

## DEP SPECIFICATION

# DESIGN OF ANCHOR PILES FOR MOORING SYSTEMS (BASED ON API RP 2SK)

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## DESIGN AND ENGINEERING PRACTICE



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## 1. INTRODUCTION

### 1.1 SCOPE

This DEP specifies requirements and gives recommendations for the design of mooring anchor piles for Floating Production Systems (FPS) and Floating Liquefied Natural Gas (FLNG) facilities.

For the purposes of this DEP the following definitions apply:

- Mooring anchor piles are defined as either piles installed by driving using an underwater hammer (driven anchor piles) or piles installed by use of suction (suction anchor piles).
- FPS's include semisubmersibles, spars, ships and other monohull floating structures.

Design and analysis of foundation piles for tension leg platforms is specifically excluded from the scope of the DEP.

This DEP may be used for the design of mooring anchor piles for Mobile Offshore Drilling Units (MODUs) and for the design of initiation or restraint piles for flowlines and risers, when these piles are loaded below the seafloor.

This DEP provides some specific guidance on the geotechnical design of mooring anchor piles in typical deepwater soils, where moored FPSs are typically installed. For the purposes of this DEP, typical deepwater soils are considered to be comprised of clay with occasional sand layers. No specific guidance is provided for geotechnical design of mooring anchor piles in non-standard soil types (e.g., carbonate soils) or highly interlayered soils.

This is a revision of the DEP of the same number dated September 2011; see (1.5) regarding the changes.

### 1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI, the distribution of this DEP is confined to Shell companies and, where necessary, to Contractors and Manufacturers/Suppliers nominated by them. Any authorised access to DEPs does not for that reason constitute an authorization to any documents, data or information to which the DEPs may refer.

This DEP is intended for use in facilities related to offshore exploration and production. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process shall be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements could be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regards to the safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible.

### 1.3 DEFINITIONS

#### 1.3.1 General definitions

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party that manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party that initiates the project and ultimately pays for it. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

### 1.3.2 Specific definitions

| Term                                  | Definition                                                                                                                                                                                                                      |
|---------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Approve, Approved, or Approval</b> | Principal's written agreement, prior to ordering material and/or beginning work, that the submitted item has been performed in accordance with the project requirements.                                                        |
| <b>Driven Anchor Pile</b>             | Open ended cylindrical pile, used as an anchor in a mooring system, which is installed into the seafloor by driving using an underwater hydraulic hammer.                                                                       |
| <b>Basis of Design</b>                | Project specific design criteria for anchor piles, subject to the management of change process.                                                                                                                                 |
| <b>Review</b>                         | Principal's right, but not obligation, to comment on the submitted item. Contractor may begin construction of the item following submittal.                                                                                     |
| <b>Set-up</b>                         | The increase in axial capacity of a mooring anchor pile, with time after pile installation.                                                                                                                                     |
| <b>Suction Anchor Pile</b>            | Open tipped cylindrical pile, used as an anchor for a mooring system, which is installed into the seafloor by suction. Suction is typically achieved by closing the top of the pile and pumping out water from inside the pile. |

### 1.3.3 Abbreviations

| Term        | Definition                               |
|-------------|------------------------------------------|
| <b>AISC</b> | American Institute of Steel Construction |
| <b>CP</b>   | Cathodic Protection                      |
| <b>DnV</b>  | Det Norske Veritas                       |
| <b>DSS</b>  | Direct Simple Shear                      |
| <b>FEM</b>  | Finite Element Method                    |
| <b>FPS</b>  | Floating Production System               |
| <b>MODU</b> | Mobile Offshore Drilling Unit            |
| <b>PCPT</b> | Piezocone Penetrometer Testing           |
| <b>SI</b>   | International System of Units            |
| <b>SRD</b>  | Soil Resistance to Driving               |

### 1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section or clause number is shown in brackets ( ). Other documents referenced by this DEP are listed in (13).

## 1.5 SUMMARY OF MAIN CHANGES

This DEP is a full revision of the DEP of the same number dated September 2011. The following are the main, non-editorial changes.

| Section/Clause | Change                                                                                                                                                                               |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1.1            | The DEP also references underlying standard ISO19901-7.<br>Scope extended to FLNG facilities                                                                                         |
| 5.3            | Analysis of pile holding capacity is, where possible, referenced to API RP 2GEO.<br>References to API RP 2A-WSD are updated to reflect the 22 <sup>nd</sup> edition of the standard. |
| 5.3.2          | Qualitative requirements for selection of pile locations are added.                                                                                                                  |
| 5.3.4          | Additional guidance on the trenching of forerunners is added to address recent observations offshore West Africa.                                                                    |
| 5.3.5          | Analysis of set-up in normally consolidated clays is referenced to Bogard et al (2000).                                                                                              |
| 6.2            | Analysis of pile installation is, where possible, referenced to API RP 2GEO.                                                                                                         |
| 6.4            | Analysis of pile holding capacity is, where possible, referenced to API RP 2GEO.<br>References to API RP 2A-WSD are updated to reflect the 22 <sup>nd</sup> edition of the standard. |
| 7.0            | References to API RP 2A-WSD are updated to reflect the 22 <sup>nd</sup> edition of the standard.                                                                                     |
| 8.2            | The requirement for the analysis of buckling of suction piles under predicted installation pressures is added.                                                                       |
| 8.2.2          | Methods for determination of soil reactions for structural analysis of suction piles are added.                                                                                      |
| 11.            | Additional guidance on vent holes for suction piles is added.                                                                                                                        |
| 11.2           | Example drawings of pile markings removed                                                                                                                                            |
| 12.1           | Actions by Principal updated.                                                                                                                                                        |
| 12.2           | Contents of structural design report are updated to include predicted ultimate and allowable buckling pressured for suction pile installation.                                       |
| 13.            | References to ISO 19901-7, Bhattacharjee et al (2014) and Bogard et al. (2000) are added. Reference to API RP 2RD is removed.                                                        |

## 1.6 COMMENTS ON THIS DEP

Comments on this DEP may be submitted to the Administrator using one of the following options:

|                                                                      |                                                                                                                                                                                                                                                           |
|----------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Shell DEPs Online</b><br>(Users with access to Shell DEPs Online) | Enter the Shell DEPs Online system at <a href="https://www.shelldeps.com">https://www.shelldeps.com</a><br><br>Select a DEP and then go to the details screen for that DEP.<br><br>Click on the "Give feedback" link, fill in the online form and submit. |
|----------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

|                                                                     |                                                                                                                                                                                                                                                                   |
|---------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>DEP Feedback System</b><br>(Users with access to Shell Wide Web) | Enter comments directly in the DEP Feedback System which is accessible from the Technical Standards Portal <a href="http://www.shell.com/standards">http://www.shell.com/standards</a> .<br><br>Select "Submit DEP Feedback", fill in the online form and submit. |
| <b>DEP Standard Form</b><br>(Other users)                           | Use DEP Standard Form 00.00.05.80-Gen. to record feedback and email the form to the Administrator at <a href="mailto:standards@shell.com">standards@shell.com</a> .                                                                                               |

Feedback that has been registered in the DEP Feedback System by using one of the above options will be reviewed by the DEP Custodian for potential improvements to the DEP.

#### 1.7 DUAL UNITS

This DEP contains both the International System (SI) units, as well as the corresponding US Customary (USC) units, which are given following the SI units in brackets. When agreed by the Principal, the indicated USC values/units may be used.

#### 1.8 NON NORMATIVE TEXT (COMMENTARY)

Text shown in italic style in this DEP indicates text that is non-normative and is provided as explanation or background information only.

#### 1.9 PROJECT SPECIFIC REQUIREMENTS

Project specific criteria for the design of mooring anchor piles, such as loads, soil parameters, installation criteria and class requirements are presented in the Basis of Design. Where a conflict exists between the Basis of Design and this DEP, then the Basis of Design governs.

#### 1.10 APPLICATION TO MODUs

When used for the design of initiation or restraint piles, the service load combinations described in the DEP shall be replaced by project specific load combinations.

## **2. GENERAL REQUIREMENTS**

### **2.1 OVERVIEW**

1. Each project shall generate a Basis of Design, which specifies project-specific criteria to supplement or modify the requirements given in this DEP.
2. If the mooring anchor piles are to be classed, then Classification Society Rules that exceed or contradict requirements in this DEP shall be clarified in the Basis of Design.

### **2.2 FUNCTIONAL REQUIREMENTS**

1. Functional requirements for mooring anchor pile design shall be specified per API RP 2SK, Section E.1.2.
  - a. Where Section E.1.2 of API RP 2SK uses the term “should”, it shall be interpreted as a “shall” requirement unless otherwise instructed by the Principal.
2. Permissible limits of stress and fatigue shall not be exceeded during loadout and transport of the anchor piles nor during planned removal of the anchor piles.

### **2.3 EXTERNAL STANDARD**

1. The design of anchor piles shall comply with the requirements of API RP 2SK or ISO 19901-7.
2. This DEP supplements the external standard, where specific instructions, clarifications, or deviations are necessary.
  - b. Unless otherwise noted by this DEP, the content of the external standard shall be the minimum standard for design.

## **3. LOAD COMBINATIONS AND SAFETY CATEGORIES**

### **3.1 GENERAL**

1. Mooring anchor piles shall be designed for load combinations that are associated with the following conditions:
  - a. Loadout and Transportation – refer to (3.2);
  - b. Installation – refer to (3.3);
  - c. Removal– refer to (3.4);
  - d. Service – refer to (3.5);
  - e. Accidental Events – refer to (3.6).
2. Safety categories (3.7) are defined for service load combinations and shall determine the allowable loads and stresses to be used in design.

### **3.2 LOADOUT AND TRANSPORTATION**

#### **3.2.1 General**

1. Loadout and transportation load combinations shall be determined in accordance with project specifications for loadout, transportation and installation of structures and the specific guidance in (3.2.2) and (3.2.3), as applicable.

#### **3.2.2 Driven pile loadout and transportation**

1. Loadout and transportation loads for driven anchor piles shall be determined based on the guidance in API RP 2T, section 10.3.3.6 (excluding 10.3.3.6e and 10.3.3.6f).

**3.2.3 Suction pile loadout and transportation**

1. Loadout and transportation loads for suction anchor piles shall be determined based on the guidance in in API RP 2SK, Appendix E, sections E.5.1.2 and E.5.2.5.

**3.3 INSTALLATION****3.3.1 General**

1. Mooring anchor pile installation shall comprise all operations from completion of pile loadout and transport (3.2) until the pile reaches final penetration.

**3.3.2 Handling**

1. Handling loads shall comprise, but not be limited to, the functional loads due to:
  - a. weight of pile and appurtenances;
  - b. weight of mooring system components attached to pile;
  - c. weight of installation / removal equipment;
  - d. reactions due to mooring system components attached to pile; and
  - e. reactions due to installation / removal equipment.

**3.3.3 Static loads during driven pile installation**

1. Static loads associated with stabbing of a hammer on a pile shall be computed as per API RP 2T, Section 10.3.3.6d.

**3.3.4 Fatigue loading during driven pile installation**

1. Fatigue loading results from the dynamic impact of the hammer during pile driving operations and shall be computed as per API RP 2T, Annex D, Section D.3.1, (first paragraph).

**3.3.5 Suction pile installation**

1. Suction anchor piles shall be designed for the maximum underpressure required for pile embedment (6.2) in accordance with API RP 2SK, Appendix E, Section E.5.2.3.

**3.4 REMOVAL**

1. Mooring anchor pile removal shall comprise operations necessary for contingency removal of the pile at any penetration up to or including the target penetration.
2. Removal loads shall be computed based on contingency procedures, which are documented in the project installation manual or equivalent.
3. Removal conditions for suction anchor piles shall also comply with the requirements as per API RP 2SK, Appendix E, Section E.5.2.4.

**3.5 SERVICE**

*Service loads result from wind, wave and current forces acting on the Floating Production System (FPS).*

**3.5.1 Extreme loads**

1. Service extreme loads shall correspond to the maximum mooring line tensions computed by global analysis of the FPS.
2. Load cases shall correspond to those used for mooring system strength design and be dependent on the following:
  - a. the FPS configuration (number of risers);
  - b. FPS condition (e.g., flooded compartment);