Pile/sleeve connections
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Edited under the HSE Technical Support Agreement by BOMEL Ltd
Ledger House
Forest Green Road
Fifield
Maidenhead
Berkshire SL6 2NR
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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 However, SI289 was revoked by the Offshore Installations (Design and Construction, etc) Regulations, 1996, which also introduced the verification provisions into the Offshore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 The ‘Guidance’ was formally withdrawn in its entirety on 30 June 1998 (see HSE OSD Operations Notice 27\(^{(3)}\)).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 reformatting 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](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 the design, materials and construction of grouted connections between the supporting piles of offshore structures and jacket legs/pile sleeves. It is based on guidance previously contained in Section 22 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 PILE/STRUCTURE CONNECTIONS

Where all or some of a structure’s piles pass through the legs, the primary pile/structure connection is typically made by welding the pile to the structure above water and/or by grouting the leg/pile annulus. Where skirt piles are used alone or to supplement the leg piles, the connections between the piles and the pile skirt sleeves are generally made by grouting to provide load transfer between structure and piles although a process of providing connection by swaging the pile to its sleeve has been successfully implemented.

The performance of grouted connections between piles and jacket/tower type structures may therefore be critical to the structural integrity of fixed steel Offshore Installations.
2. DESIGN PROCEDURES

The following recommendations for design procedures have been derived from model and full scale laboratory tests on specimens representing the geometry of typical connections used for North Sea structures and are similar to those presented in OTC 3788(4). They are intended to cover all instances where grouted connections form the primary means of load transfer between the structure and its piles. Further information is given in OTP 11 1982(5).

2.1 FACTORS AFFECTING THE STRENGTH OF A GROUTED CONNECTION

The following have been shown to be the principal factors affecting the strength of a grouted connection:

- grout compressive strength and elastic modulus
- tubular and grout annulus geometries
- outstand and spacing of mechanical shear connectors
- grouted length to pile diameter ratio
- surface condition of tubulars
- long term grout shrinkage or expansion.

(Surface condition and grout shrinkage / expansion are only of significance in plain pipe connections).

There is a need for special consideration where tensile loads predominate as there is some evidence that the strength of grouted connection is reduced under these loading conditions.

2.2 RANGE OF APPLICATION

The strength formulation given in Section 2.3 below may only be applied to connections which satisfy the following geometrical ratio limits and which, for connections using mechanical shear connectors, also satisfy the requirements of Section 3.1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ratio Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleeve geometry</td>
<td>$50 \leq (D/t)_s \leq 140$ *</td>
</tr>
<tr>
<td>Pile geometry</td>
<td>$24 \leq (D/t)_p \leq 40$ *</td>
</tr>
<tr>
<td>Grout annulus geometry</td>
<td>$10 \leq (D/t)_g \leq 45$</td>
</tr>
<tr>
<td>Grouted connection length to pile diameter ratio</td>
<td>$L/D_p \geq 2$</td>
</tr>
<tr>
<td>Shear connector height ratio</td>
<td>$0 \leq h/D_p \leq 0.006$ **</td>
</tr>
<tr>
<td>Shear connector spacing ratio</td>
<td>$0 \leq D_p/s \leq 8$ **</td>
</tr>
<tr>
<td>Shear connector ratio</td>
<td>$0 \leq h/s \leq 0.04$ **</td>
</tr>
<tr>
<td>Shear connector shape factor</td>
<td>$1.5 \leq w/h \leq 3$</td>
</tr>
</tbody>
</table>

where w is the nominal width of the shear connector including welds.
Whilst D/t ratios are given for sleeve and pile geometries, the design of these components should be in accordance with relevant steel design methods.

** The lower limit 0 represents a plain sleeve without shear connectors.

The notation is illustrated in Figure 1.

The above limits are imposed because of the range of geometries for which test data are available. The restriction on shear connector shape factor (width/outstand) is consistent with connectors formed either by welded square bar or approximately semicircular weld beads and generally covers current practice.

These limitations should not be taken to exclude the use of connections outside the stated ranges providing that it is demonstrated that the strength of such connections can be reliably estimated. Connections with pile and sleeve D/t ratios below the lower limits (i.e. more radially stiff) can be conservatively designed by assuming the limiting D/t ratios in calculations. Alternatively, test data may be used as the basis for design. However, care must be taken in using the results of limited test programmes to prove a characteristic bond strength equivalent to that given in Section 2.3 below. Statistical analysis of test data requires the imposition of substantial reduction factors in the calculation of characteristic bond strength values from a small amount of data. Statistical tables are given in CIRIA Technical Note 44(6).

### 2.3 STRENGTH FORMULATION FOR GROUTED CONNECTIONS

- The characteristic bond strength of a grouted connection, with or without mechanical shear connectors satisfying the requirements of Section 2.2, is given by:

\[
f_{bcu} = K C_L (9 C_s + 1100 h/s) (f_{cu})^{1/2}
\]

where:
- \(f_{bcu}\) is the characteristic bond strength (in N/mm\(^2\))
- \(f_{cu}\) is the characteristic grout compressive strength (in N/mm\(^2\))
- \(K\) is the stiffness factor defined below
- \(C_L\) is the coefficient for grouted length to pile diameter ratio
- \(C_s\) is the surface condition factor
- \(h\) is the minimum shear connector outstand (in mm)
- \(s\) is the nominal shear connector spacing (in mm)

\[
K = [m (D/t)_g]^{-1} + [(D/t)_p + (D/t)_s]^{-1}
\]

where:
- \(m\) is the modular ratio of steel to grout
- \(D\) is the outside diameter
- \(t\) is the wall thickness

and suffixes \(g\), \(p\) and \(s\) relate to grout, pile and sleeve respectively.

- In the absence of other data the modular ratio \(m\) may conservatively be taken as 18 for the long term (i.e. 28 days or more).
The available data on the parameter $C_L$ are limited. In the absence of data relating to a specific tubular and shear connector geometry, the following values of $C_L$ should be assumed:

<table>
<thead>
<tr>
<th>$L/D_p$</th>
<th>$C_L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>0.9</td>
</tr>
<tr>
<td>8</td>
<td>0.8</td>
</tr>
<tr>
<td>$\geq 12$</td>
<td>0.7</td>
</tr>
</tbody>
</table>

where $L$ is the nominal grouted connection length.

Intermediate values for $L/D_p < 12$ should be calculated by linear interpolation.

The surface condition factor $C_s$ should be taken according to the following:

i) if shear connectors are present and satisfy the requirement $h/s \geq 0.005$ then $C_s$ may be taken as 1.0.

ii) for plain pipe connections and for connections with shear connectors but with $h/s < 0.005$, then, in the absence of test data, $C_s$ should be taken as 0.6.

The values in i) and ii) above refer to shotblasted or lightly rusted surface conditions. Other conditions (e.g. painted surfaces) should receive special consideration.

2.4 SAFETY FACTORS

In determining the permissible working bond stresses from the characteristic bond strength calculated using the above formulation, the following safety factors given below should be applied.

a) **Grout displacing water**

<table>
<thead>
<tr>
<th>Loading Condition</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme</td>
<td>4.5</td>
</tr>
<tr>
<td>Operating</td>
<td>6.0</td>
</tr>
</tbody>
</table>

b) **Grout displacing drilling mud or other similar material**

<table>
<thead>
<tr>
<th>Loading Condition</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme</td>
<td>6.0</td>
</tr>
<tr>
<td>Operating</td>
<td>8.0</td>
</tr>
</tbody>
</table>
2.5 APPLIED STRESSES

In calculation of applied bond stresses for comparison with the permissible working bond stress, due account should be taken of the distribution of overall structure loads between various piles in a group or cluster. The design loads for the connection should be the highest calculated load with due consideration of the range of possible in-situ soil stiffness.

Bond stress is defined as the applied axial load divided by the pile to grout nominal contact area. The overall deflection of a grouted connection at the working load may need consideration in the design of the structure.
Figure 1  Pile-sleeve connection
3. MECHANICAL SHEAR CONNECTORS

It is strongly recommended that mechanical shear connectors are used, since their presence can result in connection strengths of several times that of plain pipe connections with resulting economy for the complete structure. The use of mechanical shear connectors increases the reliability of the connection and eliminates the effect of long term grouting shrinkage on the connection capacity.

Mechanical shear connectors may take the form of continuously welded bars or weld beads attached to the steel surfaces in contact with the grout and may be arranged in hoop or helical formation. Other forms of shear connectors require special consideration.

Where the design of the grouted connections takes account of the presence of shear connectors, the following recommendations apply:

- Shear connectors should be present on both the pile and sleeve surfaces which are in contact with the grout.
- The shear connector spacing should be uniform along the length of the connection.
- The outstand and spacing of shear connectors on the sleeve and pile should be the same. If this is not the case then the characteristic bond strength should be assessed both for the outer surface of the pile and the inner surface of the sleeve and the lower value used to calculate the connection capacity.
- For driven piles, shear connectors should be applied to sufficient length of the pile to ensure that, after driving, the part of the pile in contact with the grout has shear connectors.
- Shear connector cross-section and welds on each grout/steel interface should be designed to transmit the total load applied to the grouted connection.
4. GROUT MATERIALS AND PROCEDURES

4.1 MATERIALS

Materials which may be used for grouted connections include:

- Portland cement grouts with or without inert fillers mixed preferably with fresh water, although seawater may be used. There may be special circumstances where the use of seawater is undesirable because of corrosion and other durability effects.

- Fresh water/high alumina cement grouts providing that, to take account of the conversion process, the design is based on the minimum strength appropriate to the curing temperature, service temperature and water:cement ratio. In this respect the water:cement ratio should not be greater than 0.4.

Admixtures may be used to improve properties of the slurry or set grout provided that it is established that they have no harmful effect on the performance of the connection. Calcium chloride or admixtures containing significant levels of chloride ions should not be used.

4.2 OFFSHORE GROUTING PRACTICES

For the design relationships given in this document to be applicable, the following procedures must be used.

The grout should be injected at the lowest point of the annulus so that any fluid present is completely displaced. Reliable means of ensuring complete filling of the annulus with sound grout should be incorporated, such as a) provision for samples of material at the top of the annulus to be returned to the surface by piping or by divers, or b) the provision of proven remote monitoring devices at the top of the annulus.

4.3 GROUT MATERIALS AND PROCEDURES

Guidance on the strength-time characteristics of typical grout mixes can be obtained from OTC 3083(7).

4.4 ASSESSMENT OF COMPLIANCE OF GROUT STRENGTH

4.4.1 Mix specification

Evidence that the proposed mix will meet the specified strength at a given age should be obtained from previous production data or trial mixes. The mean strength calculated from these data should exceed the specified characteristic grout compressive strength by either:

\[
1.64 \sigma (0.86 + \sqrt{2/n}) \quad \text{for } 10 \leq n < 100 \text{ or }
\]
\[
1.64 \sigma \quad \text{for } n \geq 100
\]

where:
\[ \sigma \text{ is the standard deviation calculated from } n \text{ results} \]
\[ n \text{ is the number of test results (not to be less than 10).} \]

Where previous production data is to be used in the above criteria, it should be from test results from separate grout batches selected over an immediately prior period, not exceeding two years, and using the materials and plant which are proposed for the work.

Where laboratory trial mixes are used to provide data, at least three separate batches of grout should be prepared and at least six cubes should be made from each batch for each age at which compliance is to be determined.

**4.4.2 Offshore quality control**

During the grouting of each connection, samples of grout should be taken from randomly selected batches. The rate of sampling should take account of the nature of the work.

At least four samples, each of three cubes, should be taken for each connection. One cube for each sample should be tested to assess compliance (usually at 28 days). The remaining cubes may be tested at earlier ages to indicate the grout quality.

Until tested the specimens should be subjected to a curing regime representative of the curing conditions of the grouted connection. i.e. underwater and at the appropriate seawater temperature.

Strength compliance can be assumed if no test result in each set of four is below the specified characteristic grout compressive strength.

In the event of non-compliance the action taken should have due regard for the nature and degree of non-compliance and the implications for safety.

**4.4.3 Grout specimens**

The formula for characteristic bond strength given in Section 2.3 above is based on the characteristic grout compressive strength as determined by tests on 75mm cubes at the design age (usually 28 days). Other cube sizes and cylinders may be used to determine and check grout strength providing a conversion factor is applied as determined by appropriate tests. It should be noted that for any given mix the conversion factor will depend on the age of the grout.

Testing of grout specimens to determine grout compressive strength should be in accordance with BS 1881\(^{(8)}\).
5. REFERENCES


