

DEP SPECIFICATION

GEOTECHNICAL AND FOUNDATION ENGINEERING - ONSHORE

DEP 34.11.00.12-Gen.

February 2011

(DEP Circular 99/11 has been incorporated)

(DEP Circular 68/12 has been incorporated)

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DESIGN AND ENGINEERING PRACTICE



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These views are based on the experience acquired during involvement with the design, construction, operation and maintenance of processing units and facilities. Where deemed appropriate DEPs are based on, or reference international, regional, national and industry standards.

The objective is to set the recommended standard for good design and engineering practice to be applied by Shell companies in oil and gas production, oil refining, gas handling, gasification, chemical processing, or any other such facility, and thereby to help achieve maximum technical and economic benefit from standardization.

The information set forth in these publications is provided to Shell companies for their consideration and decision to implement. This is of particular importance where DEPs may not cover every requirement or diversity of condition at each locality. The system of DEPs is expected to be sufficiently flexible to allow individual Operating Units to adapt the information set forth in DEPs to their own environment and requirements.

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1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements 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 the Eurocodes - EN 1997-1 (Eurocode 7) and EN 1998-5 (Eurocode 8) 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 Eurocodes is not 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 (11) and thus are not covered by this DEP. Furthermore 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 shall 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 January 2010; 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 refineries, chemical plants, gas plants, exploration and production facilities and supply/distribution installations. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process should 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

Refer also to Clause 1.5 of EN 1990 and Clause 1.5 of EN 1997.

NON CONFLICTING GUIDANCE is guidance given in codes, standards and other reference documents that does not conflict with EN 1997.

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced by this DEP are listed in (11).

1.5 SUMMARY OF MAIN CHANGES

This DEP is a revision of the DEP of the same number dated January 2010. The following are the main, non-editorial changes.

In this revision normative requirements have been summarised.

Amendment A03

1.6 COMMENTS ON THIS DEP

Comments on this DEP may be submitted to the Administrator using the DEP Feedback Form by:

- Entering comments directly in the DEP Feedback System on the Technical Standards Portal <http://swww.shell.com/standards> (mandatory for users with access to Shell Wide Web);
- Clicking on the DEP Feedback Form button on the DEPs DVD-ROM main page (for users without access to Shell Wide Web);
- Requesting a copy of the DEP Feedback Form from the Administrator at standards@shell.com (for users without access to Shell Wide Web).

For the last two options, the completed DEP Feedback Form can be attached to an email and submitted to the Administrator at standards@shell.com. Only feedback that is entered into the Feedback Form will be considered.

1.7 DUAL UNITS

In this DEP, the International System of units (SI) shall be understood to prevail over US Customary (USC) units. USC units are provided in brackets following the SI units for information.

2. DESIGN BASIS

2.1 OBJECTIVE

Amended per
Circular 99/11

The objective of the Geotechnical and Foundation Engineering DEP is to provide requirements for all aspects of onshore ground engineering related to oil and gas facilities.

This DEP shall be read in conjunction with and is complementary to the following DEPs:

- a) DEP 34.00.01.10-Gen., Earthquake Design for Onshore Facilities
- b) DEP 34.00.01.30-Gen., Structural design and engineering
- c) DEP 34.11.00.10-Gen., Site Investigations
- d) DEP 34.11.00.11-Gen., Site preparation and earthworks, including tank foundations and tank farms
- e) DEP 34.13.20.31-Gen., Roads, paving, surfacing, slope protection and fencing
- f) DEP 34.19.20.31-Gen., Reinforced concrete foundations and structures
- g) DEP 34.28.00.31-Gen., Onshore Steel Structures
- h) DEP 34.51.01.33-Gen., Above ground vertical storage tanks - Design and construction (based on API 650)
- i) DEP 35.00.10.10-Gen., Design of jetty facilities (amendments/supplements to BS 6349-1/2/4)

2.2 STANDARDS OF PRACTICE

2.2.1 Eurocodes

This DEP specifies design requirements to be used in conjunction with the Eurocodes - EN 1997-1 (Eurocode 7) and EN 1998-5 (Eurocode 8) for geotechnical and foundation engineering.

The partial factors specified in EN 1997-1 are supplemented by National Annexes which set out alternative methods and the Nationally Determined Parameters (NDPs) for individual countries. This Appendix sets out the (UK) NDPs that shall be adopted when design is carried out for projects in countries where EN 1997-1 has not been adopted as the national standard or where there is no National Annex.

Amended per
Circular 68/12

Structures classified as medium or high consequence in accordance with DEP 34.00.01.10-Gen. shall be considered as special structures and shall be designed to meet the specified performance requirements with the additional requirements of this DEP.

Design Approach 1 shall be employed for ULS designs as detailed in EN 1997-1. The design approaches are explained in detail in EN 1997-1 Clause 2.4.7.3.4.

2.2.2 Alternative Codes of Practice

Amended per
Circular 99/11

In some countries, national codes and design standards are mandatory and these may conflict with parts of EN 1997-1. This DEP permits the use of certain codes as an alternative to the Eurocodes. A definitive list of national standards that may be used as an alternative to EN 1997-1 is kept by the Onshore Geotechnical SME. For countries where national codes are not included in this list, the Eurocode shall generally take precedence unless agreed otherwise by the appropriate technical authority.

For projects in the US or countries where American standards and practice are normally followed, the following codes may be employed subject to agreement by the Principal:

- ACI 318 / 318R – Building Code Requirements for Structural Concrete and Commentary.
- ACI 350 / 350R – Code Requirements for Environmental Engineering Concrete Structures and Commentary.
- ACI 543R – Design, Manufacture, and Installation of Concrete Piles.
- AASHTO LRFD Bridge Design Specification.

A consistent set of codes of practice following the same design approach shall be adopted for the design. The codes of practice adopted for each geotechnical and foundation design shall be set out in the Geotechnical Design Report. Geotechnical and foundation design codes shall be compatible with codes used for other elements of Civil Engineering design.

The Contractor shall also determine when national and/or local regulations are more stringent than the applied codes. 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 the national or local regulations.

2.2.3 Hazard consequence levels

Three hazard consequence levels shall be used for Shell projects. The categories depend on the consequence of failure of a structure or facility. For complete definitions refer to DEP 34.00.01.10-Gen.

2.2.4 Geotechnical design categories

Structures shall be classified into Geotechnical Categories, in accordance with EN 1997-1 based on the complexity of the structure, the ground conditions and the loading, and the level of risk that is acceptable to the structure.

2.3 IDENTIFICATION OF DESIGN SITUATIONS

2.3.1 Fundamental Requirements

The detailed specification of design situations shall include consideration of the following as appropriate:

- a) general suitability of the ground on which the structure is located with respect to overall stability and ground movements;
- b) disposition and classification of the various zones of soil, rock and elements of construction which are involved in any calculation model;
- c) the environment within which the design is set;
- d) actions, their combinations and load cases;
- e) in the case of structures resting on or near rock the effect of discontinuities and dipping bedding planes;
- f) potential for deterioration of the ground as a result of the works;
- g) tolerance of the structure and interconnecting pipework to deformations;
- h) effect of the proposed structure on existing structures and services;
- i) behaviour of ground and foundation under earthquake loading
- j) maintenance philosophy for the structure.

Both short term and long term design situations shall be considered.

These considerations are applicable for 'normal' ground conditions where material behaviour is consistent and the risk of unpredictable behaviour is low. Additional design consideration and expertise may be necessary for 'problem' soils (e.g. calcareous soils), rocks, and geological settings.

2.3.2 Ground Characterisation

A ground model shall be developed by an experienced engineering geologist or geotechnical engineer in accordance with DEP 34.11.00.10-Gen. which describes the disposition and classification of the various zones of soil and rock and elements of construction. This should be based on:

- desk study including maps, photos, satellite imagery, digital elevation models etc.;
- walkover survey;
- results of geophysical surveys;
- results of ground investigations and associated laboratory testing.

Assessment of geohazards shall be performed according to DEP 34.11.00.10-Gen.

2.3.3 Structures on or near rock

Consideration shall, as appropriate, be given to:

- a) irregular rock surface topography;
- b) dipping bedding planes;
- c) interbedded hard and soft strata;
- d) faults, joints and fissures;
- e) possible instability of rock blocks;
- f) solution cavities such as swallow holes or fissures filled with soft material, and continuing solution processes;
- g) durability and soundness.

2.3.4 Environment

Consideration shall, as appropriate, be given to:

- a) variation in ground water levels including the effects of dewatering, perched water tables, regional water abstraction, possible flooding, failure of drainage systems;
- b) effects of freezing and thawing, including permafrost;
- c) effect of seasonal moisture content changes, changes to surface evaporation and the effects of vegetation on drainage and soil strength;
- d) potential for water ingress leading to wetting of soils in arid and semi arid areas;
- e) effects of long duration droughts;
- f) effects of scour and erosion;
- g) effects of biodegradation and gases emerging from the ground;
- h) effects of weathering;
- i) other effects of time and environment, e.g. the effect of holes created by solution and animal activities.

2.3.5 Seismicity

Amended per
Circular 68/12

Seismicity and Seismic Hazard Assessment shall be according to the DEP 34.00.01.10-Gen.

The requirements for seismic design given in this DEP shall be followed unless it has been determined in accordance with DEP 34.00.01.10-Gen. that seismic loading can be neglected.

2.3.6 Actions and Load Cases

The actions to be considered in geotechnical design shall be as given in Clause 2.4.2 of EN 1997-1. Imposed actions from structures shall be determined in accordance with (3.5.6.2) to (3.5.6.6). The design report and calculations shall state clearly whether supplied actions are factored or unfactored and, if factored, which type of safety factors have been applied. Also reference shall be made to the source documents which specify the loads.

2.3.6.1 Compressive and Tensile Actions

The compressive and tensile actions on foundations shall be calculated according to the principles outlined in EN 1997-1 with the load combinations as specified in DEP 34.00.01.30-Gen. Loads during erection, hydrotesting, operation and maintenance shall be considered where appropriate.

2.3.6.2 Lateral actions

Where relevant, lateral loads (e.g. from wind, waves, soil, thermal effects or seismic loading) shall be taken into account in the design of foundations.

Wind and thermal loads shall be calculated in accordance with the principles outlined in DEP 34.00.01.30-Gen.

Amended per Circular 68/12

Seismic loads shall be calculated in accordance with the principles outlined in DEP 34.00.01.30-Gen. and DEP 34.00.01.10-Gen.

Lateral soil loads shall be calculated in accordance with this DEP (Chapter 8).

Wave and hydrodynamic loading shall be calculated in accordance with DEP 34.00.01.30-Gen.

2.3.6.3 Dynamic and cyclic actions

Where relevant, dynamic actions on foundations (e.g. from machines or earthquakes) shall be taken into account for the design of the foundations. The natural frequency of the foundation-ground system shall be evaluated - see DEP 34.00.01.30-Gen and this DEP (Chapter 5).

Consideration shall be given to possible deterioration of bearing capacity and/or stiffness under cyclic and dynamic loading. Soil parameters shall be determined accordingly.

2.3.6.4 Abnormal actions

Abnormal actions arising from explosions, collisions, etc. shall be considered as outlined in DEP 34.00.01.30-Gen.

2.3.6.5 Load combinations

The load combinations set out in DEP 34.00.01.30-Gen. shall be considered.

2.3.7 Tolerance to deformations

Limiting values of displacement or strain for the serviceability limit state shall be realistically assessed as values representing an unacceptable condition.

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

Requirements for settlement criteria for the design of storage tanks are detailed in (3.5) and DEP 34.51.01.33-Gen. Consideration shall be given to the influence of construction sequence and time dependency and whether total, post construction or post hook-up displacements are critical.

2.3.8 Interaction with adjacent structures

Implementation of a new structure in the vicinity of an existing structure may have adverse effects on the existing structure and/or on the new structure. In the design and during construction possible interactions shall be analysed.

Such checks shall include but not be limited to:

- a) excavations or fills which may cause horizontal and vertical soil deformations that may affect adjacent piles, shallow foundations or surface/buried pipelines and services;
- b) dewatering, which may cause settlements of foundations or surface/buried pipelines and services or cause down drag loads on piled foundations;
- c) loading of a new foundation adjacent to an existing foundation which may cause tilting of either one or both foundations or settlement of surface/buried pipelines and services;
- d) vibrations, heave and horizontal soil displacement due to pile driving that may cause settlements of adjacent structures or damage to sensitive equipment in adjacent structures, or to drainage pipes, services, etc.;
- e) creation or interruption of natural drainage paths;
- f) Integrity of all existing temporary works structures.

2.4 REQUIREMENTS FOR SPECIFIC GEOTECHNICAL DATA

2.4.1 Fundamental Requirements

Geotechnical data acquisition shall be according to DEP 34.11.00.10-Gen.

2.4.2 Evaluation of geotechnical parameters

Properties of soil and rock masses, as quantified for design calculations by geotechnical parameters shall be determined from the test results, either directly or through correlation, theory or empiricism, and from other relevant data in accordance with Clause 2.4.3 of EN 1997-1.

Evaluation of the results of ground investigations shall be in accordance with Clause 3.4.3 of EN 1997-1, and any limitations in the data commented upon in the Geotechnical Design Report.

The characteristic value of a soil or rock parameter shall be selected as a cautious estimate of the value affecting the occurrence of the limit state. The selection of values shall be in accordance with Clause 2.4.5.2 of EN 1997-1.

2.5 SELECTION OF DESIGN METHOD

2.5.1 Fundamental Requirements

Verification that limit states are not exceeded shall involve one or more of the following approaches:

- use of calculations ;
- adoption of prescriptive measures;
- experimental models and load tests;
- an observational method.

The method(s) to be used for demonstrating that limit states will not be exceeded shall be identified by a Geotechnical Contractor.

2.5.1.1 Geotechnical design by calculation

Geotechnical design by calculation requires consideration of the following elements:

- a) Actions (either as imposed loads or imposed displacements);
- b) Properties of soil or rock materials;
- c) Geometrical data describing the problem under consideration;
- d) Limiting values of deformations, stresses etc.;
- e) A calculation model.

The calculation model should accurately describe the problem under consideration and may consist of:

- an analytical model;
- a semi-empirical model;
- a numerical model.

Design by calculation shall follow the procedures given in Clause 2.4 of EN 1997-1 in which design values of actions, material parameters or resistances are obtained by applying partial factors to characteristic values.

Unless agreed otherwise with the Principal, where National Annex is not available or when working outside Europe, Design Approach 1, defined in EN 1997 shall be adopted together with the UK Nationally Determined Parameters (NDP) given in Appendix 1 of this DEP.

More severe values of partial factors shall be considered in cases of abnormally great risk or unusual or exceptionally difficult ground or loading conditions. Where it can be justified on the basis of possible consequences, less severe values may be used for temporary structures or transient situations. A reduced return period for earthquake and/ or environmental loadings may be applied, subject to the agreement of the Principal. All changes shall be justified in the design report for review and comment by the Principal/Technical Authority.

2.5.1.2 Geotechnical design by prescriptive measures

Design by prescriptive measures shall only be used where comparable experience of similar situations makes design calculations unnecessary. It may also be used to ensure durability against frost action and chemical or biological attack for which calculations are not required.

2.5.1.3 Load tests and tests on experimental models

When the results of load tests or tests on large or small-scale models are used to justify or validate a design, or in order to compliment another design approach, the following factors shall be given consideration:

- Difference in ground conditions between the test location and the construction location;
- Time effects, especially if the test or model duration is significantly different to the duration of loading during construction;
- Scale effects (especially for small models).

2.5.1.4 Observational method

Where prediction of geotechnical behaviour is difficult, the adoption of the observational approach, in which the design is approved within pre-determined constraints during construction, may be applied.

The following requirements shall be met before construction commences:

- a) Acceptable limits of behaviour shall be established;
- b) The range of possible behaviour shall be assessed and it shall be shown that there is an acceptable probability that the actual behaviour will be within the acceptable limits;

- c) A system of monitoring shall be established that provides timely and accurate data to ensure that performance is within acceptable limits;
- d) The response time of the monitoring system and the speed with which results are analysed shall be sufficiently rapid to allow rapid evolution of the design if behaviour diverges from that expected;
- e) A plan of contingency actions shall be devised, which will be adopted if the monitoring reveals behaviour outside of acceptable limits.

A maintenance plan shall be established to ensure that any failures of the monitoring system are rectified without detriment to the performance of the system.

The observational method is acceptable for ground improvement and temporary dewatering, but for the construction of permanent works may only be used with the approval of the Principal.

2.6 SELECTION OF GEOTECHNICAL DESIGN CONCEPTS

Foundation types with proven track records in similar ground conditions and/or in the area shall always be considered. Innovative designs that result in substantial cost or schedule benefits may also be considered but shall be referred to the Principal based on the recommendations of an experienced geotechnical engineer for approval.

All designs shall be made with due allowance for safety, constructability, costs, programme, reliability, risks, performance and practicality of the structures in mind.

2.7 LIMIT STATES

The limit state design procedure shall be undertaken in two stages;

- set up design situations; and
- show that limit states will not be exceeded in the design situations.

The selected design situations shall be sufficiently severe and so varied as to encompass all conditions which can reasonably be foreseen to occur during the construction and use of the structure.

Various methods may be used to demonstrate that limit states will not be exceeded in the design situations. Methods that may be used are given in (2.5).

2.8 GEOTECHNICAL DESIGN REPORT

To allow concept and detailed design of a facility, a geotechnical design report shall be produced. The level of detail within the geotechnical design report shall be appropriate to the project phase and the availability of ground investigation data. For some projects, where staged ground investigation is undertaken across several design stages, more than one geotechnical design report may be created, with the level of detail increasing as the project progresses.

The geotechnical design report shall demonstrate safe and efficient design. As a minimum this shall include the following items, where relevant:

- 1) a description of the site and surroundings;
- 2) a description of the ground conditions, based on the ground investigations and other available sources of information, and with reference to the ground investigation report ;
- 3) a description of the proposed construction, including loads and limit states (allowable deflections) and assessed geotechnical category;
- 4) the codes and standards applied for the geotechnical design;
- 5) the design approach adopted and corresponding factors of safety with a justification of the values used;

- 6) characteristic values of soil and rock properties;
- 7) foundation design recommendations together with any risks identified and justification regarding their acceptability;
- 8) the geotechnical design calculation results, including drawings;
- 9) a listing of items to be reviewed at a later stage (e.g. by a specialist contractor), those to be checked during construction and those requiring maintenance or monitoring;
- 10) the seismic hazard assessment and design criteria.

NOTE: The Seismic Hazard Assessment and design criteria shall be developed by a specialist seismic expert according to the DEP 34.11.00.10-Gen. and shall be referred to or included in the geotechnical design report.

- 11) the requirements for supervision of the construction and monitoring (including items to be checked) and the actions to be taken dependant on monitoring results (including all the information listed in Clause 2.8 of EN 1997-1)
- 12) requirements for maintenance.

If significant changes are made to the geotechnical design at a later stage, an addendum to the geotechnical design report shall be issued to reflect the changes.

2.9 REVIEW AND ACCEPTANCE OF GEOTECHNICAL DESIGN

Review of the geotechnical design report shall consider the specified design requirements. If available, other data such as site test results and the performance of similar designs in similar ground conditions shall be taken into account. Items to be considered shall include, but not be limited to:

- a) fitness of the geotechnical design for its purpose ;
- b) weaknesses, sensitivity to variations in site conditions and workmanship, potential savings ;
- c) constructability;
- d) operability and maintenance;
- e) Safety during construction, operation and decommissioning.

2.10 SUPERVISION OF CONSTRUCTION

Supervision of construction of geotechnical structures by qualified staff is of major importance, as these structures are usually buried and are often impossible to inspect and difficult to repair following construction.

A plan of supervision shall be set out in the Geotechnical Design Report and carried out in accordance with Clauses 4.1 to 4.4 of EN 1997-1.

An Inspection and Test Plan shall be developed in parallel with the geotechnical design. This shall include all relevant QA/QC and integrity testing associated with construction and safety issues.

2.11 MONITORING

When required, monitoring shall be carried out in accordance with the plan set out in the Geotechnical Design Report and Clauses 4.1 and 4.5 of EN 1997-1.

Settlements during load tests and hydrottests, and of structures where the performance is sensitive to total or differential settlement shall be monitored.

2.12 MAINTENANCE

Any maintenance required to ensure the safety and serviceability of the structure for the geotechnical design (e.g. painting of sheet pile walls, anchors, drainage system permissible settlement, retaining wall deflection) shall be specified in the Geotechnical Design Report.

2.13 UNITS OF MEASUREMENT

SI units according to DEP 00.00.20.10-Gen. shall be used in the geotechnical and foundation engineering activities.

2.14 MATERIALS

All materials shall be of approved types conforming to the relevant international and national standards.

All materials shall be accompanied by the appropriate testing, calibration and certification documents.

3. SPREAD FOUNDATIONS

3.1 SCOPE

This section specifies requirements for:

- pad and strip foundations;
- raft foundations;
- storage tank foundations.

Design requirements for machine foundations are specified in (6).

3.2 GENERAL REQUIREMENTS

3.2.1 Standards of Practice - Eurocodes

In accordance with Figure 2.1, design shall be according to Eurocodes - EN 1997-1 (Eurocode 7) and EN 1998-5 (Eurocode 8) for shallow foundations. Design Approach 1 shall be employed for ULS designs as detailed in EN 1997-1. For geographical locations where a National Annex does not apply the (UK) Nationally Determined Parameters (NDPs) (Appendix A) shall be adopted.

3.2.2 Standards of Practice - US

See Section 2.2.2.

3.2.3 Foundation depth

The depth of foundations shall be selected in accordance with EN 1997-1 Section 6.4.

3.2.4 Settlement Criteria for Foundations

Settlement limits for total or differential settlement shall be defined for the foundation by the CONTRACTOR responsible for design of the topsides for review and comment by PRINCIPAL.

Calculations of settlement shall follow requirements of EN 1997-1 Section 6.6.2.

The method used to define differential settlement shall be clearly identified.

3.2.5 Durability

In the geotechnical design report, an assessment shall be made on the aggressivity of the environment to allow requirements for concrete mix design in accordance with Appendix 1 of DEP 34.19.20.31-Gen.

3.2.6 Construction issues

Consideration shall be given to the effect of groundwater on the characteristics of the bearing stratum. In cases where the bearing layer may be susceptible to rapid softening the time between excavation and construction shall be as short as possible. Groundwater control methods and schemes shall be selected that do not adversely affect the characteristics of the bearing stratum (for example by causing heave or settlement) or the performance of adjacent foundations.

Amendment A03

Consideration shall be given to installation of earthing connections in accordance with Standard drawings S68.042 and S68.003 during design.

3.3 PAD AND STRIP FOUNDATIONS

The design of foundations shall be in accordance with Clause 6 of EN 1997-1 using either:

- a direct method; or
- an indirect method; or
- a prescriptive method.

The direct method shall be used for Geotechnical Category 3 structures.

The indirect method may be used for Geotechnical Category 2 structures subject to the following conditions:

- a) well established and documented successful experience shall 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;
- d) the method is not applicable for soft clays and highly organic soils for which settlement calculations are always required;
- e) the method is not applicable for collapsible soils.

Presumed bearing values given in relevant local building codes or derived using other methods shall only be used with the agreement of the Principal.

The effect of groundwater, and changes in groundwater level, on the performance of foundations shall always be carefully considered.

3.3.1 ULS calculations for shallow foundations by the direct method

3.3.1.1 Design Approach

Unless required otherwise by a National Annex or agreed by the Principal, shallow foundations shall be designed in accordance with EN 1997-1 using Design Approach DA-1.

3.3.1.2 Calculation method

Bearing resistance calculations shall generally be in accordance with Annex D of EN 1997-1.

Depth correction factors shall not be applied when calculating the bearing resistance of conventional shallow foundations. However, where spread foundations are constructed at substantial depth 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:

For undrained conditions calculated in accordance with Annex D of EN 1997-1 the bearing resistance formula (equation D.1) becomes,

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

and d_c may be taken as,

$$d_c = 1 + 0.27\sqrt{(D/B)} \text{ for } D/B \leq 3$$

where D is the foundation depth and B the foundation width.

For drained conditions calculated in accordance with Annex D of EN 1997-1 the bearing resistance formula (equation D.2) becomes,

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

$$d_\gamma = 1$$

Values of d_c and d_q given in Figure 3.1 may be used but N_γ should then be taken as,

$$N_\gamma = 1.5(N_q - 1)\tan\phi$$

NOTE: These values are from Brinch Hansen (1968) but see also Lyamin et al (2007)

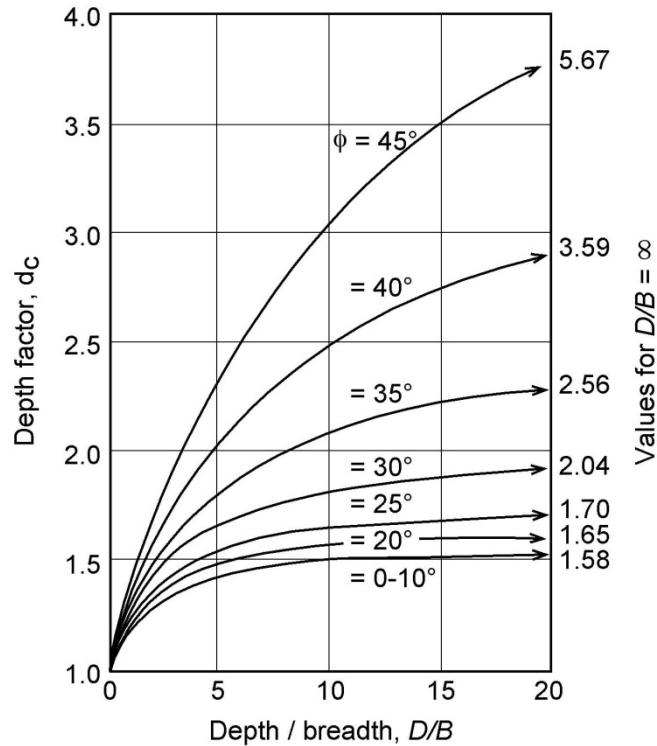


Figure 3.1 Depth correction factor d_c

Where a competent soil layer overlies a weaker layer the following failure mechanisms shall be considered:

- punching failure, see Figure 3.2(a);
- extrusion/squeezing, see Figure 3.2(b);
- bearing failure, see Figure 3.2(c).

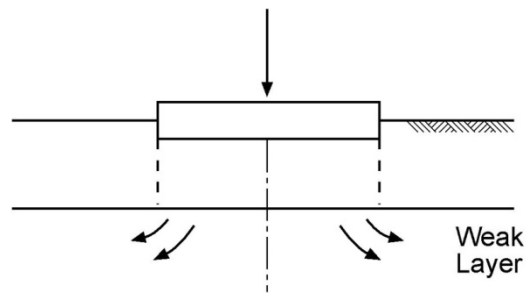


Figure 3.2(a) Punching Failure

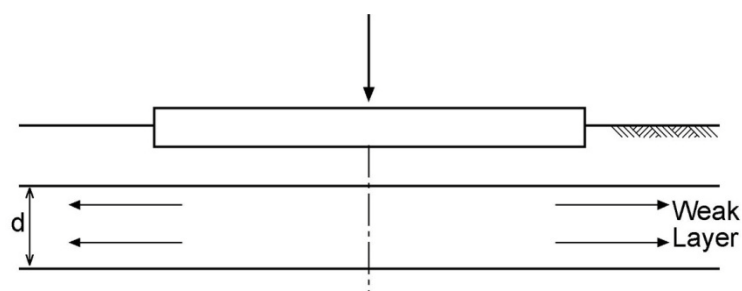


Figure 3.2(b) Extrusion Failure

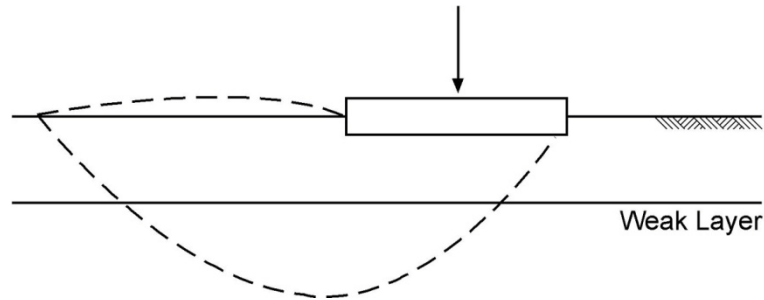


Figure 3.2(c) Bearing Failure

Methods that may be used for calculating the bearing resistance (Figure 3.2(c)) includes:

- Limit equilibrium calculations in which the layered soil profile is modelled and allowance is made for bulging of the competent layer ;
- Non linear finite element analysis using the strength reduction technique.

The net bearing resistance, q_r , for extrusion within a thin weak layer (Figure 3.2(b)) may be taken as,

$$q_r = N_c s_u$$

where s_u is the undrained shear strength of the clay and,

$$N_c = (B/2d + \pi + 1) \text{ for a strip foundation with width } B \text{ and } B/d \geq 2$$

$$N_c = (B/3d + \pi + 1) \text{ for a circular foundation with diameter } B \text{ and } B/d \geq 6$$

3.3.1.3 Overall stability

Where the foundation is on or close to sloping ground, the design shall be checked for the overall stability of the ground mass in accordance with EN 1997-1.

3.3.1.4 Foundations on rock

For design of foundations on highly tectonised or disturbed rock masses, a direct or indirect design method should be used.

The charts given in EN 1997-1 Annex G should not be applied to:

- shallow foundations on weak carbonate rocks (e.g. chalk with porosity > 35%);
- highly tectonised or disturbed rock masses;
- when there are bedding planes or discontinuities that could adversely affect stability;
- on sloping ground.

For design of foundations on chalk, reference shall be made to CIRIA C574.

3.3.1.5 Eccentric loading

The reaction determined from SLS loads should generally be within the middle third. Where large eccentricities could occur, the design value of the actions should be carefully reviewed including construction tolerances.

3.3.2 SLS calculations for shallow foundations by the direct method

Where shallow foundations are designed by the direct method, the total vertical settlement, S , shall be taken as,

$$S = S_0 + S_1 + S_2$$

Where S_0 = immediate settlement

S_1 = consolidation settlement

S_2 = creep settlement

Where site formation works or the construction of structures result in raising or lowering of ground level or changes in groundwater level, consideration should be given to the settlement resulting from these works as well as the settlement due to foundation loading.

Lateral displacement shall be considered where:

- Horizontal or inclined loads are present;
- The foundation is placed on a slope;
- The bearing strata are significantly inclined.

The uncertainties relating to settlement predictions shall be recognised, and where appropriate ranges given to reflect this.

3.4 RAFT FOUNDATIONS

Raft foundations should be used where:

- lightly loaded structures are constructed on soft or variable ground where it is necessary to spread the load or bridge across weaker zones;
- differential settlement needs to be reduced and loads spread more evenly on the ground;
- pad foundations would occupy a large part of the available area;
- compensated foundations are used to reduce net loading.

The performance of a raft foundation depends on the relative flexibility of the raft and ground. An assessment of soil-structure interaction shall generally be required for Geotechnical Category 2 and 3 structures.

3.5 STORAGE TANK FOUNDATIONS

3.5.1 Steel storage tanks

Requirements for tank pads and bunds are given in DEP 34.11.00.11-Gen Section 5.

Design of foundations for conventional storage tanks shall comply with the requirements of DEP 34.51.01.31-Gen. and the additional non-conflicting guidance in EN 14015:2004 Annex I.

Where the tank is underlain by soft compressible ground, particular consideration shall be given to tank edge stability and the tank bottom settlement profile.

3.5.1.1 Tank Stability

Base shear failure

For tanks founded on weak soils both base shear failure and edge shear failure shall be considered.

Edge shear failure

For tanks with a flexible bottom edge failure mechanisms shall be considered.

3.5.1.2 Tank Settlement

Predictions of tank settlement shall be made for all loading cases including:

- Under full hydrotest;
- After long term service.

Tank distortion shall be considered resulting from:

- edge – centre differential settlement;
- perimeter differential settlement;
- overall tilt.

The calculated design settlements shall be less than the maintenance settlement criteria for conventional storage tanks given in EEMUA159 Volume 1. The choice of stiffness parameters (most probable, cautious estimate, worst credible) shall take in account the cost and impact on production of re-levelling the tanks during their construction and lifetime.

If re-levelling of the tanks is not accepted as part of the design, the worst credible combination of soil stiffness parameters shall be used in the calculations (e.g. for tank dishing calculations softest credible stiffness at tank and stiffest credible stiffness at tank edge).

If re-levelling of the tanks is possible during the lifetime of the facility but not desirable, a cautious estimate of soil stiffness parameters shall be used in the calculations.

Where re-levelling of the tanks is possible and favoured, the most probable soil stiffness shall be used, together with a sensitivity analysis. The design report shall assess the probability of the acceptable tank settlements being exceeded. Where it is anticipated that design settlements shall be exceeded, this shall be reflected in the monitoring program.

Differential settlement between tanks and pipe connections shall also be considered.

The tank settlement behaviour shall be monitored during hydrotesting, which in some cases will be the most onerous load case. Requirements for testing and inspection are given in DEP 64.51.01.31-Gen.

3.5.2 Cryogenic storage tanks

Soil-structure interaction analyses shall be carried out for static (short term hydrotest and long term loading) and seismic load cases. The analyses shall incorporate non linear soil properties unless it is demonstrated from the results of the geotechnical investigation that a linear response may reasonably be assumed. Where the ground conditions and imposed loads do not vary significantly in the circumferential direction, an axisymmetric model may be used. Where there is significant variation in the circumferential direction, a 3 dimensional analysis shall be undertaken

Analyses for seismic loading shall consider a lower and upper bound range of soil properties according to the recommendations given in ASCE 4.

3.6 FOUNDATIONS IN ARID REGIONS

In arid regions the following shall be considered:

- Potential influence of water on ground behaviour;
- Potential for collapse settlement;
- Potential for expansive clays;
- Possible reduction in bearing capacity with depth due to presence of a soil crust.

3.7 FOUNDATIONS IN COLD REGIONS

This DEP does not cover the design of foundations in permafrost regions for which specialist advice shall be obtained.

3.8 FOUNDATIONS ON EXPANSIVE SOILS

Where shallow foundations are constructed on expansive soils, possible changes in water content that may occur independently from those occurring as a consequence of foundation loading shall be considered. These include:

- changes to evaporation or infiltration at the ground surface due to covering the surface;
- changes to the evapotranspiration regime due to the planting or removal of vegetation and in particular trees;
- infiltration of water due to irrigation or leakage from service pipes.

3.9 SEISMIC DESIGN

3.9.1 Philosophy of Seismic Design

Amended per
Circular 68/12

Structures shall be classified as high, medium or normal consequence in accordance with DEP 34.00.01.10-Gen. They shall be designed using one or two levels of earthquake using partial factors as defined in Appendix 2 to achieve the appropriate performance requirements determined from Section 4 of that DEP. Either one or two performance criteria shall be satisfied for all structures. The structure and foundation shall remain operational (elastic) under moderate, frequent events with tolerable deformation allowed under larger, less frequent events. These are termed the Ultimate Limit State (ULS) and Accident Limit State (ALS) respectively.

EN 1998-5 gives the requirements for seismic design of foundations, retaining walls and slopes. The corresponding values of partial factors to be used in conjunction with EN 1997-1 Design Approach 1 and serviceability requirements are given in Appendix 2.

3.9.2 Foundation Performance

3.9.2.1 Potential Modes of Deformation

All potential modes of deformations shall be considered.

3.9.2.2 Required Performance

Compliance with the requirements of EN 1998-5 may be particularly onerous for some structures when subject to moderate to high seismic loading (e.g. slopes whose failure is of minor consequence). Subject to the approval of the Principal, permanent displacements under the ULS and ALS may be permitted and a performance based assessment of the structure may be undertaken covering both ULS and ALS load cases in order to achieve a more economic design. The designer shall ensure in this case that ongoing serviceability following the ULS event, and safe shutdown/life safety requirements following the ALS event are not compromised.

The selection of the seismic force for design (E_{Fd}) depends on whether the structural design assumes ductile (i.e. dissipative) or elastic design (see EN 1998-5, clause 5.3.1).

- For structures that are designed to remain elastic, E_{Fd} shall be obtained from an analysis without capacity design considerations;
- For structures that are designed to be ductile, E_{Fd} shall be based on capacity design principles accounting for the development of possible overstrength. As a simplified rule for common foundations, the action effects can be calculated according to the following equation (see EN 1998-1, clause 4.4.2.6):

$$E_{Fd} = E_{F,G} + \gamma_{Rd} E_{F,E}$$

where γ_{Rd} is the overstrength factor taken equal to 1.4

$E_{F,G}$ is the action effect due to non-seismic actions

$E_{F,E}$ is the action effect from the analysis of the seismic design situation.

3.9.2.3 Seismic Displacements

EN 1998-5 requires that foundations of structures remain elastic under both the ULS and ALS design earthquakes. However, for some structures, particularly in high seismicity regions, these design requirements may be particularly onerous and designing for allowable displacements may result in significant economies by comparison to alternative 'elastic' design approaches.

In cases where the transient seismic loadings exceed the available foundation resistance, permanent displacements will occur. The accelerations at which displacement commences are termed threshold accelerations. In many cases the peak earthquake accelerations can exceed the threshold or "critical" values by a substantial margin with minimal foundation displacement occurring. Although EN 1998-5 requires that foundations remain elastic, for foundations above the water table, where the soil properties remain unaltered and the sliding will not affect the performance of any lifelines connected to the structure, a limited amount of sliding may be tolerated.

3.9.2.4 Performance Based Design

When a performance based assessment of the structure is carried out, results of analyses shall be presented in terms of ranges of predicted plastic deformations, and incorporate uncertainty in both load and material properties. The requirement in ASCE 4 shall be adopted to define the upper and lower bounds for soil stiffness. Justification for the adoption of interpreted parameters shall be presented. Analyses should focus on justification of adequate performance rather than satisfying a code-based safety factor.

**Amended per
Circular 68/12**

To assess serviceability following an earthquake, the soil stiffness, appropriately degraded due to cyclic loading, shall be used to assess permanent foundation displacements, and ensure tolerances of the structure are not exceeded (see 3.5.7). For hazardous or sensitive structures, structures with irregular loading, or subject to moderate to large seismic loading, a dynamic soil structure interaction (DSSI) analysis should be carried out. Reference should be made to the DEP 34.00.01.10-Gen and Appendix 4 of this DEP for guidance on DSSI modelling. DSSI analyses shall conform to ASCE 4.

3.9.3 Seismic Design Approach

3.9.3.1 General Requirements

The requirements in EN 1998-5 for the seismic design of foundations shall be followed for normal structures using the partial factors given in Appendix 2.

Where, with the agreement of the Principal, AASHTO (2007) has been adopted for design, the load and resistance factors given in Appendix 3 may be used.

The same methodology as used in static design for assessment of particular modes of failure (limit states) may be adopted, but with additional pseudo-static inertial loads from the structure applied to the foundation. In addition, reduced ground resistance due to seismic load shall also be considered, both in terms of inertia loading, and cyclic degradation of strength and stiffness.

3.9.3.2 Sliding Capacity

Load combinations shall be selected such that the maximum horizontal load coincides with minimum vertical loading. Conventional Mohr Coulomb soil strengths (ϕ') for dry or free-draining non-liquefiable soil materials, or cyclically degraded undrained shear strength ($S_{u(cyc)}$) for cohesive materials should be used for the soil-foundation interface. Cyclic undrained strength ($\tau_{cy,u}$) shall be considered for loose and saturated cohesionless deposits.