HSE
Health & Safety
Executive

Concrete

OFFSHORE TECHNOLOGY REPORT

2001/046

Concrete

Edited under the HSE Technical Support Agreement by BOMEL Ltd
Ledger House
Forest Green Road
Fifield
Maidenhead
Berkshire SL6 2NR

HSE BOOKS

First published 2002

ISBN 0 7176 2392 0

CONTENTS

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 However, SI289 was revoked by the Offshore Installations (Design and Construction, etc) Regulations, 1996, which also introduced the verification provisions into the Offshore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 The 'Guidance' was formally withdrawn in its entirety on 30 June 1998 (see HSE OSD Operations Notice 27[(3)]).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

This Offshore Technology (OT) Report provides technical information on Offshore Installations or parts of Installations constructed in concrete which, in service, would be fixed to the seabed. It is based on guidance previously contained in Section 23 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.

During tow out and placing, such Installations may be afloat but this condition should be regarded as temporary. Concrete Installations intended to operate afloat are addressed in OTO Report 2001 048.

The information on concrete presented in this document is supported by the background report OTH 89 304[(4)]. A number of background reports were published as a result of the Concrete in the Oceans programme. An overview of the programme is contained in reports OTH 87 248[(5)] and OTH 87 249[(6)]. Where specific Concrete in the Oceans reports are relevant to particular sections of this document they are referenced in those sections.

2. DESIGN AND DETAILING

2.1 STANDARDS

Except where supplemented or amended by the information given in this document, it is suggested that reinforced, prestressed and precast concrete should comply with the requirements of BS 8110: Part 1[(7)], 1997 and Parts 2[(8)] and 3[(9)], 1985. In using these codes, it should be noted that the partial safety factor for reinforcement given in BS 8110: Part 1: 1997 is 1.05. In the 1985 version it was 1.15.

Standards and/or codes other than British may be used, provided that an equivalent degree of safety and integrity will be achieved, and that where no equivalent British publication exists, reference may be made to appropriate other specifications and/or codes in general use.

Where a code cannot be used in its entirety, selection from the recommendations in two or more specifications or codes may be made but only after proper consideration of the derivation and structure of the documents, and only if safety and sound engineering practice can be maintained.

2.2 LIMIT STATE DESIGN

Consideration should be given to the use of Limit State design for the design of concrete structures. In the Limit State method, loading effects should be compared with the relevant resistance of the structure (Ultimate Limit State), or the effects of service loads should be compared with specific values of deflection, cracking or other service requirements (Serviceability Limit State).

Certain phenomena cannot be treated rigorously by these methods and other appropriate procedures should be used.

2.3 LIMIT STATES

a) Ultimate limit state
This is defined in BS 8110: Part 1, Clause 2.2.2. In addition, the effects of impact and implosion should be taken into account. Every effort should be made to design against progressive collapse in the event of an accident with a view to safeguarding personnel.

b) Serviceability limit state
This is defined in BS 8110: Part 1, Clause 2.2.3 and is clarified with regard to fatigue, deflection, cracking (Sections 2.9 to 2.11) and oil storage (Section 2.18).

2.4 LOADS

The loads are discussed in OTO Report 2001 013.

As stated in BS 8110: Part 1, Clause 2.4.1.3, partial safety factors for loads take account of the following:

- Possible increases in load beyond those considered in deriving the characteristic loads.
- Inaccurate assessment of effects of loading and unforeseen stress distribution within the structure.
- The variations in dimensional accuracy achieved in construction.
- The importance of the limit state being considered.

The average recurrence periods for environmental design conditions given in OTO Report 2001 010 are such that they give an acceptable probability of their occurrence. There is, therefore, no need to apply a separate partial safety factor to these conditions other than the load factor applied to the loads calculated from the design environmental conditions.

It may be permissible to use lower load factors to allow for more accurate knowledge of one or more of the individual components used to define the factor. Such adjustments for a particular condition or load case will require justification.

Load and material factors as indicated in Sections 2.5, 2.6 and 2.7 may be used for design. Where it can be demonstrated that alternative factors published in a recognised standard or code of practice are appropriate, these alternatives may be used. However, the only satisfactory solutions are likely to be obtained from a complete coherent published set of factors. Such alternatives will need to be consistent with loads defined in OTO Report 2001 013.

No detailed study on reliability indices for concrete structures has been undertaken. For a particular structure, such studies may be undertaken to justify alternative load and material factors to those suggested herein.

2.5 LOAD FACTORS FOR THE ULTIMATE LIMIT STATE

The design load for the Ultimate Limit State should be determined by multiplying the loads discussed in OTO Report 2001 013, plus the additional operational wave loading requirement defined herein, by partial safety factors for loads. When designing elements of the structure, the probable combination and arrangement of loads that will cause the most severe stresses in the elements should be determined. Some of the probable combinations of loads which should be considered, and the load factors which should be used with these conditions, are given below. The factors to be used for other load conditions should be determined and, where appropriate, these will need to be compatible with those given below.

The variable names Gk, Qk, Hk and Vk represent nominal (i.e. unfactored) design values for dead, imposed, hydrostatic and environmental loads respectively. It is important to realise that although the same variable names are used for all load conditions, the actual magnitude of these design loads may differ from one condition to another.

Where two load factors are given for a particular load, the value which produces the most severe stress should be used.

a) Operating conditions
Load combinations suggested for this condition are as follows:

Design dead load	1.2Gk
Design imposed load	1.6Qk
Design hydrostatic load	0.9Hk or 1.2Hk
Design environmental load	1.4Vk

Note that if the nominal (i.e. unfactored) design values for the operating conditions do not differ from the extreme environmental conditions, then only the requirements given in Section 2.5 b) need be considered.

b) Extreme environmental conditions
Load combinations suggested for this condition, with maximum imposed loads, are as follows:

Design dead load	1.2Gk
Design imposed load	1.2Qk
Design hydrostatic load	0.9Hk or 1.2Hk
Design environmental load	1.2Vk

Load combinations for this condition, with minimum imposed load, are as follows:

Design dead load	0.9Gk
Design imposed load	0.9Qk
Design hydrostatic load	0.9Hk or 1.2Hk
Design environmental load	1.4Vk

For the above load combination the dead and imposed loads on selected parts of the structure should be increased to 1.2Gk and 1.2Qk respectively if this produces a more severe loading condition.

c) Temporary load conditions
During construction ashore (not subject to environmental loads other than wind) the load combination and load factors are given in BS 8110: Part 1, Clause 2.4.3.1.1. During construction afloat and towing, the load combinations and load factors should be as given for operating conditions above except that the environmental loads used should be appropriate to the construction or towing condition under consideration.

Load conditions suggested for deck mating, in the deep submergence phase, are as follows:

Design dead load	1.1Gk
Design imposed load	1.3Qk
Design hydrostatic load	1.1Hk
Design environmental load	1.2Vk

Load conditions suggested for flooding down and setting on the bottom are as follows:

Design dead load	1.1Gk
Design imposed load	l.3Qk
Design hydrostatic load	0.9Hk or 1.1Hk
Design environmental load	1.2Vk

d) Additional loads to be considered
The direct loading effects of prestress on the concrete section, when included with concurrent load combinations, should be accounted for by taking a prestress load factor of 1.1 or 0.9, whichever produces the most unfavourable result. For the indirect loading effects, such as moments in statically indeterminate systems due to prestress, the load factor should be taken as 1.0.

Where the effects due to differential settlements, creep, shrinkage, temperature or absorption may be significant, they should be accounted for by using a load factor of 1.1, unless a rational analysis shows otherwise.

2.6 LOAD FACTORS FOR THE SERVICEABILITY LIMIT STATE

The design loads suggested for a Serviceability Limit State are as follows:

Design dead load	1.0Gk
Design imposed load	1.0Qk
Design hydrostatic load	1.0Hk
Design environmental load	1.0Vk

In assessing the deflection of the structure as a whole, or any part or section of the structure, the arrangement of the imposed load should be that causing the largest deflection. Deflections should be based on the extreme environmental condition unless there is considered to be an additional operational requirement for a Serviceability Limit State.

The design loads given above apply when estimating the immediate deflections of a structure but, in most cases, the additional deflections due to creep, shrinkage and temperature over the life of the structure will need to be estimated.

The deflection due to creep depends on the dead load and imposed loads of long duration. Where the full imposed load is unlikely to be permanent the deflection due to creep may be calculated on the assumption that only the dead load and that part of the imposed load likely to be permanent are effective. This deflection may be upward.

For the assessment of the cracking Serviceability Limit States, refer to Section 2.11.

2.7 STRENGTH OF MATERIALS

The following materials factors are suggested:

a) Ultimate Limit State
When assessing the strengths of a structure, or any part or section of a structure, the appropriate values of the material factors are 1.5 for concrete and 1.15 for steel. When, considering the effects of excessive loads, caused by misuse or accident or localized damage, the values may be taken as 1.3 for concrete and 1.0 for steel.

b) Serviceability Limit State
When assessing the deflection of a structure, or any part or section of a structure, the appropriate values of the material factors are 1.0 for both concrete and steel. The properties of the materials relevant to deflection assessment (i.e. moduli of plasticity, creep, drying, shrinkage, thermal movement, etc.) are those associated with the characteristic strength of the materials. When assessing the stresses or crack widths at any section within a structure, the values of the material factors should be taken as 1.3 for concrete and 1.0 for steel.

The above values of the material factors assume normal site control and supervision. Where full quality assurance procedures are applied to site quality control procedures appropriate to a major offshore platform construction, the material factor for concrete may be reduced. The adequacy of the value to be used (which is unlikely to be less than 1.2) will need to be demonstrated.

2.8 SHEAR

In the design of reinforced and prestressed concrete members, where the shear failure mechanism is as assumed in BS 8110, the recommendations of the BS8110 can be followed. In other cases and where the shear failure mechanism is not well defined, the resultant principal tensile stresses should be calculated.

A linear analysis should be used with Ultimate Limit State load factors for calculation of the principal tensile stresses. Where the calculated principal tensile stresses exceed $0.24\sqrt{f_{cu}}$ then either:

- Prestressing may be used to adjust the principal tensile stresses.
- Reinforcement may be provided to resist the total resultant tensile force.

The Ultimate Limit State load factor to be used in conjunction with the prestressing force should be taken as 0.8.

For cases in which the resultant pattern of forces resisting the applied loads after cracking is identifiable, the elements resisting these loads should be designed for the Ultimate Limit State using the appropriate material strengths. In addition, the principal tensile stresses should be checked for the Serviceability Limit State.

2.9 FATIGUE

The information on fatigue presented in this section is supported by four background reports: OTH 87 235[10], OTH 87 241[11], OTH 87 242[12] and OTH 87 243[13].

a) Design
It should be demonstrated that the structure is not susceptible to fatigue failure. The minimum fatigue life is likely to be 20 years or the required service life whichever is the greater. Compliance with the remaining sections of this clause is likely to satisfy these requirements.

The resistance to fatigue of sections subjected to significant cyclic loading should be checked. Particular attention should be given to fatigue resistance at sudden changes in cross-section and at openings.

Load factors of 1.0 should be used for all loads in checking fatigue resistance. Any amplification of stress due to dynamic response of the structure should be considered.

It is suggested that no further checks for fatigue, at a given section, need be carried out if the following conditions are satisfied:

- For straight high yield reinforcing bars to BS 4449(14): 1978 and BS 4461(15): 1978 the maximum tensile stress range does not exceed 140 N/mm^2. For loads having more than 1 million cycles the maximum tensile stress range is not greater than 35 N/mm^2.
- For concrete the maximum resultant compressive stress does not exceed 0.33 f_{cu}. No significant membrane tensile stresses exist and flexural tensile stresses are limited to $0.20\sqrt{f_{cu}}$.
- The detailing of reinforcement in areas of significant cyclic loading, with respect to bends, laps, butt welds and mechanical connectors satisfies the points given in Section 2.9 b) below.

In lieu of the above conditions or where fatigue resistance is likely to be a serious problem, a more complete analysis based on the principle of cumulative damage could be substituted. This analysis should include the use of appropriate S-N curves for the materials, environment and stress conditions being examined. It should also consider low cycle high amplitude fatigue. The limiting values to be used for Palmgren-Miner's sum for the design structure life are suggested to be 1.0 for reinforcement and 0.2 for concrete.

b) Reinforcement detailing

For reinforcement in areas subject to significant cyclic loading, the following suggestions are given with respect to detailing:

- The presence of bends in a reinforcing bar causes a reduction in fatigue resistance. Bends with an internal radius less than 10 bar diameters are unlikely to prove satisfactory. Where bends with internal radii greater than ten and less than twenty-five bar diameters are used consideration should be given to reducing the reinforcement stress limits given in the first bullet point in 2.9 a). A reduction factor of 0.5 for an internal radius of 10 bar diameters is suggested, increasing linearly to a factor of 1.0 for an internal radius of 25 bar diameters.
- The calculated length of straight laps may be doubled.
- Cranked laps are best avoided.
- Butt welding of reinforcement is best avoided wherever possible.

  Where butt welds in reinforcement are used, it is suggested that the reinforcement stress range limits should be half the values given in the first bullet point of 2.9 a) above unless it can be demonstrated that, without such limitations, their fatigue strength is adequate.

- If the use of mechanical reinforcement connectors is proposed it will be necessary to demonstrate that their resistance to fatigue is adequate.

2.10 DEFLECTION

The deflection of the structure or any part of the structure should not adversely affect the efficiency of the structure. In accordance with BS 8110: Part 1, Clause 2.2.3.2 and subsequent requirements for individual member types, it should be demonstrated that deflections are not excessive.

For tall slender structures, in particular, it is suggested that the effects of lateral displacement should be considered as should the acceleration during displacement and the effects of vibration.

In any calculation of deflections, reference should be made to the design properties of materials and design loads presented in Sections 2.6 and 2.7 b) of this document.

2.11 CRACKING

For the calculation of surface crack widths the method presented in BS 8110: Part 2, Clause 3.8 may be followed. The crack widths should be calculated using the Serviceability Limit State load factors as presented in Section 2.6 of this document. Two separate environmental conditions are suggested as follows:

- An extreme serviceability environmental condition using loads having an average recurrence period of not less than 50 years.
- A normal serviceability environmental condition using loads having an average recurrence period of one month.

Note that the nominal value of dead and imposed loads should be similar for both cases unless there are differences specified in the design for the extreme condition.

It is suggested that calculated crack widths should satisfy the following requirements, which supplement the recommendations in BS 8110: Part 1, Clause 2.2.3.4:

- Under normal conditions, crack widths for the splash and atmospheric zones should not exceed 0.1mm and for the submerged zone should not exceed 0.3mm.
- For the submerged zone there is evidence that cracking may have a negligible effect on the corrosion of reinforcement. Unless lower limits are required for oil storage as set out in Section 2.18 of this document, crack widths under the extreme conditions should not exceed 0.6mm. This provision can normally be assumed to be satisfied without further checks provided standard reinforcement detailing is followed. No crack width limits are suggested for the splash and atmospheric zones for the extreme conditions.
- Limited evidence exists that under load conditions which cause frequently repeated opening and closing of cracks (known as dynamic cracking), there may be excessive localised corrosion in the upper part of the submerged zone. The sections in this zone should preferably be designed to remain in compression under frequently repeated loads unless the effects of localised corrosion can be assessed to be minimal with regard to overall structural integrity.
- The detailed crack width calculations given in the first three bullet points above are not likely to be required for areas of the structure where the embedded steel is covered by an effective cathodic protection system.

- In the calculation of crack widths, allowance needs to be made for the effects of a principal tensile stress being inclined to the main reinforcement, and the tension stiffening effect of the concrete would be neglected. Where members are subjected dominantly to an axial tension, adjustments will need to be made to the suggested procedure.
- If water ingress is required to be avoided in hollow sections where the concrete may go into tension across its full thickness, membrane tensile stresses sufficient to cause cracking across the full depth of the section will need to be avoided. This suggestion may be relaxed if it can be shown that limited water penetration is not detrimental to the structure or its equipment.
- Consideration should also be given to construction cracking and the effect on the long-term performance of the structure.
- It is assumed that any prestressing tendons are in properly grouted ducts near the centre of the section and for this reason no specific crack control measures relating to prestressing have been included. If prestressing is used as the primary means of crack control, it is suggested that the requirements of BS 8110: Part 1 should be adopted.

2.12 COVER

Appropriate cover to all reinforcement and prestressing should be provided in all zones. It is suggested that the nominal cover should be not less than the greatest of the following:

- The cover shown in Table 1.
- 1.5 x the nominal maximum size of aggregate.
- 1.5 x the maximum diameter of reinforcement or prestressing tendons.
- For bundled bars the greater of either 1.5 x the diameter of the largest bar in the bundle or the diameter of the equivalent bar but not more than 100mm (the equivalent bar is a single bar having the same cross sectional area as the bundle of bars).

Table 1 Cover to Reinforcement and Prestressing Tendons

Zone *	Nominal Cover (mm)
Submerged	45
Splash	70
Atmospheric	55

* As defined in OTO Report 2001 011

Allowance should be made in the design for the cover tolerance suggested in Section 4.7 of this document.

For any particular structure, the reasons for providing cover should be assessed and, hence, the appropriate cover can be determined. In the submerged zone there is evidence that, for prevention of reinforcement corrosion, only minimal cover is required and it may be appropriate to adopt lesser cover than suggested above but such lesser cover may be detrimental to structural requirements.

For thin-walled sections in the atmospheric zone cover it is suggested that BS 8110: Part 1, Clause 3.3 may be appropriate.

For certain types of structural configuration additional cover may be required in shafts to prevent deterioration due to acidic water or hydrogen sulphide gas.

No additional cover is suggested for prestressed concrete. The resistance to corrosion protection of post-tensioned prestressing tendons is dependent on the achievement of complete grouting of the ducts. Suggestions on how this could be achieved are given in Sections 3.8 and 4.10 of this document.

2.13 REINFORCEMENT DETAILING

BS 8110: Part 1, Clauses 3.12 and 4.12 provide guidance on the arrangement, curtailment and areas of reinforcement and prestressing tendons.

2.14 MINIMUM REINFORCEMENT

A minimum amount of reinforcement is generally required to obtain adequate crack distribution and to avoid excessive steel stresses during crack formation. It is suggested that the minimum area of reinforcement, A_s, at any one face of a member should be not less than:

$$A_s = \frac{\left(0.37\sqrt{f_{cu}}\right)\cdot b \cdot d_e}{f_y}$$

where:

f_{cu} = characteristic strength of concrete
f_y = characteristic tensile strength of steel
b = width of member
d_e = effective tension zone (1.5 x cover + 10 x bar diameter)

2.15 DRAWDOWN

Drawdown is, for the purpose of this document, defined as reduced internal hydrostatic pressure relative to external hydrostatic pressure. This may be achieved by drawing down the internal water level relative to the external water level.

Caution should be exercised in the use of drawdown to resist operating or environmental loads. Where drawdown is used, it will be necessary to demonstrate that accidental loading due to impact or temperature effects, as defined in Sections 2.16 and 2.19, will not cause loss of drawdown sufficient to impair the ability of the structure to meet the Ultimate Limit State requirements.

The design of the drawdown system will need to be such as to allow maintenance without loss of drawdown.

2.16 IMPACT

It is suggested that damage due to impact should be evaluated with respect to both dropped objects and ship collision as an extreme accidental load. The loads will need to be specified separately based upon an acceptable probability of the load occurring.

The impact loading will need to be analysed in conjunction with the load combinations suggested for operating conditions in Section 2.5, with an overall load factor and material factor of 1.0. Local failure under these conditions is acceptable but it will be necessary to demonstrate that such failure will not lead to global failure of the structure under operating or extreme environmental loads. Consideration should be given to the effects of possible loss of drawdown.

Suggestions for the analysis of impact energy and damage due to dropped objects and ship collision are given below:

a) Dropped objects

The entire submerged zone of a structure will need to be assessed for impact damage, arising from dropped objects, in relation to perforation and scabbing. The effects of an energy absorbing protection layer, where provided, should be included in the analysis.

Dropped objects will need to be considered with respect to two characteristic categories of slender and bulky objects. Typical parameters are suggested in Table 2 for each category.

Impact velocities quoted assume that terminal velocity is reached before impact. When these velocities are considered inappropriate, actual velocities may be calculated allowing for free fall through air, impact with water and fall 'end-on' through water.

Table 2 Typical Parameters of Dropped Objects

Category	Description of Object	Cross Section (m^2)	Velocity (m/sec)	Weight (tonnes)
Slender Object	Caisson	0.9 x diam.	18.0	19.0
Bulky Object	Mud Pump	2.0 x 2.0	12.0	30.0

b) Ship collision

The structure will need to be analysed for impact damage arising from collision by a ship. Consideration should be given to all stages during the structural life including construction, towing, installation and operation.

Suggestions for ship impact loadings are given in OTO Report 2001 013.

Local failure will need to be assessed with respect to punching shear and local bending. Consideration should be given to global failure at all stages of the structural life with respect to overall stability of the structure and possible progressive collapse.

2.17 IMPLOSION

Submerged cellular structures will be subjected to hydrostatic pressure and will need to be analysed for implosive buckling.

Suggested load configurations and factors for the analysis are given in Section 2.5 of this document. Load factors may be reduced to 1.1 for short term hydrostatic loading when creep effects are taken into account.

It is suggested that the hydrostatic head used for the assessment of implosion in the permanent condition should be based on the greatest still water depth in conjunction with the highest astronomical tide and storm surge. Differential pressure changes due to wave and current action may be considered as secondary, but it is suggested that they should be assessed (particularly the former). Temporary hydrostatic loading will need to be based on an assessment of the worst combination of conditions that may occur.

Consideration should be given to checking the stability of the structure for the maximum hydrostatic pressure for the following two categories:

- Wall stability against implosion analysed as an Ultimate Limit State.
- Stresses and concrete sections analysed for both Ultimate and Serviceability Limit States applying both compression and bending moments in addition to second order effects.

The buckling strength of both complete and partial cellular structures may be determined from empirical methods based on concrete cylindrical members. Comprehensive analysis may be required for more complex configurations and loadings. Analysis of the buckling strength should typically allow for additional effects due to imperfections with respect to out-of-roundness, load duration, prestressing and reinforcement.

The information on implosion presented in this section is supported by the background report OTH 87 236 [16].

2.18 OIL CONTROL SYSTEMS AND STORAGE

The design of storage systems should consider both the structural and the process engineering requirements for storage of oil, gas, liquid gas or similar fluids at pressure. It should be demonstrated that the proposed storage and control systems will not lead to handling problems.

It is suggested that the storage structure should be designed so that under any combination of loading no tensile membrane stress occurs of a magnitude sufficient to cause cracking across the full thickness of the section. Some flexural tensile stress may, however, be unavoidable, but this is acceptable providing a compression zone equivalent to not less than 1/3 of the width of the section or 200mm is present. The effects of differential pressure and thermal loading, where appropriate, should be allowed for in the crack width calculations.

Where design configurations cause localised stress concentrations that make it impossible to limit the width of cracks to those suggested, or if it can be shown in the event of minor damage the size of crack cannot be so limited, the oil storage system will need to be designed so that the pressure of the oil within the structure is always below that of the surrounding sea.

2.19 TEMPERATURE EFFECTS

Consideration should be given to demonstrating that the structure or parts of the structure will not become unserviceable due to temperature effects. Temperature ranges of gas, fluid or cryogenic materials as well as sea and air should be considered.

Both the Ultimate and Serviceability Limit States should be checked with respect to load combinations and load factors suggested in Sections 2.5 and 2.6 of this document treating the temperature stress as an imposed load. When considering the Serviceability Limit State, the arrangement of the imposed load will need to be such that the largest deflections and crack widths occur.

Design temperatures will depend on the system configuration adopted and the contingency requirements in the event of failure of the system. Data on the temperature of sea water is given in OTO Report 2001 010. The temperature of oil flowing from a production well may range from 70° to 100°C.

Temperature differentials of up to 45°C, after cooling, may occur.

Cracking is more likely with rapid heating and cooling but is unlikely to occur with temperature differentials below 20°C. Where minimum reinforcement as defined by Section 2.14 is provided, cracking is likely to be less than the Serviceability Limit State requirements defined in Section 2.11 for temperature differentials below 45°C. Calculations will need to be carried out when additional loading, including shrinkage, creep effects and geometrical configurations are considered significant with respect to maximum stress levels.

The calculation of stresses due to temperature effects will need to allow for both steady state and transient temperature conditions. In addition, the effects of differential filling of individual oil storage cells will also need to be considered with respect to both local and global effects.

Consideration should be given to the influence of temperature on creep, and the re-distribution of stresses evaluated if this is considered to be significant.

The elastic modulus adopted in the calculation of thermal stresses will need to allow for the influence of temperature. The reduction in stiffness of the concrete will need to be allowed for where cracking occurs.

The information on temperature effects presented in this section is supported by the background report OTH 87 234 [(17)].

2.20 FIRE RESISTANCE

Where there is a possibility of fire, the required minimum period of fire resistance will need to be defined. It will be necessary to demonstrate that the structure has adequate protective measures to withstand this minimum period. Reference can be made to BS 8110: Part 2, Section 4.

2.21 LIGHTNING PROTECTION

The structure will need to be provided with adequate protection against the effects of lightning. The lightning protection system will need to be designed and constructed, where applicable, to comply with the relevant standards.

Consideration should be given to the effects of low impedance paths through prestressing tendons.

2.22 MONITORING

Very severe loads may be developed during movement of an Offshore Installation from the construction site to its permanent location and during the operations associated with setting it on the seabed. To confirm the design assumptions, suitable instruments may need to be installed to monitor the behaviour of the structure and its foundations during these stages, and subsequently for general monitoring and to assist in the assessment of the structure.

3. SPECIFICATION AND WORKMANSHIP

3.1 MATERIALS

a) Standard materials
Except where supplemented or amended by information in this section, it is suggested that concrete and its constituent materials, including reinforcement and pre-stressing tendons, should comply with the appropriate requirements of BS 8110.

b) Non-standard materials
Non-standard materials are defined as those not covered by a British Standard Specification or Code of Practice. These may be used provided that full account is taken of their effects on design requirements and that satisfactory performance data is available to demonstrate their suitability.

c) Materials investigations
The sources and characteristics of all materials to be used will need to be properly investigated and recorded.

3.2 CEMENT

a) Cement type
It is suggested that the cement used should be one of the types shown in Table 3.

The selection of the types of cement to be used will need to be based on full consideration of their particular characteristics and the requirements involved. The use of High Alumina cement to BS 915 [18] and Supersulphated cement to BS 4248 [19] is likely to require prior agreement.

Table 3 Cement Types

Type	In accordance with
Active Hydraulic Binders:	
Rapid-hardening Portland cement	BS 12 [20]
Ordinary Portland cement	BS 12
Blended Hydraulic Binders:	
Portland Blastfurnace cement	BS 146 [21]
Low Heat Portland Blastfurnace cement	BS 4246 [22]
Portland Pulverized-fuel ash cement	BS 6588 [23]
Pozzolanic cement with pulverized-fuel ash as pozzolan	BS 6610 [24]

b) Latent hydraulic binders
Latent hydraulic binders, such as ground granulated blastfurnace slag, pulverized-fuel ash or silica fume may be separately combined with ordinary Portland cement in the site mixer.

It is suggested that the properties of the ordinary Portland cement and of the latent hydraulic binder should, both separately and in combination at the particular relative proportions to be used, comply with the appropriate British Standard specification requirements. Those for the combined product should be the overriding requirements.

c) Tricalcium Aluminate

It is suggested that for ordinary and rapid-hardening Portland cements the tricalcium aluminate (C3A) content should be not less than 5% and not greater than 12%. For C3A contents outside this range, it will be necessary to demonstrate that there are no adverse effects on the performance of the concrete during construction or in-service.

3.3 AGGREGATES

a) Standard specification

Coarse and fine aggregate may be uncrushed and/or crushed natural and/or artificial mineral substances with particle sizes, shapes and other properties suitable for the production of concrete qualities appropriate to the concrete performance requirements. For information refer to BS 8110: Part 1, Clause 6.1 and BS 5328: Part 1 (25) Clause 4.3.

b) Dimensional changes

Certain aggregates have high moisture movement characteristics and their use can result in concrete suffering higher drying shrinkage and moisture movement than is normally expected. It will be necessary to assess such materials in accordance with appropriate test procedures and recommendations and demonstrate that their use will not be detrimental. For information refer to BS 8110: Part 2, Clause 7.4.

c) Alkali-silica reaction

Some aggregates may be susceptible to deleterious reaction with alkalis normally present in the cement or from other sources including sea water. Appropriate measures to avoid or minimize the risks of any such reaction will need to be taken. For information refer to BS 8110: Part 1, Clause 6.1 and BS 5328: Part 1 Clause 5.2.4.

d) Lightweight aggregates

Lightweight aggregates may be used where it can be demonstrated that their use is appropriate and due allowance is made for their properties. For information refer to BS 8110: Part 1, Clause 6.1 BS 5328: Part 1 and BS 3797.

3.4 WATER

For information on mixing and curing water refer to BS 5328: Part 1, Clause 4.7.

Sea water should not be used as mixing or curing water for any concrete containing reinforcement, prestressing tendons or any other embedded metal.

3.5 ADMIXTURES

a) Standard specification
For information on admixtures refer to BS 8110: Part 1, Clause 6.1 and BS 5328: Part 1, Clause 4.4

b) Approval and performance
For information on the approval and performance of admixtures refer to BS 8110: Part 1, Clause 6.1 and BS 5328: Part 1. Verification trials should, additionally, establish the dosage or dosage range required to achieve the desired effects and consequences of under or over dosage. They may initially be carried out under laboratory conditions but the performance of the selected admixtures will always need to be verified under full scale production conditions.

c) Air-entraining admixtures
For information on air-entraining admixtures refer to BS 8110: Part 1, Clause 6.1 and BS 5328: Part 1 Clause 4. An air-entraining admixture may be used to mitigate the effects of harsh or coarsely graded fine aggregates or to minimize any tendency of a concrete to bleed or suffer cracking due to plastic settlement.

The admixture should be of such a type and the dosage of sufficient quantity that the total air content at the point of placing can be readily maintained within the limits specified and that the required amount and quality of entrained air is obtained in the hardened concrete. It is suggested that the spacing factor should not exceed 0.2.

3.6 CONCRETE MIXES

a) Concrete grade
It is suggested that all concrete mixes should be 'designed mixes' as defined by BS 5328: Part 1, Clause 8.2.2. Mix criteria to achieve the required durability, strength, workability and other fresh and hardened concrete properties will need to be determined. Appropriate trial mixes and testing will need to be undertaken to ensure that the mix design will achieve these properties. For information, subject to the considerations herein, refer to BS 5328: Part 1 as follows:

Constituent Materials of Concrete	Clause 4
Durability of Concrete	Clause 5
Other Properties of Hardened Concrete	Clause 6
Properties of Fresh concrete	Clause 7
Basis for Specifying Concrete	Clause 8

It is suggested that the minimum grade of concrete should be as given in Table 4.

Table 4 Minimum Grades of Concrete

Zone*		Exposure Condition	Minimum Grade
Submerged	(a)	Directly exposed to salt water	C40
	(b)	Directly exposed to crude oil or subject to severe abrasion	C50
Splash	(a)	Directly exposed to salt water or salt water spray	C40
Atmospheric	(a)	Directly exposed to marine atmosphere	C40
	(b)	Protected from direct exposure to marine atmosphere	C30
		*As defined in OTO Report 2001 011	

For concrete in the submerged, splash and exposed atmospheric zones a minimum cement content of 400 kg/m^3 will need to be used. The free water/cement ratio for these zones will need to be 0.40 or less, unless it can be demonstrated that by using higher values the concrete is still suitable for the purpose.

Suggested requirements for concrete protected from direct exposure to marine atmosphere are as follows:

- For nominal maximum size of aggregate of 40mm, the minimum cement content will need to be 330 kg/m^3.
- For nominal maximum size of aggregate of 20mm, the minimum cement content will need to be 360 kg/m^3.
- The free water/cement ratio will need to be 0.50 or less, unless it can be demonstrated that by using higher values the concrete is still suitable for the purpose.

The possible degradation of concrete due to presence of stagnant water, hydrogen sulphide, organic acids and other components should be considered. The oil/air interface in closed storage vessels may be a critical zone.

There is evidence that concrete suffers a reduction of strength, particularly tensile strength, on immersion at depth, followed by some recovery. The use of age factors should, therefore, be approached with caution and it would need to be demonstrated that any such strength reduction will not be detrimental to the structure.

b) Chloride content
For information on the maximum permissible total chloride content of concrete refer to BS 5328: Part 1, Clause 5.2.2.

c) Sulphate content
For information on the maximum sulphate content refer to BS 5328: Part 1, Clause 5.2.3.

d) Design assumptions
The properties of the hardened concrete will need to be verified by appropriate sampling and testing procedures after the concrete materials and mix proportions to be used have been established.

3.7 REINFORCEMENT

For information on reinforcement refer to BS 8110: Part 1, Clause 7.1.

3.8 PRESTRESSING TENDONS

a) Standard specification
For information on prestressing tendons refer to BS 8110: Part 1, Clause 8.1.

It is suggested that quenched and tempered steels and/or alloy steels with ultimate strength levels greater than 1200 N/mm^2 should not be used for prestressing tendon or couplers because of their greater susceptibility to premature failure by hydrogen-induced stress corrosion under unfavourable conditions which may occur during construction or service of concrete offshore structures.

b) Storage and condition of prestressing tendons
It is suggested that the handling and storage of prestressing tendons should comply with the recommendation given in BS 8110: Part 1, Clause 8.2 and the cutting of tendons should be in accordance with BS 8110: Part 1, Clause 8.5.

Protective coatings and wrappings for tendons will need to be chemically neutral. The use of suitable inhibited oil coatings and/or vapour phase inhibitors is suggested, together with suitable impermeable wrappings. The possible effect of any coatings, etc. on bond and on local retardation of the grout should be considered. Suitable protection will need to be given to the threaded ends of bars. Account will need to be taken of the effect of residual coatings on bond.

It is suggested that the surface condition of prestressing tendons should comply with BS 8110: Part 1, Clause 8.3 and any pitting evident to the naked eye should be cause for rejection of prestressing tendons.

c) Protection of prestressing tendons during construction
To avoid damage from any stray currents during welding operations electrical plant associated with the operation will need to be adequately earthed, independent of the reinforcement and prestressing tendons in the structure.

3.9 DUCTS FOR PRESTRESSING TENDONS

a) Standard specification
For information on ducts and prestressing tendons refer to BS 8110: Part 1, Clause 8.9 and Annex A.

In BS 8110 Annex A it is suggested that ducts are usually formed from corrugated steel. Joints in the ducts will need to be adequate to maintain alignment during concreting operations and be watertight. Care will need to be taken in choosing the diameter of the duct to facilitate optimum filling with grout, considering the diameter of the tendons and the length and profile of the ducts.

b) Storage
Ducts should be stored clear of the ground and be protected from the weather, from corrosion contamination and from mechanical or thermal damage.

c) Venting and drainage
It is suggested that in long horizontal ducts, air vents should be provided at intervals no greater than 15m, at crests and at any major changes in duct section. Drainage pipes at low points may be provided but their installation and operation is often difficult and may not be universally accepted. In long vertical ducts it is suggested that air vents should be provided at maximum intervals at 30m.

4. CONSTRUCTION

4.1 STANDARD SPECIFICATION

Except where supplemented or amended by the information in this section, it is suggested that concrete workmanship and construction should comply with the requirements of BS 8110.

4.2 CONCRETE MIX AND GRADE

For information on concrete mixes and grades, refer to Section 3.6 of this document.

4.3 CONSTRUCTION JOINTS

It is suggested that construction joints should be prepared in accordance with the requirements given in BS 8110: Part 1, Clauses 6.2.9. Particular attention will need to be paid to those sections of the structure that are to remain water-tight or oil-tight irrespective of whether water-tightness or oil-tightness is required to be a permanent or temporary situation.

4.4 CURING

It is suggested that curing of concrete should be undertaken in accordance with BS 8110: Part 1, Clause 6.2.3.

Concrete will need to be cured with fresh water. Where there is any doubt about the ability to keep the concrete surfaces permanently wet, a heavy duty membrane curing compound will need to be used.

4.5 CONCRETING IN COLD WEATHER

For information on concreting in cold weather refer to BS 8110: Part 1, Clause 6.2.4.

4.6 CONCRETING IN HOT WEATHER

For information on concreting in hot weather refer to BS 8110: Part 1, Clause 6.2.5. The temperature rise due to heat of hydration should be considered in determining a maximum acceptable concrete temperature at the time of placing.

4.7 COVER

The nominal cover to all reinforcement should be as given in Section 2.12. Special consideration will need to be given to the methods of achieving the cover within the tolerances given in Section 4.8.

4.8 TOLERANCES

Acceptable tolerances for construction will need to be established and due allowance made for these in the design. Table 5 gives suggested values.

Table 5 Suggested Tolerances

Description	Suggested Tolerances
Thickness of beams and raft walls	+0mm to -20mm
Thickness of slipformed walls	+0mm to -10mm
When the sliding forms have been completed and finally adjusted any point of the active parts of the forms shall be accurate to	+50mm to -50mm
Deviation from vertical, d (in cm) for a height, h (in metres)	$< 3 \times \sqrt[3]{h}$
Deviation (in cm) in the plane of straight or curved walls of length L (in metres)	< 0.1(5+2L) or < d (whichever is the smaller)
Horizontal Levels	+15mm to -15mm
Deviation on the positioning of inserts	+50mm to -50mm

For cover, specified in accordance with Section 2.12, it is suggested that the minimum tolerances should be as defined in BS 8110: Part 1, Clause 7.3. The maximum tolerance should be +10mm. Where larger tolerances are considered appropriate, the nominal cover will need to be increased to compensate.

4.9 REINFORCEMENT

For guidance on reinforcement and reinforcement fixing refer to BS 8110: Part 1, Section 7; and Section 3.7 of this document.

4.10 PRESTRESSING

For guidance on prestressing tendons and prestressing refer to BS 8110: Part 1, Section 8; and Sections 3.8 and 3.9 of this document.

4.11 GROUTING OF PRESTRESSING TENDONS

a) Standard specification
For guidance on the grouting of prestressing tendons refer to BS 8110: Part 1, Annex A.

b) Cohesion and bleeding
For information on cohesion and bleeding refer to BS 8110: Part 1, Clause 8.9 and Annex A3.3.

For long vertical ducts, it is suggested that the bleeding should not exceed 1% after 3 hours and 2% maximum, under the same conditions. Any water separated at the surface of this grout will need to be reabsorbed after either 24 hours for normal grouts or 48 hours for retarded grouts. It is suggested that the total expansion of the grout should not exceed 10%.

c) Grouting trials
It is suggested that grouting trials should be carried out for long vertical ducts and long horizontal ducts with extended intervals between the vents, using the equipment, grout mix including admixtures, and grouting procedures proposed, to check that the ducts can be completely filled without voids, entrapped water, or excessive bleeding, etc.

d) Timing of grouting
Grouting should be carried out as soon as practicable after the tendons have been stressed, and preferably within three days. It is suggested that the maximum time interval between stressing and grouting should not exceed 21 days.

4.12 PLANNING

The sequence of construction and the operations to be carried out at each stage should be considered concurrently with the initial design studies so that the loading conditions at all stages can be determined.

The basic planning should be such as to ensure that, under all loadings, including construction plant loadings:

- there is adequate time for the concrete to gain the strength required to support the loads and adequate durability before exposure to the environment; and
- when the structure is afloat there is sufficient freeboard of mature concrete to prevent an open structure from being overtopped at any time, taking account of any roll, pitch or heave which will occur during bad weather.

Accurate records of draft, internal water levels and concrete mass will need to be obtained throughout each stage of construction, and predictions compared with the records. The design of subsequent stages should be modified to take account of any discrepancies.

Records of design and construction should be kept for future reference.

5. TOW-OUT

All aspects of towing will need to be studied to ensure that the structure is not exposed to loadings greater than those for which it was designed. A detailed survey of the intended tow route, lay-by areas for storm protection and final location will need to be made to ensure safe passage of the structure. Particular attention should be paid to areas where the seaway is restricted in either depth or width.

Model testing should be considered to determine handling characteristics, in particular stability under tow and the response to motion of the structure. This testing should include an assessment of the structure stability when subjected to accidental damage.

It is suggested that at all times under tow the structure should conform to the requirements of the IMO Collision Regulations [26].

6. PLACING THE STRUCTURE

All aspects of the installation of the structure, including its immersion and placing on the seabed, should be properly planned to avoid undue stress on the structure.

The condition of the seabed should be checked beforehand so that any preparation such as dredging, levelling and trimming or strengthening can take place before the structure is placed in position.

The stability of the structure should be continuously analysed during ballasting and care must be taken to ensure that an unstable situation is not reached.

Variation in buoyancy with depth and time should be taken into account during immersion of the structure.

7. BALLASTING/DEBALLASTING

Because of the complex pumping and piping arrangements required to enable ballasting/deballasting to be carried out, special attention should be paid at the time of construction to maintain access to the various pumps for maintenance purposes.

Where drawdown is used in the structure, particular attention will need to be paid to removing and/or sealing such pipework or fittings so that accidental future leakage cannot occur.

8. INSPECTION AND TESTING DURING CONSTRUCTION

For information on the inspection and testing of concrete, reinforcement and other structural components reference should be made to the relevant section in BS 8110. It is suggested that particular attention should be paid to ensuring that the specified design tolerances are achieved.

9. REFERENCES

1. Department of Energy. Offshore Installations: Guidance on Design, Construction and Certification, 4th Edition. HMSO, Consolidated Edition, 1993 (plus Amendment No. 3, 1995). [Withdrawn 1998 by Operations Notice 27].

2. SI 1974 / 289 – The Offshore Installations (Construction and Survey) Regulations 1974, HMSO, 1974. [Revoked and has been replaced by SI 1996 / 913 – The Offshore Installations and Wells (Design and Construction etc.) Regulations, 1996 – ISBN: 0 110 54451 X].

3. Health and Safety Executive. Status of Technical Guidance on Design, Construction and Certification. Operations Notice 27. Revised and Reissued, August 1998.

4. Department of Energy. Guidance for Concrete Structure: Background Report. OTH 89 304. [Available on HSE web site as OTO Report 96 050.]

5. Department of Energy. Concrete in the Oceans: Coordinating Report on the Whole Programme. OTH 87 248.

6. Department of Energy. Concrete in the Oceans: Management Summary of the Whole Programme. OTH 87 249.

7. British Standards Institution. BS 8110 – Structural Use of Concrete. Part 1: 1997 – Code of Practice for Design and Construction. [In the 1997 version of BS 8110 the partial safety factor for reinforcement is 1.05. In the 1985 version it was 1.15.]

8. British Standards Institution. BS8110 – Structural Use of Concrete. Part 2: 1985 – Code of Practice for Special Circumstances.

9. British Standards Institution. BS 8110 – Structural Use of Concrete. Part 3: 1985 – Design Charts for Singly Reinforced Beams, Doubly Reinforced Beams and Rectangular Columns.

10. Department of Energy. Review of Fatigue in Concrete Marine Structures. OTH 87 235.

11. Department of Energy. Fatigue and Corrosion Fatigue Performance of 16mm Diameter Reinforcing Steel. OTH 87 241.

12. Department of Energy. Fatigue and Corrosion Effects in Reinforced Concrete Beams and Partially Submerged in Seawater and Subjected to Reverse Bending. OTH 87 242.

13. Department of Energy. Fatigue Strength of Reinforced Concrete in Seawater – Results from Phase II. OTH 87 243.

14. British Standards Institution. BS 4449 – Specification for Carbon Steel Bars for the Reinforcement of Concrete. 1978. [This has been superseded by BS 4449: 1997.]

15. British Standards Institution. BS 4461 – Specification for Cold Worked Steel Bars for the Reinforcement of Concrete. 1978. [This has been superseded and withdrawn. It has been replaced by BS 4449: 1997, see Reference 14.]

16. Department of Energy. A Review of Methods of Design Against Implosion of Concrete Cylinders in Offshore Structures. OTH 87 236.

17. Department of Energy. The Effects of Temperature Changes on the Walls of Concrete Oil Storage Structures. OTH 87 234.

18. British Standards Institution. BS 915 – Specification for High Alumina Cement. Part 2 – Metric Units. 1972. [This standard has been partially replaced by parts and sections of BS 4550 – Methods of Testing Cement.]

19. British Standards Institution. BS 4248 – Specification for Supersulphated Cement. 1974. [Partially replaced by parts and sections of BS 4550 – Methods for testing cement.]

20. British Standards Institution. BS 12 – Specification for Portland Cement. 1996. [To be withdrawn on 1 April 2002 and replaced by BS EN 197-1: 2000 – Cement – Part 1: Composition, Specification and Conformity Criteria for Common Cements.]

21. British Standards Institution. BS 146 – Specification for Portland Blast Furnace Cements. 1996. [This standard is to be revised to remove any conflict with BS EN 197-1 and to include current BS 4246 Cement.]

22. British Standards Institution. BS 4246 – Specification for High Blast Furnace Cement. 1996. [This standard will be withdrawn to a time-scale dictated by the revision of BS 146.]

23. British Standards Institution. BS 6588 – Specification for Portland Pulverised-fuel Ash Cements. 1996. [This standard is to be withdrawn on 1 April 2002 and replaced by BS EN 197-1: 2000.]

24. British Standards Institution. BS 6610 – Specification for Portland Pulverised-fuel Ash Cements. 1996.

25. British Standards Institution. BS 5328 – Concrete. Part 1 – Guide to Specifying Concrete. 1997.

26. International Maritime Organisation. International Regulations for Preventing Collisions at Sea. 1972. [1990 edition incorporates amendments adopted in 1981, 1987 and 1989 plus a supplement with amendments adopted in 1993.]

Printed and published by the Health and Safety Executive
C0.50 06/02

HSE BOOKS

MAIL ORDER
HSE priced and free
publications are
available from:
HSE Books
PO Box 1999
Sudbury
Suffolk CO10 2WA
Tel: 01787 881165
Fax: 01787 313995
Website: www.hsebooks.co.uk

RETAIL
HSE priced publications
are available from booksellers

HEALTH AND SAFETY INFORMATION
HSE InfoLine
Tel: 08701 545500
Fax: 02920 859260
e-mail: hseinformationservices@natbrit.com
or write to:
HSE Information Services
Caerphilly Business Park
Caerphilly CF83 3GG

HSE website: www.hse.gov.uk

OTO 2001/046

£10.00

ISBN 0-7176-2392-0

9 780717 623921