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Foundations

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CONTENTS (CONTINUED)

FOREWORD

This document provides technical information previously contained in the Fourth Edition of the Health and Safety Executive's *'Offshore Installations: Guidance on Design, Construction and Certification'* (1990 edition plus amendments)[(1)]. The 'Guidance' was originally published in support of the certification regime under SI289, the Offshore Installations (Construction and Survey) Regulations 1974[(2)]. However, SI289 was revoked by the Offshore Installations (Design and Construction, etc) Regulations, 1996, which also introduced the verification provisions into the Offshore Installations (Safety Case) Regulations, 1992. The 'Guidance' was formally withdrawn in its entirety on 30 June 1998 (see HSE OSD Operations Notice 27[(3)]).

The withdrawal of the 'Guidance' was not a reflection of the soundness (or otherwise) of the technical information it contained; some sections (or part of sections) of the 'Guidance' are currently referred to by the offshore industry. For this reason, after consultation with industry, relevant sections are now published as separate documents in the HSE Offshore Technology (OT) Report series.

It should be noted that the technical content of the 'Guidance' has not been updated as part of the re-formatting for OTO publication, although prescriptive requirements and reference to the former regulatory regime have been removed. **The user of this document must therefore assess the appropriateness and currency of the technical information for any specific application. Additionally, the user should be aware that published sections may cease to be applicable in time and should check with Operations Notice 27, which can be viewed at http://www.hse.gov.uk/hid/osd/notices/on_index.htm, for their current status.**

1. INTRODUCTION AND SCOPE

1.1 SOURCE OF INFORMATION

This Offshore Technology (OT) Report provides technical information on foundation design of Offshore Installations, intended to be supported on the seabed. It is based on guidance previously contained in Section 20 of the Fourth Edition of the Health and Safety Executive's 'Offshore Installations : Guidance on Design, Construction and Certification'[1] which was withdrawn in 1998. As discussed in the Foreword, whilst the text has been re-formatted for Offshore Technology publication, the technical content has not been updated. The appropriateness and currency of the information contained in this document must therefore be assessed by the user for any specific application.

1.2 SCOPE AND REFERENCE DOCUMENTS

Foundations for piled and gravity Offshore Installations are included in this document, together with footings for mobile jack-ups and anchorages for catenary moorings.

This document should be read in conjunction with a background report by Semple 1986[4], which contains additional information and references.

Offshore Technology Report OTO 2001 012 provides information on site investigations.

2. FOUNDATIONS : GENERAL

2.1 FOUNDATION TYPES

Fixed Installations are supported on piles or gravity bases while mobile jack-up Installations may be supported on spread footings. Piles usually consist of open-ended steel pipe installed either through the legs of a jacket or through guides attached to the legs. Piles for steel structures other than the conventional jacket or tower may be installed through and then connected to a template on the seabed.

Gravity structures rely on weight distributed over a large contact area to provide stability against lateral forces and overturning moments. Jack-up Installations usually have an independent footing, or spud can, at the base of each leg, whereas those designed specifically for weak soil conditions may have a mat foundation connecting the legs.

2.2 APPLICABILITY OF CODES OF PRACTICE

Documents providing recommendations for design and installation of offshore structures have been published in several countries. These documents may be orientated towards circumstances encountered in the country of origin. Before applying the recommendations of any code, their applicability to the specific offshore situation should be critically examined.

2.3 GENERAL DESIGN CONSIDERATIONS

The soils supporting an Offshore Installation are subjected to forces arising from the structure weight, the environmental and imposed loads acting on the structure, and direct wave loads. The performance of the structure and the seabed should be considered together.

A foundation should be designed to carry the most severe static and variable loads without approaching the bearing capacity or causing excessive deformations with respect to maintaining the air gap, structural integrity and topside operation of the Installation. Consideration should also be given to the effect of deformations on pipeline connections to a fixed platform, and to the stresses that displacements can induce in casing strings.

Offshore foundation design has some particular aspects. The prefabricated nature of structures limits the changes that can be made to the design after installation. Special attention should be given to the assessment of environmental loads, possible changes of forces transmitted to the foundations, and to the effects of cyclic and transient loadings on soil strength and stiffness and on the structural response. Limited knowledge exists on failure modes where large cyclic lateral and vertical forces and moments are superimposed on static vertical forces.

2.4 FACTORS OF SAFETY

Safety factors based on permissible stresses may be used in designing foundations for offshore structures. However, it should be noted that most gravity base platforms have been designed using partial safety factors, and this is considered acceptable.

The safety factor to be used depends on reliability of the soil data, load estimates, analytical methods and construction or installation technique. Values quoted in Sections 3.8, 3.10, 4.7 and 5.8 are the minimum values, given average reliability of design quantities and construction or installation procedures.

2.5 SEAFLOOR STABILITY

Consideration should be given to the possibility of large seafloor movements if a structure is to be located on weak soils on or near a slope, however gentle, or in a seismically active region. The effect of wave action on the seafloor should be included in the analysis if it significantly contributes to destabilising forces.

Consideration should also be given to sandwave mobility in the region, and to the effects of local depressions such as pockmarks or the imprints of jack-up footings. Pockmarks may indicate the presence of shallow gas accumulations, which should be taken into account in the siting of a fixed structure, particularly a drilling platform.

Seafloor movements can impose significant lateral and vertical forces on a foundation in addition to reducing its load bearing capacity. These effects should be properly accounted for in the design where seafloor instability is predicted.

2.6 SCOUR

Consideration should be given to scour potential around the foundation. Unless it can be demonstrated that scour will not occur, scour effects should be assessed and allowed for in the design. Alternatively, those areas where scour might occur can be covered with suitable protective materials to prevent loss of underlying soils. Regular subsea inspection should be carried out to assess the degree of scour.

2.7 WELL DRILLING OPERATIONS

The effect on a foundation of conductor installation procedures should be reviewed with particular attention given to the possibility of wash-out, hydraulic soil fracture or other drilling problems endangering the foundations. The planning, supervision and execution of conductor installation should reflect the sensitivity of foundation integrity to drilling operations.

2.8 SUBSIDENCE

Consideration should be given to the seafloor subsidence that may result from extraction of reservoir hydrocarbons. Factors that should be taken into account in predicting subsidence include the expected reduction in reservoir pressure, the compressibility, thickness and areal extent of the production zone, and the depth and type of overburden. Subsidence prediction requires co-operation between reservoir and geotechnical engineers. Predictive methods should be supported by empirical evidence.

3. PILED FOUNDATIONS

3.1 STABILITY DURING PLACING

The location should be inspected prior to placing an Offshore Installation, and any significant obstructions removed. Topographic irregularities should be identified and allowances made in the design of the structure and the placement procedure to achieve an acceptable tolerance on elevation and verticality. Variations to the sequence of pile installation should be considered to minimise, or correct, unacceptable movements.

Consideration should be given to the stability of a jacket under the most extreme load conditions likely to occur between touch down and connecting the piles to the structure.

3.2 PLANNING FOR PILING

Prior to performing field operations, the foundation installation procedure should be planned in detail, and the necessary components and systems designed. A formal technical specification should be prepared setting out criteria for the number of piles and their installed penetrations that will be considered adequate.

All pile installation operations should be recorded by persons competent to judge if these operations are departing materially from plan. During pile driving, a continuous record should be maintained on the number of blows per unit penetration. The final penetration of each pile tip should be determined.

The self-weight penetration of piles should be predicted, and consideration given to pile runaway during driving.

The depth to which piles can be driven should be predicted. Consideration should be given to the increase in driving resistance that may occur after a driving delay as this could result in premature pile refusal. Where piling may be difficult, consideration should be given to using instruments to measure the driving energy imparted to the pile as an aid to judging pile acceptability.

The drilling technique for grouted piles should be selected considering the requirements for stable, clean holes and for uniform displacement of drilling fluid by the grout. The pile should be positioned centrally in the hole to provide a uniform annulus between pile and soil. Means should be provided for determining that the annulus is completely filled with grout of the required quality.

Enlarged pile bases should be limited to cohesive soils or rocks in which the excavation can be expected to remain open during the base construction period.

3.3 PILING PROBLEMS

Installation planning should anticipate construction problems with appropriate preparation for remedial measures. However, some construction expedients, particularly jetting near the tip of a driven pile, could adversely affect pile capacity. Remedial work should not proceed unless the pile capacity is considered to be seriously deficient. The effect of the remedial work should be evaluated with due regard to design adequacy, and arrangements made for quality control.

3.4 PILE MAKE-UP

Pile make-up should be selected to accommodate variations in final pile penetration. A relevant consideration is the length of pile over which weld beads should be placed to effect shear transfer within the grouted sleeve. Provision of a thickened wall section at the pile head should be considered as a means of reducing local stresses where hard driving is expected. A thickened section may also be considered for strengthening the tip or for the purpose of reducing internal skin friction during driving.

The outside surface of the pile should be free of mill varnish or excessive amounts of scale.

3.5 STEEL STRESSES IN PILES

A pile should be designed to carry the maximum axial, bending and shear stresses caused by installation or in-service loading conditions. The wall thickness of laterally unsupported sections should be adequate to prevent buckling. The effects of fatigue on the pile due to driving and subsequent in-service loading should be considered.

The pile handling and installation methods assumed by the designer should be noted on the Installation drawings or specifications.

Lifting, pitching and stabbing the pile, placing and supporting a hammer on the pile top, and the effect of any free-standing battered pile length should not induce pile wall stresses exceeding the allowable value for static loading conditions (see Offshore Technology Report OTO 2001 015).

Dynamic stresses caused by pile driving should be assessed using wave propagation analysis. The sum of the dynamic driving stresses and the static stresses during the driving process should not exceed the specified minimum yield strength.

Pile restraint by the structure should be considered in determining in-service pile stresses which should not exceed the allowable values (see OTO 2001 015). The pile bending moment diagram and distribution of axial stresses below the seafloor should be established by appropriate pile-soil load transfer analyses. Due consideration should be given to the possible removal of soil support by scour (Section 2.6), and to the effects of soil displacements induced by adjacent foundations should a jack-up Installation be planned in close proximity to the platform (Section 5.10).

3.6 DESIGN OF PILED FOUNDATIONS

Pile size, number and layout should be selected considering the compression, uplift and lateral foundation loads and moments experienced by the structure under all critical loading conditions. In computing pile loading, the weight of the pile-soil plug system and hydrostatic uplift should be considered.

The ability of pile groups to efficiently combine individual pile resistances should be assessed. In so doing, the end bearing should be selected with due regard to the deflections associated with developing of ultimate end bearing on a large bearing area.

Appropriate allowances should be made for general and local scour in assessing pile penetration requirements (Section 2.6).

3.7 AXIAL PILE CAPACITY

Load capacity should be determined using static formulae to estimate skin friction and end bearing. The methods should be supported by empirical evidence.

For compressive loading of an open-ended pipe pile, due consideration should be given to the alternative end bearing failure modes of plugged and unplugged piles, and to the possibility of a reduction in internal skin friction if an internal driving shoe is present at the pile tip.

The maximum skin friction contributions along the pile are not necessarily additive, and the peak shaft resistance and end bearing may not be simultaneously mobilised. Accordingly, consideration should be given to relative deformations between soil and pile as well as compressibility of the pile-soil system.

Recently, an extended research programme by a group from Imperial College has led to new more reliable (lower computed to measured coefficients of variation) methods for assessing the axial capacities of offshore piles (MTD Publication 96/103[(5)]).

3.8 FACTORS OF SAFETY FOR PILED FOUNDATIONS

Design pile penetration should develop adequate capacity to resist maximum computed axial loads. Allowable loads should be determined by dividing the capacity by a safety factor. The minimum safety factor is 1.5 for the extreme loading condition (see Offshore Technology Report OTO 2001 013), and 2.0 for conditions likely to occur not more than once, on average, each month.

These safety factors also apply to anchorages for catenary moorings where lateral loads are applied directly to the piles.

If piles are connected together so that loads can be redistributed, for example at a jacket leg, then the safety factors should apply to the piles as a group.

More stringent safety factors for piled foundations of tethered buoyant structures are given in Section 3.10.

3.9 LOAD-DEFLECTION IN RESPONSE OF PILES

Analyses used in foundation design should ensure compatibility between the structure and soil-pile system. The possibility of non-linear soil behaviour should be recognised and accounted for in analysis. Foundation deflections and rotations should not exceed serviceability limits for the structure.

Cyclic loading history need not be explicitly considered in assessing the axial response of jacket piles but should be considered in predicting lateral pile stiffness.

Due allowance should be made for the greater deflections and pile head rotations experienced by pile groups compared with those of an isolated pile under the average pile loads of the group. In developing a linear stiffness matrix or an equivalent member representative of a group at working load level, consideration should be given to the interactions that occur, due to individual pile head restraint, between lateral forces and moments applied to the group.

3.10 PILES FOR TETHERED BUOYANT STRUCTURES

Piled foundations for tethered buoyant structures should comply with the guidance for piles of jacket structures, except in respect of pile penetration.

Pile shaft capacity should be assessed using static formulae, as for jacket piles, and consideration should be given to the loss of skin friction caused by irrecoverable lateral soil movement and cyclic load reduction of soil strength. For piles required to sustain uplift forces in still water, consideration should also be given to creep effects on axial capacity. No allowance should be made for resistance beneath the pile tip.

The safety factor to be used in determining the required pile penetration should reflect the magnitude of sustained uplift forces acting on the piles, and the degree to which load redistribution is possible within the foundation system. Foundations with no capability for redistributing loads away from an overloaded pile to other piles, and that require the piles alone to sustain buoyancy forces from the structure, should be designed with greater safety factors than highly redundant foundations with piles carrying no load under still water conditions. Based on these considerations, and for extreme loading conditions (see Offshore Technology Report OTO 2001 013), a safety factor against failure of a pile group in the range 2.0 to 3.0 should be selected after allowances have been made for the possible reductions in skin friction indicated above. The safety factor for the most heavily loaded pile in the foundation should not be less than 1.5.

4. FOUNDATIONS FOR GRAVITY STRUCTURES

4.1 FOUNDATION TYPES

The foundation may comprise a single caisson base or multiple bases supporting a space frame. Consideration should be given to providing skirts beneath the foundation, particularly where wells are to be drilled from the platform, in order to retain the surface layers, limit scour, allow under-base grouting and transmit foundation forces to stronger soils below.

4.2 CONSIDERATIONS FOR INSTALLATION

The seabed should be checked at an early stage for unevenness, slope, boulders and other debris. Significant obstructions should be removed before the structure is founded.

Procedures should be specified, together with limits for acceptable control measurements and contingency procedures should these limits be reached.

Dowels extending a few metres below the base may be provided to aid positioning, and to minimise seabed ploughing by permanent structural members should the platform skid during touchdown.

A ballasting system may be necessary with the capability to load the base eccentrically to correct structure tilt. In designing the ballasting system, including water evacuation from skirt compartments, differential water pressures should be limited to minimise wash out or flow of soil from beneath the base.

Consideration should be given to grouting any voids remaining between the foundation and the seabed in order to secure a uniform soil reaction on the base and avoid erosion of soil by piping during environmental loading. Provision should be made for control of grout pressure and water expulsion in order to avoid piping.

On completion of installation, the foundation should be inspected for evidence of scour, and for skirt penetration and damage. A record should be kept of all observations.

4.3 LOADS AND REACTIONS DURING INSTALLATION

Skirt and dowel penetration resistances should be predicted using a range of soil parameters. An upper bound estimate should be used in assessing total penetration force to which some over-capacity should be added to ensure the skirts and dowels penetrate as planned. Ballasting requirements should be based on an unfavourable distribution of soil resistances beneath the foundation, and a seafloor slope assumption that is consistent with the seabed survey accuracy. The possibility of skirt penetration resistances being less than expected should be considered in estimating base contact stresses.

Dowels intended to restrain structure movement prior to base seating may be subjected to large lateral forces on touchdown. If no dowels are provided, any skirts or cross walls must be able to resist these forces as well as horizontal forces from the likely sea states during installation, and differential water pressures in skirt compartments.

Consideration should be given to the distribution of topographic high spots in predicting base stresses, particularly where strong soils are predicted at the seafloor. The seafloor unevenness assumed in design should be compatible with the seabed survey results considering measurement accuracy and frequency of topographic measurements within the landing area.

4.4 OPERATING LOADS AND REACTIONS

Sequences of equivalent static forces should be used in analysing the foundation behaviour under storm conditions. Consideration should be given to dynamic amplification of environmental forces. Vertical hydrodynamic pressure variations across a submerged caisson and the related variation in pore water pressure under the base should also be considered.

The foundation should be designed to withstand the range of reactions predicted by soil load-displacement analyses. Soil-structure interaction should be considered in assessing force distributions within the structure, particularly where there is to be a multiple base foundation.

Consideration should be given to redistribution of base contact stresses with time after installation, and to vertical load transfer from skirts to the base. The additional contact stresses due to structure rocking during storms should be allowed for in the design.

Possible effects on base contact stresses of variation in subgrade reaction near conductor groups should be considered.

Skirts should be designed for the lateral soil stresses induced by storm forces, with due regard given to load transfer between base and soil.

4.5 FOUNDATION EQUILIBRIUM

The foundation should be designed to eliminate general shear failure in bearing and sliding under the most severe equivalent static loading condition. Overturning should also be considered.

Hydraulic gradients induced by base rocking should be limited in order to avoid piping failure at the base perimeter. For a structure with skirts, such considerations may replace the normal criterion of providing a positive stress over the whole base area under the most extreme loading condition. No uplift stresses should be allowed in the design of a base without skirts.

Analyses for the extreme equivalent static loading condition should be based on undrained soil behaviour except in the case of dilatant granular soil for which drained conditions should be assumed to avoid reliance on negative excess pore water pressures. The maximum wave should be assumed to occur late in the design storm. Consideration should be given to the effects of cyclic loading in decreasing soil effective stress and undrained shear strength during the storm. Assessment of these effects should be based on appropriate soil test data.

Calculations should account for combined vertical, lateral and moment loading, and layering in the foundation soils.

4.6 CYCLIC LOAD FAILURE

Consideration should be given to the possibility that repeated storm forces may induce excessive displacements, possibly associated with soil extrusion from beneath the base, at shear stress levels below those leading to general shear failure in static bearing or sliding.

4.7 FACTORS OF SAFETY : GRAVITY STRUCTURE FOUNDATIONS

The bearing and sliding stability of gravity structures should be assessed using the permissible stress or limit state methods.

In the permissible stress approach, the soil shear strengths should be divided by a safety factor to provide design strengths. The minimum safety factor should be 1.5 for the extreme loading condition (see Offshore Technology Report OTO 2001 013), and 2.0 for conditions likely to occur not more than once, on average, each month.

In the limit state approach, the material factors for the extreme loading condition should be 1.3 for undrained shear strength and for cohesion defined in effective stress terms, and 1.2 for the tangent of the angle of internal friction. Load factors for limit state design of concrete structures are given in Offshore Technology Report OTO 2001 046.

For a structure supported on multiple bases and designed for redistribution of forces between bases at incipient failure of an individual base, the safety factors may be taken to apply to the foundation as a whole. If the structure cannot transfer these extra forces then the safety factors should be applied to the individual bases.

4.8 FOUNDATION RESPONSE

Settlements should be estimated and their consequences taken into account. The likely settlement-time behaviour should be considered with regard to the effect of structure movements on casing strings and risers. Initial, consolidation and creep settlement caused by permanent structure loads should be evaluated.

Additional settlements during storms should be assessed together with likely lateral and rotational movements of the foundation. Consideration should be given to the likelihood of increased consolidation settlements following storms.

For structures on multiple bases, particular attention should be given to predicting differential settlements. Account should be taken of the interactions that occur between the bases through the soil in assessing foundation stiffness.

Dynamic analyses may be necessary to calculate force amplification for the design wave, and for recurring, short-period waves of relevance to cyclic soil degradation and structural fatigue. Studies should be performed parametrically to assess the influence of uncertainties in soil parameters.

4.9 PERFORMANCE MONITORING

Measurements of dynamic motions and settlements should be related to environmental conditions to assess foundation performance. Any changes in dynamic response should be related, where possible, to changes in soil parameters. Subsea inspection should assess the condition of the foundation, scour and of the durability of scour prevention measures (Section 2.6).

5. FOUNDATIONS FOR JACK-UP INSTALLATIONS

5.1 APPLICABILITY

This section applies to mobile jack-up Installations engaged in normal exploration, drilling or other activities involving a limited period at a particular site.

5.2 FOUNDATION TYPES

Load is transferred to the soil through independent foundations at the base of each leg or through a foundation common to all legs. These foundations are respectively termed footings or spud cans, and mats. The footing base is usually shaped to aid penetration into strong soils. Mats may be equipped with skirts to improve sliding resistance and minimise scour effects in weak and erodible soils.

5.3 PARTICULAR REQUIREMENTS

Foundations should be preloaded to proof test their capacity with respect to the maximum design loads at the particular location (Section 5.8).

The likely foundation load-penetration behaviour should be predicted by a competent person. The prediction should be based on analysis of geotechnical data for the location or on experience of satisfactory performance of similar foundations in the vicinity.

Particular attention should be given to the preloading of a three-legged unit with water ballast. There is no possibility for redistribution of load away from a leg if its soil support is suddenly reduced. Stability of such units during preloading is particularly susceptible to variation in footing penetration resistance with depth below the seafloor.

5.4 SCOUR

Erosion of granular soils can develop quickly during storms leading to rapid additional footing penetration. Particular care should be taken with cone-shaped footings and mats that are susceptible to increased penetration due to scour. Consideration should be given to scour prevention measures (Section 2.6).

5.5 OPERATIONAL CONSTRAINTS

A jack-up should have an adequate length of leg to accommodate the maximum foundation penetration below the seafloor and the required air gap.

In a layered soil profile, weaker layers may lie under stronger. Consideration should be given to the possibility of a spud can punching through a strong soil, and rapidly penetrating some distance into weaker soils, when leg loads are increased while elevating the hull.

Punch-through can also occur in unstratified weak clay if a delay of several hours occurs during preload operations. Increasing the leg load after the delay can result in initially little or no footing movement followed by a sudden increase in penetration.

In the event of a jack-up being located at a site having seafloor depressions caused by a previous Installation, consideration should be given to the possibility of a differential leg penetration, and the unit sliding towards a depression.

Extracting footings from weak clays can be difficult, even with the use of a jetting system, and there are presently no reliable methods of predicting leg extraction problems. Careful consideration should be given to the suitability of a jack-up for a site if deep penetration in clay is expected and the site is exposed to changeable and severe environmental conditions.

5.6 PREDICTION OF SPUD CAN PENETRATION

Analyses to predict footing load-penetration behaviour should be performed by applying bearing capacity theory to the footing considered at successively deeper penetrations. Due consideration should be given to particular features of the footing penetration problem that differ from assumptions inherent in analytical models. These include installation of the footing by penetration, which involves failure of the soil underlying the footing, and the irregular cross-sections and base profiles of most footings.

Particular attention should be given to variations in the soil shear strength profile, due to changes in soil type or consistency, that may give rise to footing punch-through.

Consideration should be given to the possibility of footing penetration changing due to scour, or any other factor, thereby changing a nominally safe foundation into one where punch-through could occur.

Footings in weak clays of uniform shear strength can penetrate well below the seabed. Calculations should be performed parametrically to assess the influence of uncertainties in ascribing a value to the soil shear strength and in the extent to which soil infills the void between footing and seafloor.

5.7 MAT FOUNDATIONS

Mat supported Installations cannot be re-levelled and so have a limited tolerance to tilting. Consideration should be given to the mat tilt that may be induced by eccentric loading. Sliding stability may be deficient in very weak soils.

Mat penetration, sliding stability and settlement, both total and differential, should be predicted with due regard to inclined, eccentric loading under storm conditions. Consideration should be given to the relatively high degree of shear strength mobilisation likely to be present in the soils beneath a mat.

5.8 SAFETY OF FOUNDATIONS FOR JACK-UP INSTALLATIONS

Safe installation of a jack-up depends on predetermining the likely range of foundation load-penetration behaviour, and understanding its consequences. Prediction of the load-penetration behaviour, including the terminal penetration and punch-through potential, should permit selection of a suitable unit for the site and specification of safe installation procedures.

The foundations should be preloaded at each location. Where investigation has demonstrated that bearing capacity increases continuously with depth, the preload should at least equal the predicted maximum vertical load (see OTO 2001 013). In other cases, including potential punch-through conditions, a greater preload may be required.

To minimise storm-induced penetration in the particular case of footings at or very near the seafloor, consideration should be given to preloading such that the degree of soil shear strength mobilisation is equal to that predicted for the extreme storm loading condition.

The factor of safety against sliding, applied to soil shear strength, should be at least 1.5.

Overturning moments should be assessed using the most critical combination of variable loads and with due regard to any instructions for ballasting the jack-up under storm conditions. Jack-ups with independent footing support should have a safety factor of at least 1.1 with moments calculated about the most unfavourable axis through the centre of one or two footings. For mat-supported Installations the minimum safety factor should be 1.5 with moments calculated about the most highly stressed edge of the mat.

5.9 SAFETY DURING PRELOADING

Preloading should be performed with the hull as close as practical to sea level to minimise the consequences of rapid differential leg penetration. The required preload should be held until no perceptible leg movement has occurred for a sustained period, the duration of which should be determined for a particular site by a competent person.

Where a punch-through is predicted at a load to be attained during water ballasting then the likely rate and magnitude of the associate penetration should be assessed. Consideration should be given to structural characteristics as these vary, some jack-ups being better suited than others to particular sites and conditions of differential leg penetrations.

If water jetting is used to penetrate a granular soil where a punch-through has been predicted, but is not successful, then the jack-up should be moved away from the disturbed soils.

The person supervising the placing of the Installation should be aware of the predicted footing load-penetration behaviour for the site. If the soil conditions present particular difficulties for the jack-up, then a person conversant with foundation soil behaviour should be present during the operation. Significant differences between predicted and actual footing behaviour should be resolved before continuing the operations.

Preloading should be conducted in accordance with appropriate procedures.

5.10 JACK-UPS NEXT TO PLATFORMS

Careful consideration should be given to the effects of installing and removing a jack-up adjacent to, or on, the foundations of a permanent structure. The soils will be disturbed, additional loads may be applied to the permanent foundation, scour may increase, and a depression will be left in the seafloor when the jack-up moves away. Particular attention should be given to the effect that jetting may have on the integrity of an adjacent foundation.

5.11 FOUNDATION STIFFNESS

Unless the site conditions are known, the soil stiffness for fatigue analysis of a jack-up should be conservatively assessed based on the weakest soil that is compatible with the foundation preload requirement. The reduction in soil stiffness with increasing shear stress should be considered in developing foundation response characteristics for leg strength analysis.

6. OPERATIONAL DATA (FOUNDATIONS)

For bottom-supported Installations information should be available to personnel on the Installation regarding the characteristics of the foundation, bottom penetration and limiting values for scour and other seabed conditions.

7. REFERENCES

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