Geotechnical and Foundation Design

August 2014

Guidance Note
NI 605 DT R00 E

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MARINE & OFFSHORE DIVISION
GENERAL CONDITIONS

ARTICLE 1

1.1. - BUREAU VERITAS is a Society the purpose of whose Marine & Offshore Division (the "Society") is the classification (" Classification ") of any ship or vessel or offshore unit or structure of any type or part of it or system therein collectively hereinafter referred to as a "Unit" whether linked to shore, river bed or sea bed or not, whether operated or located at sea or in inland waters or partly on land, including submarines, hovercrafts, drilling rigs, offshore installations of any type and of any purpose, their related and ancillary equipment, subsea or not, such as well head and pipelines, mooring legs and mooring points or otherwise as decided by the Society.

The Society:

- "prepares and publishes Rules for classification, Guidance Notes and other documents (" Rules ");
- "issues Certificates, Attestations and Reports following its interventions (" Certificates ");
- "publishes Registers.

1.2. - The Society also participates in the application of National and International Regulations or Standards, in particular by delegation from different Governments. Those activities are hereafter collectively referred to as " Certification ".

1.3. - The Society can also provide services related to Classification and Certification such as ship and company safety management certification; ship and port security certification, training activities; all activities and duties incidental thereto such as documentation on any supporting means, software, instrumentation, measurements, tests and trials on board.

1.4. - The interventions mentioned in 1.1., 1.2. and 1.3. are referred to as " Services ". The party and/or its representative requesting the services is hereinafter referred to as the " Client ". **The Services are prepared and carried out on the assumption that the Clients are aware of the International Maritime and/or Offshore Industry (the "Industry") practices.**

1.5. - The Society is neither and may not be considered as an Underwriter, Broker in ship's sale or chartering, Expert in Unit's valuation, Consulting Engineer, Controller, Naval Architect, Manufacturer, Shipbuilder, Repair yard, Charterer or Shipowner who are not relieved of any of their expressed or implied obligations by the interventions of the Society.

ARTICLE 2

2.1. - Classification is the appraisement given by the Society for its Client, at a certain date, following surveys by its Surveyors along the lines specified in Articles 3 and 4 hereafter on the level of compliance of a Unit to its Rules or part of them. This appraisement is represented by a class entered on the Certificates and periodically transcribed in the Society's Register.

2.2. - Certification is carried out by the Society along the same lines as set out in Articles 3 and 4 hereafter and with reference to the applicable National and International Regulations or Standards.

2.3. - **It is incumbent upon the Client to maintain the condition of the Unit after surveys, to present the Unit for surveys and to inform the Society without delay of circumstances which may affect the given appraisement or cause to modify its scope.**

2.4. - The Client is to give to the Society all access and information necessary for the safe and efficient performance of the requested Services. The Client is the sole responsible for the conditions of presentation of the Unit for tests, trials and surveys and the conditions under which tests and trials are carried out.

ARTICLE 3

3.1. - **The Rules, procedures and instructions of the Society take into account at the date of their preparation the state of currently available and proven technical knowledge of the Industry. They are a collection of minimum requirements but not a standard or a code of construction neither a guide for maintenance, a safety handbook or a guide of professional practices, all of which are assumed to be known in detail and carefully followed at all times by the Client.**

Committees consisting of personalities from the Industry contribute to the development of those documents.

3.2. - **The Society only is qualified to apply its Rules and to interpret them. Any reference to them has no effect unless it involves the Society's intervention.**

3.3. - The Services of the Society are carried out by professional Surveyors according to the applicable Rules and to the Code of Ethics of the Society. Surveyors have authority to decide locally on matters related to classification and certification of the Units, unless the Rules provide otherwise.

3.4. - **The operations of the Society in providing its Services are exclusively conducted by way of random inspections and do not in any circumstances involve monitoring or exhaustive verification.**

ARTICLE 4

4.1. - The Society, acting by reference to its Rules:

- "reviews the construction arrangements of the Units as shown on the documents presented by the Client;
- "conducts surveys at the place of their construction;
- "classes Units and enters their class in its Register;
- "surveys periodically the Units in service to note that the requirements for the maintenance of class are met.

The Client is to inform the Society without delay of circumstances which may cause the date or the extent of the surveys to be changed.

ARTICLE 5

5.1. - **The Society acts as a provider of services. This cannot be construed as an obligation bearing on the Society to obtain a result or as a warranty.**

5.2. - **The certificates issued by the Society pursuant to 5.1. here above are a statement on the level of compliance of the Unit to its Rules or to the documents of reference for the Services provided for.**

In particular, the Society does not engage in any work relating to the design, building, production or repair checks, neither in the operation of the Units or in their trade, neither in any advisory services, and cannot be held liable on those accounts. Its certificates cannot be construed as an implied or express warranty of safety, fitness for the purpose, seaworthiness of the Unit or of its value for sale, insurance or chartering.

5.3. - **The Society does not declare the acceptance or commissioning of a Unit, nor of its construction in conformity with its design, that being the exclusive responsibility of its owner or builder.**

5.4. - The Services of the Society cannot create any obligation bearing on the Society or constitute any warranty of proper operation, beyond any representation set forth in the Rules, of any Unit, equipment or machinery, computer software of any sort or other comparable concepts that has been subject to any survey by the Society.

ARTICLE 6

6.1. - The Society accepts no responsibility for the use of information related to its Services which was not provided for the purpose by the Society or with its assistance.

6.2. - **If the Services of the Society or their omission cause to the Client a damage which is proved to be the direct and reasonably foreseeable consequence of an error or omission of the Society, its liability towards the Client is limited to ten times the amount of fee paid for the Service having caused the damage, provided however that this limit shall be subject to a minimum of eight thousand (8,000) Euro, and to a maximum which is the greater of eight hundred thousand (800,000) Euro and one and a half times the above mentioned fee. These limits apply regardless of fault including breach of contract, breach of warranty, tort, strict liability, breach of statute, etc.**

The Society bears no liability for indirect or consequential loss whether arising naturally or not as a consequence of the Services or their omission such as loss of revenue, loss of profit, loss of production, loss relative to other contracts and indemnities for termination of other agreements.

6.3. - All claims are to be presented to the Society in writing within three months of the date when the Services were supplied or (if later) the date when the events which are relied on of were first known to the Client, and any claim which is not so presented shall be deemed waived and absolutely barred. Time is to be interrupted thereafter with the same periodicity.

ARTICLE 7

7.1. - Requests for Services are to be in writing.

7.2. - **Either the Client or the Society can terminate as of right the requested Services after giving the other party thirty days' written notice, for convenience, and without prejudice to the provisions in Article 8 hereunder.**

7.3. - The class granted to the concerned Units and the previously issued certificates remain valid until the date of effect of the notice issued according to 7.2. here above subject to compliance with 2.3. here above and Article 8 hereunder.

7.4. - The contract for classification and/or certification of a Unit cannot be transferred neither assigned.

ARTICLE 8

8.1. - The Services of the Society, whether completed or not, involve, for the part carried out, the payment of fee upon receipt of the invoice and the reimbursement of the expenses incurred.

8.2. - **Overdue amounts are increased as of right by interest in accordance with the applicable legislation.**

8.3. - **The class of a Unit may be suspended in the event of non-payment of fee after a first unfruitful notification to pay.**

ARTICLE 9

9.1. - The documents and data provided to or prepared by the Society for its Services, and the information available to the Society, are treated as confidential. However:

- "Clients have access to the data they have provided to the Society and, during the period of classification of the Unit for them, to the **classification file** consisting of survey reports and certificates which have been prepared at any time by the Society for the classification of the Unit ;
- "copy of the documents made available for the classification of the Unit and of available survey reports can be handed over to another Classification Society, where appropriate, in case of the Unit's transfer of class;
- "the data relative to the evolution of the Register, to the class suspension and to the survey status of the Units, as well as general technical information related to hull and equipment damages, may be passed on to IACS (International Association of Classification Societies) according to the association working rules;
- "the certificates, documents and information relative to the Units classed with the Society may be reviewed during certificating bodies audits and are disclosed upon order of the concerned governmental or inter-governmental authorities or of a Court having jurisdiction.

The documents and data are subject to a file management plan.

ARTICLE 10

10.1. - Any delay or shortcoming in the performance of its Services by the Society arising from an event not reasonably foreseeable by or beyond the control of the Society shall be deemed not to be a breach of contract.

ARTICLE 11

11.1. - In case of diverging opinions during surveys between the Client and the Society's surveyor, the Society may designate another of its surveyors at the request of the Client.

11.2. - Disagreements of a technical nature between the Client and the Society can be submitted by the Society to the advice of its Marine Advisory Committee.

ARTICLE 12

12.1. - Disputes over the Services carried out by delegation of Governments are assessed within the framework of the applicable agreements with the States, international Conventions and national rules.

12.2. - Disputes arising out of the payment of the Society's invoices by the Client are submitted to the Court of Nanterre, France, or to another Court as deemed fit by the Society.

12.3. - **Other disputes over the present General Conditions or over the Services of the Society are exclusively submitted to arbitration, by three arbitrators, in London according to the Arbitration Act 1996 or any statutory modification or re-enactment thereof. The contract between the Society and the Client shall be governed by English law.**

ARTICLE 13

13.1. - **These General Conditions constitute the sole contractual obligations binding together the Society and the Client, to the exclusion of all other representation, statements, terms, conditions whether express or implied. They may be varied in writing by mutual agreement. They are not varied by any purchase order or other document of the Client serving similar purpose.**

13.2. - The invalidity of one or more stipulations of the present General Conditions does not affect the validity of the remaining provisions.

13.3. - The definitions herein take precedence over any definitions serving the same purpose which may appear in other documents issued by the Society.

GUIDANCE NOTE NI 605

Geotechnical and Foundation Design

August 2014

SECTION 1 GENERAL

1 Scope

1.1 Application

1.1.1 The present Guidance Note provides the methodologies, requirements and recommendations to be considered for the certification of the design of foundations of offshore structures.

1.1.2 The provisions of the present Guidance Note are to be considered for the certification of anchoring devices of permanently moored offshore units in order to grant the **POSA** notation to the mooring system (see NR493 Classification of Mooring Systems for Permanent Offshore Units, [4.1.1]).

1.1.3 The provisions of the present Guidance Note are to be considered for certification of the foundation system of tendons of tension leg platforms devices of permanently moored offshore units in order to grant the **TLS or TLS PLUS** notation (see NR578 Rules for the Classification of Tension Leg Platforms, [4.1.1]).

1.1.4 The foundations of fixed offshore structures and the anchoring devices of floating offshore structures are hereafter considered as foundations. Except otherwise specified, the same requirements are applicable to the foundation of both fixed and floating structures.

1.1.5 The certification of foundations of offshore structures is to take into account the different phases of the design life:

- installation
- extreme loads on site
- accidental events on the structure, such as seismic loadings or collisions on the structure
- operations and operational conditions on site
- decommissioning.

2 Definition

2.1 Type of foundations

2.1.1 General

The foundations can be divided into four categories, depending on the shape and the depth of the foundation.

The methodology used in foundation capacity analyses and installation analyses depends on the type of foundations.

2.1.2 Shallow foundations

When the foundation depth is smaller or of an equivalent size to the foundation width, the foundation is considered to be a shallow foundation. Shallow foundations can be composed of gravity bases, shallow jackets with mud mats, etc.

2.1.3 Deep foundations

When the foundation depth is bigger than 10 times the foundation width, the foundation is considered to be a deep foundation. Vertical and horizontal loadings of the foundation can be considered as independent. These foundations are generally based on piled solutions.

2.1.4 Intermediate foundations

When the foundation depth is smaller than 10 times the foundation width, the foundation is considered to be an intermediate foundation. Vertical and horizontal loadings of the foundation cannot be considered as independent. These foundations are generally based on short piles or caissons solutions.

2.1.5 Foundations for the anchoring of floating units

Other types of foundations can be encountered for floating units, based on ship anchoring conventional designs. These foundations are referred as anchors with a different certification scheme.

Conventional anchors are not allowed for offshore structure anchoring. Dedicated design for offshore anchoring are to be used.

Different type of anchors can be encountered, such as:

- drag anchors
- vertically loaded (plate) anchors
- torpedo anchors.

Gravitary solutions (dead man anchors) can also be used for floating unit anchoring. The provisions on shallow foundations fully apply to these structures, with additional criteria for load definitions.

Piled solutions (long piles, short piles and caissons) can also be used for floating unit anchoring. The provisions on deep and intermediate foundations fully apply to these structures, with additional criteria for load definitions.

2.2 Symbols and abbreviations

2.2.1

(P)CPT : (Piezo-)cone penetration test

SPT : Standard penetration test

FEM : Finite element method

T_d : Design load corresponding to the considered design case

T_s : Static part of the design load

T_v : Variable part of the design load

S_u : Shear strength of the soil due to cohesion

σ_n : Normal effective hydrostatic stress on the soil particle

ϕ' : Critical state friction angle of soil

τ_{max} : Shear strength of soil

τ_d : Allowable shear strength of soil for the considered design case

γ_s : Partial factor on static load

γ_v : Partial factor on variable load

γ_m : Partial factor on material (soil) strength

D : Foundation width/diameter

V : Vertical load on the foundation

H : Horizontal load on the foundation

M : Over-turning moment on the foundation

e : Load excentricity

$e = M / V$

3 Effects influencing foundations design

3.1 Effects influencing the foundation design of fixed offshore structure

3.1.1 For fixed offshore structures, the subsoil has to have sufficient capacity to bear static and cyclic loadings. Permanent displacements (settlements) and cyclic displacements do not have to impair the structure integrity, the foundation strength and the structure serviceability. Instability of the structure and installation parameters are to be assessed, such as self penetration and pile drivability for driven piles.

Foundation stiffness is to be assessed for dynamic structural analyses of the structure under cyclic loadings (wind, waves, earthquake...). Liquefaction potential of soil is to be assessed.

Scouring and erosion effects are to be estimated, in particular for shallow water or when high deep water currents have been identified.

3.2 Effects influencing the foundation design of floating offshore structure

3.2.1 The loading mode of foundations for floating offshore structures is different from the one for fixed structures. Indeed, the loading is composed of uplift vertical or inclined forces, and the capacity of anchoring devices resides in counteracting these uplift and lateral effects.

The spreading of foundations location is also much larger than for fixed structure, so a good compromise is to be met between recognition and dimensioning against uncertainties on soil variability.

Installation is one of the major parameters for anchoring devices, and incomplete soil investigation or foundation design may lead to refusal, damage or mis-installation of the anchor (harder layer, coral or rock outcropping, interaction with seabed features as cables, wreck…).

4 References

4.1 Bureau Veritas Rules Notes

4.1.1

a) NR445, Rules for the Classification of Offshore Units

b) NR493, Classification of mooring systems for permanent offshore units

c) NR578, Rules for the Classification of Tension Leg Platforms

d) NI 534, Guidance Note for the Classification of Self-Elevating Units.

4.2 Recognized standard and reference documents

4.2.1 ISO standards

a) ISO 14688 series Geotechnical investigation and testing -- Identification and classification of soil

b) ISO 14689-1 Geotechnical investigation and testing -- Identification and classification of rock -- Part 1: Identification and description

c) ISO 17892 series Geotechnical investigation and testing -- Laboratory testing of soil

d) ISO 19901-2 Petroleum and natural gas industries -- Specific requirements for offshore structures -- Part 2: Seismic design procedures and criteria

e) ISO 19901-4 Petroleum and natural gas industries -- Specific requirements for offshore structures -- Part 4: Geotechnical and foundation design considerations

f) ISO 19901-8 (under development) Petroleum and natural gas industries -- Specific requirements for offshore structures -- Part 8: Marine soil Investigations

g) ISO 19905-1 (under development) Petroleum and natural gas industries -- Site-specific assessment of mobile offshore units -- Part 1: Jack-ups

h) ISO 22475 series Geotechnical investigation and testing -- Sampling methods and groundwater measurements

i) ISO 22476 series Geotechnical investigation and testing -- Field testing.

4.2.2 ASTM standards

a) ASTM D2487 - 11 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

b) ASTM D3213 - 08 Standard Practices for Handling, Storing, and Preparing Soft Intact Marine Soil

c) ASTM D4220 - 95 Standard Practices for Preserving and Transporting Soil Samples.

4.2.3 Other standards

a) EN 1997 Eurocode 7: Geotechnical design

b) EN 1997 Eurocode 8: Design of structures for earthquake resistance

c) API RP 2GEO Geotechnical and Foundation Design Considerations

d) API RP 2T Planning, Designing, and Constructing Tension Leg Platforms

e) NORSOK G-001: Marine Soil Investigation

f) BSH Standard for Geotechnical Site and Route Surveys - Minimum Requirements for the Foundation of Offshore Wind Turbines and Power Cable Route Burial Assessments

g) BSH Standard Ground Investigation for Offshore Wind Farms

h) Society of Naval Architects and Marine Engineers (SNAME), Guidelines for Site Specific Assessment of Mobile Jack-Up Units, Technical & Research Bulletin 5-5A.

4.2.4 Other reference documents

a) "Geotechnical and geophysical investigations for offshore and near-shore developments", ISSMEG TC1, sept. 2005

b) "Guidance document on planning and execution of geophysical and geotechnical ground investigations for offshore renewable energy developments", OSIG

c) Supachawarote, C., Randolph, M. F. & Gourvenec, S. 2004. "Inclined Pull-out Capacity of Suction Caissons", ISOPE

d) Andersen KH, Jostad HP, 2002, "Shear Strength Along Outside Wall of Suction Anchors in Clay after Installation", ISOPE

e) Deng W, Carter JP, 2002, "A Theoretical Study of the Vertical Uplift Capacity of Suction Caissons", ISOPE

f) Terzaghi, K., 1943. Theoretical Soil Mechanics. John Wiley & Sons

g) MEYERHOF, G.G. (1963) Some recent research on the bearing capacity of foundations. Canadian Geotechnical Journal

h) Hansen, J.B., 1970. A Revised and Extended Formula for Bearing Capacity. Bulletin of the Danish Geotechnical Institute

i) VESIC, A.S. (1973) Analysis of ultimate loads of shallow foundations. ASCE Journal of the Soil Mechanics and Foundation Division

j) Meyerhof, G G (1953) The bearing capacity of foundations under eccentric and inclined loads Proc 3rd International Conference on Soil Mechanics and Foundation Engineering, Zurich

k) Prakash, S., and Saran, S. 1971. Bearing capacity of eccentrically loaded footings. Journal of the Soil Mechanics and Foundations Division, ASCE, 97(1): 95-117

l) Purkayastha, R.D., and Char, A.N.R. 1977. Stability analysis for eccentrically loaded footings. Journal of the Geotechnical Engineering Division, ASCE

m) Highter, W. H., and J. C. Anders. 1985. Dimensioning footings subjected to eccentricloads. J. Geotech. Eng, ASCE

n) EM 1110-1-2908 "Rock Foundations", US Army Corps of Engineers (1994).

SECTION 2 SOIL INVESTIGATIONS

1 General

1.1 Application

1.1.1 For classification purpose, detailed soil design data are to be submitted for information by the party applying for classification as specified in Part B, Ch 2, Sec 2, Articles [5], [6] and [8] of NR445 Rules for the Classification of Offshore Units.

Review of foundations is performed based on the provided soil design data.

Soil investigations are under the responsibility of the party applying for the classification or the certifications of the structure.

Guidance for the soil survey program is provided in the present Section.

1.1.2 This guidance can be extended to any offshore and near-shore structures. Coastal structures are to be considered on a case by case basis.

1.1.3 Soil investigation programs, specifications and procedures for survey operations are in accordance with recognized standard (see Sec 1, [4.2]).

1.1.4 Type and extent of soil investigations are in general linked to the type of foundation chosen by the designer or, at least, to the predimensioning of the different possible solutions.

If the final type of foundation is not fixed when the soil data are provided by the designer, it is the responsibility of the party applying for classification to ascertain that the extent and quality of the soil data are correct, complete and compatible with the retained foundation design.

1.1.5 For concept approval of new foundation design, specifications for soil investigations for detailed design and specific site assessment are to be provided for review.

1.2 Soil data for geotechnical design and risk mitigation

1.2.1 Knowledge of seabed soils and rocks is essential to properly and safely design and build foundations, in particular for offshore and near-shore structures.

1.2.2 Major risks on foundations are related to uncertainties on the properties of soils and rocks on site. Therefore, it is recommended to perform relevant investigations to evaluate these risks thoroughly, as recommended by the best practice:

- Consistent soil data are to be provided to mitigate geotechnical risks in all the phases of the life of the unit, as defined in Sec 1, [1.1.5].
- In addition to normal life conditions, major geotechnical risks (such as seismicity, sand wave motions, scouring...) are to be determined thanks to soil investigations. Detailed data for the mitigation of these risks are to be provided for foundation design.

1.3 Main steps of soil investigation

1.3.1 Location

The site where the structure is to be installed is to be specified, including geographical position of the site, of the structure and its foundations. A general arrangement of the foundation of fixed structures or mooring pattern is to be provided.

1.3.2 Soil investigations

Soil design data are to be based on extensive soil investigations. The detailed Soil Survey reports and Design soil data are to be provided for review.

It is recommended to base soil investigations on a set of surveys and desk studies, including:

- Geological desk studies identifying general bedrock and soil formations, sedimentation process occurring in the area through history, predictive soil stratigraphy, occurrence of possible geological hazards such as slope instabilities, faults, seismicity of the area, salt tectonics, risks of gas eruptions, indication for further geophysical surveys.
- Sea-bottom survey identifying soil bathymetry and outcropping structures through bathymetrical and magnetic surveys. Extent and precision of sea-bottom survey are to match the requirements of the chosen foundation design.
- Sub-bottom profiling through geophysical (seismic) survey identifying soil stratigraphy, rock outcropping, main sub-bottom units, risks of shallow gases in the vicinity of the foundations and providing indications for further geotechnical survey. Extent and precision of sub-bottom survey are to match the requirements of the chosen foundation design.
- Geotechnical survey through in-situ penetration tests, core sampling and laboratory tests, identifying soil design parameters and their variations with location and depth.

2 Geophysical survey

2.1 General

2.1.1 Geophysical surveys are based on sea-bottom and sub-bottom surveys.

2.1.2 The aim of sea-bottom survey is to identify bathymetry, rock outcropping, existing metallic objects on the seabed. A particular attention is to be taken on existing objects that may interfere with foundations and anchoring in near shore area and shallow water due to the extended human activity.

2.1.3 The aim of sub-bottom profiling is to identify the stratigraphy of the soil, in particular soil main layers, faults, depth of rock layer, outcropping, gas pockets.

2.1.4 On oil and gas field, it is recommended to pay a particular attention on pockmarks and active gas eruptions.

2.1.5 Geophysical investigations are to be performed in accordance to a recognized standard (see Sec 1, [4.2]).

2.2 Sea-bottom surveys

2.2.1 Bathymetrical surveys are based on acoustic devices. Extent and precision of the bathymetrical surveys depend on the chosen foundation solution. Acoustic surveys are also to identify visible outcropping, pockmarks and dropped object. It is recommended to identify near bottom metallic objects (dropped objects, wrecks, pipelines, cables...) through magnetic survey.

2.2.2 In particular for shallow foundations, it is recommended to have a accurate measure of the variability of bathymetry, meeting the tolerances of the chosen foundation solution.

2.3 Sub-bottom surveys

2.3.1 Sub-bottom profiling is based on seismic devices. Extent of sub-bottom profiling is depending on the chosen foundation solution.

2.3.2 Extent of the survey and depth of profiling is to be at least the extent of the area influenced by the foundation. It is recommended to pay particular attention on gas pockets, when risks have been identified in the area.

2.4 Extent of geophysical surveys

2.4.1 High resolution bathymetry, seabed features detection and sub-bottom profile are to be assessed as a minimum for an area centred on the offshore structure of about:

- 1 x 1 km for shallow water
- 2 x 2 km for deepwater (dependant of the forseen foundation/mooring pattern on the seabed)
- 5 x 5 km when geohazards have been identified.

A larger regional survey larger may be needed in certain geological contexts.

2.4.2 Depth of sub-bottom profiling is to reach the first hard layer (rock basement) or to be deeper than the depth of the foundation increased by 150% of the width of the foundation.

3 Geotechnical survey

3.1 General

3.1.1 Geotechnical surveys are based on in-situ penetration tests, core sampling and laboratory testing of core samples. For each type of tests, different type of testing devices or practices may be proposed depending on predicted soil in presence, stratigraphy and required penetration depth.

3.1.2 Geotechnical investigations are to be performed in accordance with a recognized standard (see Sec 1, [4.2]).

3.1.3 As a good practice, location of each geotechnical investigation (in-situ or core sampling) is identified on bathymetrical and sub-bottom profiling maps in order to interpolate soil conclusions of geotechnical surveys within the field.

3.2 On-site testing

3.2.1 On-site surveys are based on penetration tests and core sampling for further laboratory testing.

3.2.2 Penetration tests provide a continuous profiling of the soil (strength estimation with depth).

The following penetration tests are available:

- cone penetration tests - CPT
- standard penetration tests - SPT (generally 1 measure every meter)
- other penetration as T-bar or ball penetration tests.

3.2.3 For dense cohesionless soils, SPT can be used for penetration tests. For all soils, CPT are preferred. T-bar or ball penetration tests can also be use when available in cohesive soils to avoid influence of pore pressure on soil strength evaluation.

3.2.4 Additional sensors can be implemented on the head of CPT devices to estimate other designing parameters of soil, such as:

- Friction sleeve for soil friction measurement (standard device)
- Piezo-cone for water pressure measurement (standard device of PCPT)
- Thermal conductivity probe for heat dissipation measurement in soil (design of pipelines against bucking...)
- Electrical conductivity cones for soil corrosiveness measurement, but also detection of pollutions and changes in porosity
- Seismic cone for evaluation of shear wave velocity (seismic risks assessments)
- Dilatometer for measurement of horizontal soil pressure.

3.2.5 Core sample should remain as little affected as possible by coring and transportation. It is recommended to check that variation of void ratio due to coring and transportation remains lower than 5% for reliable laboratory surveys.

When the variation of void ratio is higher than 5%, interpretations of results of testing of core sampling are to be performed with special care. It is recommended to condition and transport the core samples in accordance with a recognized standard.

3.2.6 Different types of corers can be used for soil coring depending on the required ranges of penetration and soil sample quality, such as seafloor drilling devices, gravity push-in and piston corers, for deep soil coring and deep soil properties evaluation. Box and grab corers can be used for shallow soil coring and seabed properties evaluation.

3.3 Laboratory testing

3.3.1 General

Laboratory test campaign is necessary to draw correlation ratios between in-situ penetration tests and soil strength parameters, and to draw other designing soil parameters, such as:

- soil classification
- soil density, unit weights and water content
- undrained soil strength
- angle of shearing for cohesionless soils and for drained resistance of cohesive soils
- sensitivity
- consolidation characteristics.

Special tests can be performed to assess characteristics of particular soils:

- characterisation of carbonate soils and compressibility of carbonated sands
- strength anisotropy
- thixotropy
- interface behaviour with steel
- cyclic and seismic properties of soils
- corrosiveness and soil electrical conductivity.

It is recommended to carry out laboratory tests on representative samples in accordance with recognized standards (see Sec 1, [4.2]). The quality of the samples has a large influence on the reliability of the test results.

3.3.2 On-board laboratory tests

First laboratory tests are performed on board of the survey vessel for first estimations and correlations of soil parameters and to assess soil disturbance due to sampling, conditioning and transportation. Void ratio and undrained shear strength evaluation are generally performed using portable devices. Extended soil testing is generally performed in onshore testing facilities with typical methods of onshore geotechnical surveys.

3.3.3 Soil classification

Soil classification is necessary to draw soil parameters, highly dependent on the type of soils. Soil characterisation is based on particle size distribution, colour and water content.

For fine grained soils (clays and loose to medium dense silts), Atterberg limits are generally estimated for correlation of in-situ and laboratory testing with typical clay behaviour from state of the art.

Soil density parameters such as submerged and dry unit weight, particle density, water content, and void ratio are measured. For coarse grained soils, relative density is assessed to draw or correlate soil strength and friction parameters.

3.3.4 Soil chemical content

The chemical content of soil such as carbonate and organic content is generally assessed due to their influence on soil strength.

Due to the detrimental effects of some soil chemical content on structures, the pH, the sulphur, sulphide and chloride are generally assessed.

For steel structures, presence of corrosion-inducing bacteria such as SRB and soil electric resistivity is also assessed.

3.3.5 Soil strength

Soil strength is characterized by the cohesive shear strength and the critical state friction angle or peak friction angle. This strength is modified by:

- soil consolidation
- cyclic loading of the soil
- soil anisotropy
- undrained and drained condition
- soil remoulding and thixotropy.

3.3.6 Soil strength on-board testing

It is recommended to assess soil strength parameters by adequate means. Onboard laboratory testing devices as fall cone, torvane and pocket penetrometer provide fair soil strength estimations but not sufficient for soil strength characterisation.

3.3.7 Soil strength onshore testing

During onshore testing, soil strength is generally estimated on direct shear tests, triaxial unconsolidated and consolidated compression tests for drained and undrained conditions (angle of shearing). Other testing methods can also be used for strength estimation.

For clays, soil anisotropy is assessed through compression and extension triaxial tests.

3.3.8 Cyclic soil strength

When cyclic loading is important on the structure, soil strength under cyclic loading is generally to be assessed through cyclic triaxial tests for stress amplitudes, mean stress and equivalent numbers of cycles representative of the loading of the structure.

3.3.9 Undrained and drained soil strength

For structures where soil conditions and loadings may result in a drainage of the soil, such as shallow foundations on clays, the undrained and the drained shear strength of the soil are both to be assessed.

In general for cohesive soils such as clays:

- the undrained shear strength is considered as purely cohesive
- both cohesive and frictional parts of the strength are generally considered for drained conditions.

For cohesionless soils, the drained shear strength is considered as purely frictional.

3.3.10 Remoulded strength

For clays, soil strength in remoulded conditions is tested and soil sensitivity (ratio of strength between intact and remoulded conditions) is assessed. Strength regain with time (thixotropy) is also assessed for deep foundations.

3.3.11 Interface friction

For piles and skirted foundations, interface friction with steel structures can be assessed trough shear boxes and ring shear tests.

Interface behaviour (friction parameters) can also be drawn from full scale values during installation and retrieval of piles in similar soils or from typical values from recognized design codes (see Sec 1, [4.2]).

3.3.12 Consolidation and soil compressibility

For clays and carbonated sands (and in a lower scale for coarser soils), compressibility (initial loading and reloading compression modulus) and consolidations can be assessed by oedometer tests.

For clays and silts, assessment of present consolidation state and over-consolidation ratio are recommended to draw correlations on testing results for both shallow and deep foundations.

When some of the soil parameters are deduced from typical values of well-described soils, it is also recommended to compare soil consolidation with typical values of these reference soils.

For shallow foundations, it is recommended to carefully assess consolidation and compressibility of soils for settlement assessments.

3.3.13 Seismic soil properties

If seismic risks are identified at the structure site, it is recommended to address by relevant testing parameters for seismic risk assessment, such as cyclic strength of soil and soil dynamic parameters (initial shear modulus and soil damping at small strain).

3.4 Guidance on geotechnical surveys

3.4.1 General

The extent of required soil survey depends on the type and size of foundation retained in the design.

As geotechnical surveys are generally performed before choice of foundation solutions and foundation pre-dimensioning, extent of soil investigation is to be carefully defined in order to avoid further soil investigation campaign or structure over-dimensioning at detailed design stage due to a lack of soil information collected during initial survey campaign.

3.4.2 Soil Investigations for shallow foundations

A minimum of 4 to 5 boreholes is recommended to a depth of:

- 150% of structure larger width
- 50m
- till first hard rock bedding (testing of rock bedding may be necessary), whichever is the smaller.

with continuous sampling on the first 15 m followed by regular sampling steps with less than 0.5 m equally spread, alternated with down-hole CPT.

Generally, 1 borehole per corner of the structure and one in the centre is recommended.

When major soil variation is identified under the structure footprint, additional boreholes may be recommended.

A minimum of 10 (P)CPT, equally spread along the structure, is recommended to a depth of:

- 150% of structure larger width
- 50m
- till first hard rock bedding, whichever is the smaller.

(P)CPT are be to performed in close vicinity of each borehole for the calibration of (P)CPT results.

Soil investigation may be adapted for less wide structure.

3.4.3 Soil Investigations for intermediate to deep foundations

A minimum of 1 or 2 boreholes per pile group is recommended to a depth of:

- 4 pile diameter
- pile length plus 1 pile diameter (or 5 meter)
- pile length plus pile group width, whichever is the greater.

with continuous or near continuous sampling to 15 m and alternated with down-hole (P) CPTs with gaps less than 0.5 m.

A minimum of 1 (P)CPT to 30 m per pile is recommended, with one (P)CPT at about 5m of each borehole for the calibration of (P)CPT test results.

Soil investigation may be adapted for solutions with wide spreading of foundations or when limited soil variability is encountered.

3.4.4 Soil Investigations for anchors

One borehole per anchoring point or per cluster of anchoring point is recommended.

In addition, one (P)CPT per anchoring point, with one being less than 10m from borehole is recommended.

Testing depth is depending on the type of anchoring device.

For drag anchors, testing is to be performed till a penetration from 5-10 m in sand to 20 m in soft clay, or down to first hard layer.

For vertically loaded anchors (VLA) and torpedo anchors, testing is to be performed till a penetration at least 5 meters below the anticipated penetration depth of the fluke.

These values may be modified depending on anchor design.

3.4.5 Soil Investigations for jack-up platforms

Soil investigations for jack-up platform are to be in accordance with SNAME Bulletin 5/5A and ISO 19905-1 (see Sec 1, [4.2.3]).

3.4.6 Laboratory testing

The following laboratory testings on recovered soil samples from boreholes are recommended, for all the types of foundations:

- general soil characterisation (depending on soil type)
- general soil chemical characterisation
- oedometer tests
- permeability tests
- simple shear tests and anisotropically consolidated compression and extension triaxial tests, monotonic and cyclic.

Shear wave velocity, initial shear modulus measurement and resonant column tests are generally to be performed when seismic risks are identified.

For deep foundations and anchors, a particular attention is to be drawn on interface friction, to be investigated by proper means.

3.4.7 Definition of design soil data

Soil data from geological, geophysical and geotechnical survey are to be integrated in order to determine design soil data. These soil data are to be summed up in a consistent manner for foundation design.

Detailed soil profiles providing data on the variability of soil parameters is to be provided for sensitivity analyses on foundation strength and foundation installation constraints.

Alternatively, only lower bound and upper bound soil profiles may be provided.

When different soil profiles are encountered on the site, different design soil profiles may be provided.

When design parameters cannot be obtained by conventional tests or when soil material for testing does not allow performing some test, results from already performed tests in similar soil material or results from the State of The Art may be used to derive design soil data.

SECTION 3 FOUNDATION DESIGN

1 General

1.1 General Requirements

1.1.1 The foundation design is to cover the different phases of the life of the structure, namely installation, extreme loads on site, accidental events on the structure, such as seismic loadings or collisions on the structure, operations and operational conditions on site and decommissioning.

1.1.2 The foundation design is to be based on design soil data obtained from the site surveys on the specific site, as described in Sec 2.

1.1.3 Documents to be provided

The design is to be documented by detailed design reports to be submitted for review. The following documents are to be submitted:

- Detailed results of soil investigation surveys and design soil data
- General arrangement of the foundation pattern on the site with bathymetry and location of the boreholes and penetration tests performed during site investigation
- Detailed drawings of the foundation
- Weight report of the structure
- Design loads on the structure
- Geotechnical reports for installation, and decommissioning if any
- Specifications and procedures for installation, and decommissioning, if any
- Geotechnical capacity reports for on site operating, extreme, damaged and accidental conditions
- Reports for the mitigation of geotechnical risks such as seismic design, scouring, sand waves motions
- Reports of the assessment of detrimental environmental actions on the foundation structure, such as corrosion on steel foundations, and design reports of the protection against these actions, if any
- For shallow foundation, settlement, soil reaction and soil stiffness analysis reports.

1.1.4 Analytical calculations of foundation design

The design of offshore foundation is to be performed through analytical analyses.

Analysis procedure is detailed in the present Section of the Note. Calculations are to be performed in accordance with a recognized design code (see Sec 1, [4.2]) and calibrated with actual results from experienced cases or relevant model tests when available.

1.1.5 Calculations by FEM

The foundations design can be performed through finite element analysis. The finite element analysis code is to be qualified for geotechnical analyses.

For the qualification of the finite element calculations and the justification of the soil parameters and models used in the calculation, results of finite element analyses are to be compared to analytical analyses on basic load cases, to model tests results or data from experienced cases of the same type of foundations in the same type of soil. Discrepancies are to be justified.

1.1.6 Seismic design

When seismic loadings have been identified as a critical issue for the structure, seismic design of the foundation is to be assessed in accordance with ISO 19901-2 and detailed seismic design report is to be provided for review.

1.1.7 Tolerances

The foundation design strength is to be checked considering the influence of fabrication and installation tolerances (position, verticality, orientation...).

The most onerous combination of fabrication and installation tolerances is to be considered in the design.

Foundation position, verticality and orientation is to be duly monitored during installation. The installation is to be witnessed by the Society. In case of discrepancies between installation and specified tolerances, detailed analyses of consequences and mitigation plans are to be provided for review.

1.2 Design criteria

1.2.1 Load and resistance methodology

Except otherwise indicated in the following paragraphs, the ultimate capacity of foundations is to be checked with regard to load and resistance methods defined in ISO 19900 series.

It has to be verified that for each design case, the design factored loads are lower than the factored resistance.

Partial safety factors for the design capacity check are presented in [1.3].

1.2.2 Criteria for installation and decommissioning of intermediate and deep foundations

Criteria for the installation and decommissioning of intermediate and deep foundations are detailed in [3.3] of the present Section.

The most onerous soil profile accounting for soil profile variations in the installation area is to be considered for installation design.

When no indication on soil variability has been provided, a soil profile multiplied by material factor γ_m can be used.

Generally, the upper bound soil profile is the most onerous soil profile for installation and decommissioning.

1.2.3 Criteria and design procedure for tension leg platforms

Criteria and design procedure for tension leg platform are to be in accordance with NR578.

1.2.4 Criteria and design procedure for jack-up platforms

Criteria and design procedure for jack-up platform are to be in accordance with SNAME Bulletin 5/5A and ISO 19905-1 (see Sec 1, [4.2.3]).

1.3 Partial safety factors

1.3.1 Design loads decomposition

The design loads T_d (forces and moments) on the structure is to be decomposed within static loads T_s and variable loads T_v as following:

$T_d = T_s + T_v$

The static loads comprise:

- the hydrostatic loads (weights and buoyancies on the structures, pretension of the mooring lines)
- the constant load induced by the damages in accidental conditions.

The variable loads comprise the environmental loads and the variable part of accidental loadings.

1.3.2 Factored load

The factored design loads T_f to be considered in criteria check is to be factored by a static partial factor γ_s on static loads and a variable partial factor γ_v on variable loads, and a load calculation factor γ_L on both components as following:

$T_f = (\gamma_s T_s + \gamma_v T_v)\ \gamma_L$

Partial action factors and material factors shall be applied with consistency throughout the design process. In particular, the ratio between the resultant horizontal action and the resultant vertical action on the foundation will influence the design equations. It is important to determine which vertical partial action factor produces the more conservative result.

1.3.3 Factored resistance

The resistance calculations is to consider soil materials with strength factored by the material factor γ_m as following for soil capacity check against external loads:

$$\tau_d = \frac{\tau_{max}}{\gamma_m} = \frac{S_u + \sigma_n \tan\phi'}{\gamma_m}$$

Calculation of soil capacity is to be performed as per [2] and [3]

1.3.4 Orientation of design loads and foundation resistance

Generally, design loads and corresponding foundation (soil) resistance can be expressed as a combination of the following elementary loadings:

- Vertical bearing loads, corresponding to bearing loads on the supporting soil in the vertical axis of the foundation.
- Vertical uplift loads, corresponding to uplift loads on the supporting soil (suction, friction on the side) in the vertical axis of the foundation.
- Horizontal bearing loads, corresponding to bearing loads on the supporting soil in the horizontal axis of the foundation.
- Horizontal sliding loads, corresponding to friction loads on the supporting soil in the horizontal axis of the foundation.
- Over-turning moment, corresponding to the over-turning moment applied on the foundation at the center of gravity of the foundation, or at the center of the contact surface of the foundation with the soil, whichever is the most convenient for the calculation of the soil capacity.

Soil planarity and foundation tolerances on verticality due to fabrication and installation are to be accounted in the evaluation of these loads.

As a general matter, the loads and resistances on the foundation are to be considered in the same direction.

In most of the cases, the global soil resistance to inclined loadings is lower than the resistance to each elementary loading taken independently, except otherwise stated in this section. Thus, for inclined loadings, recognized critical state envelope of combined loadings are to be considered to assess the global soil resistance.

1.3.5 Soil data for capacity check

For soil capacity check under design and accidental loadings, the factored lower bound soil profile is to be considered.

Alternatively, when no lower bound profile has been defined, the variability in soil profile is to be considered.

When part of the capacity is relying on soil unit weight, the most onerous case between upper bound and lower bound soil density for capacity is to be considered.

Effects of cyclic loadings are to be assessed.

1.3.6 Design cases for foundation capacity check

The following load cases are to be considered for the foundation capacity check under extreme and accidental loadings:

- Design case in intact condition
- Damaged conditions for redundancy check
- Accidental case for abnormal conditions.

These design cases are defined in the Offshore Rules NR445, Part B, Sec 2. For specific facilities such as mooring of floating units, TLP, jack-up, please also refer to the corresponding Note (see Sec 1, [4.1]).

1.3.7 Partial factors

Different load and resistance partial factors are defined for the different design cases (see Tab 1).

For design case in intact condition, two design criteria are defined. The most onerous case between design intact case 1 and 2 is to be considered.

Material factor γ_m may be taken equal to 1,2 for sands when friction angle has been obtained from laboratory tests.

For higher redundancy of the structure, the design case in damaged conditions can be considered as a design case in intact condition (for classification marks **POSA HR** and **TLS PLUS**).

Table 1 : Partial factors for foundation capacity check

Design case	Partial factors		
	Static load factor γ_s	Variable load factor γ_v	Material factor γ_m
Design intact case 1	1,3	0,7	1,3
Design intact case 2	1	1,3	1,3
Redundancy case	1	1	1,3
Accidental case	1	1	1

1.3.8 Loads on the foundations of floating structures

The design loads on the foundations of floating structures coming from mooring analyses are to be factored as per [1.3.2], considering the following load calculation factor γ_L:

- by 1,15 when quasi-dynamic mooring calculation methods have been used for mooring load calculations (see definition in NR493).
- by 1,05 when fully coupled mooring calculation methods have been used for mooring load calculations.

The mooring loads at anchor pad-eye are to be considered.

The design loads and their direction at pad-eye are to consider the mooring line catenary in soil, accounting for bearing and friction resistance of soil on mooring line.

The load direction at pad-eye are to take into account soil variability. The most onerous case between the unfactored upper bound and lower bound soil profile has to be considered to define load direction for both geotechnical and structural capacity check. Alternatively, in absence of indication in the soil data report, the soil variability may be taken equal to the material factor to define mooring line load direction.

1.3.9 Loads on the foundations of floating structures in close proximity of another installation

For units in close proximity to another installation (fixed or floating structure), when the failure of successive mooring lines may result in the collision of the structure, an increased load calculation factor γ_L is to be applied on mooring loads in the lines whose failure leads to a transient response that moves the moored unit toward the other installation.

The load calculation factor γ_L is to be multiplied by 1,25 in design and redundant case and 1,40 in accidental (transient) case (see NR493).

1.4 Structural strength of the foundation

1.4.1 The structural strength of the foundation is to be checked with regards to the provisions and requirements of NR445. Structural strength to extreme loads (yielding and buckling) and fatigue strength is to be assessed for the different phases of the design life. For anchoring devices, provisions and requirements of NR493 also apply.

1.4.2 Corrosion of the steel structures and degradation of the concrete structures are to be accounted in the design. Soil corrosiveness is to be assessed. Protection against corrosion is to be provided when relevant. Specifications and calculations reports of protection against corrosion are to be submitted for review.

For deep and intermediate foundations, the structure is not to be protected by coating under the mudline. On painted part of the foundation under the mudline, the friction capacity of the soil is to be considered as not effective.

When steel structure under the mudline are not protected against corrosion, a minimum corrosion margin of 0.2 mm/year per face metal exposed to the soil is to be considered.

Note 1: When corrosion-inducing bacteria are identified in the vicinity of the foundation, higher corrosion rate are to be applied. These corrosion rates are to be submitted for review.

Note 2: Higher corrosion rates may be defined based on local regulations or on-site data.

1.4.3 Soil reactions on the structure for the different design cases (see [1.3.6]) are to be calculated for further structural check of the foundation. Upper bound and lower bound soil profiles without material factors are to be considered.

Soil reactions for fatigue loading conditions are to be calculated. Justification of the loads combinations used for soil load calculations for fatigue loading is to be provided.

1.4.4 Soil loads for the different combinations of fabrication and installation tolerances are to be provided. The most onerous case is to be retained for structural strength calculation. This case may be different for extreme and for fatigue loadings.

2 Shallow foundation

2.1 General

2.1.1 General requirements

As a minimum for shallow foundations, the documents or information of [1.1.3] are to be submitted for review.

2.1.2 Soil preparations

When bathymetry does not allow the foundation to be installed in the identified location for the offshore structure (soil planarity, slope angle…), soil preparation may be adopted.

In case of necessary soil preparation under the shallow foundation structures, detailed analyses of the settlement, capacity of the soil after preparation and detailed specifications of soil preparations, soil preparation material and tolerances on soil preparations are to be provided for review. Scouring effects on soil preparations are to be addressed by adequate analyses in order to reduce risks for scouring.

2.1.3 Installation and removal

Installation is to be planned to ensure the foundation can be properly seated at the intended site without excessive disturbance to the supporting soil. Where removal is anticipated, an analysis is to be made of the forces generated during removal to ensure that removal can be accomplished with the means available.

Effects of instantaneous (elastic) settlements during installation are to be assessed and monitored during installation. In case of discrepancies between settlement estimations and installation records, detailed analyses of consequences and mitigation plans are to be provided for review.

2.1.4 Scouring

Scouring on seabed around foundation footprint may occur due to vortices induced by current and wave loading on the soil. This scouring may result in a loss of foundation capacity and degradation of soil preparations. Scouring depth is to be evaluated by proper mean and consequences of scouring on the structure are to be assessed.

Scouring protection may be provided around the structure. Specification of scouring protections is to be provided for review. Inspection and maintenance plan of scouring protection and mitigation of the possible limited scouring under scouring protection is to be defined.

As guidance, in absence of more detailed data on scouring in equivalent soils with equivalent shape of foundations, scouring depth can be estimated by the following formula:

$$S = 1,3\,D\left[1 - e^{-0,03\left(\frac{u_{max}T}{D} - 6\right)}\right]$$

With:

S : Scouring depth

D : Structure width

T : Period of the fluid particle motion due to current and waves

u_{max} : Maximum speed of the fluid particle near seabed, taken as the combination of current speed and wave particle speed (which is not null for shallow water).

2.2 Ultimate holding capacity

2.2.1 General

The ultimate loading capacity of shallow foundations is to be assessed. Detailed analysis report is to be submitted for review. Vertical (bearing and/or uplift), horizontal and overturning capacity of the foundation is to be assessed. Effects of cyclic loading are to be considered.

The capacity is to be assessed by analytical calculations. When capacity is obtained by FEM calculations, results are to be verified on the bases of analytical calculations, at least on basic cases such as pure vertical and pure horizontal loadings.

For shallow foundations on rock, provisions of EM 1110-1-2908 "Rock Foundations" (see Sec 1, [4.2.4] item k)).

2.2.2 Vertical Bearing and Over-turning capacity

The vertical bearing capacity is to be calculated using recognized formulations such as Terzaghi (1943), Skempton (1953), Meyerhof (1963), Hansen (1970) or Vesic (1973). The choice of the formulation is to be justified in function of the domain of validity in term of shape of the foundation, inclination of the load, of the foundation and of the seabed, depth of burial of the foundation basis, influence of the water-table. When relevant, soil friction on the skirt of the foundation may be accounted by proper mean.

The eccentricity of the resulting loads due to over-turning moment at the application point on the soil is to be considered using recognized methods such as Meyerhof method of effective area (1953) for rectangular footings, Purkayatash and Char reduction factor method for granular soils (1977), Highter and Andres effective area method (1985), in particular for circular footings. Load eccentricity is defined as following, in function of vertical load V and overturning moment M:

$e = M / V$

For high eccentricity, more developed methods such as FEM calculations may be used.

2.2.3 Horizontal Bearing capacity

The horizontal bearing capacity is to be calculated considering friction on the foundation base and skirts. Horizontal passive bearing capacity of the buried part of the foundation may also be considered and calculated by proper means.

2.2.4 Combined loadings

When no loading direction can be identified as critical and predominant on the others, soil capacity under a combination of vertical, horizontal and over-turning moment loading cannot be considered separately. In order to assess soil capacity under combined loading, global soil capacity can be derived from yield envelopes that are to be duly justified. Combined loading capacity can also be obtained through finite element calculation

2.3 Settlements

2.3.1 Static deformations of soil under shallow foundations due to static loadings such as instantaneous, primary and secondary settlements are to be assessed and submitted for review.

2.3.2 Effects of settlements are to be accounted for the foundation design, and proven not to impair structural integrity and serviceability of the offshore structure. Typical times for settlement to occur are to be estimated. Settlement calculations are to be submitted for review.

2.3.3 Risks and effects of differential settlement due to non homogeneity of soil properties or to eccentricity of loadings are to be assessed.

3 Deep and intermediate foundation

3.1 General

3.1.1 General requirements

As a minimum for deep and intermediate foundations, the documents or informations listed in [1.1.3] are to be submitted for review.

3.1.2 Installation

The installation of deep and intermediate foundation is to be assessed by proper calculations to be submitted for review. Specifications, procedures and inspection program are to be submitted for review.

3.1.3 Scouring

The scouring and its effects on the foundation capacity is to be assessed and detailed analysis reports are to be provided for review. The provision of [2.1.4] also applies for deep and intermediate foundations.

Negative friction due to the weight of scouring protection is to be accounted in soil capacity evaluation.

3.2 Ultimate holding capacity

3.2.1 General

The ultimate loading capacity of deep and intermediate foundations is to be assessed for each design condition. Vertical (bearing and/or uplift), horizontal and over-turning capacity of the pile is to be assessed.

Effects of cyclic loading and of pile group are to be considered.

The capacity is to be assessed by analytical calculations. When capacity is obtained by FEM calculations, results are to be verified on the basis of analytical calculations, at least on basic cases such as pure vertical, pure horizontal and pure over-turning loadings.

3.2.2 Vertical bearing and uplift capacity for plugged and unplugged condition

The vertical bearing/uplift capacity of the deep and intermediate foundations is to be assessed.

For open-end piles and caissons, two failure modes exist regarding vertical capacity:

- Plugged condition: the soil plug inside the open-end pile completely sticks to the pile and the capacity of the soil corresponds to the friction capacity of the outer-side of the pile and the bearing/uplift capacity of the pile structure plus the soil plug. The end-bearing area corresponds to the cross section area of the structure of the pile and of the soil plug inside the pile. The buoyant weight of the soil inside the pile is to be considered.
- Unplugged condition: the soil plug inside the open end pile does not completely stick to the pile and the capacity of the soil corresponds to the friction capacity of the inner-side and outer-side of the pile and the bearing/uplift capacity of the pile structure without the soil plug. The end-bearing area corresponds to the cross section area of the structure of the pile only.

Both plugged and unplugged conditions are to be assessed and the most stringent case is to be considered.

The Society can concede that one of these conditions can be discarded when justified by field or laboratory data on similar foundations on similar soils.

3.2.3 Soil friction for vertical bearing and uplift capacity

Soil friction factor on pile is to be accounted from laboratory data or field data in similar soils. Friction factors from recognized standard may be used with special considerations on the applicability of the normative values.

For piles in cohesion-less soils, lateral soil pressure is to be determined by some reliable method that accounts for the amount of soil disturbance due to installation or based on values from recognized design codes (see Sec 1, [4]).

Reduction of skin friction capacity due to torsion moments on the pile is to be accounted.

3.2.4 Vertical uplift capacity accounting passive suction at pile end

For suction piles and suction caissons remaining sealed after installation, an additional uplift capacity may develop in plugged condition resulting from the development of in-service (normally passive) suction in dynamic situation. This additional capacity is to be factored by a factor ε, varying from 0 to 1. The factor is depending on particular soil condition and device, and is to reflect:

- The confidence on the development of in-service suction (as proven by experience or through experiments)
- Its anticipated mobilisation, especially under dynamic actions.

This factor is generally limited to 0.5, and will be reviewed on a case by case basis by the Society.

When the possibility of in-service suction is established, ε may be taken as the ratio between the maximum vertical load range in a load cycle and the maximum vertical load for the considered extreme seastate, or may be derived by other appropriate method.

3.2.5 Horizontal and moment bearing capacity

Horizontal and Overturning capacity loading are to be assessed using load-displacement (p-y) curves for deep foundations. The pile is to be considered as a beam where p-y curves are implemented linearly on the beam. The capacity is to be estimated by an incremental increase of load on the structure in the beam model.

The soil ultimate capacity is obtained when additional increment of load will not result in an increment of soil resistance or when displacement of the pile is reaching unacceptable values of displacement or rotations of the top of the pile.

Allowable displacements are to be estimated from criteria and tolerances on the design for the foundation structure and superstructure.

In absence of more detailed data for the actual soil conditions of the site, the load displacement curves from the following publications can be used:

- For soft clay: OTC 1204, Correlations for Design of Laterally Loaded Piles in Soft Clay, by H. Matlock, April 1970.
- For stiff clay (S_u > 70 kPa) or when a strain-softening behaviour of the clay is identified: OTC 2312, Field Testing and Analysis of Laterally Loaded Piles in Stiff Clay, by L. C. Reese and W. R. Cox, April 1975.
- For sand: "An Evaluation of p-y Relationships in Sands," by M. W. O'Neill and J. M. Murchison. A report to the American Petroleum Institute, May 1983, or API RP-2GEO.

It is also to be checked that no gap is forming at pile top behind the pile under horizontal loads and over-turning moment, that would decrease pile bearing capacity.

3.2.6 Inclined loadings

For deep foundations, vertical and horizontal/overturning loadings can be considered separately when horizontal displacements of the pile are negligible with regards to pile verticality.

For intermediate foundations, soil capacity under a combination of vertical, horizontal and over-turning moment loading cannot be considered separately, except when one loading has been identified as critical and predominant on the others. In order to assess soil capacity under combined loading, global soil capacity can be derived from holding capacity envelopes from the State of the Art. Combined loading capacity can also be obtained through finite element calculation.

For short piles used for mooring line anchoring, when the load application point is located at less than 5% of the length from the point where the inclined loading will not generate over-turning moment on the foundation, holding capacity envelop from Supachawarote (2004) may be used.

3.2.7 Thixotropy

During installation, in particular for cohesive soils, the soil is remoulded during pile driving and the complete holding capacity will be obtained after a set-up time due to thixotropy and consolidation. The set-up time to obtain optimal holding capacity is to be in line the project schedule and constraints (weight of the superstructure, environmental loads and operability limits). For anchors, the time between pile installation and hook-up is to be considered.

3.3 Installation

3.3.1 General

Installation of offshore intermediate and deep foundation is generally performed by pile driving or suction embedment. Other methods from onshore civil work such as drilling and grouting are to be used with special care. These solutions may be used for near-shore and costal areas.

3.3.2 Self-penetration

Self penetration of piles under its own weight and the weight of installation devices attached to the piles is to be assessed for upper bound and lower bound soil profiles. The self-penetration depth can be calculated as following:

$$W = q_{tip} A_{tip} + \int_{h=0}^{H} q_{fric} \, dA_{fric}$$

with:

W : Buoyant weight of the pile and attached installation devices

H : Self penetration depth

q_{tip} : Limiting bearing pressure of pile tip at the depth H

A_{tip} : Cross-section area of pile tip

q_{fric} : Friction of the pile at the depth h

dA_{fric} : Elementary friction area of the pile at depth h.

3.3.3 Pile driving

For driven piles, pile driving after self-penetration is to be calculated by proper means. Specifications and procedures for pile driving are to be submitted for review. Hammer properties, minimum and maximum number of blows is to be assessed by drivability analyses using advanced calculation methods such as wave equation.

Compressive and tension stresses in pile during driving are to be provided for the structural assessment of pile yielding, buckling and fatigue strength. Structural strength assessment is to be provided for review. Fatigue damage accumulated during driving is to be accounted in the total fatigue life of the pile structure. The fatigue damage during driving can be considered with a safety factor of 1, provided that upper-bound soil conditions have been considered in the driving analyses.

Risk of soil refusal during driving is to be assessed. Pile refusal is defined by a driving resistance exceeding either 250 blow count per foot of penetration on five successive feet or 800 blow count on one foot. Definitions of pile refusal may be strengthened by Contractors specifications or when a high number of blow counts would lead in a failure of the pile in fatigue.

Mitigation plans in case of soil refusal are to be set and submitted for review when risks of refusal have been identified. In case of pile refusal, corrective actions are to be set after review of the corrective action plan by the Society. The fatigue strength of the pile is to be reassessed considering logs of pile driving.

3.3.4 Suction embedment of piles in cohesive soils

For suction piles and caissons, the pile embedment in soil is provided by applying an under pressure inside pile caisson after self penetration of the pile in soil. The under pressure is to remain in cohesive soils between minimum pressure for suction embedment, the maximum allowable pressure before failure of the soil plug inside the caisson and the maximum allowable pressure for the structural buckling strength of the caisson. These pressures vary with embedment depth. The capacity of the pumping system is also to be considered.

The minimum under-pressure p_{min} required at penetration depth H can be calculated as following:

$$p_{min} = \frac{N_C S_u(H) A_{tip} + N_C S_u(H_{stiff}) A_{stiff} + \int_{h = H_{self}}^{H} \alpha S_u(h)(dA_{in} + dA_{out})}{A_{plug}}$$

with:

- H_{self} : Self penetration depth
- H_{stiff} : Depth where stiffeners bottom end is located in the soil
- $S_u(h)$: Undrained shear strength at depth h
- α : Friction coefficient of soil
- N_C : Tip bearing coefficient for circular footing

  N_C at depth z can be taken as following for circular footings of diameter D in clays:

  $$N_C = 6{,}2\left[1 + 0{,}34\ \arctan\left(\frac{z}{D}\right)\right] \le 9$$

- A_{stiff} : Cross-section area of pile stiffeners and outfitting
- A_{plug} : Cross-section area of the soil plug in pile
- dA_{in} : Elementary friction area of the inner part of the pile at depth h considering pile can and stiffeners
- dA_{out} : Elementary friction area of the outer part of the pile at depth h considering pile can and outfittings.

The maximum allowable under-pressure p_{max} before failure of the soil plug inside the caisson at penetration depth H can be calculated as following:

$$p_{max} = \frac{N_{REB} S_u(H)}{\beta} + \frac{\int_{h=0}^{H} \alpha S_u(h)(dA_{in})}{A_{plug}}$$

with:

- N_{REB} : Tip reverse end-bearing coefficient for circular footing equal to N_C
- β : Safety factor on reverse end bearing pressure equal to 1,5.

The embedment is also considered to stop when the plug heave reaches the top of the pile.

3.3.5 Suction embedment of piles in cohesion-less soils

The under-pressure inside suction pile is to remain between minimum pressure for suction embedment, the hydrostatic pressure at seabed, the maximum allowable pressure where soil starts to flow upward inside the caisson (effective vertical stress inside the caisson becoming negative), and the capacity of the pumping system (triggerring cavitation in shallow water).

The maximum allowable under-pressure p_{max} inside the caisson can be estimated as following at penetration depth H:

$p_{max} = \beta \min (p_h , 2\ w_s H)$

with

- β : Safety factor on maximum allowable pressure, equal to 0,9
- p_h : Hydrostatic pressure at seabed
- w_s : Soil total unit weight.

The suction under-pressure is also to remain above the maximum allowable under-pressure for the structural buckling strength of the caisson. These pressures vary with embedment depth. The embedment is also considered to stop when the plug heave reaches the top of the pile.

3.3.6 Plug heave in suction piles

During the installation of the suction pile, the soil will be displaced inside and outside the pile by the steel volume which enters into the soil. The plug heave of the soil inside the pile is to be assessed. This heave increases the possible weight of soil inside the pile that is to be considered when critical for the design. Seafloor inclination and installation tolerance in term of inclination have to be taken into account in the calculation.

It has to be considered that 50% of the soil is displaced inside the pile during self penetration and hammering and that 100% of the soil moves inside the pile during suction embedment.

4 Anchoring devices

4.1 General

4.1.1 Anchoring devices for permanent or temporary offshore floating units are generally to be type approved by the Society, in particular for drag anchors and vertically loaded anchors. Special type of anchors and anchor designed for a specific project are reviewed on a case by case basis.

4.1.2 Type approval of anchoring design

Basis for type approval are reminded in NR493. Type approved anchoring devices are defined, as a minimum by an ultimate holding capacity and a related uplift angle at anchor pad-eye for a specified range of soil properties, to be assessed by type tests on prototypes in soil conditions representative of the specified range of soil properties. Type tests specifications and reports are to be submitted for review. Type tests are to be witnessed by the Society.

Type approval can be provided on one anchor design for different sizes of anchors with homothetic scaling and different soil parameters. In this case, as a minimum, relations between, anchor size, soil parameters and minimum ultimate holding capacity is to be set and analysis report for the definition of the relation are to be provided for review.

4.1.3 Design documentation to be submitted

As a minimum for anchoring devices, the following documents or information are to be submitted for review:

- reference standards and methodologies for foundation design calculation
- drawings of the foundation
- drawings of the bathymetry of the site
- detailed soil data, including the study of possible geohazards
- design loads on the structures
- analyses of installation of the anchoring device
- analyses of soil capacity under extreme and cyclic loads.

4.2 Design criteria for anchoring device

4.2.1 Design cases for anchor capacity

The following load cases are to be considered for the anchor capacity check under extreme and accidental loadings with different partial factors:

- Design case in intact condition
- Damaged conditions for redundancy check with one line broken
- Accidental case in transient phase during line breaking.

For floating structures when higher redundancy is required by the contractor (**POSA HR**), mooring system with one line broken may be considered as an intact design condition and mooring systems with two lines broken as a damaged condition for redundancy check. In this case, return periods of extreme environmental loads may be adapted.

4.2.2 Design criteria for drag anchors

Drag anchors strength is to be assessed with regards to the provisions of ISO 19901-7 and NR493. Global safety factors between unfactored anchor holding capacity and unfactored design load are to be considered for drag anchors as defined in Tab 2.

4.2.3 Design criteria for other types of anchors

For anchoring design other than drag anchors, provisions of [1] applies. The design methodology is to be in accordance with [2] or [3], whichever is the most relevant. For anchor types where the provisions of [2] or [3] cannot be applied, the design will be reviewed on a case by case basis.

Table 2 : Design criteria for drag anchors

Global safety factor	Minimum safety factor between anchor holding capacity and design load	
	Quasi-dynamic mooring analyses	Dynamic mooring analyses
Intact conditions	1,60	1,50
One line broken case	1,15	1,05
Transient case	1,15	1,05
Note 1: For units in close proximity of another installation, provisions on mooring line design loads of [1.2.8] also apply.		

4.3 Test loading of anchoring device

4.3.1 The anchors are to be tested under load during anchor installation. The load at vessel fairlead for the test load of anchors is not to be taken lower than the following, depending on the type of anchors (see NR493, Sec 3, [10.5]):

- Drag anchors: 80% of the extreme design tension in intact conditions
- Vertically loaded anchors: as required to achieve the target penetration and holding capacity
- Anchor piles and suction piles: 110% of the specified pretension at fairlead.

4.3.2 The test load may be higher than the specified minimum value in order to ensure the good setting of mooring fittings or an optimal line profile in the soil.