



China Classification Society

**GUIDELINES FOR STRUCTURAL CONTINUOUS
ASSESSMENT AND EMERGENCY RESPONSE OF
MOBILE OFFSHORE UNITS**

2012

China Classification Society

April 2013

CONTENTS

Chapter 1 General.....	1
1.1 Scope of application.....	1
1.2 Purpose.....	2
1.3 Drawings and documents	2
1.4 Acceptance criteria.....	3
1.5 Application and responsibility	3
Chapter 2 Idea of Structural Integrity Management of Mobile Offshore Units....	5
2.1 Definition	5
2.2 Data	5
2.3 Assessment.....	6
2.4 Survey plan	7
2.5 Survey implementation	8
Chapter 3 Structural Survey of Mobile Offshore Units	9
3.1 General provision.....	9
3.2 Structural survey	9
Chapter 4 Contents of Structural Continuous Assessment of Mobile Offshore Units	13
4.1 General provision	13
4.2 Overall performance and global strength assessment	13
4.3 Local strength assessment.....	17
4.4 Fatigue strength assessment	17
4.5 Stability assessment	20
Chapter 5 Method of Structural Continuous Assessment of Mobile Offshore Units	24
5.1 General provision.....	24
5.2 Hydrodynamic calculation of lattice leg in jack-up unit	24
5.3 Finite element modeling technology of hull-leg connection of jack-up unit	28
5.4 Calculation of dynamic response of jack-up unit in deep water	31

5.5 Simulation calculation of interaction between jack-up legs and soil	31
5.6 Ground stability analysis.....	33
5.7 Hydrodynamic calculation of semi-submersible unit.....	37
5.8 Determination of design wave for semi-submersible unit.....	39
5.9 Mooring analysis of semi-submersible unit	44
5.10 Calculation of air gap of semi-submersible unit	47
Chapter 6 Site Specific Assessment in Mobile Offshore Unit	48
6.1 General provision	48
6.2 Site specific assessment for mobile jack-up unit.....	48
6.3 Site specific assessment for offshore semi-submersible unit	53
Chapter 7 Emergency Response Service for Mobile Offshore Unit (MODU-ERS)	55
7.1 General provision	55
7.2 Types of emergency response.....	55
7.3 General procedures for emergency response.....	56
7.4 Post-management of emergency response service	56
7.5 Introduction of CCS emergency response service for mobile offshore unit (CCS-MODU-ERS)	57
Chapter 8 Introduction of MSER System	60
8.1 System introduction	60
8.2 System composition	60
8.3 System functions and characteristics.....	65
8.4 System application practice.....	66
8.5 System application prospect.....	67
Appendix 1. Specific Site Assessment of Jack-up Units	68

Chapter 1 General

1.1 Scope of application

1.1.1 For mobile offshore units, continuous structural condition assessments may be required periodically during the service life, so as to determine their applicability. Such condition assessment usually results from the modification and damage of these units, and significant changes in loads of these units, such as the changes in weight loads or environmental loads.

1.1.2 For a mobile offshore unit that will operate on a new site, especially where the environmental conditions are close to the limit conditions specified in the operation manual, structural condition assessment is required to determine whether the capacity of the units meets the requirements of the environmental load on the new site.

1.1.3 For a mobile offshore unit beyond its design life, condition assessments are required for the key structures of the unit, to determine the conformity of the fatigue life of the unit with the requirements.

1.1.4 In case of unexpected events (such as leg punch-through, unit towing collision and anchor chain breakage) of a mobile offshore unit, the structural safety of the unit should be assessed as soon as possible, and emergency response measures should be taken accordingly.

1.1.5 Structural continuous assessment and emergency response of mobile offshore units are provided for the owners as technical support services, which are independent and complete certifications for the actual condition of the units based on the detailed inspection, thickness measurement, performance test, analysis and calculation.

1.1.6 The Guidelines cover the introduction to the theory of structural integrity management for mobile offshore units, the contents and methods of structural continuous assessment, the process of site specific assessment, the methods and procedures of emergency response and the lifecycle management system for the mobile offshore unit structure - Model, Survey, Emergency Response (hereinafter referred to as the MSER system).

1.1.7 The Guidelines are applicable to the structural condition assessment and emergency response calculation of mobile offshore units.

1.1.8 For the CCS-classed mobile offshore units with the service life longer than 30 years, their structural continuous assessment shall meet the relevant requirements in the CCS circular

Provisions on Strengthening Survey Management of Aged Mobile Units [HGYY (2009) Circular No.3, No.27 overall].

1.2 Purpose

1.2.1 The purpose of structural continuous assessment of mobile offshore units is to provide owners with a technical document and statement on the actual condition of the unit related to the unit structure and maintenance of normal unit operation, so as to verify the conformity of the unit with the technical requirements in codes, standards and classification society rules. The Guideline can be provided by the owner to the interested parties for use during the operation, and used to guide the Surveyors to conduct field surveys.

1.2.2 The purpose of emergency response calculation of mobile offshore units is to quickly calculate and assess the actual structural condition of the unit in case of unexpected events and determine the appropriate emergency response measures accordingly, so as to provide technical support to the owners for decision-making.

1.2.3 The structural continuous assessment of mobile offshore units may also provide the technical support for the repair and maintenance of the unit structure required for its reasonable operation.

1.2.4 With the theory of structural integrity management of mobile offshore units, the lifecycle structural safety management of mobile units can be realized from design, construction, survey and modification to daily operation, which is of great significance to the safe operation and scientific management of the unit.

1.2.5 By introducing the theory of structural integrity management, the MSER system can be effectively applied to the mobile offshore units, providing technical support for unit managers' scientific decision-making, regular maintenance of units, and surveys by competent authorities.

1.3 Drawings and documents

1.3.1 For the structural continuous assessment of mobile offshore units, relevant drawings and documents should be collected. If any drawings and documents are missing, field measurement is required. The data provided by the applicant to CCS shall be accurate and reliable. Besides, the measurement and processing of these data are extremely important for the overall planned condition assessment and maintenance schemes.

1.3.2 For the emergency response calculation of mobile offshore units, the applicant shall provide CCS with the detailed description of the emergency, the external conditions at that time and the

specific damage of the unit.

1.3.3 For the site specific assessment of mobile offshore units, the applicant shall provide CCS with the environmental conditions of the operating site with a return period of at least 50 years, including the water depth, wind, waves, currents and seabed soil conditions (if necessary).

1.3.4 The required drawings and documents shall include:

- ① Characteristic data, mainly including the original general layout of the unit, unit structure diagram, material description, deck load diagram, operation manual and related construction data.
- ② Condition data, including the data about all previous unit modification, survey data, damage assessment data, thickness measurement data, corrosion data, unit assessment data, strengthening/modification/repair data, etc.

1.4 Acceptance criteria

1.4.1 The structural continuous assessment of mobile offshore units shall follow the rules, standards or guidelines of the classification society the units are classed in at the time of construction.

1.4.2 The calculation process of emergency response of mobile offshore units shall follow the current rules, standards or guidelines of the classification society the units are classed in and the internationally-/domestically-recognized rules, standards or guidelines.

1.4.3 Generally, the site specific assessment of mobile offshore units shall follow the current rules, standards or guidelines of the classification societies the units are classed in and the internationally/domestically recognized rules, standards or guidelines.

1.5 Application and responsibility

1.5.1 For the mobile offshore units applied to join the MSER system, a finite element model for structural continuous assessment shall be established by Offshore Engineering Technical Center of CCS and incorporated into the MSER system of CCS for providing the follow-up technical services to the owners.

1.5.2 For the mobile offshore units that do not applied to join the MSER system, if the service provided by the Guidelines is required, the applicant shall submit a written application to the Offshore Engineering Technical Center of CCS, and provide the drawings and technical documents required for such service.

1.5.3 The applicant shall notify CCS at least 3 weeks before the survey and testing, and arrange the necessary conditions for survey according to the survey plan provided by the Offshore Engineering Technical Center of CCS.

1.5.4 The applicant shall arrange the relevant testing and surveys according to the relevant requirements of the Guidelines. CCS shall supervise the ultrasonic thickness measurement, nondestructive testing, underwater testing, equipment inspection, experiment, etc., so as to assist the owner to ensure the correctness and fairness of the test data and test results.

1.5.5 The applicant shall provide the necessary working conditions for CCS and facilitate the field survey and supervision, and shall be obliged to require its subcontractors to cooperate with CCS.

1.5.6 The applicant is required to pay the relevant fees according to the contract.

Chapter 2 Theory of Structural Integrity Management of Mobile Offshore Units

2.1 Definition

The structural integrity management of the mobile offshore unit refers to an assessment system to ensure the applicability of the offshore mobile facilities in the whole life cycle from putting into operation to decommissioning. In terms of the modification, damage, load change, site adaptability, life extension and emergency response of the unit, this system can be used to realize the quick and continuous assessment of the unit structure, and provide a reasonable framework for structural damage assessment, applicability assessment, survey plan, maintenance and repair of the unit, etc. The general program of structural integrity management for mobile offshore units is shown in Figure 2-1.

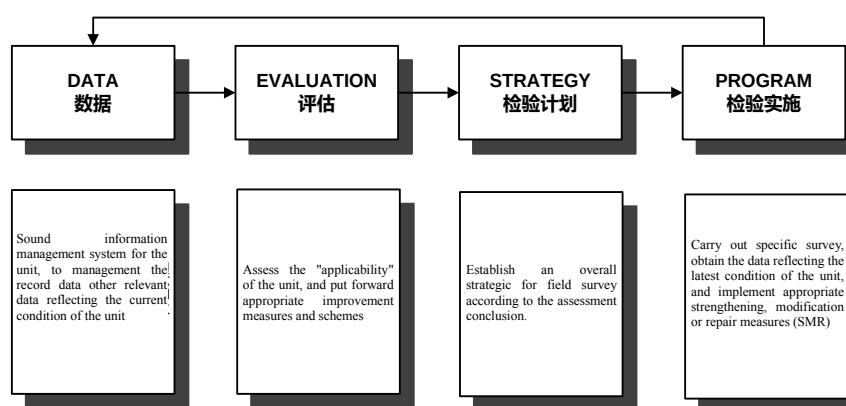


Figure 2-1 Structural Integrity Framework of Mobile Offshore Units

As shown in Figure 2-1, the general theory of structural integrity management of mobile offshore units includes four basic elements, namely data, assessment, planning and implementation.

2.2 Data

Latest and accurate data are the basis of ensuring the structural integrity management, and the data can be classified into the characteristic data and condition data. The characteristic data mainly include the information on the initial condition of completed unit, the as-built drawings and documents, and the construction data. The condition data mainly include the information reflecting the change of the characteristic data of the unit during its life cycle, such as all previous unit modification data, survey data, damage assessment data, thickness measurement data,

corrosion data, unit assessment data and strengthening/modification/repair data. These data shall fully and truly reflect the actual structure condition of the unit. An effective data management system shall be established to save, modify and update the characteristic data and condition data.

2.3 Assessment

Assessment is a process to assess the influence of the latest unit data on the structural integrity management, including the calculation and assessment of the unit structure when necessary to show the applicability of the unit structure, as well as providing input for plan adjustment of unit survey, monitoring and maintenance. The assessment can cover:

- ① the unit modification, resulting in changes in the structure,
- ② the damages to the unit structure,
- ③ the significant load changes on the unit, including the weight load or environmental load,
- ④ the site adaptability of the unit,
- ⑤ life extension assessment of the unit,
- ⑥ other emergency response.

Generally, the structure of the mobile offshore unit is designed based on a specific marine environmental condition (such as the water depth, air gap, wind, waves and current), by the main means of direct finite element calculation with the supplementary of the empirical formula of the rules. Therefore, the finite element model of the unit structure shall be established for the structural assessment of the unit, which is the core of the assessment.

During the assessment, the latest unit data shall be input, and the structural strength of the unit shall be checked and calculated based on the environmental conditions specified in the unit operation manual according to the rules and standards of the classification society the unit is classed in during construction.

The assessment content shall include the global strength, local strength, fatigue strength and stability of the unit.

If the unit is assessed to be unqualified, appropriate strengthening or mitigation measures shall be taken to the unit, including reducing the variable load and applying the unit under lower environmental conditions.

The assessment process is shown in Figure 2-2.

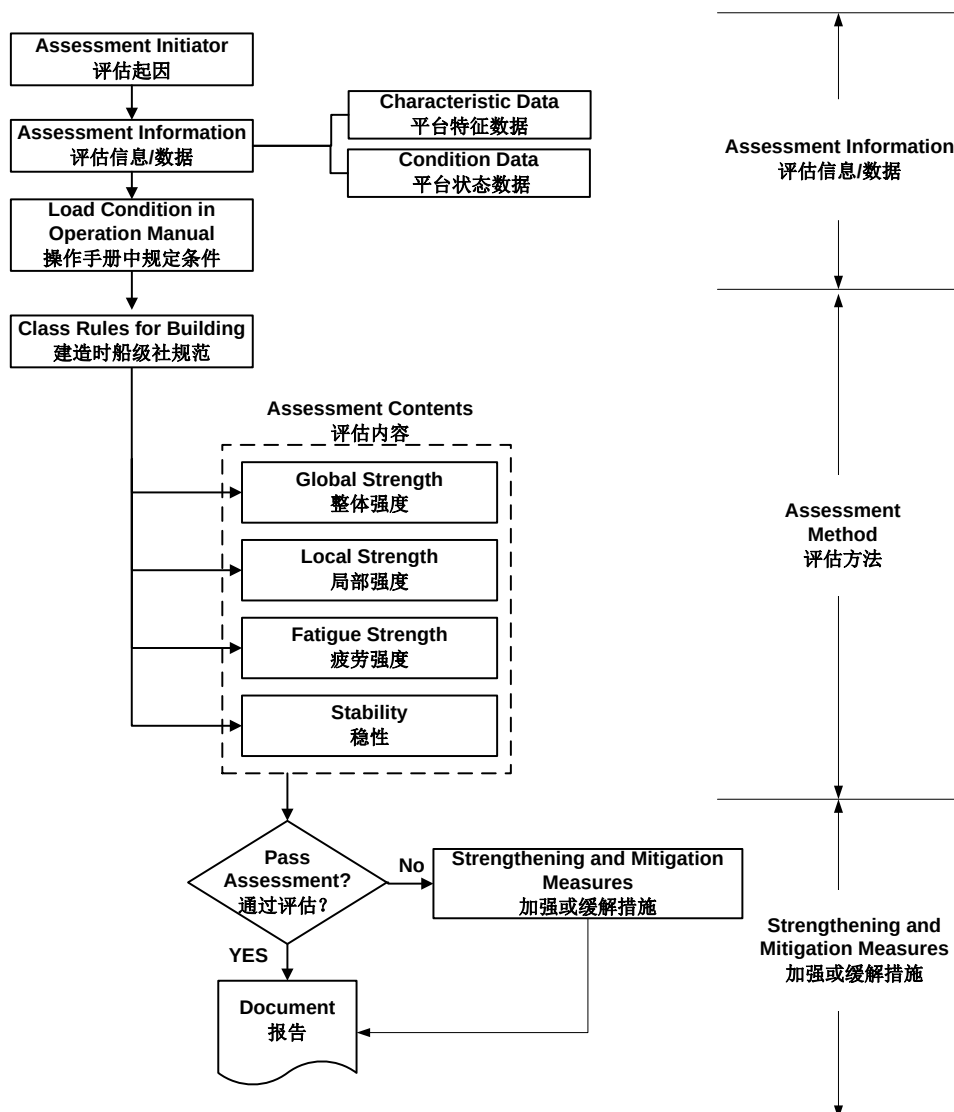


Figure 2-2 Structural Assessment Process of Mobile Offshore Unit

2.4 Survey plan

The structural survey of mobile offshore units can generally be completed during the docking survey or repair survey, which can be conducted according to the survey requirements of the classification society, or conducted temporarily as required by the actual situation. The survey plan shall be established according to the assessment conclusion, which is the overall and strategic arrangement of unit surveys, including the survey cycle and the scope arrangement, in a cycle of several years. Besides, the plan can be appropriately adjusted according to the changes of unit conditions during the life cycle. The scope required for the survey plan shall at least include:

- ① Surveys of the main structures and connecting parts;

- ② Thickness measurement and flaw detection of the main structures and connecting parts;
- ③ Corrosion and deformation of the unit structure;
- ④ Structural pressure test of the main compartment;
- ⑤ Check of the internal and external watertight integrity;
- ⑥ Survey of the high-stress areas and the focused parts;
- ⑦ The scheme of strengthening or mitigation measures;
- ⑧ Check of other special areas.

In addition, the range and accuracy of thickness measurement shall meet the data requirements for assessment and modeling.

2.5 Survey implementation

According to the requirements of the survey plan, the specified field survey shall be completed, and the maintenance, repair, strengthening and mitigation measures for the unit structure shall be fulfilled. The final data shall be fed back to the data system of integrity management, so as to maintain the latest condition of unit data and realize a cycle of structural integrity management. Through such periodic assessment cycle, the structural integrity management of mobile offshore units in the life cycle can be realized.

To sum up, by introducing the concept of structural integrity management and relying on the management mode with the cycle of data, assessment, survey plan and survey implementation, the requirements of structural damage assessment, applicability assessment, survey plan, strengthening and mitigation measures can be fulfilled for the mobile offshore units, thus providing technical guarantee for the safe operation and scientific management of the unit throughout its life cycle.

Chapter 3 Structural Survey of Mobile Offshore Units

3.1 General provision

3.1.1 The structural survey of mobile offshore units can generally be completed during the docking survey or repair survey, which can be conducted according to the survey requirements of the classification society, or conducted temporarily as required by the actual situation.

3.1.2 The survey plan shall be established according to the assessment conclusion, with several years as a cycle, and adjusted appropriately according to the changes of unit conditions during the life cycle. In addition, the survey plan shall meet the requirements of unit structure assessment.

3.1.3 The CCS Offshore Engineering Technical Center shall, according to the actual situation, work out a detailed inspection and survey plan with the owner in advance.

3.1.4 The inspection and survey of mobile offshore units shall be carried out according to the survey plan, which shall fully reflect the actual condition of the unit. The inspection and survey results of the unit structure are the important basis for continuous structural assessment of the unit.

3.1.5 The structural survey of the mobile offshore unit shall be completed under the supervision of the CCS Surveyor.

3.2 Structural survey

3.2.1 The exposed part of the main unit structure, deck, deckhouse, superstructure, the structures connected with the deck, including the supporting structure of drilling or processing devices, derrick base, crane foundation and its supporting structures, and the accessible internal compartments shall be generally surveyed to confirm their satisfactory conditions.

3.2.2 The relevant items of the external structure of the unit shall also be surveyed.

3.2.3 The overall appearance survey of seawater ballast tanks shall be focused on, and the corroded areas shall have the thickness measured.

3.2.4 Structural hydraulic test shall be carried out for the main compartment.

3.2.5 The survey of load line related items mainly includes:

- ① checking the positions of deck lines and load lines;
- ② checking the main body or superstructure for any changes affecting the calculation of the position of the load line;
- ③ inspecting the superstructure end bulkheads and the openings on such bulkheads, as well as

their closing arrangements;

- ④ inspecting the weathertight securing arrangements of hatchways and other openings on the freeboard and superstructure decks;
- ⑤ inspecting the ventilators and air pipes, including their coamings and closing arrangements, and in particular, the weld connections between air pipes and deck, as well as the external portion of all air pipe heads on exposed decks;
- ⑥ checking the watertight integrity of the closing arrangement of any side openings below freeboard deck;
- ⑦ inspecting the scuppers, water inlets and discharge outlets;
- ⑧ inspecting the side scuttles and deadlights;
- ⑨ inspecting the bulwarks, including the positions of side discharge openings, with particular attention to any side discharge openings fitted with shutters;
- ⑩ inspecting the guardrails, gangways, walkways and other means provided for protection of the crew and for access to and from the living quarters and working spaces;

3.2.6 Additional survey scope of surface unit

In addition to the above-mentioned applicable survey items, it is also necessary to inspect the deck structure around the wellhead (moon pool), and the section change position, opening and step of any other structure, or opening between the deck and the main structure, the supporting structure of the main structural members or the side structure connected with the main structure.

3.2.7 Additional survey scope of jack-up units

In addition to the above-mentioned survey items, the following items shall be added:

- ① All legs, including chords, diagonal and horizontal braces, gussets, racks, joints and leg guides shall be examined. Tubular or similar type legs shall be examined externally and internally, including the internal stiffeners and pinholes as applicable;
- ② Structure in, around and under jack-house and leg trunks shall be examined. NDT may be required for the suspected areas;
- ③ Leg jacking system and other jacking systems shall be examined externally;
- ④ Leg connections to bottom mats or spudcans shall be examined and subjected to NDT;
- ⑤ The jetting piping systems or other external pipe fittings shall be surveyed, particularly the

pipe fittings that pass through the bottom mats or spudcans;

- ⑥ Bottom mats or spudcans shall be surveyed.

3.2.8 Additional survey scope of semi-submersible unit

In addition to the above-mentioned applicable survey items, the connections of columns and diagonals to the upper hull, lower hull or pontoons, the joints of the main supporting structures, diagonals, braces and horizontals, the gussets and the brackets shall be surveyed. Besides, the internal continuation or support structure for the above shall be surveyed. Further, NDT may be required for the suspected areas.

3.2.9 Additional survey scope of submersible unit

In addition to the above-mentioned applicable survey items, the connections of columns and braces to the upper/lower hulls, as well as the anti-slip pile, shall be surveyed. NDT may be required for the suspected areas.

3.2.10 In addition to the above survey items, the key areas mentioned in the survey plan shall also be surveyed.

3.2.10 Structural thickness measurement and flaw detection

3.2.10.1 General requirement

- ① Any part of the structure with substantial corrosion or suspected thickness, if any, shall subjected to the thickness measurement survey;
- ② All crucial joints shall be surveyed by NDT.
- ③ The range and accuracy of thickness measurement shall meet the relevant requirements of the model of structural assessment.

3.2.10.2 Thickness measurement

- ① The most representative area that may suffer the most serious corrosion shall be selected as the measurement position;
- ② The corrosion degree shall be determined according to the average value of the measurements at 5 points in every 1 m^2 of the plate and 3 points in every 1 m of the member in the substantially corroded area;
- ③ For the member with substantial corrosion, if any, the Surveyor may expand the thickness measurement range if necessary;
- ④ Thickness measurement shall be carried out by a company certified by CCS with a ultrasonic

instrument, of which the accuracy shall be confirmed to be satisfactory by the surveyor. The measurement personnel shall hold a qualification certificate acceptable to CCS.

- ⑤ Thickness measurements shall be witnessed by the surveyor to ensure the accuracy of the measuring results. The surveyor may also accept the thickness measurements not witnessed by him/her, but sampling inspection may be conducted, if necessary, to ascertain the accuracy of the measurements.
- ⑥ The thickness measurement record shall indicate the measurement position, the measured thickness, the model of the instrument used, the measurement date, the signature of the measurement personnel, and the signature of the surveyor.

Chapter 4 Contents of Structural Continuous Assessment of Mobile Offshore Units

4.1 General provision

4.1.1 In general, a finite element model of the unit structure shall be established for the structural continuous assessment of mobile offshore units. Besides, the structural strength of the unit shall be calculated and checked with the latest unit condition data obtained from field survey and inspection based on the environmental conditions specified in the unit operation manual, according to the rules and standards of the classification society the unit is classed in during construction.

4.1.2 The structural continuous assessment of mobile offshore units usually takes several years as a cycle, which can be combined with the docking survey of units, so as to determine the applicability of unit structures. In case of emergency and other requirements, structural continuous assessment can also be carried out for the mobile offshore unit.

4.1.3 The structural continuous assessment of mobile offshore units generally includes the overall performance and global strength assessment, local strength assessment, fatigue strength assessment and stability assessment of the unit.

4.2 Overall performance and global strength assessment

4.2.1 The purpose of overall performance and global strength assessment of mobile offshore units is mainly to analyze whether all aspects of performance and global strength of units meet the requirements of the relevant rules and the unit operation safety in the current condition.

4.2.2 The overall performance assessment of the offshore jack-up units is mainly to ensure the overall safety performance under the elevated working condition, including the strength of legs, the bearing capacity of fixation system (jacking system), the bearing capacity of spudcans, the anti-overturning stability, the preloading performance and the retention capacity of gears during preloading.

Generally, the finite element analysis method can be used to analyze the overall performance of offshore jack-up units, and the model can be simplified appropriately. For example, the hull can be simulated by beams with considerable stiffness; the simulation of the leg shall ensure the consistent stiffness with the actual leg and the accuracy of the hydrodynamic coefficients C_d and

C_M . The loads are mainly classified into the functional loads and the environmental loads. Specifically, the functional loads include the fixed loads and the variable loads, while the environmental loads mainly include the wind, wave and ocean current loads, the P-Delta effect load and the inertia load applied by the wave. Generally, the environmental loads shall be taken from 0 to 360 degrees.

The strength assessment of legs is mainly based on the results of finite element analysis, with the yield and buckling checked according to the requirements of the relevant rules.

Generally, the bearing capacity assessment of the fixation system (jacking system) is to simulate the fixation system (jacking system) using a bar with considerable stiffness in the finite element model, during which the bearing capacity of the fixation system (jacking system) can be checked by analyzing its stress.

The bearing capacity assessment of spudcans is to obtain the maximum leg reaction through calculation, which shall be kept less than the allowable pressure of spudcans to ensure its safety.

Anti-overturning stability refers to the unit's ability to resist overturning caused by the environmental loads under the combined action of the weight, buoyancy and seabed on the unit. According to the *Rules for Classification of Mobile Offshore Units* (2012) by CCS, the safety factor for anti-overturning of jack-up units shall not be less than 1.1 under the conditions of operating or survival conditions. The safety factor K_S for anti-overturning can be calculated according to the following formula.

$$K_S = \frac{M_S}{M_O}$$

Where, the righting moment M_S and the overturning moment M_O can be expressed as,

$$\begin{aligned} M_S &= M_D + M_L + M_S \\ M_O &= M_E + M_{Dn} + P\Delta \end{aligned}$$

Where, M_D refers to the righting moment generated by the dead weight of the unit; M_L refers to the righting moment generated by the weight of legs and spudcans; M_S refers to the righting moment caused by the adsorption and friction of the seabed on the spudcan, which is generally not considered unless calculated in detail; M_E refers to the overturning moment caused by wind, waves and currents on the unit; M_{Dn} refers to the overturning moment caused by wave inertia force;

$P\Delta$ refers to the overturning moment caused by P-Delta effect of the hull.

Pre-loading capacity is the ability to assess whether the pressure applied to the legs can meet the requirements of pre-loading after the ballast tanks of the unit are completely filled with seawater. The ballast required by the unit can be calculated according to the following formula,

$$P_{Ballast} = P_{reaction} \times 3 - W_{hull} - W_{L\&C} - W_{Variable}$$

Where, $P_{Ballast}$ refers to the ballast required by the unit; $P_{reaction}$ refers to the maximum spudcan reaction calculated by the finite element method; W_{hull} refers to the empty ship weight; $W_{L\&C}$ refers to the weights of legs and spudcans; $W_{Variable}$ refers to the variable load weight.

The assessment of gear retention capability during preloading refers to the analysis on whether the load applied to the gear exceeds the gear bearing limit when the jack-up unit is under the maximum preloads, so as to ensure the gear to work safely.

4.2.3 The global strength assessment of the offshore jack-up unit is to analyze whether the hull has enough strength and stiffness to resist the adverse effects of environmental loads and functional loads. The failure form of hull strength mainly includes the yield and buckling of the hull plate or beam, and the main working conditions can be classified into the elevated conditions and the towing conditions. Under the elevated condition, the largest stress is usually detected on the hull in the case of the preloading and cantilever beam extended, a large stress is detected on the ballast tank plate and deck of the hull under preloading case, a large stress is usually detected on the main deck and bulkhead at the base of the cantilever beam under the cantilever beam extended case, and the large structural stress is applied to the trunk all around. Under the towing condition, the leg and leg fixing structure are usually detected with large stress.

4.2.4 The motion performance analysis of offshore semi-submersible units is to predict the maximum motion response and hydrodynamic load of the unit in a short time period according to the design environmental conditions, such as random spectrum specified in the operation manual, and the results are provided as inputs for the overall or local structural design of the unit. The motion performance analysis of semi-submersible units is generally calculated in frequency domain or time domain.

4.2.5 The global strength assessment of offshore semi-submersible units is to analyze whether the

current overall structural condition of the unit meets the structural strength requirements of the rules under the action of weight loads and environmental loads. Generally, the global strength assessment of offshore semi-submersible units is conducted with the design wave analysis method. Firstly, the design wave with the variables maximized shall be determined according to the load characteristics of the unit structure, including the transverse Split force, longitudinal shear force, torque, longitudinal acceleration of the upper deck, transverse acceleration of the upper deck and vertical acceleration of the upper deck. Then, the hydrodynamic load calculated according to the design wave is applied to the finite element model of the unit, and the stress response of the unit under various working conditions is analyzed. Finally, the yield and buckling strength of the unit structure are checked according to the rules.

4.2.6 Mooring assessment of offshore semi-submersible units is to analyze the strength of the mooring system of semi-submersible unit and determine whether the current mooring condition meets the strength requirements of the rules. The mooring analysis of offshore semi-submersible units is generally completed through frequency domain or time domain analysis to calculate the maximum tension of the mooring system and the maximum deviation of the unit. The operational safety of the mooring system shall be determined according to the requirements of the relevant rules and operation safety.

4.2.7 The air gap analysis of offshore semi-submersible units is to calculate and analyze the distance between the upper hull and the wave crest of the semi-submersible unit under various working conditions, so as to ensure that the unit has enough air gap to prevent the upper hull from being impacted by waves. The air gap analysis of offshore semi-submersible unit is generally performed through frequency domain or time domain analysis. The typical calculation points are selected at the lower part of the hull on the unit, and the distance between the wave crest and the calculation point is analyzed to ensure that the requirements of the rules are met.

4.2.8 The global strength assessment of offshore submersible units is to analyze whether the current structural condition of submersible units meets the structural strength requirements of the rules under the action of weight loads and environmental loads. Under the submersible condition, the loads of the submersible unit mainly include the weight loads and the environmental loads, such as the wind, wave and current loads. The calculation conditions mainly include the working conditions and the survival conditions. In the global strength assessment of the submersible unit,

special attention shall be paid to the influence of 20% area lost by seabed scouring on the strength of the mat structure and the strength of columns and diagonals. In addition, the stability of the submersible unit, including the anti-sinking and anti-sliding stability of the seabed, shall be calculated and analyzed to ensure that the safety factor meets the requirements of the rules.

4.3 Local strength assessment

4.3.1 The local strength assessment of mobile offshore unit mainly focuses on the modeling and analysis of the local structure with large loads and complex structures during the operation of the unit, so as to determine whether the current condition of the local structure meets the requirements of the rules. The model of the local structure shall reflect an enough structural range, with the grid division of the finite element model detailed enough, the setting of boundary conditions meeting the actual conditions, and the applied external loads reflecting the actual load condition. The local structural strength of mobile offshore units shall meet the yield and buckling strength requirements of the rules.

4.3.2 The local structural strength assessment of the offshore jack-up units generally includes the strength analysis and assessment of the jack house, spudcans, superstructure, heli-deck, crane foundation, cantilever beam, drilling floor, main engine base and other equipment bases.

4.3.3 The local structural strength assessment of the offshore semi-submersible unit generally includes the strength analysis and assessment of the crane foundation, windlass foundation, derrick substructure, superstructure, heli-deck, main engine foundation and other equipment foundations . In the local structural strength assessment of the semi-submersible unit, the consideration of loads shall include the inertial force caused by unit motions.

4.3.4 The local structural strength assessment of the offshore submersible unit generally includes the strength analysis and assessment of the mat, crane foundation, derrick substructure, superstructure, heli-deck, main engine foundation and other equipment foundations.

4.4 Fatigue strength assessment

4.4.1 The fatigue strength assessment of mobile offshore units is generally based on the wave scatter diagram of the working sea area, and the fatigue strength of the structural details prone to fatigue is analyzed using the spectral fatigue analysis method to predict its residual fatigue life.

4.4.2 The details considered for offshore jack-up units fatigue assessment generally include the welded joints of the lattice leg and the joint between the leg and spudcan. The details considered

for offshore semi-submersible units fatigue assessment generally include the connection joints of the columns to the upper and lower hull, as well as the connection joints of diagonals to the columns and upper hull. The details considered for offshore submersible units fatigue assessment generally include the connection joints of the column to the upper and lower hull.

4.4.3 The general process of spectral fatigue strength analysis is as follows:

(1) Short-term distribution of random variables of stress amplitudes

Generally, the alternating stress process under a specific sea condition is regarded as a narrow-band stationary random process with a mean value of zero. According to the random process theory, the stress amplitude obeys the Rayleigh distribution, and the probability density function is,

$$p_s(S) = \frac{S}{\sigma_x^2} \exp\left(-\frac{S^2}{2\sigma_x^2}\right) \quad 0 \leq S < +\infty$$

Where, S refers to the stress amplitude; σ_x refers to the standard variance of the stress amplitude process.

(2) Response spectra of the stress amplitude variable and its numerical characteristics

Assuming the stress amplitude response spectrum of the above structure to be $G_{xx}(\omega)$, its value can be obtained by spectral analysis method.

$$G_{xx}(\omega) = |H_\sigma(\omega)|^2 \cdot G_{\eta\eta}(\omega)$$

Where, $|H_\sigma(\omega)|^2$ refers to the stress amplitude-frequency transfer function, and $G_{\eta\eta}(\omega)$ refers to the wave energy spectrum. Generally, the P-M spectrum can be used, that is,

$$G_{\eta\eta}(\omega) = \frac{H_S^2}{4\pi} \left(\frac{2\pi}{T_Z}\right)^4 \omega^{-5} \exp\left(-\frac{1}{\pi} \left(\frac{2\pi}{T_Z}\right)^4 \omega^{-4}\right)$$

Assuming that m_0 and m_2 are the 0th moment and the 2nd moment of the stress amplitude response spectrum, respectively, then

$$m_n = \int_0^{+\infty} \omega^n G_{xx}(\omega) d\omega \quad n = 0, 2$$

According to the random process theory, the standard variance of the stress amplitude variable can

be expressed as,

$$\sigma_x = \sqrt{\int_0^{+\infty} G_{xx}(\omega) d\omega} = \sqrt{m_0}$$

The frequency of occurrence of the stress amplitude per unit time shall be:

$$f_0 = \frac{1}{2\pi} \sqrt{\frac{m_2}{m_0}}$$

(3) Miner's cumulative fatigue damage

When the fatigue load spectrum is expressed by a continuous probability density function corresponding to a certain time period, the calculation of fatigue cumulative damage degree can be expressed as,

$$D = \int_L \frac{dn}{N} = \int_0^{+\infty} \frac{N_j p_s(S) dS}{N} = N_j \int_0^{+\infty} \frac{p_s(S)}{N} dS$$

Where, N refers to the number of cycles required to achieve failure under the action of a single cyclic load with a stress range of S ; N_j refers to the total number of cycles of the stress range under the j -th sea condition in a year, and its value can generally be expressed as,

$$N_j = 31536 \times 10^3 \times P\% \times f_0$$

Where, $P\%$ refers to the probability of the j -th sea condition in the wave scatter diagram.

The S-N curve can be selected according to the rules based on the different positions of calculation joints.

Considering that the waves come from the bow, oblique and vertical directions at the frequencies of 1/4, 1/2 and 1/4 respectively, the fatigue damage of the unit can be accumulated according to the wave scatter diagram in the working sea area in one year, that is,

$$D = \frac{1}{2} \sum_j \left(N_j \int_0^{+\infty} \frac{p_s(S)}{N} dS \right)_{Diagonal} + \frac{1}{4} \left[\sum_j \left(N_j \int_0^{+\infty} \frac{p_s(S)}{N} dS \right)_{Bow} + \sum_j \left(N_j \int_0^{+\infty} \frac{p_s(S)}{N} dS \right)_{Beam} \right]$$

Therefore, its fatigue life is,

$$T_{life} = 1/D$$

4.5 Stability assessment

4.5.1 The stability assessment of mobile offshore units generally includes the intact stability assessment, damaged stability assessment, on-bottom stability and sinking/floating stability of the unit.

4.5.2 The stability check criteria mentioned in this section are the requirements of the CCS's *"Rules for Classification of Mobile Offshore Units"* (2012).

4.5.3 In general, the intact stability and damaged stability assessment of mobile offshore units shall be based on the current actual condition of the unit, including the wind-loaded area, watertight partition, weathertight partition and water inlet location, to calculate and analyze the intact stability and damaged stability of the unit and accordingly determine their conformity with the requirements of the rules. The requirements for the intact stability criteria of mobile offshore units are:

- (1) For jack-up units, the area under the righting moment curve to the second intercept or the angle of flooding, whichever is smaller, should be at least 40% greater than the area under the wind heeling moment curve at the same limiting angle;
- (2) For the column-stabilized units, the area under the righting moment curve to the second intercept or the angle of flooding, whichever is smaller, should be at least 30% greater than the area under the wind heeling moment curve at the same limiting angle;
- (3) For the submersible units, the area under the righting moment curve to the second intercept or the angle of flooding, whichever is smaller, should be at least 40% greater than the area under the wind heeling moment curve at the same limiting angle;
- (4) In all cases, the righting moment curve should be positive over the entire range of angles from upright to the second intercept. In the full range of draughts for all conditions of floating operation, the initial metacentric height corrected by free surface should be not less than 0.15 m.

The requirements of damaged stability criteria for mobile offshore units are as follows:

- (1) The jack-up units shall have sufficient freeboard, reserve buoyancy and stability. Thus, the damage waterline should be below the lower edge of any opening where progressive flooding may take place when any compartment is subjected to the specified damage during any operating or transit conditions under the combined action of the wind heeling moment from any direction at a wind speed of 25.8 m/s (50 kn), sinking, trim and heel.

(2) The residual stability for jack-up units after the flooding of any single compartment shall meet the requirements of the following formula,

$$RoS = \theta_m - \theta_s \geq \max \left\{ \left(7^\circ + 1.5\theta_s \right), 10^\circ \right\}$$

where, RoS refers to the stability range; θ_m refers to the vanishing angle of stability; θ_s refers to the angle of list after flooding of a single compartment.

(3) The semi-submersible units shall have sufficient freeboard and watertight partitions to provide sufficient buoyancy and stability to meet the following requirements for any operating or transit conditions under the wind heeling moment from any direction at a wind speed of 25.8 m/s (50 kn):

- ① The inclination angle of the unit shall be no more than 17° after the specified damage;
- ② Any openings below the damage waterline shall be made watertight, and openings within 4 m above the damage waterline shall be made weathertight;
- ③ In case of the specified damage, the area of the righting moment curve, subject to the damage set out above shall have, from the first intercept to the area of weathertight integrity required by ② or the second intercept, whichever is smaller, shall not be less than the area of 7°. Within this range, the righting moment curve should be at least twice the wind heeling moment, both being measured at the same angle.

(4) The submersible units shall have sufficient freeboard, reserve buoyancy and stability so that the damage waterline should be below the lower edge of any opening through which progressive flooding may take place when any compartment is subjected to the specified damage during any operating or transit conditions under the combined action of the wind heeling moment from any direction at a wind speed of 25.8 m/s (50 kn), sinking, trim and heel.

4.5.4 In addition to the assessment of intact stability and damaged stability, the KG curve of the unit shall also be calculated to ensure the safety of unit loading.

4.5.5 The on-bottom stability of mobile offshore units is mainly for the jack-up units and the submersible units.

4.5.5.1 Anti-overturning stability. Under the bottom-resting conditions, the units shall have adequate anti-overturning stability under the action of the combined environmental loads as appropriate. The safety factor for anti-overturning is shown in Table 4-1. To calculate the overturning moment, the requirements for selecting the pinned point of the lever include:

(1) the jack-up units without spudcans shall be considered being pinned 3 m below the seabed, or any other appropriate pinned point may be taken according to actual penetration of legs; the jack-up units with spudcans shall be considered being pinned at half of the maximum penetration below the seabed or that of the spudcan height, whichever is less.

(2) for the jack-up units with mats, submersible units and other types of units, the pinned point should be taken at the surface of the seabed.

Table 4-1 Safety Factor for Anti-overturning

Condition	Jack-up unit	Submersible unit
Operation	1.1	1.6
Survival	1.1	1.4

4.5.5.2 Anti-sliding stability. Under the bottom-resting condition, the units shall have adequate capability to withstand the horizontal sliding under the horizontal loads as appropriate. In case of poor soil quality on the seabed, the sliding surface shall be the contact area or profile of the mat or lower hull with the soil, without considering the sliding in the deep foundation. The anti-sliding stability of the units shall comply with the following:

$$\frac{R_H}{F_H} \geq K_H$$

where, R_H refers to the sliding resistance, including the adhesion and friction of the soil, the passive soil pressure, and the sliding resistance generated by the anti-sliding device;

F_H refers to the sliding force, including all horizontal forces acting on the unit; K_H refers to the safety factor for anti-sliding, which shall not be less than 1.4 for the normal operating conditions and not less than 1.2 for the survival conditions.

4.5.4.3 Bearing capacity of foundation. When the units are resting on the seabed under the environmental loads and gravity loads as appropriate, the foundation stresses of the seabed should be less than the bearing capacity of the foundation and excessively differential settlement should be prevented.

4.5.5 The sinking/floating stability of mobile offshore units is mainly for the submersible units, of which the criteria are as follows:

- (1) Throughout the sinking process, the initial metacentric height, corrected for the free surface of liquid, shall not be less than 0.15 m for uniform sinking/floating and not less than 0.05 m for heeling.
- (2) The calculated water depth used to calculate the sinking/floating stability shall be included in the depth of the unit penetrating the seabed.

Chapter 5 Method of Structural Continuous Assessment of Mobile Offshore Units

5.1 General provision

5.1.1 This chapter mainly expounds the solutions to the main key technical points of structural continuous assessment of jack-up units and semi-submersible units, to which reference can be made partially to in the assessment calculation of submersible units.

5.2 Hydrodynamic calculation of lattice leg in jack-up unit

5.2.1 Wave current load

Wave and current loads acting on small-scale members with $\lambda > 5D$ can be calculated by the following Morison formula.

$$\Delta F = \Delta F_{drag} + \Delta F_{inertia} = 0.5\rho DC_D v_n |v_n| + \rho C_M A \ddot{u}_n$$

Therein, the drag force is calculated by the following:

$$\Delta F_{drag} = 0.5\rho DC_D v_n |v_n|$$

The inertia force is calculated by the following:

$$\Delta F_{inertia} = \rho C_M A \ddot{u}_n$$

where, ΔF refers to wave force per unit length of the member perpendicular to its axis; ΔF_{drag} refers to the drag force per unit length of the member perpendicular to its axis; $\Delta F_{inertia}$ refers to the inertial force per unit length of the member perpendicular to its axis; λ refers to the wavelength; D refers to the characteristic dimension of the section of a member, such as the diameter of a pipe member; ρ refers to the seawater density; C_D refers to the drag coefficient; C_M refers to the inertia coefficient;

$v_n = u_n + V_{C_n}$ refers to the sum of the velocity vectors of wave water particle and the ocean current perpendicular to the member axis, that is, the combined water particle velocity; u_n refers to the velocity of the wave water particle in the direction perpendicular to the member axis; V_{C_n} refers to the current velocity in the direction perpendicular to the member axis; $\ddot{u}_n$ refers to the acceleration of the water particle in the direction perpendicular to the member axis; A refers to the cross-sectional area of the member.

5.2.2 Hydrodynamic model of jack-up leg

The hydrodynamic model of jack-up legs can be established with two methods, i.e. the

detailed model and the equivalent model.

(1) Detailed model: the model of all relevant members of the leg are established based on their own Morison eigenvalue ($C_D D = C_{D_i} D_i$, $C_M A = C_{M_i} \pi D_i^2 / 4$), as shown in 5.2.3.

(2) Equivalent model: the hydrodynamic model of a bay of the lattice leg shall be established based on the equivalent vertical pipe member located at the geometric center of the actual leg, and accordingly the equivalent Morison eigenvalues are $C_D D = C_{D_e} D_e$ and $C_M A = C_{M_e} A_e$.

$$C_{D_e} D = D_e \sum C_{D_{ei}}$$

$$C_{D_{ei}} = [\sin^2 \beta_i + \cos^2 \beta_i \sin^2 \alpha_i]^{3/2} C_{D_i} \frac{D_i l_i}{D_e s}$$

Where, C_{D_e} refers to the equivalent inertia coefficient; D_e refers to the equivalent diameter of the leg, for which $\sqrt{(\sum D_i^2 l_i)/s}$ is recommended;

$C_{D_{ei}}$ refers to the equivalent value of the drag coefficient of the independent member i ; C_{D_i} refers to the drag coefficient of the independent member i , as shown in 5.2.3; D_i refers to the characteristic scale of the member i , as shown in 5.2.3; l_i refers to the length between the joint centers of the member i ; s refers to the length of a bay for the leg; α_i refers to the included angle between the direction of water flow and the axis of the member projected to a horizontal plane, as shown in Figure 5-1; β_i refers to the angle at which the member inclines from the horizontal plane, as shown in Figure 5-1; $\sum$ refers to the sum of all members in a leg bay.

For the horizontal and vertical members, appropriate simplification can be made for $C_{D_{ei}}$:

Vertical members (such as chords), $C_{D_{ei}} = C_{D_i} (D_i / D_e)$;

Horizontal members: $C_{D_{ei}} = \sin^3 \alpha C_{D_i} (D_i l_i / D_e s)$.

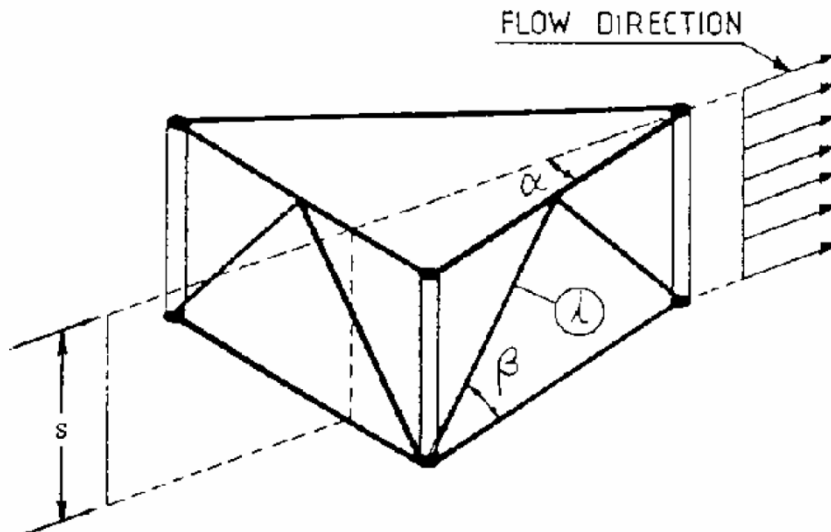


Figure 5-1 Hydrodynamic Calculation of Lattice Leg

$$C_{Me}A = A_e \sum C_{Mei}$$

$$C_{Mei} = [1 + (\sin^2 \beta_i + \cos^2 \beta_i \sin^2 \alpha_i)(C_{Mi} - 1)] \frac{A_i l_i}{A_e s}$$

where, C_{Me} refers to the equivalent inertia coefficient; A_e refers to the equivalent area per unit height of the leg, which can be calculated as $(\sum A_i l_i)/s$; C_{Mei} refers to the equivalent value of the inertia coefficient of the independent member i ; C_{Mi} refers to the inertia coefficient of the independent member i , as shown in 5.2.3; A_i refers to the equivalent area of the independent member i , which can be calculated as $\pi D_i^2/4$, as shown in 5.2.3.

5.2.3 Hydrodynamic coefficient of leg members of jack-up unit

5.2.3.1 See Table 5-1 for the recommended values of hydrodynamic coefficients of tubular members (with the diameter $< 1.5\text{m}$).

Table 5-1 Hydrodynamic Coefficient of Tubular Members

Surface condition of members	C_{Di}	C_{Mi}
Smooth	0.65	2.0
Rough	1.00	1.8

If the influence of the marine growth thickness on the hydrodynamic coefficient is considered, the characteristic scale of the member is:

$$D_i = D_{\text{original}} + 2t_m$$

where, D_{original} refers to the original characteristic scale of the member, and t_m refers to the thickness of the marine growth.

5.2.3.2 Hydrodynamic coefficient of lattice leg gusset plate

The wave-current load generated by the gusset plate in the vertical plane can be calculated using the drag coefficient $C_{Di} = 2.0$ and applied to the projected part of the gusset plate visible in the water flow direction. Correspondingly, the characteristic scale and length of the gusset plate are shown in Figure 5-2, $A = D_i l_i$ and $D_i = l_i$. $C_{Mi} = 1.0$, ignoring the thickness of the marine growth.

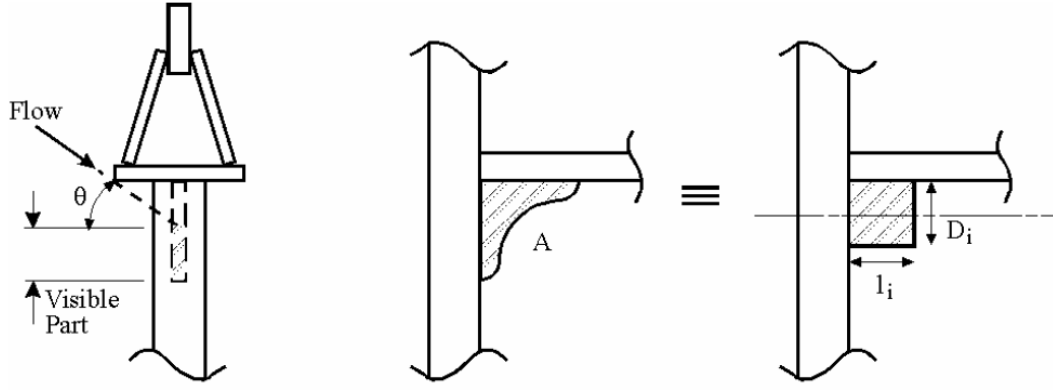


Figure 5-2 Lattice leg gusset plate

5.2.3.3 Hydrodynamic coefficient of chord of split tubular lattice leg

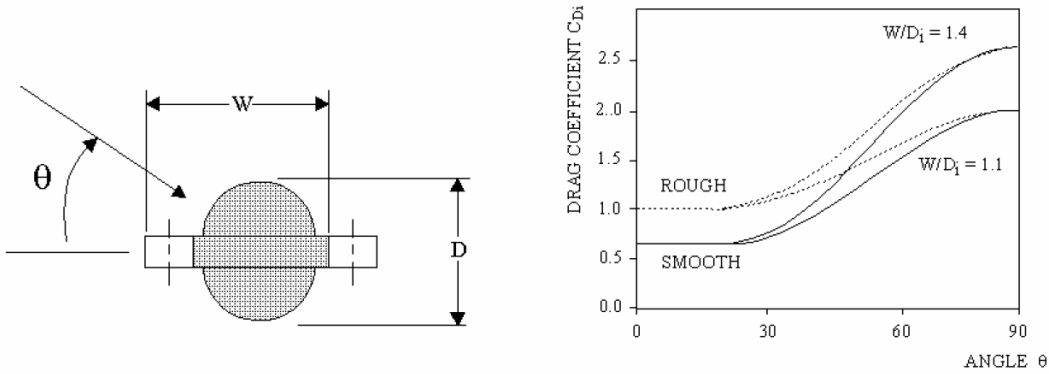


Figure 5-3 Split tubular leg chord and C_{D_i} typical value

For the split tubular lattice leg chord shown in Figure 5-3, the drag coefficient C_{D_i} relative to the characteristic scale $D_i = D + 2t_m$ can be calculated according to the following formula:

$$C_{D_i} = \begin{cases} C_{D_0} & ; 0^\circ < \theta \leq 20^\circ \\ C_{D_0} + (C_{D_1} W/D_i - C_{D_0}) \sin^2[(\theta - 20^\circ)9/7] & ; 20^\circ < \theta \leq 90^\circ \end{cases}$$

where, θ refers to the wave incident angle, as shown in Figure 5-3; C_{D_0} refers to the drag coefficient of pipe members, which is taken as per Table 5-1; C_{D_1} refers to the drag coefficient relative to the projected diameter W in the direction perpendicular to the water flow of the rack panel, with the value determined by the following formula:

$$C_{D_1} = \begin{cases} 1.8 & ; W/D_i < 1.2 \\ 1.4 + 1/3 \left(\frac{W}{D_i} \right) & ; 1.2 < W/D_i < 1.8 \\ 2.0 & ; 1.8 < W/D_i \end{cases}$$

The equivalent area $\pi D_i^2/4$ and the inertia coefficient $C_{M_i} = 2.0$ of the member can be applied to all the water incident angles and member surface conditions.

5.2.3.4 Hydrodynamic coefficient of triangular lattice leg chord

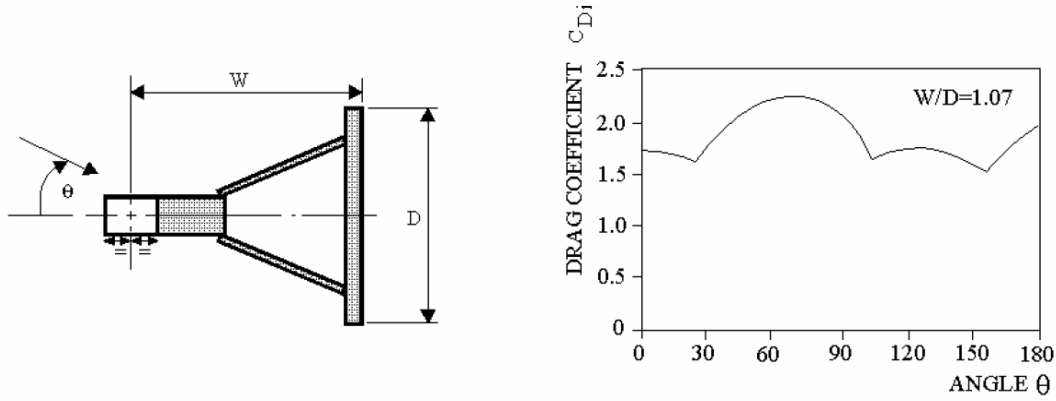


Figure 5-4 Triangular leg chords and C_{Di} typical values

For the triangular lattice leg chord shown in Figure 5-4, the drag coefficient C_{Di} relative to the characteristic scale $D_i = D$ (the width of the back plate) can be calculated according to the following formula:

$$C_{Di} = C_{Dpr}(\theta)D_{pr}(\theta)/D_i$$

The projected diameter $D_{pr}(\theta)$ can be calculated by the following formula:

$$D_{pr}(\theta) = \begin{cases} D\cos(\theta) & ; 0 < \theta < \theta_o \\ W\sin(\theta) + 0.5D|\cos(\theta)| & ; \theta_o < \theta < 180 - \theta_o \\ D|\cos(\theta)| & ; 180 - \theta_o < \theta < 180 \end{cases}$$

The angle is $\theta_o = \tan^{-1}(D/(2W))$ when a half of the rack panel is shielded.

The drag coefficient C_{Dpr} for the projected diameter can be calculated as follows:

$$C_{Dpr} = \begin{cases} 1.70 & ; \theta = 0^\circ \\ 1.95 & ; \theta = 90^\circ \\ 1.40 & ; \theta = 105^\circ \\ 1.65 & ; \theta = 180^\circ - \theta_o \\ 2.00 & ; \theta = 0^\circ \end{cases}$$

(Linear interpolation can be performed for the intermediate angles)

Relative to the equivalent area $\pi D_i^2/4$ of the member, the inertia coefficient $C_{Mi} = 2.0$ (as a flat plate) can be applied to all water incident angles and member surface conditions.

5.2.3.5 For leg chords of other cross-section types, the hydrodynamic coefficients shall be determined according to the relevant literature and/or appropriate model tests. Appropriate relative roughness, Keulegan-Carpenter number and Reynolds number shall be considered in the model test.

5.3 Finite element modeling technology of hull-leg connection of jack-up unit

5.3.1 Simulation of connection between upper/lower guide structures and legs

The connection between the upper/lower guide structures and the legs shall be simulated as a horizontal displacement that restricts the contact between the main chord and the guide structure through the linear spring or freedom degree release. The nominal position of the lower guide structure relative to the leg can be determined by the sum of the penetration depth of the leg into the mud, the water depth and the air gap. However, at least two positions of the lower guide structures at the joint of the leg and in the middle of the span between the two joints of the leg shall be considered for the strength assessment of the leg.

5.3.2 Simulation of connection between jacking gear and leg

The jacking gear shall be simulated to resist the vertical load and the corresponding horizontal load in the form of linear spring or cantilever beam based on the gear stiffness provided by the manufacturer. The load value for the unit displacement at the free end of the cantilever beam shall be equal to the stiffness of the jacking gear provided by the manufacturer. The deviation of the contact point between the gear and the rack from the neutral axis of the main chord shall also be properly considered in the model.

5.3.3 Simulation of connection between fixation system and leg

The fixation system shall be simulated to resist the vertical and horizontal loads in the form of linear springs or cantilever beams based on the vertical and horizontal support stiffness of the fixation system. A calculation method of linear spring stiffness coefficient for simulating the connection between fixation system and leg is recommended as follows:

$$K_{ry} = \frac{1}{1/K_{ry_fix} + 1/K_{ry_leg}}$$

$$K_{rz} = \frac{1}{1/K_{rz_fix} + 1/K_{rz_leg}}$$

$$K_v = \frac{1}{1/K_{v_fix} + L_1/EA}$$

where,

$$K_{ry_fix} = 3EI_{leg_y}/L_1$$

$$K_{rz_fix} = 3EI_{leg_z}/L_1$$

$$K_{ry_leg} = 3EI_{leg_y}/L_2$$

$$K_{rz_leg} = 3EI_{leg_z}/L_2$$

where, K_{ry} refers to the y-direction rotational stiffness coefficient of the connection between the fixation system and the leg; K_{rz} refers to the z-direction rotational stiffness coefficient of the

connection between the fixation system and the leg; K_v refers to the vertical displacement stiffness coefficient of the connection between the fixation system and the leg; E refers to the elastic modulus; A refers to the cross-sectional area of the leg; K_{ry_fix} refers to the y-direction rotational stiffness coefficient of the fixation system; K_{rz_fix} refers to the z-direction rotational stiffness coefficient of the fixation system; K_{ry_leg} refers to the y-direction rotational stiffness coefficient of the leg; K_{rz_leg} refers to the z-direction rotational stiffness coefficient of the leg; K_{v_fix} refers to the vertical displacement stiffness coefficient of the fixation system, which can be calculated from the actual structural form of the fixation system; I_{leg_y} refers to the moment of inertia about the y-axis for the section of the leg between the upper and lower guide structures; I_{leg_z} refers to the moment of inertia about z-axis for the section of the leg between the upper and lower guide structures; L_1 refers to the vertical length of the fixation system, as shown in Figure 5-5; L_2 refers to the length between the lower guide structure and the fixation system, as shown in Figure 5-5.

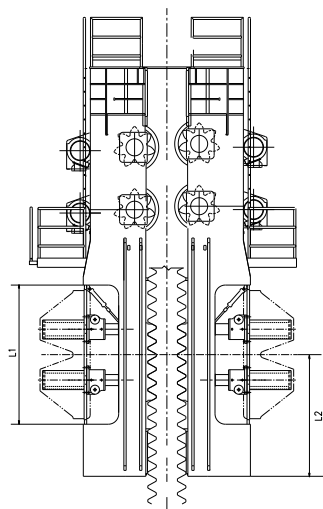


Figure 5-5 Fixation system and lower guide structure

5.3.4 Simulation of connection between shock pad and leg

Generally, the floating jacking system is equipped with a set of shock pads at the top and bottom of each jacking cases. The jacking system can move up and down freely before contacting the upper and lower cushion pads. When the unit is elevated, the jacking system contacts with the upper shock pad, and when the unit floats, the jacking system contacts with the lower shock pad. The shock pads shall be simulated to resist the vertical load only, based on the stiffness data

provided by the manufacturer. It shall be noted that the stiffness characteristics of the shock pad may be nonlinear.

5.3.5 Simulation of the connection of the jacking house and the related supports to the legs

The jacking house and the related supports have a direct impact on the capability of the upper guide structure to resist the horizontal loads, and shall be simulated based on its real stiffness.

5.4 Calculation of dynamic response of jack-up unit in deep water

5.4.1 The dynamic effect of jack-up unit due to the waves or the combined action of the waves and currents can be considered using the following single degree of freedom (SDOF) method:

$$DAF = \frac{1}{\sqrt{\left\{1 - \left(\frac{T_n}{T}\right)^2\right\}^2 + \left(2\xi\frac{T_n}{T}\right)^2}}$$

$F_{in} = (DAF - 1)BS_{Amplitude}$ (Acting on the center of gravity of the main hull)

$$BS_{Amplitude} = \frac{(BS_{(Q-S)Max} - BS_{(Q-S)Min})}{2}$$

where, DAF refers to the dynamic amplification factor; T_n refers to the natural vibration period of the jack-up unit; T refers to the wave period ($T = 0.9T_p$); T_p refers to the peak wave period; ξ refers to the damping ratio, which is generally not more than 7%. F_{in} refers to the inertial force acting on the center of gravity of the main hull;

$BS_{Amplitude}$ refers to the amplitude of quasi-static base shear force in a wave period; $BS_{(Q-S)Max}$ refers to the maximum quasi-static wave/current base shear force; $BS_{(Q-S)Min}$ refers to the minimum quasi-static wave/current base shear force.

Note: This SDOF method may not be conservative in the following cases: ① $\frac{T_n}{T} > 0.5$, with T_n close to the period value corresponding to the peak value of the shear transfer function of the unit base, and ② the sea areas with relatively high current values.

5.4.2 The dynamic amplification factor (DAF) can also be obtained with the detailed stochastic dynamic response analysis (frequency-domain or time-domain method).

5.5 Simulation calculation of interaction between jack-up legs and soil

5.5.1 In general, the legs of jack-up units shall be assumed to be pinned at the inflection point.

(1) For jack-up units with bottom mats, the inflection point can be considered to be located at the lower part of the bottom plate of bottom mat.

(2) The penetrating legs shall be considered being pinned at 3 m below the seabed to simulate the boundary conditions of their finite element model.

(3) For jack-up units with independent spudcans, the inflection points of the horizontal and vertical loads acting on the lower part of each leg shall be set at the following distance from the bottom of spudcans on the geometric vertical axis of legs/spudcans:

- 1) Half of the maximum penetration depth if the spudcan is partially penetrated into the seabed;
- 2) Half height of the spudcan if the spudcan is fully penetrated into the seabed.

5.5.2 In case that the interaction between legs and soil is considered in the finite element model of the unit, the elastic support constraint between legs and soil can be considered according to the stiffness coefficients in the following three directions:

$$\text{Vertical stiffness coefficient: } K_1 = \frac{2G_v B}{(1-\nu)}$$

$$\text{Horizontal stiffness coefficient: } K_2 = \frac{16G_h B(1-\nu)}{(7-8\nu)}$$

$$\text{Rotational stiffness coefficient: } K_3 = \frac{G_r B^3}{3(1-\nu)} \text{ (determined by iterative calculation)}$$

where, G_v refers to the shear modulus of soil for vertical load; G_h refers to the shear modulus of soil for horizontal load; G_r refers to the shear modulus of soil for rotating load; B refers to the effective diameter of the uppermost part of the bearing surface of the spudcan in contact with the soil (B is the width for the rectangular spudcans); ν refers to the Poisson's ratio.

The rotational stiffness coefficient K_3 needs to be determined by the following alternative calculation:

(1) $K_1 = \frac{2G_v B}{(1-\nu)}$, $K_2 = \frac{16G_h B(1-\nu)}{(7-8\nu)}$ and $K_3 = \frac{G_r B^3}{3(1-\nu)}$ are adopted as the initial elastic stiffness applied to the unit model to analyze the response of the unit under the action of gravity, environmental force and inertial force;

(2) The reaction of the spud in three directions, namely the vertical force Q_v , the lateral force Q_H and the rotational moment Q_M , after being calculated in the above (1), is substituted into the following F_y formula for analysis. If $F_y < 0$, the rotational stiffness is reduced, and the model is calculated repeatedly:

$$F_y = 16 \left[\frac{Q_v}{V_{Lo}} \right]^2 \left[1 - \frac{Q_v}{V_{Lo}} \right] \left[\left[1 - \frac{Q_v}{V_{Lo}} \right] - \left[\frac{Q_H}{H_{Lo}} \right]^2 - \left[\frac{Q_M}{M_{Lo}} \right]^2 \right]$$

where, V_{Lo} refers to the maximum vertical load of single spud under preloading;

For sand: $H_{Lo} = 0.12V_{Lo}$, $M_{Lo} = 0.075V_{Lo}B$;

For clay: $H_{Lo} = c_{uo}A + (c_{uo} + c_{ul})A_s$, $M_{Lo} = 0.1V_{Lo}B$;

c_{uo} refers to the undrained cohesive shear strength of the soil at the maximum bearing surface (D below the mud surface; D is the distance from the mud surface to the maximum bearing surface of the spudcan); c_{ul} refers to the undrained cohesive shear strength of the soil at the bottom of the spudcan; A refers to the effective bearing area of the spudcan, taking the cross-sectional area of the uppermost part of the bearing surface of the spudcan in contact with the soil; A_s refers to the lateral projected area of the buried depth area of the spudcan;

(3) The calculation in (2) shall be repeated until the calculated value $F_y > 0$ of each spudcan on the unit is obtained; if Q_M is reduced to zero, and F_y is still less than zero, then the calculation fails;

(4) If the calculated result $F_y > 0$ with (Q_v, Q_H, Q_M) calculated by stiffness given in (1) for the first time, the rotational stiffness finally applied on the unit model shall be $K_3 = f_r \frac{G_r B^3}{3(1-\nu)}$, which is corrected by multiplying the stiffness reduction factor f_r :

$$f_r = \sqrt{(1 - r_f) + 0.1e^{100(r_f-1)}}$$

$$r_f = \frac{\left\{ \left[\frac{Q_H}{H_{Lo}} \right]^2 + \left[\frac{Q_M}{M_{Lo}} \right]^2 \right\}^{0.5}}{4 \left[\frac{Q_v}{V_{Lo}} \right] \left[1 - \frac{Q_v}{V_{Lo}} \right]}$$

It is indicated that $F_y < 0$ is calculated from (Q_v, Q_H, Q_M) when $r_f > 1$.

5.6 Foundation stability analysis

5.6.1 Before the jack-up unit moves to operation on site, it is generally necessary to perform submarine geological survey and analyze the foundation stability to ensure the operation safety of the unit.

5.6.2 Preloading analysis

The offshore jack-up unit, once in place, needs to be preloaded. Preloading is to increase weight load by ballast water to make the ground pressure of unit spudcans reach the value specified in the operation manual. Preloading analysis is to ensure the foundation stability at the leeward spud, which can be determined according to the following formula:

$$Q_v \leq \phi_s V_{Lo}$$

where, ϕ_s refers to the allowable coefficient, which can be taken as 0.9; V_{L0} refers to the single pile preloads; Q_v refers to the leeward spud reaction when the unit is in elevated mode, which can be calculated by the following formula:

$$Q_v = V_D + V_L + 1.15(V_E + V_{Dn})$$

where, V_D refers to the spud reaction caused by the weight of the hull; V_L refers to the spud reaction caused by the maximum variable load; V_E refers to the spud reaction caused by wind, wave, current and P-Delta effects; V_{Dn} refers to the spud reaction caused by the inertia force of wave; the coefficient 1.15 in the formula is the amplification factor given by considering the uncertainty of environmental factors.

5.6.3 Analysis of soil bearing capacity for pinned

The analysis of soil bearing capacity refers to the analysis on the capability of foundation to resist the sinking and sliding of jack-up spuds under the lateral and vertical loads. The method provided in this section is applicable to the case with articulation as the boundary condition of the unit model.

5.6.3.1 Soil bearing capacity at the leeward spud

The foundation at the leeward spud shall fulfill the following formula:

$$\vec{Q}_{vH} \leq \phi_s \vec{F}_{vH}$$

where, ϕ_s refers to the allowable coefficient, which can be taken as 0.9; the vector $\vec{Q}_{vH}$ is the horizontal and vertical reaction of the downwind spud, which can be calculated according to the following formula:

$$\vec{Q}_{vH} = \vec{VH}_D + \vec{VH}_L + 1.15(\vec{VH}_E + \vec{VH}_{Dn})$$

where, the vector $\vec{VH}_D$ refers to the lateral and vertical spud reaction caused by the weight of the hull; $\vec{VH}_L$ refers to the lateral and vertical spud reaction caused by the maximum variable load; $\vec{VH}_E$ refers to the lateral and vertical spud reaction caused by wind, wave, current and P-Delta effects; $\vec{VH}_{Dn}$ refers to the lateral and vertical spud reaction caused by the inertia force of wave.

The vector $\vec{F}_{VH}$ is the horizontal and vertical bearing capacity of seabed foundation, which can be calculated according to the following formula:

$$\begin{aligned} F_{VH} &= A \left\{ 0.5 \gamma' B N_{\gamma} S_{\gamma} d_{\gamma} \left[1 - (F_H / F_{VH})^* \right]^{m+1} + p_0' N_q S_q d_q \left[1 - (F_H / F_{VH})^* \right]^m \right\} \text{--- Sand} \\ F_{VH} &= A \left\{ N_c c_u S_c d_c \left[1 - (1.5 F_H^* / N_c A c_u) \right] + p_0' N_q S_q \left[1 - (F_H / F_{VH})^* \right]^{1.5} d_q \right\} \text{--- Clay} \end{aligned}$$

where, A refers to the projected area of the contact between the spudcan and soil; γ' refers to the soil density; B refers to the diameter of the spudcan; N_{γ} and N_q refer to the bearing capacity coefficients; S_{γ} , S_q and S_c refer to the shape coefficients of bearing capacity; d_{γ} , d_q and d_c refers to the depth coefficient of bearing capacity; c_u refers to the undrained cohesive shear strength; p_0' refers to the overburden pressure: p_0' is 0 when there is no soil backfill; m refers to the shape coefficient of the spudcan support, which is generally taken as 1.5 for the circular spudcan.

The lateral bearing capacity can be calculated according to the following formula:

$$\begin{aligned} F_H &= F_H^* + 0.5 \gamma' (k_p - k_a) (h_1 + h_2) A_s \quad \text{--- Sand} \\ F_H &= F_H^* + (c_{u0} + c_{u1}) A_s \quad \text{--- Clay} \end{aligned}$$

where, k_p refers to the passive earth pressure coefficient; k_a refers to the main dynamic earth pressure coefficient, and is reciprocal to k_p ; h_1 refers to the penetration depth of spudcans at the maximum area, which is taken as 0 if the spudcans are not completely penetrated into the soil; h_2 refers to the penetration depth of the spudcan tip into the soil; A_s refers to the lateral projected area of the spudcan into soil; c_{u0} and c_{u1} refer to the undrained cohesive shear strength at the maximum area and at the tip of the spudcan respectively.

The vertical-lateral bearing capacity curve (the $F_{VH}-F_H$ curve) of foundation can be obtained from the above two formulas, which can be multiplied by ϕ_s to obtain the allowable bearing capacity curve. When the vertical and lateral forces at the downwind spud are obtained, comparison will be made with the $F_{VH}-F_H$ curve, and the foundation stability is considered to

be reliable and safe if the forces are within the envelope of the curve.

5.6.3.2 Soil bearing capacity at windward spud

The bearing capacity of soil at the windward spud shall meet the anti-sliding requirements, namely

$$Q_H \leq \phi_s F_H$$

where, ϕ_s refers to the allowable coefficient, which is 0.8 for sandy soil and 0.64 for clay; F_H refers to the lateral bearing capacity of the foundation:

$$\begin{aligned} F_H &= Q_v \tan \delta + 0.5 \gamma' (k_p - k_a) (h_1 + h_2) A_s && \text{--- Sand} \\ F_H &= A c_{u0} + (c_{u0} + c_{u1}) A_s && \text{--- Clay} \end{aligned}$$

5.6.4 Analysis of soil bearing capacity-elastic support

When the interaction between spud and soil is considered in the unit calculation model, the boundary condition shall be defined as elastic support. In case that the elastic support is used, the stiffness coefficients in three directions shall be considered, namely the vertical stiffness coefficient K_1 , the horizontal stiffness coefficient K_2 and the rotational stiffness coefficient K_3 . See section 5.5 for the specific calculation method and process. The final reaction of spud shall satisfy that: ① the yield limit function value F_Y shall be greater than or equal to zero; ② Q_v, Q_H shall meet the requirements of Section 5.6.3.1; ③ the sliding resistance shall meet the requirements of Section 5.6.3.2; ④ the checking range shall cover all the spud of the unit.

5.6.5 The foundation stability analysis process of offshore jack-up units is shown in Figure 5-6.

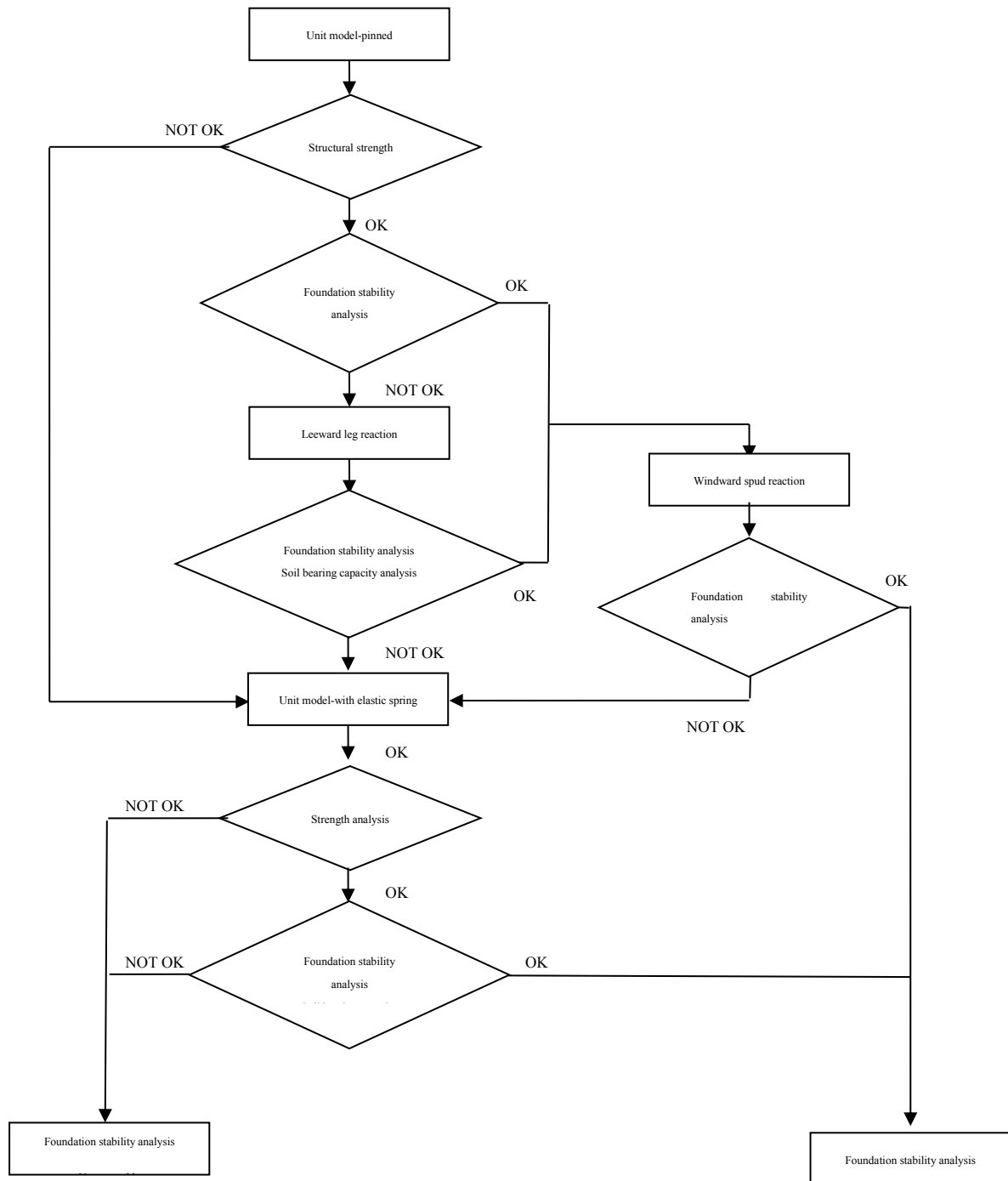


Figure 5-6 Foundation stability Analysis Process

5.7 Hydrodynamic calculation of semi-submersible unit

5.7.1 In the calculation of hydrodynamic RAO of semi-submersible units, assumption is usually made for unit motions and wave force under the action of regular waves with unit amplitudes, as well as a linear relationship with wave heights.

5.7.2 For hydrodynamic calculation of semi-submersible units, the internationally-acceptable hydrodynamic calculation software shall be selected, and the following rules shall be followed to

establish the hydrodynamic wet surface model:

- (1) The modeling scope shall include the outer surface of the hull/bar in contact with the external seawater under water;
- (2) Quadrilateral elements are recommended for the wet surface, and the triangular element can also be adopted locally to ensure the quality of the element. The characteristic length of the wet surface element shall not be greater than 1/7 of the minimum regular wavelength;
- (3) According to the characteristics of wave force, the hydrodynamic models of plate shells and bar structures are simulated by the Panel model and Morison model respectively;
- (4) The bars in Morrison model are input in the form of equivalent circular cross-section, and the hydrodynamic coefficients are recommended as follows: $C_d = 0.65$ and $C_m = 1.6$ for smooth bars; $C_d = 1.05$ and $C_m = 1.2$ for rough bars;
- (5) The mass attributes of the unit can be input in the form of mass model or mass attribute data (the weight, center-of-gravity position, inertia radius and rotational inertia).

5.7.3 The following rules shall be followed to input the environmental parameters for hydrodynamic calculation of semi-submersible units:

- (1) For the frequency-domain calculation of regular waves, the wave direction angle interval shall be no more than 45° , and the wave direction angle range shall be $0-360^\circ$. For example, the wave direction angle can be $0-180^\circ$ for the single-panel symmetry modeling of wet surface or $0-90^\circ$ for the double-panel symmetry modeling of wet surface;
- (2) For the frequency-domain calculation of regular waves, the wave period or frequency shall at least cover the whole wave frequency range, and fully reflect the changing trend of the transfer function curve with the period or frequency and the maximum response amplitude.

5.7.4 After the frequency-domain calculation of regular waves is completed, the following contents shall be checked for verification:

- (1) Input parameters, such as weight, center-of-gravity, inertia radius, water depth, wave period and direction angle;
- (2) The displacement volume, center-of-buoyancy, waterline area and wet-surface area obtained by the hydrodynamic model;
- (3) The calculated initial metacentric height, natural period, etc.

5.4.5 After the frequency-domain calculation of regular waves is completed, the results include the

following:

- (1) The added mass and the potential damping of unit;
- (2) RAO (transfer function) of unit motions in all directions;
- (3) The first-order wave frequency load RAO;
- (4) The average drift load RAO;
- (5) The specified section load RAO.

5.4.6 After the frequency-domain calculation of regular waves is completed, short-term statistical prediction of motion/load shall be carried out to obtain the frequency-domain statistical results of motion/load in all directions, if structural strength analysis is needed.

5.8 Determination of design wave for semi-submersible unit

5.8.1 The calculation methods of design waves for the overall structure analysis of semi-submersible units can be classified into the random analysis method and the deterministic analysis method.

5.8.2 Calculation of control parameters

The main control parameters in the global strength calculation of semi-submersible units include the following, as shown in Figure 5-7.

- (1) The split force between the pontoons of semi-submersible units, F_S ;
- (2) The longitudinal shear force between the pontoons of semi-submersible units, F_L ;
- (3) The pitching torques of semi-submersible units, M_T ;
- (4) The vertical bending moment of semi-submersible units, M_B ;
- (5) The longitudinal acceleration of the unit deck center, a_L ;
- (6) The transversal acceleration of the unit deck center, a_T ;
- (7) The vertical acceleration of the unit deck center, a_V ;

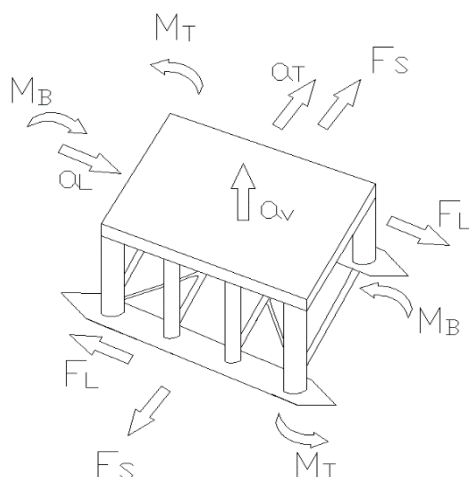


Figure 5-7 Hydrodynamic Response Parameters of Semi-submersible Unit

5.8.2.1 Split force between pontoons of semi-submersible unit, F_S

Under the action of the transverse waves with a wavelength of about $2B$ (where B is the molded breadth), the maximum possible split force between pontoons is the control load of the following structures:

- (1) The horizontal cross brace;
- (2) The main deck structure and the connection between columns (without cross brace).

5.8.2.2 Longitudinal shear force between pontoons of semi-submersible unit, F_L

Under the action of the oblique wave with a wavelength of about $1.5D$ (where D is the diagonal length), the maximum longitudinal shear force may be generated between pontoons, while the horizontal braces will suffer the maximum bending moment. Due to the maximum longitudinal shear force and the split force between pontoons, multiple wave directions shall be considered in structural design to determine the most adverse working conditions.

5.8.2.3 Pitching torque of semi-submersible unit, M_T

Under the action of the oblique waves with a wavelength of about D (where D is the diagonal length), the maximum pitching moment may be generated between pontoons, which is the control load of the following structures:

- (1) The horizontal diagonal and vertical brace;
- (2) Main deck structure (without cross brace).

Due to the maximum pitching torque and the split force between pontoons, multiple wave directions shall be considered in structural design to determine the most adverse working

conditions.

5.8.2.4 Vertical bending moment of semi-submersible unit, M_B

Under the action of longitudinal waves with the wave length equal to or slightly greater than L (where L is the molded length), the maximum vertical bending moment may be generated between pontoons, with two possible situations:

- (1) The cross section of the wave crest in the unit;
- (2) The cross section of the wave trough in the unit.

5.8.2.5 Longitudinal acceleration of unit deck center, a_L

The maximum longitudinal acceleration occurs in the longitudinal wave condition. The maximum longitudinal acceleration of a typical semi-submersible unit is usually 0.2–0.25 g under survival condition and 0.1–0.15 g under operating condition.

5.8.2.6 Transversal acceleration of unit deck center, a_T

The maximum transversal acceleration occurs in the transverse wave condition. The maximum longitudinal acceleration of a typical semi-submersible unit is 0.15–0.2 g under the survival condition, and the maximum longitudinal acceleration is usually 0.1–0.15 g under the operating condition.

5.8.2.7 Vertical acceleration of unit deck center, a_V

Generally, the vertical acceleration will not be the control factor of semi-submersible units, and the maximum vertical acceleration of typical semi-submersible units is generally 0.2–0.25 g under the survival condition.

5.8.3 Random analysis method

5.8.3.1 Irregular wave steepness

The steepness of irregular waves is defined as follows:

$$S_s = \frac{2\pi H_s}{g T_z^2}$$

Where, g refers to the acceleration of gravity; H_s refers to the significant height of the irregular wave; T_z refers to the zero-crossing period of irregular wave.

The irregular wave steepness under the once-in-a-century sea condition generally does not exceed the value determined by the following formula:

$$S_s = \begin{cases} \frac{1}{10}, & T_z \leq 6s \\ \frac{1}{15}, & T_z \geq 12s \\ \text{linear interpolation,} & 6s < T_z < 12s \end{cases}$$

5.8.3.2 The calculation formula of the characteristic wavelength L_C based on the characteristic period T_C is as follows:

$$L_C = \frac{g}{2\pi} T_C^2$$

5.8.3.3 The period range is recommended to be 3–25s for the frequency-domain calculation of regular wave. The period near the predicted T_C shall be properly densified, and the period interval shall be 0.2–0.5s, so as to obtain a more accurate T_C . Besides, the period shall be densified again near the more accurate T_C to obtain the more accurate T_C . The period interval far away from T_C can be increased appropriately, and the recommended interval is 1–2 s.

5.8.3.4 Calculation of the response amplitude (*RAO* of control parameters) under the unit regular wave amplitude

5.8.3.5 Determination of irregular waves

According to the selected wave steepness, a series of irregular spectra can be determined. The zero-crossing period of irregular waves is recommended to be 3–18s, and the interval is 0.5s or 1s. The significant wave height is determined by the zero-crossing period and the wave steepness.

5.8.3.6 Calculation of the energy spectrum of irregular waves

The energy spectrum of irregular waves is calculated by the significant wave height and zero-crossing period of irregular waves, and the spectrum form can be JONSWAP, PM or other suitable spectrum according to the sea conditions in the operation area.

5.8.3.7 Calculation of response spectrum

The response spectrum is calculated by the following formula:

$$S_R(\omega) = [RAO(\omega)]^2 * S_W(\omega)$$

where, $S_R(\omega)$ refers to the response spectrum; $S_W(\omega)$ refers to the wave spectrum.

5.8.3.8 Calculation of maximum response

The maximum response under the action of irregular waves is calculated according to the following formula:

$$R_{max} = \sqrt{m_0} * \sqrt{2 \ln(N)}$$

where, m_n refers to the n order moment of the response spectrum, $m_n = \int_0^\infty \omega^n * S_R(\omega) d\omega$, and it is the zero-order moment of the response spectrum in case of $n = 0$; N refers to the number of cycles during the storm conditions, $N = D/T_a$; D refers to the duration, which is generally 10,800 s (3 hours); T_a refers to the average zero-crossing period of the response, $T_a = 2\pi\sqrt{m_0/m_2}$.

5.8.3.9 Calculation of the design wave amplitude

The calculation formula of design wave amplitudes is as follows:

$$A_D = F_{LOAD} * (R_{max}/RAO_C)$$

where, F_{LOAD} is the load coefficient, which can be selected from 1.1 to 1.3 according to the adaptability of irregular wave spectrum to the designed sea area; RAO_C is the peak value with the period T_C in the RAO function.

Therefore, $2A_D$ and T_C are the design wave height and period used in the overall structural analysis.

5.8.4 Deterministic analysis method

5.8.4.1 The maximum design wave height of regular waves is calculated based on the steepness of regular waves, which is generally determined by the unit owner or designer according to the once-in-a-century regular wave conditions.

5.8.4.2 Regular waves steepness

The wave steepness of regular waves is defined as follows:

$$S = \frac{2\pi}{g} \frac{H}{T^2}$$

where, g is the acceleration of gravity; H is the height of regular wave; T is the period of regular wave.

Regular wave steepness generally does not have to exceed the value determined by the following formula:

$$S = \begin{cases} \frac{1}{7}, & T \leq 6s \\ \frac{1}{7 + \frac{0.93}{H_{100}[T^2 - 36]}}, & T > 6s \end{cases}$$

where, H_{100} is the maximum design wave height with 100 year return period of the regular wave.

5.8.4.3 The direction and length of characteristic wave shall be determined by the geometric

parameters and the load control parameters of the unit, as shown in Section 5.8.2.

5.8.4.4 The response amplitude (*RAO* of control parameters) under unit regular wave amplitude can be calculated.

5.8.4.5 The response values of different periods and wave heights can be obtained by multiplying the *RAO* function value with the wave height in the corresponding period (the wave height can be determined by the period and wave steepness *S*). It is suggested that the wave period range shall not be less than 3 s and not more than 18 s.

5.8.4.6 The wave height and period corresponding to the maximum value of the above response values are selected as the design wave height and period used in the overall structural analysis of the semi-submersible unit.

5.9 Mooring analysis of semi-submersible unit

5.9.1 This section gives the general assessment method for the mooring system of semi-submersible units under the combined action of environmental forces, such as wind, waves and currents, and other external forces. Mooring analysis shall be carried out by the recognized professional mooring analysis software according to the relevant requirements of the *Rules for Classification of Mobile Offshore Units* (2012) by CCS for mooring calculation.

5.9.2 Assessment method

The assessment methods of mooring system can be classified into:

- (1) the quasi-static analysis method, and
- (2) the dynamic analysis method, including the frequency-domain method and the time-domain method.

5.9.3 Calculation conditions

Mooring system assessment shall consider the following conditions:

- (1) Intact operating condition
- (2) Intact survival condition
- (3) Damaged operating condition
- (4) Damaged survival condition

When other structures exist near the unit, the transient motion performance of the mooring unit under the damaged conditions shall also be analyzed, including:

- (1) the transient operating condition, and

(2) the transient survival condition.

5.9.4 Environmental load simulation

Mooring analysis shall consider the environmental forces of wind, waves and currents and other possible external loads.

5.9.4.1 It is recommended to simulate the wind load by the superposition of the maximum hourly average wind speed and the wind spectrum, or directly by the wind load generated by the maximum average wind speed in one minute. The wind coefficient of the unit can be calculated through model test or according to the *Rules for Classification of Mobile Offshore Units* (2012) by CCS.

5.9.4.2 Appropriate wave spectrum shall be used for waves, and the number of seeds for generating irregular wave time history shall generally not be less than 3 for irregular wave analysis.

5.9.4.3 The simulation time of irregular waves shall not be less than 3 hours, and the time step length shall not be more than 0.25s.

5.9.4.4 Both the average drift force and wave frequency force shall be considered in mooring analysis.

5.9.4.5 Generally, the flow coefficient shall be obtained by model test, and any other methods shall be approved by CCS before used.

5.9.4.6 The geometric nonlinearity, hydrodynamic effect and friction between mooring lines and seabed shall be considered in dynamic analysis.

5.9.4.7 If there is a buoy on the mooring line, its hydrodynamic function shall be considered.

5.9.5 Anchor chain corrosion

The corrosion of anchor chains shall be considered in the mooring analysis. The diameter of anchor chains near the splash zone and submarine friction section is reduced by 0.2-0.4 mm per service year; in the remaining part, the diameter of anchor chains decreases by 0.1-0.2 mm per service year.

5.9.6 Mooring analysis criteria

5.9.6.1 Offset

The owner/designer shall specify the allowable average offset and the allowable maximum offset of drilling operation or production operation according to the operating water depth,

environmental conditions and drilling/production riser system.

5.9.6.2 Mooring line tension

The maximum tension of mooring lines under assessment shall have the safety factor no less than that listed in Table 5-2 below.

Table 5-2 Safety Factor of Mooring Line

Design condition	Quasi-static analysis		Dynamic analysis	
	Unit adequately clear from any adjacent structures	Unit with any adjacent structures	Unit adequately clear from any adjacent structures	Unit with any adjacent structures
Intact operating condition	2.70	3.00	2.25	2.47
Intact survival condition	2.00	2.20	1.67	1.84
Damaged operating condition	1.80	2.00	1.57	1.73
Damaged survival condition	1.43	2.00/1.57*	1.25	1.37
Transient operating condition	-	-	1.22	1.34
Transient survival condition	-	-	1.05	1.16

Note: *The safety factor 2.0 applies to the mooring line which is critical to maintain the mooring unit clear from any adjacent structures.

5.6.9.3 Length of mooring lines

Where a high holding power anchor is used, the mooring line shall have sufficient outboard length so that a portion of the line is still tangent to the seabed even if the maximum offset of the mooring system is reached in a damaged condition. Shorter mooring lines could be used for the mooring systems with other anchor systems (such as anchor piles).

5.6.9.4 Holding power of anchor system

The tension of the mooring line near the anchor end cannot exceed the bearing capacity of the anchor.

5.10 Calculation of air gap of semi-submersible unit

5.10.1 Under various floating conditions, there shall be a reasonable gap between the bottom of the upper hull and the wave crest with consideration to the movement of the semi-submersible unit relative to the sea surface.

5.10.2 In the calculation of the air gap of semi-submersible units, the following factors shall be considered:

- (1) Interaction between waves and structures
- (2) Asymmetric influence of waves
- (3) Rigid body motion of unit
- (4) Influence of mooring system
- (5) Influence of wave surge at the column.

5.10.3 To calculate the air gap, typical representative target points shall be selected, and at least the following aspects shall be considered:

- (1) The joint between the bottom of the upper hull and the column;
- (2) At the boundaries of the bottom of the upper hull in all directions.

5.10.4 Generally, the air gap calculation of the semi-submersible unit is carried out with the time-domain or frequency-domain method. By calculating the movement of the unit in waves, a sufficient number of target points of the unit are considered to ensure that the distance between the unit and the wave crest meets the requirements of the rules, and the unit deck will not be attacked by waves under various working conditions.

Chapter 6 Site Specific Assessment of Mobile Offshore Unit

6.1 General provision

6.1.1 For a mobile offshore unit that will operate on a new site, especially where the environmental conditions are similar to the limit conditions specified in the operation manual, its structural condition shall be assessed as required by the owner to verify its compliance with the structural strength requirements of the environmental load at the new site.

6.1.2 The site specific assessment shall be based on the accuracy and completeness of data. The operator is responsible for providing the detailed and accurate unit data, marine environment data and geological survey data. The assessor shall give full consideration to the age of the mobile offshore unit, the actual structure condition of the unit, the certificates and survey records issued by the classification society. Besides, field survey should be conducted, if necessary.

6.1.3 To determine the marine environmental parameters of the target site, such as wind, wave, current and tidal levels, the return period shall not be less than 50 years for the survival conditions of mobile offshore units.

6.2 Site specific assessment of mobile jack-up units

6.2.1 Structural integrity

In order to analyze the structural integrity of jack-up units according to the environmental conditions of the target site, the finite element model of the unit shall be established generally, and the model stiffness, mass distribution and load simulation shall be consistent with the actual conditions.

6.2.1.1 Model stiffness

(1) Leg stiffness

The leg is generally simulated by a beam with considerable stiffness, and the stiffness of such beam shall be consistent with the actual leg, including: ① the cross-sectional area, ② the moment of inertia of section, ③ the shear area, and ④ the torsional moment of inertia.

(2) Hull stiffness

The simplified or detailed model can be used to simulate the hull stiffness. In the simplified model, beam elements can be used to simulate the hull. Considering the longitudinal and transverse bulkheads, decks and outer plates of the actual hull structure, the hull can be simulated

as a plate frame structure. The stiffness of each beam shall meet the following requirements: ① The cross-sectional area is consistent with the hull structure. ② The moment of inertia of the section is consistent with the hull structure. ③ The shear area is consistent with the hull structure. ④ The torsional moment of inertia is consistent with the hull structure.

In the detailed model, the unit deck, side plate, bulkhead and supporting structure are all simulated with the plate and beam elements, with the size and attributes of the elements consistent with the actual structure of the unit. This method has a large workload.

(3) Stiffness of leg-hull connection

As the legs in the unit are fixed by the fixation system, full consideration shall be given to the stiffness of the leg and the fixation system. Thus, the stiffness of the leg-hull connection is simulated by a spring. For the calculation method of the spring stiffness coefficient, see Section 5.3 of Chapter 5.

(4) Foundation stiffness

- ① If the spudcans are completely penetrated in the soil, the foundation stiffness is considered as articulation at half height of the spudcans;
- ② If the spudcans are not completely penetrated in the soil, the foundation stiffness is considered as articulation at half penetration depth;
- ③ If the contact between the spudcan and the soil is simulated by adding the foundation stiffness to the articulating point, its rotational stiffness, vertical stiffness and lateral stiffness can be calculated according to the method described in Section 5.5 of Chapter 5.

(5) P-Delta effect

Under the action of environmental load, the center of gravity of the unit will produce lateral displacement, and the deviation of the center of gravity will produce secondary bending moment on the leg, and thus the hull will produce greater lateral displacement. Therefore, the P-Delta effect reduces the overall stiffness of the structure, i.e.

$$K_{pd} = -W_g * L \quad Nm/rad$$

where, K_{pd} refers to the reduction of the torsion stiffness on the leg support point; W_g refers to the weight of the hull and leg on a leg; L refers to the vertical distance from the leg support point to the center of gravity of the hull.

6.2.1.2 Model mass

The mass distribution of the model shall accurately reflect the mass distribution of the actual unit structure, mainly including,

- (1) The mass of hull, mainly including hull structure mass, equipment mass and variable load mass;
- (2) The mass of leg, including the mass of the leg structure and the water in the leg;
- (3) The mass of spudcans, including the mass of spudcan body and the mass of water in spudcans.

6.2.1.3 Environmental load

The environmental loads mainly include the wind, wave and current loads, as well as the inertial load of wave. Generally, the direction of environmental loads shall include multiple directions from 0 to 180 degrees.

6.2.1.4 Contents of structural integrity analysis

The structural integrity analysis of site operation shall include:

- (1) Strength of legs. The yield and buckling check of chord, horizontal brace and diagonal brace of lattice leg shall be checked to ensure that the strength of leg meets the requirements of relevant rules. The influence of 10% area of rack panel on the overall stiffness shall be considered, but it shall not be considered in stress calculation.
- (2) Bearing capacity of fixation system/jacking system. It is necessary to ensure that the load applied to the fixation system/jacking system under the maximum environmental conditions is not greater than the bearing capacity of the fixation system/jacking system.
- (3) Bearing capacity of spudcans. It shall be ensured that the reaction of legs under the maximum environmental conditions is less than the design bearing capacity of spudcans.
- (4) Preload performance and holding capacity of jacking gear. The pre-loading capacity of the jack-up unit is the capability to assess whether the pressure applied to the legs can meet the requirements of pre-loading after the ballast tanks of the unit are completely filled with seawater. During the preloading, the load weight acting on the gear shall be ensured no more than the holding capacity of the jacking gear.
- (5) Anti-overturning stability. The anti-overturning stability of offshore jack-up units at the target site shall meet the relevant requirements in 4.5 of Chapter 4.

6.2.2 Foundation stability analysis

The foundation stability analysis is to ensure that the seabed soil can resist the sinking and sliding of the unit spud under vertical and lateral loads. Generally, the detailed geological survey shall be carried out before the operation of jack-up units at a new site, and engineering geological sampling and submarine CPT test shall also be carried out if necessary.

Based on the complete geological data, the ultimate bearing capacity of soil at different depths can be calculated according to the shape of unit spudcans with the following formula:

$$Q = q_n A + \gamma_1 V$$

where, Q refers to the ultimate bearing capacity of soil; q_n refers to the ultimate bearing capacity per unit area of spudcans; A refers to the maximum projected area of the spudcan plane; γ_1 refers to the density of soil displaced for spudcans; V refers to the volume of spudcans.

Then, the penetration depth of the unit's spud into the soil can be determined according to the ballast.

Foundation stability analysis includes the preloading analysis, and the vertical and lateral bearing capacity analysis of soil under different foundation stiffness. The specific calculation method and process can be in accordance with the method described in Section 5.6 of Chapter 5.

In addition, the stability analysis of foundation shall generally include the punch-through analysis. When there is potential punch-through risk in the seabed of the target well, the operator shall assess the punch-through depth and damage to the unit structure, and accordingly formulate a feasible punch-through response plan.

6.2.3 Other considerations

6.2.3.1 Air gap

Air gap refers to the clearance distance between the lower edge of the unit and the still water surface when the jack-up unit is elevated. Generally, the following two conditions shall be considered in the air gap assessment:

① Exploration well

$$Gap = \min(C1, 1.2) + (H_1 + H_2 + H_3)$$

where, $C1 = 0.1 * (H_1 + H_2 + H_3)$; H_1 is the astronomical tide height; H_2 is the storm surge height; H_3 is the wave crest height above the design high tide level, which is generally calculated with a return period of 50 years.

② Development well

The height and the space margin of jacket under the wellhead and drill floor turntable shall be taken into account.

6.2.3.2 Water depth

According to the leg length, the applicable water depth of jack-up operation can be calculated according to the following formula:

$$h = L - (H + Gap + d + P)$$

where, h refers to the applicable water depth of the unit; L refers to the length of unit leg; H refers to the depth of the unit hull, i.e., the distance from the bottom plate of the hull to the top of the upper guide; Gap refers to the air gap; d refers to the reserved length for the top of leg, i.e., the distance of a section reserved for the lattice leg, which shall meet the requirements of the operation manual; P refers to the penetration of leg.

6.2.4 Process of site specific assessment

The site specific assessment process of offshore jack-up units is shown in Figure 6-1.

6.2.5 Sample

Please refer to Appendix 1.

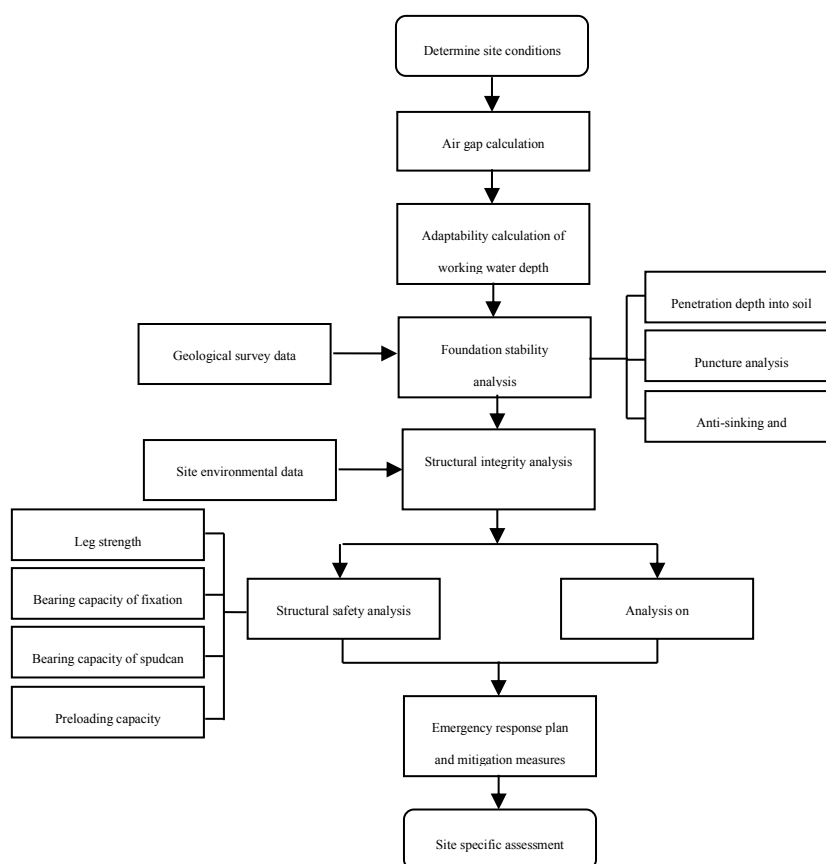


Figure 6-1 Process of Site Specific Assessment of Jack-up Units

6.3 Site specific assessment for offshore semi-submersible unit

6.3.1 Hydrodynamic calculation of offshore semi-submersible unit. The motion response and wave fluctuating pressure of semi-submersible units at the target site shall be predicted according to the method described in Section 5.7 of Chapter 5.

6.3.2 Overall structural strength assessment of offshore semi-submersible unit. The calculated wave load and other environmental loads are applied to the global finite element model of semi-submersible units to assess the strength of the global structure.

6.3.3 Strength assessment of local main structures of offshore semi-submersible unit. Using the calculated inertia force generated by the motion response of the semi-submersible unit, the strength of the local primary structures of the unit is assessed, such as the crane foundation, anchor foundation, derrick foundation, main engine foundation and other equipment foundations.

6.3.4 Mooring strength assessment of offshore semi-submersible unit. Using the environmental conditions of the target site, the strength of the mooring system is assessed according to the method described in Section 5.9 of Chapter 5. The return period of environmental conditions used in mooring strength assessment is shown in Table 6-1.

6.3.5 Air gap assessment of offshore semi-submersible unit. Using the environmental conditions of the target site, the air gap of the semi-submersible unit is calculated according to the method described in Section 5.10 of Chapter 5 to ensure that the unit has enough air gap.

Table 6-1 Return Period of Environmental Conditions

Mooring assessment of semi-submersible unit	Away from other offshore structures	Adjacent to other offshore structures
Return period of environmental conditions (year)	5	10

6.3.6 Stability assessment of offshore semi-submersible unit. The intact stability and damaged stability of the semi-submersible unit are assessed using the environmental conditions of the target site.

6.3.7 Process of site specific assessment

The site specific assessment process of offshore semi-submersible units is shown in Figure 6-2.

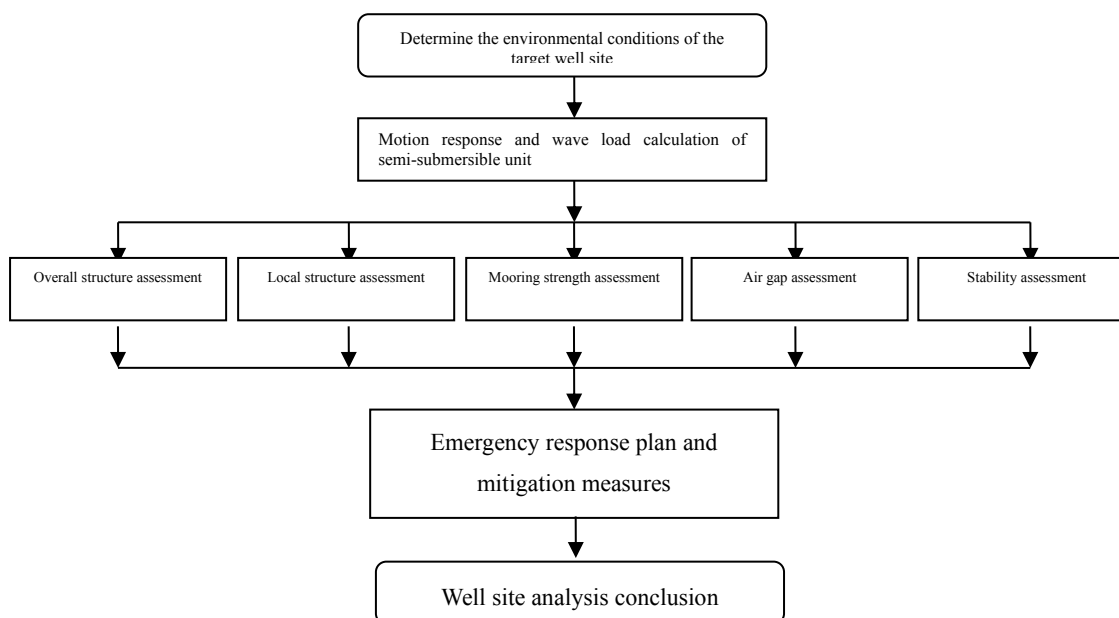


Figure 6-2 Process of Site Specific Assessment of Semi-submersible Unit

Chapter 7 Emergency Response Service for Mobile Offshore Unit (MODU-ERS)

7.1 General provision

7.1.1 Emergency response service for mobile offshore units (MODU-ERS) refers to that the onshore service organization (e.g., classification societies) build an emergency response database, concerning stability and structural strength, according to the predetermined ERS agreement with the ship owner. While the unit is in emergency situations, such as the accidents of collision, leg punch-through, anchor chain breakage, etc., the emergency response database will be enabled rapidly upon the request of the owners. Analysis in the terms of damaged stability, damaged strength and residual capacity in emergency for the units will be performed by the onshore service organizations, to provide technical support to facilitate the unit out of danger, as well as suggestions for the final decision-making of the owners.

7.1.2 The applicant shall provide the onshore service organizations with the drawings and materials of the unit as described in Section 1.3.4, and a detailed description on the emergency, the external conditions and the specific damage at that time of the unit in case of an emergency.

7.1.3 Requirements of onshore service organizations

7.1.3.1 In terms of MODU-ERS, a 24-hour emergency response mechanism shall be established, and the onshore service organizations shall provide emergency response services for mobile offshore units 24 hours a day, 365 days a year.

7.1.3.2 The onshore service organization shall prepare an *Emergency Manual* for each unit registered for MODU-ERS and provide it to the owners. The *Emergency Manual* includes the procedures for owners to initiate the emergency response services, the precautions of owners and the accident report forms.

7.2 Types of emergency response

The types of emergency response of mobile offshore units generally include:

- (1) Analysis of intact stability and damaged stability;
- (2) Floating condition analysis;
- (3) Safety operation analysis of well site;
- (4) Leg punch-through analysis of jack-up units;

- (5) Fracture analysis of anchor chain of semi-submersible units;
- (6) Typhoon resistance analysis;
- (7) Analysis of residual collision strength;
- (8) Other emergency analysis.

7.3 General procedures for emergency response

In case of emergency, the owner shall dial the 24-hour emergency telephone number of the onshore service organization to initiate the MODU-ERS according to the *Emergency Manual*, and the onshore service organization shall provide emergency response service to the owner according to the flow as shown in Figure 7-1 upon receiving the accident information provided by the owner.

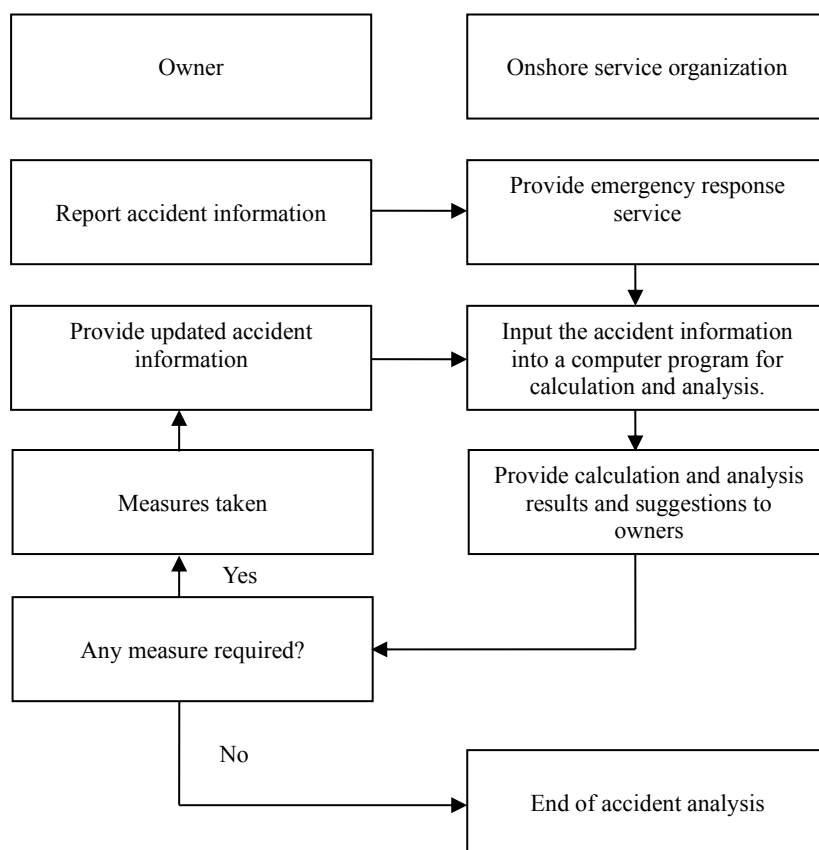


Figure 7-1 General Process of Emergency Response of Offshore Mobile Unit

7.4 Post-management of emergency response service

7.4.1 The onshore service organization shall complete the final *Technical Report on Emergency Response Service*, which shall include the unit overview, accident overview, MODU-ERS treatment process and accident treatment technology summary, and provide it to the owner as required.

7.4.2 Onshore service organizations have the responsibility to continuously track the follow-up treatment of accidents, including maintenance plans, repairs, and information collection and analysis for docking surveys.

7.5 Introduction of CCS emergency response service for mobile offshore unit (CCS-MODU-ERS)

China Classification Society (CCS) has been committed to providing computing services for ships and offshore units in emergency distress for a long time. In the context of the increasingly urgent international needs of ship and shipping safety, CCS Emergency Response Service (CCS-ERS) was officially launched as a separate service product with its own characteristics in 2005. In 2010, CCS continuously launched the product of "Emergency Response Service for Mobile Offshore Units" named CCS-MODU-ERS.

7.5.1 Service characteristics of CCS-MODU-ERS

- (1) Paid services for all mobile offshore units regardless of flags and classes;
- (2) 24-hour emergency response mechanism, with the emergency response service provided by CCS-MODU-ERS expert group for the mobile offshore units in 24 hours per day and 365 days per year;
- (3) Only one emergency phone is needed to initiate the emergency response service;
- (4) Capable of facilitating the unit owners to meet the requirements of IMO MODU, CCS MODU, national regulations, etc.;
- (5) Assist the unit owner in risk management of mobile offshore units in advance.

7.5.2 See 7.2 of this chapter for the service content of CCS-MODU-ERS.

7.5.3 Professional software of CCS-MODU-ERS. CCS has specially developed a professional software-database MSER system for ERS of mobile offshore units, which can function for various calculations, analysis and assessment on accident units and provide timely, reliable and effective solutions and suggestions to the unit owners. See Chapter 8 for the introduction of MSER system.

7.5.4 Service process of CCS-MODU-ERS

When an accident happens to a mobile offshore unit, the owner of the unit can call the CCS-MODU-ERS emergency response service number to enter the emergency response stage. The general process is as follows:

- (1) The unit owner feeds back the accident site information to CCS-MODU-ERS according to the

Emergency Manual;

(2) CCS-MODU-ERS quickly conducts technical analysis and assessment on stability and strength in emergency.

(3) CCS-MODU-ERS provides the technical analysis results and emergency treatment suggestions to unit owners;

(4) The unit owners handles the unit accident with reference to the technical analysis results and emergency treatment suggestions and feeds back the accident handling information to CCS-MODU-ERS;

(5) CCS-MODU-ERS completes the *Technical Report on Emergency Response Service* and continuously track the follow-up treatment of the accident.

The flow chart of CCS-MODU-ERS service is shown in Figure 7-2.

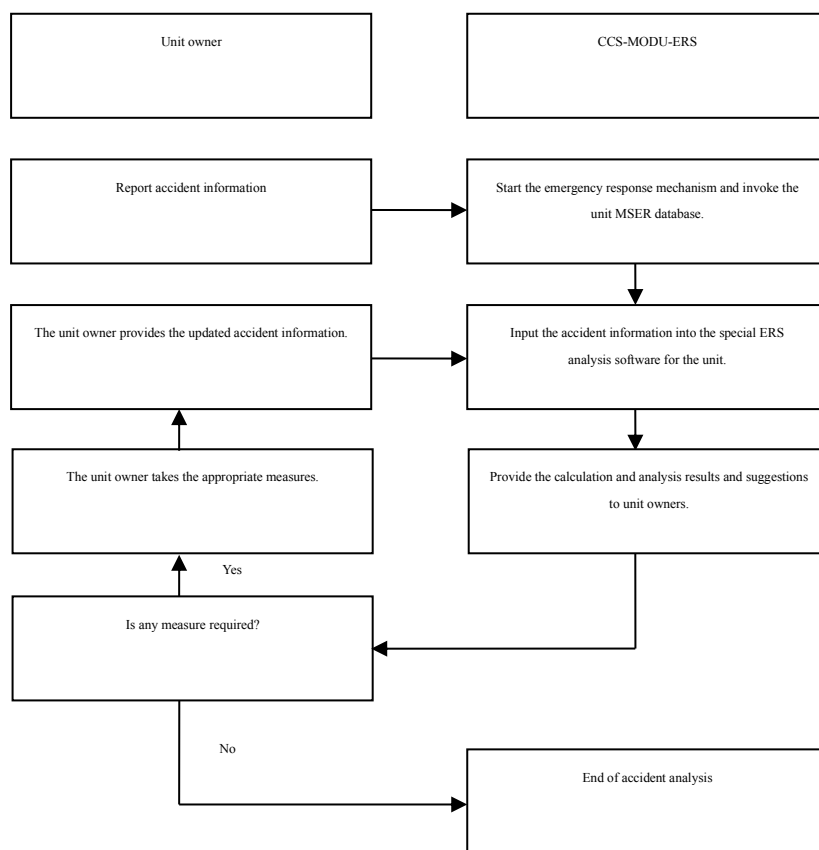


Figure 7-2 Service Process of CCS-MODU-ERS

7.5.5 Organization of CCS-MODU-ERS

The organization of CCS-MODU-ERS is shown in Figure 7-3.

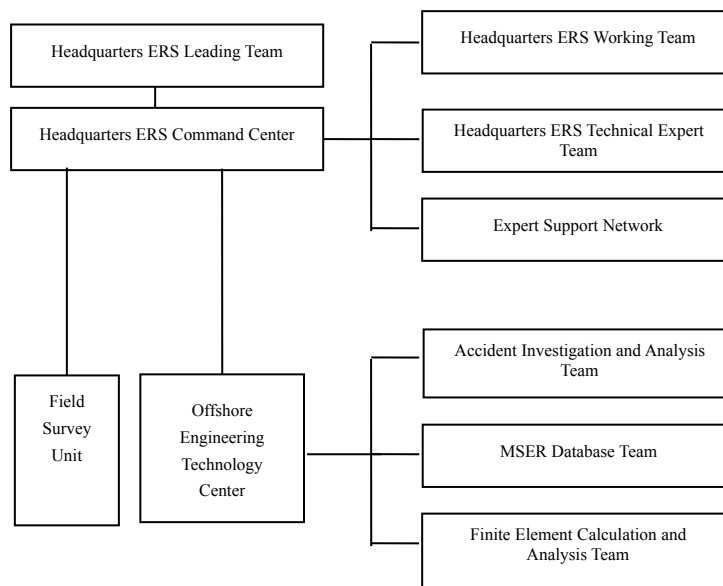


Figure 7-3 Organization Chart of CCS-MODU-ERS

Chapter 8 Introduction of MSER System

8.1 System introduction

Based on the theory of structural integrity management, China Classification Society (CCS) and China Oilfield Services Limited (COSL) have jointly developed a Model, Survey and Emergency Response system (hereinafter referred to as the MSER system,) for mobile offshore units. This system based on the structural finite element model of mobile offshore units, and induced the structural integrity management concept of data, assessment, survey plan, and survey implementation as the framework. It integrates the data management, calculation and assessment, rules verification, and the management and release of survey plan. And it is capable to realizing the life-cycle structural safety management of mobile unit from design, construction, survey and transformation to daily operation, and providing technical support for the scientific decision-making of unit managers, regular maintenance of the unit and survey by the competent authorities, with great significance to the safe operation and scientific management of the unit.

8.2 System composition

The network structure of the system is shown in Figure 8-1.

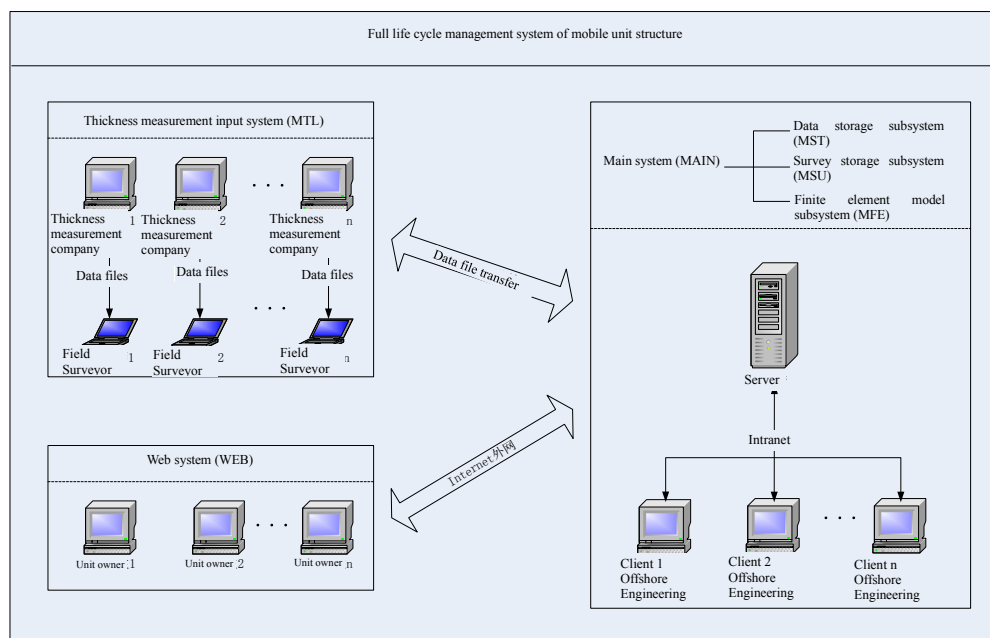


Figure 8-1 System Network Structure

The system mainly includes the following modules:

(1) MAIN system

The main system is generally used by CCS Offshore Engineering Technical Center, which includes the following parts:

① Data storage subsystem (MST subsystem)

The MST subsystem can store the drawings, records and data of the original construction and previous modification of the mobile unit, as well as the data of marine environmental conditions and the historical data of unit operation in various sea areas, so as to facilitate users to accumulate, view and download the relevant technical data of the unit.

② Survey and storage subsystem (MSU subsystem)

The MSU subsystem can store the previous inspection data of the mobile unit, such as thickness measurement and nondestructive inspection, and the previous survey data of the field ship surveyor, so that the users can easily understand the current structural condition of the unit, pay attention to the dangerous positions such as the areas with severe corrosion and deformation of the unit, and accordingly provide guidance for unit maintenance.

③ Finite element model subsystem (MFE subsystem)

The finite element models (ANSYS model and SACS model) of the unit are established based on the unit drawings in MST, after initialized the models are stored in the MFE subsystem. In case that an assessment calculation for the aged unit structure or the technical condition assessment of unit structure is started, the system can automatically update the unit finite element model by calling the measured thickness data obtained by the MTL system. Structural strength assessment can be conducted based on the latest unit condition, and the results can be checked automatically according to CCS, ABS, API, etc., so that the finite element calculation of the system could provide rapid response. At the same time, the unit finite element model stored in the system can be used for emergency response and pre-assessment of the unit before operation at any time. When the unit is greatly modified, the finite element model of the unit can be upgraded accordingly based on the modification situation, so as to ensure that the finite element model in the system corresponds to the current situation of the unit in real time and is available at any time. All data such as calculation models, standard check results and calculation reports of analysis and assessment calculation can be stored in the system for user's convenience.

④ Inspection plan generation subsystem

According to the specific unit structure and the assessment conclusion, the system can automatically generate the survey plans, including specific survey contents and thickness

measurement plans, which can be downloaded and used by field surveyors. After the final survey is completed and entered by the status data entry system, the system can automatically generate the survey reports and thickness measurement reports for users to review and refer to.

(2) Condition data entry system (MTL system)

The users of the condition enter system include the thickness measurement company and the field surveyors. In the system, a stand-alone database is adopted, and the communication between the condition enter system and the main system is realized by data file transmission. When a new thickness measurement project is started, the configuration information file of MTL system for a unit is firstly generated in the main system and submitted to the designated thickness measurement company together with the MTL installation program. After the MTL program is installed and the configuration information is imported, the thickness measurement company can use the MTL system to collect the current thickness data of the unit structure. Besides, the field surveyor can also use the MTL system to review the thickness measurement data. Then, the qualified data will be submitted to the main system for finite element calculation of the unit. Thus, the field surveyors can decide the replacement scope based on the feedback from calculation and the replacement requirements on site. After the on-site replacement, the replacement information can be input in MTL, and the main system can automatically update the finite element model in MFE subsystem upon receiving such information. At the same time, the main system also stores the previous thickness measurement data of the unit, which is convenient for users to understand the corrosion history of unit members.

(3) WEB system (web system)

The users of the web system are the owners of various units.

The WEB system accesses the server of this system through the Internet, and the owners of various units can query the basic information, drawings, thickness measurement, other inspection and survey data, analysis and assessment calculation data, environmental conditions and operation history data online through the WEB system. Meanwhile, the unit owner can also input the environmental conditions and operation history data in the WEB system.

Figure 8-2 is a typical interface of data storage database; Figure 8-3 is a typical interface of a unit status data entry system; Figure 8-4 shows the stress distribution plot outputted by the finite element model subsystem; Figure 8-5 shows the database of marine conditions in China sea area.

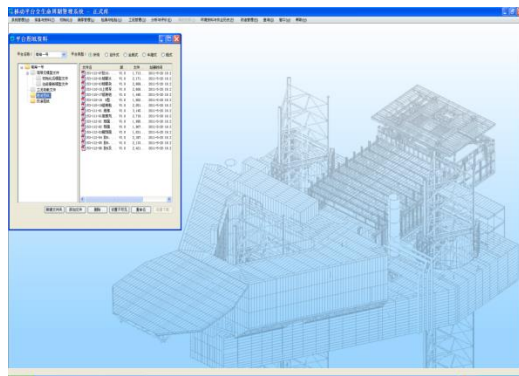


Figure 8-2 Data Storage Database

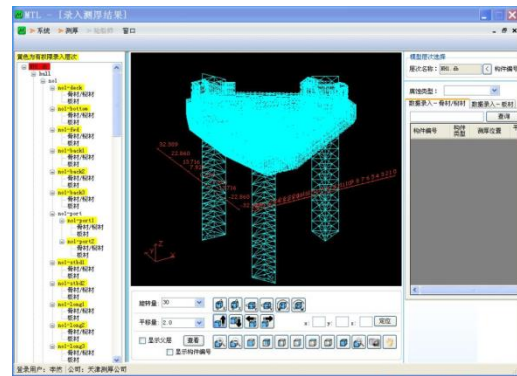


Figure 8-3 Interface of Status Data Entry System

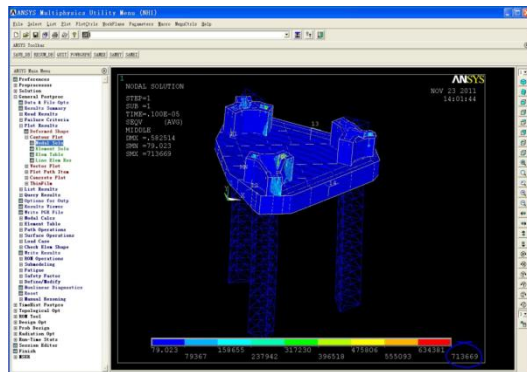


Figure 8-4 Stress distribution plot of assessment



Figure 8-5 Database of Marine Environmental Conditions

The main flow chart of the system is shown in Figure 8-6.

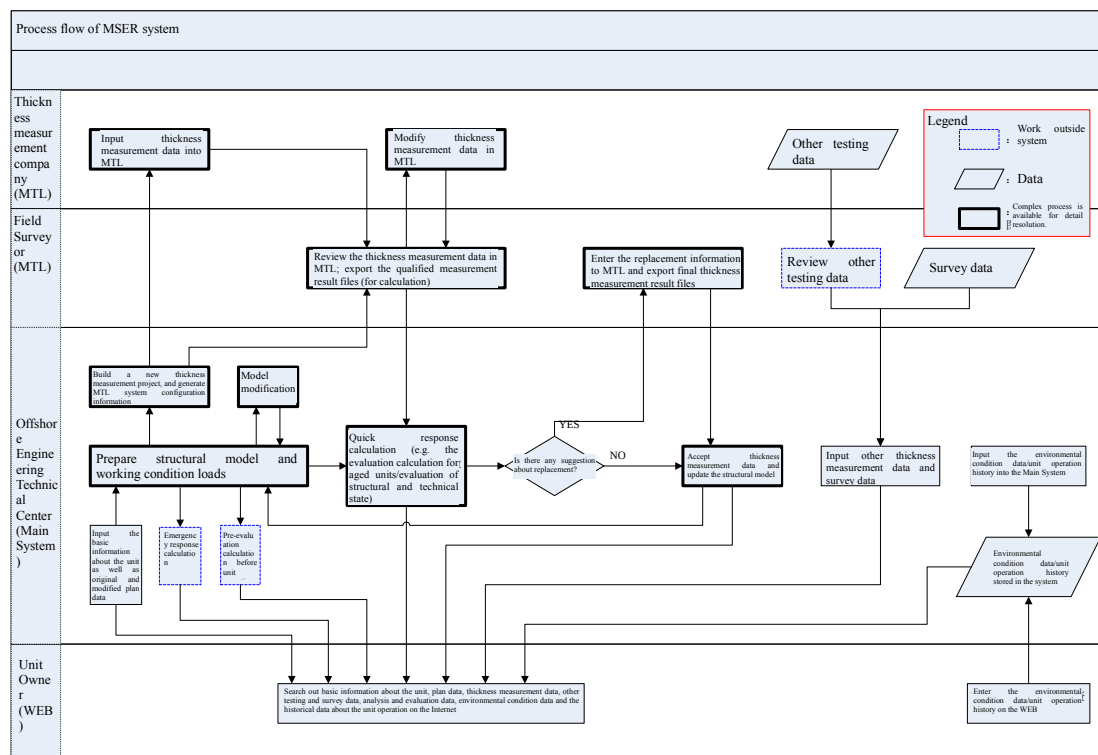


Figure 8-6 System Flow Chart

The software core technology of this system is the seamless connection between the thickness measurement data of the mobile unit and the finite element model. To realize this core

technology, the key lies in solving the following problems:

(1) It is necessary to ensure that all the members of the unit in the thickness measurement input system are always synchronized, mapped and interacted with the corresponding members in the finite element model. Therefore, the ANSYS finite element model of the unit is established at first, and the geometric information such as points, lines and planes of the model is extracted to build a geometric model of the unit in the system. Based on this geometric model, the thickness measurement data is input to update the member thickness value in the finite element model. Generally, the geometric model of the unit in the system is guaranteed to be the latest mirror image of ANSYS finite element model at any time.

(2) The accuracy and rapidity of data collected by the thickness measurement input system shall be ensured. In the system, the spatial geometric model of the unit is divided into the plane figures such as decks, bulkheads and local special members according to a tree-like hierarchical structure. Besides, the plates and keels on each plane figure can be automatically organized into thickness measurement data tables in a reasonable order. In this way, the system can customize the one-to-one and personalized thickness measuring range, drawings and reports in advance, and the thickness measurement company only needs to input the data simply. In addition, the system also provides a chart-controlled input environment, simultaneous input by assistant operators, quick input using small keyboards, input with double check, data correctness check and other functions. A review link is also set up for the field surveyors. In this way, the thickness measurement data can be input reasonably, orderly, accurately and quickly in the input system.

(3) Reasonable speculation should be made on the thickness calculation value of unmeasured members. In actual thickness measurement, it is impossible to measure all the members in every part of the unit at one time. For the thickness of the members that have not been measured, a reasonable calculation value shall also be inferred when the thickness measurement data is imported into ANSY model. Three thickness estimation strategies are considered in the system:

① time strategy: tracing back to the previous thickness measurement value; ② space strategy: learning from the corrosion amount of similar members in the same cabin space; ③ corrosion rate strategy: learning from the corrosion rate of similar members in the same cabin space.

(4) Modeling software must have good openness. The development of this system needs to read, identify, process and write back the internal data of the professional finite element software, which

requires the finite element software to be very open and allow external programs to access and operate it. ANSYS allows to meet the requirements of software openness in developing this system through secondary development. Therefore, the finite element model of the unit that needs to be seamlessly connected with the thickness measurement data in this system must be established by ANSYS.

(5) Principles for establishing unified standard finite element models. For the fine program of the finite element model, this system requires the model to be refined to the level of grid (the smallest grid formed by the intersection of truss, keels and plate in the unit frame structure), and the thickness measurement data of the thickness measurement company is also refined to the same level. In this way, the structural strength of the unit, especially the residual strength of the unit after corrosion, can be assessed more accurately and reasonably. It is also conducive to the accurate and orderly alignment of unit members with that in the finite element model during thickness measurement. At the same time, the system also establishes a set of unified practices for the coordinate system, the establishment of geometric model and the MESH method of the model.

8.3 System functions and characteristics

8.3.1 Main functions of the system

- (1) Through the integration of data storage, calculation and assessment, survey plan and survey implementation, the structural integrity management of mobile offshore units can be realized.
- (2) Continuous, dynamic and intelligent structural assessment and survey of mobile offshore units can timely and comprehensively reflect the actual condition of the unit structure and find out the existing structural safety hazards.
- (3) Through the continuous tracking and periodic structural safety assessment of the aged unit, technical support is provided for the regular maintenance of the aged unit, realizing the safe operation and management of the aged unit.
- (4) Through the assessment results of the technical condition of the mobile unit structure and the key inspection suggestions on site provided by the system, the on-site survey guidance for ship surveyors can be realized.
- (5) In case of unexpected events (such as leg punch-through, unit towing collision and anchor chain breakage) on the mobile offshore unit, it is necessary to quickly judge the safety of unit structure and provide appropriate emergency response measures.

(6) Through the analysis on storm resistance of operation site, judgment can be made for whether the mobile unit can adapt to the new environmental conditions, thereby helping the unit manager to make decisions quickly.

(7) The structural safety analysis, tracking, monitoring and management of the life cycle of the mobile unit should be realized from design, construction, survey, modification to daily operation.

8.3.2 Main characteristics of the system

(1) Finite element calculation could have rapid response. Based on the background data transmission technology, the system realizes the seamless connection between the thickness measurement data and the unit finite element calculation model, so that the unit finite element calculation of the system has the fast response ability, and the conclusions and suggestions of calculation and analysis can be timely and effectively fed back to the unit repair or reconstruction construction within the first dock repair period. In case of an emergency on the unit, structural safety assessment can be made quickly, and emergency response measures can be given.

(2) Make the thickness measurement work standard, standardized and efficient. The system provides a unified working platform for thickness measurement, and has customized one-to-one personalized thickness measurement range, drawings and reports in advance, thus realizing the standardization and high efficiency of thickness measurement.

(3) Life cycle management of mobile unit structural security. The system integrates the original design of the unit, the drawings of previous modification/repair, previous survey and inspection data, finite element model, previous calculation and analysis data, etc. Based on these complete technical data, the system has the functions of structural technical status assessment, pre-assessment before unit operation, emergency response, assessment and management of aged units, etc., thus realizing the management of the whole life cycle of the mobile unit structure.

(4) The system has good universality for various mobile units. This system is general, which can be implemented in different types of units, such as jack-up, submersible, semi-submersible and surface units, different ship-type units in the same type, and even any structural model established by ANSYS.

8.4 System application practice

After two years' practical application, the system has completed the structural assessment and survey of 17 mobile offshore units, 89 times of site specify assessment of mobile units and 11

times of emergency response analysis, verifying the stability and reliability of the system, and creating huge economic benefits for the unit operators.

8.5 System application prospect

The theory and system of structural integrity management of mobile offshore units have created a new model for the structural safety management of mobile offshore units, which will surely promote the safe operation and scientific management of mobile offshore units.

Appendix 1. Sample of Site Specific Assessment of Jack-up Unit

The unit in the case is a jack-up unit with cantilever, which adopts a triangular box-shaped main hull and is equipped with three lattice legs (one at the bow and two at the stern). An electric gear and rack jacking system is adopted, and the whole unit is equipped with 9 sets of fixation systems to lock the rack panel of the leg chord under towing and elevated operation conditions. Each leg is equipped with a round spudcan, which can be recovered from the bottom of the ship during towing. The leg is 167 m long, and the maximum working water depth of the unit is 400 ft.

The target operation well of the case unit is an area in the eastern South China Sea, where is a typhoon-prone area. After previous field investigation and geological survey, the environmental conditions and geological parameters of this well site are shown in Table 1. The finite element model established by SACS software is shown in Figure 1.

Table 1 Environmental Conditions and Geological Parameters

Environmental conditions	Typhoon season	Non-typhoon season	Typical soil parameters	
Water depth (m)	110	110	Soil density $\gamma'(MN/m^2)$	0.012
Maximum wave height (m)	20	16	Soil shear strength $c_u(MN/m^2)$	0.047
Corresponding wave period (s)	14	12.4	Soil friction angle δ (°)	38
Maximum wind speed (m/s)	54	34	Passive earth pressure coefficient k_p	4.215
Current speed (m/s) Surface	1.95	1.12	Active earth pressure coefficient k_a	0.240
Bottom	1.34	0.34	Bearing capacity coefficient N_γ, N_q	80.26, 49.36
Air gap (m)	15	11		
Lightship weight (t)	116161	116161		
Variable load (t)	29357	29357		
Lift weight (t)	145518	145518		

1.1 Penetration depth of spudcan

According to the spudcan shape of the case unit and the seabed soil condition of the target well site, the foundation bearing capacity of different pile insertion depths can be calculated, and the calculation results are shown in Figure 2. The preload of a single spud on the unit in the case is 112 MN. As indicated in Figure 2, the penetration depth of spudcans during preloading of the unit

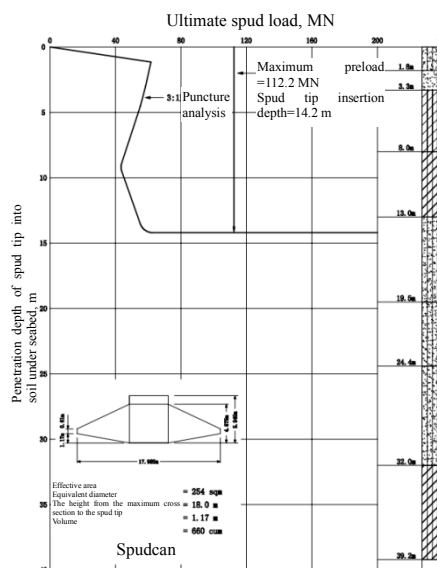


Figure 1 Finite Element Model Figure 2 Soil Bearing Capacity under Different Spud Penetration Depths

As the case unit works as an exploratory well, the air gap value can be calculated according to the formula, as shown in Table 6-2. According to the formula, it can be calculated that the operating adaptation water depth of the unit is $h = 167 - (18.4 + 15 + 8 + 14.2) = 112m$, and so the unit can adapt to the water depth of 110m at the target well site.

According to the foundation stability analysis flow in Figure 6-1, the target well site of the case unit is analyzed. The calculation results show that the foundation in typhoon season does not meet the stability requirements, but the foundation in non-typhoon season meets the stability requirements. As indicated in Figure 2, there is no risk of leg punch-through during unit ballast.

Establish the finite element model of the case unit, as shown in Figure 1. The loads applied on the unit mainly include the wind, wave, ocean current, wave inertia force and P-Delta effect load, and the wave inertia load can be calculated by SDOF method. The summary of load results is shown in Table 2.

- 69 -

strength of legs, the bearing capacity of fixation system, the bearing capacity of spudcans, the preloading capacity, the holding capacity of jacking gear during preloading and the anti-overturning stability under various environmental conditions are checked respectively. The calculation results are shown in Table 3. As indicated in Table 3, the structural integrity analysis in typhoon season cannot meet the relevant requirements, while the structural integrity analysis in non-typhoon season can meet the requirements.

Table 2 Load List

	Typhoon season					Non-typhoon season				
Environmental load direction	0°	60°	90°	120°	180°	0°	60°	90°	120°	180°
Wave and current load (kN)	12640	12738	12853	12861	12482	3987	3909	4018	4076	3784
Wind load (kN)	6311	6519	6939	7457	5970	2480	2575	2738	2933	2334
Inertial load (kN)	9301	11815	12003	10268	9433	3304	4091	4218	3665	3230
Total (kN)	28252	31072	31795	30585	27885	9772	10574	10974	10673	9348
Bending moment										
Wave and current loads (kN-m)	1103339	1115066	1124647	1125106	1089060	378947	373237	382077	388189	360497
Wind load (kN-m)	916152	951371	1010732	1084461	869265	354425	369738	391414	418259	334213
Inertial load (kN-m)	1202639	1527641	1552013	1327626	1219747	413052	511334	527267	458063	403757
P-Delta (kN-m)	578759	581477	571686	569870	569493	166416	178954	192324	178093	156351
Total (kN-m)	3800889	4175555	4259078	4107063	3747564	1312839	1433263	1493082	1442604	1254817

Table 3 Calculation Results

Contents of Structural Integrity Analysis	Typhoon season	Non-typhoon season
Utility Check of Leg Strength (U.C.)	2.44	0.90
Utility Check of Fixation System	1.62	0.88

Bearing Capacity(U.C.)		
Utility Check of Spudcan Bearing Capacity (U.C.)	1.58	0.88
Utility Check of Preloading capacity (U.C.)	1.45	0.87
Utility Check of Jacking Gear Holding Capacity (U.C.)	1.42	0.91
Safety Factor of Anti-overturning Stability (S.F.)	0.98	1.71

Note: For the first 5 items, U.C. less than 1 can meet the requirements. For the 6th item, the safety factor greater than 1.3 can meet the requirements.

1.5 Conclusion

Through the above site specific assessment on the target well site of the sample unit, the analysis of the penetration depth, the adaptability of air gap and operation water depth, the stability of foundation, structural integrity and etc. are included. The calculation results show that the unit is only suitable for the operation of this target well site in non-typhoon seasons.

After the assessment, this sample unit had drilled for 4 months safely at the target well site in non-typhoon seasons according to the assessment conclusion, and evacuated before the typhoon season.