

DEP SPECIFICATION

**GEOTECHNICAL AND FOUNDATION ENGINEERING -  
ONSHORE**

DEP 34.11.00.12-Gen.

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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 geotechnical and foundation engineering of onshore structures and civil engineering works, including jetties and waterfront structures. It does not cover the design of offshore structures.

This DEP specifies design requirements to be used in conjunction with design according to European and North American standards for geotechnical and foundation engineering. However, it is accepted that in some parts of the world or for particular types of design, the use of other standards is appropriate. The applicability of other codes is detailed in (2).

Specific requirements and recommendations relating to ground investigations, earthworks, geotechnical elements of roads, underground piping and tank pads and bunds are given in the DEPs listed in (10) and thus are not covered by this DEP. This DEP does not give recommendations for the design of tailings embankments or fluid retention structures, which is a highly specialised activity requiring expert design, based on local regulatory requirements.

This DEP covers the following main topics:

- a) Design Basis
- b) Spread Foundations
- c) Pile Foundations
- d) Machine Foundations
- e) Retaining Structures and Anchorages
- f) Marine and Waterfront Structures
- g) Embankments and Slopes
- h) Ground Improvement and Reinforcement
- i) Dewatering
- j) Geotechnical Design under Seismic Loading

This DEP will be used in conjunction with other DEPs covering the specific requirements of various types of civil engineering structures, such as concrete and steel structures, control buildings, stacks, drainage, etc.

This is a revision of the DEP of the same number dated February 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 oil and gas production, gas handling, oil refining, chemical processing, gasification, distribution and supply/marketing. 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.

The word **may** indicates a permitted option.

#### 1.3.2 Specific definitions

| Term                            | Definition                                                                                                                                                                                                                                                                      |
|---------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Non conflicting guidance</b> | Guidance given in codes, standards and other reference documents that does not conflict with EN 1997.<br><br>For European standards, refer to Clause 1.5 of EN 1990 and Clause 1.5 of EN 1997. For North American standards, refer to AASHTO LRFD Bridge Design Specifications. |

#### 1.3.3 Abbreviations

| Term          | Definition                                                         |
|---------------|--------------------------------------------------------------------|
| <b>AASHTO</b> | American Association of State Highway and Transportation Officials |
| <b>ACI</b>    | American Concrete Institute                                        |
| <b>ALS</b>    | Accidental limit states                                            |
| <b>CAPWAP</b> | Configuration and Provisioning for Wireless Access Points          |
| <b>CFEM</b>   | Canadian Foundation Engineering Manual                             |
| <b>CPT</b>    | Cone Penetration Tests                                             |
| <b>CUR</b>    | Centre of Civil Engineering Research and Codes (The Netherlands)   |
| <b>DA</b>     | Design Approach                                                    |
| <b>DSSI</b>   | Dynamic Soil-Structure Interaction                                 |
| <b>EEMUA</b>  | Engineering Equipment and Materials Users' Association             |
| <b>EN</b>     | European Norm (Standard)                                           |

| <b>Term</b>  | <b>Definition</b>                                                                                                                                             |
|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>EQU</b>   |                                                                                                                                                               |
| <b>FEA</b>   | Finite Element Analysis                                                                                                                                       |
| <b>FHWA</b>  | Federal Highway Administration Office of Highway Safety (US)                                                                                                  |
| <b>GDR</b>   | Geotechnical Design Report                                                                                                                                    |
| <b>GEO</b>   | Geotechnical                                                                                                                                                  |
| <b>N/A</b>   | Not Applicable                                                                                                                                                |
| <b>NDP</b>   | Nationally Determined Parameters                                                                                                                              |
| <b>OBE</b>   | Operating Basis Earthquake                                                                                                                                    |
| <b>ORS</b>   | Opportunity Realisation Standard                                                                                                                              |
| <b>PIANC</b> | Permanent International Association for Navigation Conferences, which now refers to itself as "The World Association for Waterborne Transport Infrastructure" |
| <b>SLS</b>   | Service Limit State                                                                                                                                           |
| <b>SPT</b>   | Standard Penetration Test                                                                                                                                     |
| <b>SSE</b>   | Safe Shutdown Earthquake                                                                                                                                      |
| <b>STR</b>   | Structural                                                                                                                                                    |
| <b>ULS</b>   | Ultimate Limit State                                                                                                                                          |
| <b>UPL</b>   | Uplift                                                                                                                                                        |
| <b>USACE</b> | United States, Army Corps of Engineers                                                                                                                        |

#### 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 (10).

#### 1.5 SUMMARY OF MAIN CHANGES

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

| <b>Section/Clause</b> | <b>Change</b>                                                                       |
|-----------------------|-------------------------------------------------------------------------------------|
| All                   | This has been a major update and the changes are too numerous to mention in detail. |

## 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://swwww.shell.com/standards">http://swwww.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.

*Non-normative text is normally indented slightly to the right of the relevant DEP clause.*

## **2. DESIGN BASIS**

### **2.1 OBJECTIVE**

*The objective of this DEP is to provide requirements for general aspects of onshore ground engineering related to oil and gas facilities.*

*This DEP is complementary to the following DEPs:*

- DEP 25.80.10.14-Gen.
- DEP 34.00.01.10-Gen.
- DEP 34.00.01.30-Gen.
- DEP 34.11.00.10-Gen.
- DEP 34.11.00.11-Gen.
- DEP 34.13.20.31-Gen.,
- DEP 34.19.20.31-Gen.,
- DEP 34.51.01.33-Gen.
- DEP 35.00.10.10-Gen.

### **2.2 STANDARDS OF PRACTICE**

*European and North American standards of practice are equally accepted and the selection of standards depends on the project location, specifications, codes and regulations. The base standards for specific applications of geotechnical and foundation engineering are summarised in Table 2.1.*

*Short titles for standards will be used throughout this DEP where appropriate.*

#### **2.2.1 Compatibility**

1. Geotechnical and foundation design standards shall be compatible with those used for other elements of civil engineering design.

#### **2.2.2 European**

1. For projects applying Eurocodes, EN 1997-1 (Eurocode 7) and EN 1998-5 (Eurocode 8) shall be used for geotechnical and foundation engineering in accordance with Table 2.1.
2. If Eurocodes are the design codes applicable to the project, the partial factors specified in EN 1997-1 shall be supplemented by National Annexes which set out alternative methods and the Nationally Determined Parameters (NDPs) for individual countries.
  - a. For projects in countries where there is no National Annex, Design Approach 1 and UK NDPs shall be adopted for design, see (Appendix C).

#### **2.2.3 North American**

1. For projects applying North American standards, AASHTO, FHWA and ACI specifications and resistance factors shall be used for geotechnical and foundation engineering in accordance with Table 2.1, with load combinations in accordance with ASCE 7.
2. If local standards, specifications, codes, practices and regulations exist for geotechnical and foundation engineering, they may be substituted only with prior written approval by the Principal.
3. The standards edition in effect on the date of contract award shall be used, except as otherwise noted.

**Table 2.1 Base Standards for Geotechnical and Foundation Engineering**

| Application                        | Component                    | European                                          |                                                                                                | American                                                                                                                                |
|------------------------------------|------------------------------|---------------------------------------------------|------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
|                                    |                              | Design                                            | Construction                                                                                   | Design and Construction                                                                                                                 |
| Shallow Foundations (3)            | Pads (Footings)              | EN 1997-1 (Eurocode 7)                            | N/A                                                                                            | AASHTO LRFD Bridge Design Specifications, Section 10                                                                                    |
|                                    | Strips                       | EN 1998-5 (Eurocode 8)                            | N/A                                                                                            |                                                                                                                                         |
|                                    | Rafts                        |                                                   | N/A                                                                                            |                                                                                                                                         |
| Pile Foundations (4)               | Driven                       | EN 1997-1, Clause 7                               | EN12699                                                                                        | FHWA NHI-05-042 - Driven Pile Foundations                                                                                               |
|                                    | Drilled Shafts               |                                                   | EN1536                                                                                         | FHWA-IF-99-025 - Drilled Shafts                                                                                                         |
|                                    | Continuous Flight Auger      |                                                   |                                                                                                | FHWA-HIF-07-039 - Continuous Flight Auger Piles                                                                                         |
|                                    | Micropiles                   |                                                   | EN14199                                                                                        | FHWA – SA – 97 – 070<br>Micropile Design and Construction                                                                               |
| Machine Foundations (5)            | Rotating                     | ISO 1940-1<br>ISO 10816-1.                        | N/A                                                                                            | ACI 351.3R-04<br>API686                                                                                                                 |
|                                    | Reciprocating                |                                                   | N/A                                                                                            |                                                                                                                                         |
| Retaining Structures (6)           | All                          | EN 1997-1 (Eurocode 7)<br>EN 1998-5 (Eurocode 8)  | EN12063 – sheet pile walls<br>EN1538 – diaphragm walls<br>EN1536 – secant/contiguous pile wall | AASHTO LRFD Bridge Design Specifications, Section 11<br>FHWA-NHI-10-024 Design and Construction of MSE Walls and Reinforced Soil Slopes |
| -Ground Improvement (9)            | VIBRATION/ COMPACTION        | EN 1997-1<br>CIRIA Report C573 and BS 8004        | EN 14731                                                                                       | FHWA-SA-95-037 Dynamic Compaction<br>FHWA-RD-83-026 Stone Columns                                                                       |
|                                    | PRELOADING/PRE-CONSOLIDATION | EN 15237                                          | EN 15237                                                                                       | FHWA/RD-86/168 Prefabricated Vertical Drains                                                                                            |
|                                    | Reinforced Soil              | BS 8006-1 and CIRIA Report C637                   | Reinforced Fill – EN14475<br>Soil Nailing – EN14490                                            | FHWA-NHI-10-024/ FHWA-NHI-10-025<br>Mechanically Stabilized Earth Walls/Reinforced Soil Slopes<br>FHWA-NHI-14-007 - Soil Nail Walls     |
|                                    | EXCAVATION AND REPLACEMENT   | CIRIA Report C573 Clause 7/DEP 34.11.00.11        |                                                                                                |                                                                                                                                         |
|                                    | ADMIXTURES                   | CIRIA Report C573 Clause 8                        | Deep Mixing - EN14679                                                                          | FHWA-HRT-13-046<br>Deep Mixing for Embankment and Foundation Support                                                                    |
|                                    | Grouting                     | CIRIA Report C573, Clause 9 and BS 8004, Clause 6 | grouting works - EN 12715<br>jet grouting - EN 12716.                                          |                                                                                                                                         |
| Marine & Waterfront Structures (7) | Quay Walls                   | (4) & (6) with<br>BS 6349 Parts 1, 2 & 4          |                                                                                                |                                                                                                                                         |
|                                    | Jetties/Dolphins             | DEP 35.00.10.10-Gen., Parts V, VI, VII & VIII     |                                                                                                |                                                                                                                                         |
|                                    | Breakwaters & Revetments     | (8) with BS 6349 Part 7                           |                                                                                                |                                                                                                                                         |

#### 2.2.4 Other Standards

1. The Contractor shall determine when national and/or local regulations are more stringent than the base codes, in which case national and/or local regulations shall be used.
2. 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 the national and/or local regulations.

*In some cases, the nomenclature and methodologies of national and/or local regulations are a clear departure from the base standards (e.g., Russian codes). In such cases, parallel designs using both local codes and base standards might be necessary to determine if they are consistent.*

3. For cold regions, the following standards should be applied:
  - a. Canadian Foundation Engineering Manual (CFEM), or
  - b. US Army Corps of Engineers (USACE) Special Report 80-34.

### 2.3 CRITERIA

#### 2.3.1 Limit states

1. Equivalent limit states according to both European (EN) and North American (AASHTO) codes shall be as summarized in Table 2.2.

| ENs | AASHTO                 | Description                                                                                                                                                              |
|-----|------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SLS | Service                | Restrictions on stress, displacement and crack width under regular service conditions.                                                                                   |
| FLS | Fatigue (and Fracture) | Restrictions on stress range at a number of expected stress range cycles (and material toughness requirements).                                                          |
| ULS | Strength               | Strength and stability to resist the specified statistically significant actions or load combinations that a structure is expected to experience during its design life. |
| ALS | Extreme                | Structural survival and prevention of consequence escalation in a major accidental or unexpected event.                                                                  |

*Specific guidance on the use of numerical analysis for limit state verification is provided in (Appendix D).*

#### 2.3.2 Displacement tolerances

1. Limiting values of displacement or strain for the serviceability limit state shall be specified by the Manufacturer/Supplier or by the Principal.

*Limiting values of displacement are usually determined by consideration of the maximum differential settlement and distortion that a structure/process equipment/piping can tolerate.*

2. Consideration should be given to the influence of construction sequence and time dependency and whether total, post construction or post hook-up displacements are critical.

### 2.3.3 Seismicity

1. The effects of cyclic and dynamic loads, as well as seismic wave propagation, on the soil shall be considered in the design, including the effects of the following:
  - a. Changes in the soil internal structure and consequent changes in volume;
  - b. Increase in pore pressure and consequent decrease in effective pressure (undrained conditions);
  - c. Degradation and strain rate effects of soil properties;
  - d. Liquefaction;
  - e. Kinematic interaction due to contrast in deformation properties between soil layers;
  - f. Amplification factors related with topography.

*Seismic waves can have different sources and are not only as the result of tectonic earthquakes. Common sources of seismic waves that need to be considered in design are rotating and alternating equipment, as well as induced earthquakes whilst producing from a subsurface reservoir.*

## 2.4 METHODS

1. Verification that limit states are not exceeded shall involve one or more of the following approaches:
  - a. use of calculations, including analytical, semi-empirical and numerical models;
  - b. adoption of prescriptive measures;
  - c. experimental models and load tests;
  - d. an observational method.
2. The methods to be used for demonstrating that limit states will not be exceeded shall be identified by the Contractor.

*Specific guidance on the use of numerical analysis for limit state verification is provided in (Appendix D).*

## 2.5 KEY DELIVERABLES

*Key documents, background data and design activities relevant for geotechnical and foundation engineering of a typical project are summarised in Figure 2.1. Design deliverables are appropriate for the Define and Execute phases.*

### 2.5.1 Geotechnical Design Premise

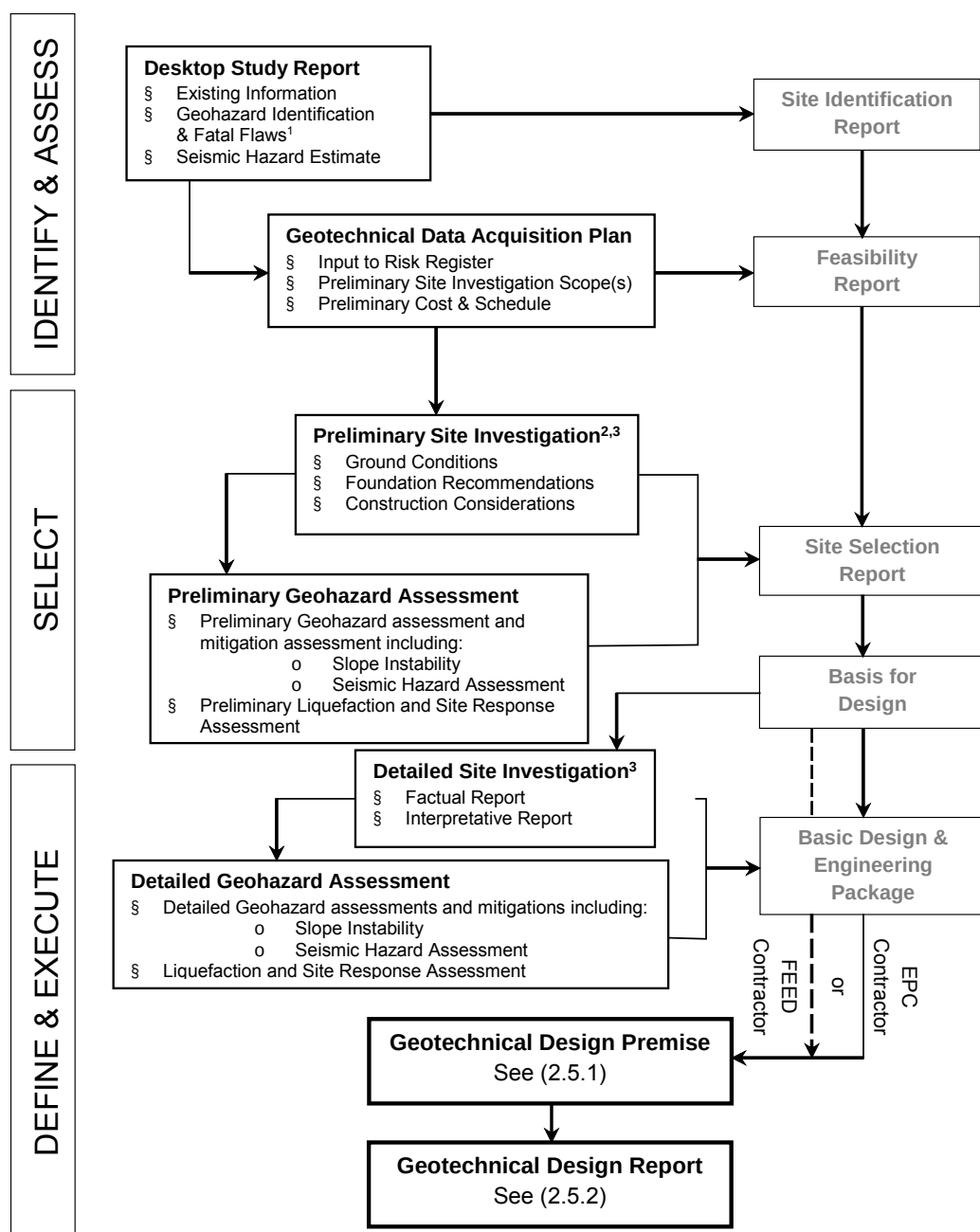
1. A geotechnical design premise shall be produced by the Contractor to define the basis of the geotechnical concept and detailed design of a structure or facility.
2. The scope of the geotechnical design premise shall include the following content for each design effort, as a minimum:
  - a. Proposed structures and functional requirements;
  - b. Relevant codes and standards;
  - c. Actions and load cases;
  - d. Limit states, serviceability and/or performance criteria;
  - e. Load, material and resistance factors, or factors of safety;
  - f. Pertinent design soil (and rock) parameters, including the effects of cyclic, dynamic and/or seismic loading;
  - g. Proposed design process, methods and models.

3. The geotechnical design premise shall be approved by the Principal before the beginning of any design activity related with the scope of this DEP.

#### **2.5.2 Geotechnical Design Report**

1. Based on the geotechnical design premise, a geotechnical design report shall be produced by the Contractor to document the geotechnical and foundation engineering design of a structure or facility.
2. The geotechnical design report shall demonstrate safe and efficient design and include the following content, as a minimum:
  - a. Design calculations and analysis results;
  - b. Safety, serviceability and/or performance criteria checks;
  - c. Drawings;
  - d. Specifications for construction, defining material properties and construction requirements  
*i.e., concrete and steel grade, maximum concrete volumes.*
  - e. An assessment of the aggressiveness of the environment to allow requirements for concrete mix design.
  - f. Inspection and test plan, defining all the verifications, tests and acceptability criteria relevant to the construction period.
  - g. Monitoring plan, defining all the verifications, tests and acceptability criteria relevant to the service life of the structure.
  - h. Maintenance plan, defining all the activities necessary to ensure the safety and geotechnical serviceability during the Operate phase.
3. The geotechnical design report shall be approved by the Principal before the beginning of any construction activity related with the scope of this DEP.

**Figure 2.1 Geotechnical Documents in Context with Key Deliverables and ORS Phases**



Note: 1 A geotechnical investigation shall be required in Identify and Access if a fatal flaw exists which could affect project feasibility.

2 Timing for preliminary site investigation shall comply with Table 6.7 of DEP 34.11.00.10-Gen.

3 Preliminary and detailed site investigations may be combined depending on project requirements

### 3. SPREAD FOUNDATIONS

#### 3.1 SCOPE

*This section specifies requirements for foundations that transmit the loads to the soil immediately below the superstructure. Examples are the following:*

- *pad foundations (footings),*
- *strip foundations, and*
- *raft foundations.*

#### 3.2 GENERAL

##### 3.2.1 Load Resistance Factor Design (LRFD) versus Allowable Stress Design (ASD)

1. Load combinations and partial factors on actions shall be in accordance with DEP 34.00.01.30-Gen. for load resistance factor design (LRFD).
2. Load cases and action factors shall be in accordance with (Appendix A) and (Appendix B).
3. A conservative allowable stress design (ASD) may be utilised if it does not affect the choice of foundation type (e.g. if applied actions are between 100% and 150% of the allowable bearing/sliding capacity).
4. ASD shall follow the requirements of the code with the partial factors on actions in accordance with (Appendix B.2) or set to 1.0 and the global factors of safety given in Table 3.1.

**Table 3.1 ASD Factors of Safety for Spread Foundations**

| Loading Condition | Load Case                  | Minimum Factor of Safety |
|-------------------|----------------------------|--------------------------|
| Bearing           | Normal Operation           | 3.00                     |
|                   | Wind/OBE Seismic (Extreme) | 2.25                     |
|                   | SSE Seismic (Abnormal)     | 1.50                     |
| Sliding           | Normal Operation           | 1.50                     |
|                   | Wind/OBE Seismic (Extreme) | 1.50                     |
|                   | SSE Seismic (Abnormal)     | 1.20                     |

##### 3.2.2 Standards of Practice - Eurocodes

1. Design shall be according to EN 1997-1 (Eurocode 7) and EN 1998-5 (Eurocode 8) for spread foundations.
2. Design Approach 1 shall be employed for ULS designs as detailed in EN 1997-1.
  - a. For geographical locations where a National Annex does not apply, the UK Nationally Determined Parameters (NDPs) shall be adopted, see (Appendix C).

### 3.2.3 Standards of Practice - North American

1. Design of shallow foundations shall be according to AASHTO LRFD Bridge Design Specifications, Section 10, using load combinations in accordance with ASCE 7 and AASHTO resistance factors.

### 3.2.4 Eccentricity on Actions or Loads

#### 3.2.4.1 European

1. Limited vertical load eccentricity shall be accepted in shallow foundations with no steep variation of compression stresses across the section.

- a. The middle third rule shall be adopted as good practice.

*For "good practice" in (3.2.3 item 1): The middle third rule (for rectangular sections), states that, in each direction, the ratio between the moment and the normal force acting on a given cross section should not be greater than 1/3 of the half dimension of the section (distance to the neutral line for a tension resistant material). This is equivalent to saying that the flexural stress is not greater than the moment that would reduce compression to zero in the least compressed side of the cross sections.*

2. In cases where large vertical or horizontal eccentricities exceed the middle third rule, the foundation model shall be adjusted in order to reduce their effects (e.g., use of foundation beams, increased normal force, change in pad dimensions).

#### 3.2.4.2 North American

1. The eccentricity on actions shall be limited in accordance with AASHTO Section 10.6.3.3 for operational load cases and Section 10.6.5 for extreme load cases.

#### 3.2.4.3 Torque

*Torsional actions decrease the overall bearing and sliding capacity of shallow foundations.*

1. In presence of eccentric horizontal loads that create torsional moments perpendicular to the plan of the footing, the recommendations of DNV-ST-0126 shall be followed.

### 3.2.5 Settlement criteria

1. Settlement limits for total or differential settlement shall be defined for the foundation by the Contractor responsible for design of the superstructure and presented in the geotechnical design premise.
2. For Eurocodes, calculations of settlement shall be in accordance with Section 6.6.2 of EN 1997-1.
3. For North American standards, settlement calculations shall be in accordance with Section 10.6.2 of AASHTO LRFD Bridge Design Specifications.
4. The influence of adjacent footings on settlements shall be analysed considering the applied stress overlapping underneath the footings.

### 3.2.6 Construction

1. The following construction aspects shall be detailed in the geotechnical design report and annotated on the AFC foundation drawings:
  - a. the bearing stratum considered in design for supporting the foundation, the minimum embedment of the foundation in the bearing stratum and expected elevation of the contact surface;
  - b. in-situ tests required to confirm design assumptions and acceptance criteria;
  - c. in cases where the bearing layer may be susceptible to rapid softening, the maximum time between excavation and concreting;

- d. where excavations deeper than 1.2 m (4 ft) are needed to reach the foundation level, definition of safe slope geometry (or any bracing temporary structure) as demonstrated by specific calculations;
  - e. groundwater control methods and schemes which do not adversely affect the characteristics of the bearing stratum (e.g., by causing heave or settlement) or the performance of adjacent foundations.
2. Installation of earthing connections should be in accordance with Standard drawings S 68.042 and S 68.003.

### 3.3 PAD FOUNDATIONS (ENs ONLY)

#### 3.3.1 General

1. The design of spread foundations with Eurocodes shall be in accordance with Clause 6 of EN 1997-1.
2. The indirect method for Eurocodes may be used only for Geotechnical Category 1 structures where all of the following apply:
  - a. well established and documented successful experience exist;
  - b. there is no explicit settlement limit specified ;
  - c. exceptional loading conditions do not prevail, such as for highly inclined or eccentric loads, highly variable or cyclic loads;
3. The indirect method shall not be applied for the following:
  - a. soft clays and highly organic soils  
*Settlement calculations are necessary;*
  - b. collapsible soils.

#### 3.3.2 ULS Calculations

1. Depth correction factors shall not be applied when calculating the bearing resistance of shallow spread foundations where  $D/B \leq 1$ .
2. Where spread foundations are constructed at substantial depth (i.e.,  $D/B > 1$ ) and the ground above founding level is at least as competent as the ground below founding level, depth correction factors may be applied as follows:
  - a. For undrained conditions calculated in accordance with Annex D of EN 1997-1 the bearing resistance formula (equation D.1 in EN 1997-1) is replaced with Equation 3.1.  

$$R/A' = (\pi + 2)c_u b_c s_c i_c d_c + q$$

Eqn. 3.1

and  $d_c$  may be taken as,

$$d_c = 1 + 0.4k$$

where

$k$  is  $\tan^{-1}(D/B)$  for  $D/B > 1$

$D$  is the foundation depth and  $B$  the foundation width.
  - b. For drained conditions calculated in accordance with Annex D of EN 1997-1 the bearing resistance formula (equation D.2 in EN 1997-1) is replaced with Equation 3.2.

$$R/A' = c' N_c b_c s_c i_c d_c + q' N_q b_q s_q i_q d_q + 0.5 \gamma' B' N_\gamma b_\gamma s_\gamma i_\gamma d_\gamma$$

Eqn. 3.2

$$d_\gamma = 1$$

$$d_c = S_{qd} - (1 - S_{qd}) / (N_c \tan \phi')$$