.4.3 When stability calculation for aluminum alloy latticed shell structure is carried out, the corresponding node displacement in the global FE calculation results is to be applied to the model boundary.

3.4.4 The influence of initial geometric defects (i.e. the installation deviation of the initial curved surface shape) is to be considered during the whole process analysis of the latticed shell. The mode of the geometric defect can be determined by the consistent mode method, and the maximum calculated value of the defect can be taken as 1/300 of the minimum span.

3.4.5 The allowable stability bearing capacity of the latticed shell Q_{UD} (the standard value for the load) is to be equal to the stable ultimate bearing capacity of the latticed shell divided by the safety factor K. When the influence of geometric nonlinearity and material nonlinearity is taken into account simultaneously, the overall stability coefficient K of aluminum alloy single-layer latticed shell structure is to be greater than 2.4.

3.4.6 For the ultimate state of bearing capacity, relevant criteria requirements are to be met according to the basic combination of loads and the most unfavorable condition selected from all combination of loads, which are the same as 2.6.7.

CHAPTER 4 STRENGTH ASSESSMENT OF SUPPORTING STRUCTURES FOR LARGE-SCALE RECREATIONAL FACILITIES ON CRUISE SHIPS

4.1 General requirements

4.1.1 This Chapter is applicable to strength assessment of supporting structures for large-scale recreational facilities on cruise ships.

4.1.2 When strength check of supporting structures and foundations is carried out, three-dimensional finite element models are to be used as much as possible for analysis. The strength criteria in this Chapter are applicable to three-dimensional finite element analysis models.

4.1.3 If a cross-beam system or plate-beam combination model is used, the model simplification is to be reasonable, and the calculation results are to be submitted to ISC for review.

4.1.4 The strength assessment in this Chapter is based on the theory of linear elasticity.

4.2 Finite element modelling

4.2.1 The elements and finite element mesh are to comply with the following requirements:

(1) The mesh is to be fine enough to represent the structural geometry as realistically as possible;

(2) Hull plates and webs of primary supporting members are simulated by plate elements while stiffeners and face plates of primary supporting members are simulated by beam elements;

(3) Normally, the aspect ratio of plate elements is not to exceed 3. Triangular plate elements are to be minimized in modeling as far as possible; the aspect ratio of plate elements is to be close to 1 as far as possible within the high stress area or area of high stress gradient, and triangular plate elements are to be avoided.

4.2.2 The local three-dimensional structure model (hereinafter referred to as the local model) is to be adopted, taking the centroid of the effective plane rectangle ($a \times b$) of the foundation as the center, and extending the corresponding length and width distance ($3a \times 3b$) of the rectangle at least twice to the four sides respectively. Extend vertically from the foundation surface to the first platform deck below deck or at least at $D/4$ (where D is the moulded depth). If no primary supporting member of the structure is set on the boundary of the model taken by the above method, the model is to be extended until the boundary falls on the primary supporting member of the structure. If the boundary conditions or the size of the model range are sensitive to the calculation results of the central region, the range of the local model is to be appropriately expanded so as not to affect the calculation results of the central region.

4.3 Calculation loads

4.3.1 The assessment is based on the design load values provided by the equipment supplier, but the checked load is not be less than 120% of the safe working load. For recreational facilities that bear lifting loads, it is not to be less than 160% of the safe working load.

4.4 Boundary conditions

4.4.1 If the model boundary is taken according to above finite element modeling method, the boundary conditions can be considered as simply supported or fixed supported.

4.5 Strength criteria

4.5.1 The criteria for supporting structures of recreational facilities subjected to lifting loads are as follows.

(1) Under various working conditions, the calculated stress of the supporting structure and foundation of the recreational facilities subjected to the lifting load is not to be greater than the permissible value in Table 4.5.1.

Permissible stress Table 4.5.1

Element type	Positive stress	Shear stress	Equivalent stress
Cross beam system	$0.67R_{eH}$	$0.39R_{eH}$	
Plate element			$0.8R_{eH}$

Note: R_{eH} is the yield stress of material, in N/mm^2.

(2) For recreational facilities subjected to lifting loads, the buckling strength assessment of the supporting structure is also to be carried out in accordance with 1.5.9, Section 5, Chapter 1, PART TWO of ISC Rules for Classification of Sea-going Steel Ships. The standard deduction thickness of the member is to be taken as 1.0mm and the minimum buckling safety factor is to be taken as 1.0.

4.5.2 The permissible stresses of the supporting structures of other recreational facilities are shown in Table 4.5.2.

Permissible stress Table 4.5.2

Element type	Positive stress	Shear stress	Equivalent stress
Cross beam system	$1.00R_{eH}$	$0.6R_{eH}$	
Plate element			$1.00R_{eH}$

Note: R_{eH} is the material yield stress, in N/mm^2.

CHAPTER 5 STRUCTURAL REFINED ANALYSIS

5.1 General requirements

5.1.1 This Chapter specifies the requirements and methods for finite element analysis of local refinement and connection joints of space frame structures.

5.1.2 The local refined model of space frame structure or connection joint of space frame structure can be inserted into the finite element model of the space frame structure, or it can be analyzed using sub-model/independent model.

5.2 Local refined analysis of space frame structures

5.2.1 Local refined analysis of space frame structures is to include at least the following areas:

(1) the structural non-continuous area where the stress calculated in accordance with the requirements of Chapters 2 and 3 is greater than 75% permissible stress;

(2) the opening area where the stress calculated in accordance with the requirements of Chapters 2 and 3 is greater than 85% permissible stress;

(3) the area where the structural model is insufficient to reflect the local shape at the structural connections.

5.2.2 Requirements for structure modeling of refined model

(1) The refined model is to be such that the stresses at the areas of concern are not significantly affected by the boundary conditions;

(2) The fine mesh area is to be modeled using plate elements, and triangular elements and distortion elements is to be avoided. The aspect ratio of elements is to be close to 1. The fine space frame size is not to be greater than 50 mm ×50 mm and a smooth structural transition is to be maintained for the refined model.

5.2.3 The boundary conditions and loads of the model are specified as follows:

(1) Where the independent sub-model is used for the model, the displacement obtained from model calculation for the space frame structure is to be applied to its boundary.

(2) In the refined local model, the local design load borne by the local region is to be applied to the refined model.

5.2.4 The yield strength criteria of hull structure are shown in Table 5.2.4.

Yield strength criteria of hull structure Table 5.2.4

Hull structure	Load type	Permissible stress (N/mm^2)			
		Average positive stress①	Average shear stress①	Average equivalent stress①	Equivalent stress
Web plating of deck transverses	Local only	-	0.35R_{eH}	0.75 R_{eH}	R_{eH}
Webs of deck girders	Local only	-	0.35R_{eH}	0.75 R_{eH}	-
Face plates of deck transverses and deck girders	Local only	0.52 R_{eH}	-	-	-
Deck girders	Local + global	200/K	-	220/K	1.25 R_{eH}
Other members			110/K	220/K	1.35 R_{eH}

Note ①: Average stress is the average stress of the element in the areas shown in A, B and C in Figure 5.2.4. Averaging is not to be carried across structural discontinuities or abutting structure.

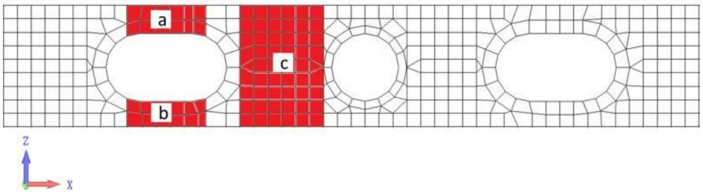


Figure 5.2.4 Average stress area of opening

5.3 Connection joints of space frame structures

5.3.1 The main connecting joints of the space frame structure are to be simulated as far as possible with the appropriate space frame size of the element. If the thickness of the member changes or steel casting is used, it can be simulated with solid elements. If the thickness does not change, such as truss pipe fittings, it can be simulated with shell elements. The models of connection joints of space frame structures are shown in Figure 5.3.1.

Figure 5.3.1 Models of connection joints of space frame structures

5.3.2 The model of connection joint of space frame structure can apply the forced displacement on the boundary and also reasonably limit the rigid body displacement. When reasonably limiting the rigid body displacement, the load applies force and bending moment. The load application diagram is shown in Figure 5.3.2.

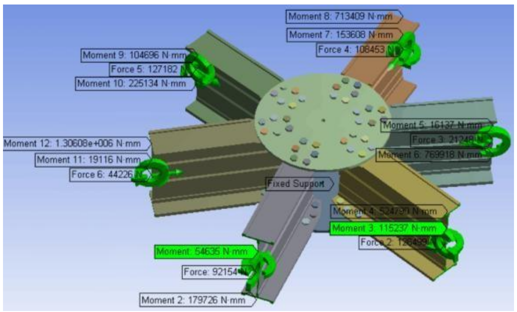


Figure 5.3.2 Load application diagram

5.3.3 The permissible stress of the joint of the space frame structure are to be checked using the equivalent stress of the element, and the criteria are shown in Table 5.3.3.

Yield strength criteria of space frame structure Table 5.3.3

Space frame structure	Equivalent stress (N/mm^2)
Steel space frame structure	R_{eH}
Aluminum alloy space frame structure	σ_{sw} (1)

Note: (1) σ_{sw} (N/mm^2): For aluminum, take $R'_{\lim}$. Refer to values in 1.3.5, Chapter 1, PART TWO of ISC Rules for Classification of Sea-going Steel Ships. R_{eH} is the yield stress of material, in N/mm^2.