TECHNICAL SPECIFICATION

REINFORCED CONCRETE FOUNDATIONS AND STRUCTURES

DEP 34.19.20.31-Gen.

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DESIGN AND ENGINEERING PRACTICE

PREFACE

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The objective is to set the recommended standard for good design and engineering practice applied by Group companies operating an oil refinery, gas handling installation, chemical plant, oil and gas production facility, or any other such facility, and thereby to achieve maximum technical and economic benefit from standardization.

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

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APPENDICES

1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and give recommendations for the design, engineering and construction of reinforced concrete foundations and structures. It shall be used in conjunction with DEP 34.00.01.30-Gen.

This DEP is a revision of the DEP of the same number dated February 1989.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIOP and SIEP, the distribution of this document is confined to companies forming part of the Royal Dutch/Shell Group or managed by a Group Company, and to Contractors nominated by them (i.e. the distribution code is "C", as defined in DEP 00.00.05.05-Gen.).

This DEP is intended for use in oil refineries, chemical plants, gas plants, onshore exploration and production facilities and supply/marketing installations.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the object of obtaining agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents references in this DEP are listed in (15).

2. PREPARATORY WORK

2.1 SETTING OUT

All work shall be set out accurately from datum and benchmarks. During execution the correct position, level and alignment of all parts of the work shall be ensured at all times.

Setting out shall meet the requirements of BS 8110-1, clause 6.2.8 (see also references to BS 5964:Part 3:1996 or ISO 4463-3:1995), with the following additions:

	Item	Distance	Permitted tolerance
1	Variation from the plumb	In 2.50 m	+/- 5 mm
2	In the lines and surfaces of columns, piers, walls and arises	In any story or 5.00 m max. and in 25.00 m	+/- 5 mm +/- 50 mm
3	Variation from the level or from the grades indicated on the drawings. Note: Sufficient slope shall cover the tolerance to avoid water pounding.	In 3.00 m in any bay or 6.00 m max.	+/-5mm +/-10mm
4	Variation in the thickness of slabs and walls		+/- 6 mm
5	Misplacement or eccentricity		+/- 10 mm

2.2 PILING AND SOIL IMPROVEMENT

Piling and soil improvement, if required, shall be in accordance with DEP 34.11.00.12-Gen.

2.3 SITE PREPARATION, EXCAVATION, BACKFILL AND TEMPORARY DRAINAGE

Site preparation, excavation, back fill and temporary drainage shall be in accordance with DEP 34.11.00.11-Gen.

2.4 BLINDING CONCRETE OR BUILDING PAPER

2.4.1 Blinding concrete

A layer of blinding concrete of 50 mm minimum thickness shall be placed under foundations. The blinding layer shall be laid immediately after excavation, draining and compacting of the bed area, in order to avoid disturbance of soil by rain or ground water.

2.4.2 Building paper

Underneath concrete paving slabs, building paper may be used directly on the soil, instead of blinding concrete. The building paper shall comply with BS 1521 or be heavy-duty polyethylene film of at least 0.15 mm thickness, in the longest length and widest width available. The overlap shall be not less than 150 mm at all joints and intersections.

3. DESIGN OF FOUNDATIONS AND STRUCTURES

3.1 BASIS OF DESIGN

3.1.1 Design data

For loading data, reference is made to DEP 34.00.01.30-Gen.

3.1.2 Design and calculations

The design and calculations of reinforced concrete structures shall be based on BS 8110 with exception of crack width control. For this subject the CEB-FIP Model Code 1990 shall be used. Reference is also made to section 3.2.4 in this respect.

The application of pre-stressed concrete may be used for the following members only:

a) walls for LNG/LPG storage tanks;

b) bridge and culvert decks in roads, main beams and/or walls to be cast-in-place;

c) structures for buildings in the administration area (outside the 200 m zone), refer DEP 34.17.00.32-Gen.;

d) piles;

e) other items outside the process plant area, where the risk of fire is limited.

3.2 DESIGN DETAILS

3.2.1 Constructional and movement joints

Where required, constructional and/or movement joints shall be provided in concrete structures.

3.2.2 Concrete cover

The minimum concrete cover on the outer reinforcement shall be as follows:

	Minimum cover
a) Cast-in-place concrete (nonpre-stressed)	
- Cast against and permanently exposed to earth	75 mm
- Exposed to earth, weather or water	50 mm
- Not exposed to weather or not in contact with the ground: slabs, walls, beams, girders, columns	40 mm
- In contact with or above sea water	
underside and sides of slabs	75 mm
top side of slab	50 mm
beams	75 mm
b) Pre-cast concrete (manufactured under plant conditions)	
- Exposed to earth, weather or water	
wall panels	40 mm
other members	50 mm
- Not exposed to weather or not in contact with the ground	
slabs, walls, joints	30 mm
beams, girders, columns	40 mm
- In contact with or above sea water	
underside and sides of slab	75 mm
top side of slab	50 mm
beams	75 mm
c) Pre-stressed concrete members	
- Cast against and permanently exposed to earth	75 mm
- Exposed to earth, weather or water	
horizontal surfaces	75 mm
non-horizontal surfaces	50 mm
- Not exposed to weather or in contact with the ground	40 mm
- In contact with or above sea water	
underside and sides of slab	75 mm
top side of slab	50 mm
beams	75 mm

3.2.3 Spacing of bars

The minimum distance between individual bars shall be the largest of:

- the maximum size of coarse aggregate + 5 mm;
- the diameter of the bar;
- 50 mm.

The centre-to-centre distance of individual bars shall be as follows:

not more than 150 mm	-	for main bars in beams where bending moments are maximum
not more than 250 mm	-	for main bars in slabs where bending moments are maximum
	-	for bars perpendicular to main bars in slabs
	-	for distribution bars in slabs
	-	for bars in walls
	-	for mild steel stirrups in beams
not more than 300 mm	-	for longitudinal bars in columns
	-	for horizontal side bars in beams
	-	for high-yield stirrups in beams
not more than 400 mm	-	for any other bars not mentioned previously, provided the cross bars are spaced not more than 250 mm

In walls and floors with a thickness of 250 mm or more, reinforcing bars shall be placed on both sides, over the full section.

In footings and foundation slabs/blocks with a thickness of 250 mm or more, reinforcing bars shall be placed on both top and bottom, over the full section.

The space between the bars shall not exceed 250 mm. In addition, horizontal side reinforcement shall be placed at minimum distances of 400 mm.

3.2.4 Crack width control

Crack width control shall satisfy the requirements of the CEB-FIP Model Code 1990.

3.2.5 Shrinkage reinforcement

When walls or slabs are not cast monolithically (restraint condition), attention shall be paid to reinforcement required due to differential shrinkage.

Shrinkage reinforcement shall be calculated and applied where necessary.

3.3 SPECIAL FOUNDATIONS AND STRUCTURES

3.3.1 Foundations for small equipment

Foundations for small pumps, staircases, etc. may be placed on reinforced concrete slabs or yard paving, provided that they are properly connected to the slabs or paving and that cable trench locations are fixed. If required, slabs or paving shall be strengthened locally.

3.3.2 Liquid-retaining structures

In addition to all other requirements for the design of structures, special precautions shall be taken regarding the liquid tightness of liquid-retaining structures. See BS 8007: 1987. All liquid retaining structures shall be water tested under atmospheric pressure conditions, unless otherwise stated.

3.3.3 Reinforced concrete stacks

Reference is made to DEP 34.24.27.31-Gen.

3.3.4 Foundations and structures subject to vibration

3.3.4.1 Design

A detailed design and vibration analysis shall be performed in accordance with DEP 34.00.01.30-Gen.

3.3.4.2 Isolation of foundations

Foundations subject to vibration shall in, principle, be properly isolated from adjacent structures.

Combined foundations shall also meet the requirements of DEP 34.00.01.30-Gen.

3.3.5 Foundations subject to temperature effects

Foundations and structures subject to temperature effects shall be designed for any temperature difference that may occur in parts of structural members and/or the whole structure.

For loading resulting from temperature differences, see DEP 34.00.01.30-Gen., subsection 2.10.

3.3.6 Box-outs and curbs

All holes in table tops which have equipment underneath shall be closed after installation of piping, equipment, etc. to prevent escalation of a fire which may occur under the table top because of draught through such holes.

All edges of table top slabs shall have a curb of minimum 100 mm height to prevent liquid and rainwater from being drained over the edge, except at locations of entrance such as staircases and connections to other platforms. The table top slabs shall be sloped to discharge drains or gullies provided with down spouts.

4. MATERIALS

4.1 CEMENT

4.1.1 Cement for general application

For general application, the cement to be used shall be normal Portland cement in accordance with BS 12 or ASTM C 150 or equivalent, unless otherwise specified.

4.1.2 Cement for special applications

If soil conditions, groundwater, sea water or refinery effluent water are harmful to normal Portland cement, the most appropriate of the following types of cement shall be used (see also Appendix 1):

- Blast furnace type cement shall be used.
- Portland blast-furnace cement in accordance with BS 146 or Portland cement type II in accordance with ASTM C 150.
- Sulphate-resisting Portland cement in accordance with BS 4027 or Portland cement type V in accordance with ASTM C 150.
- Portland blast-furnace cement in accordance with BS 146 or Portland cement type II in accordance with ASTM C 150.

When low heat dissipation of hydration is required:

- Portland cement type IV in accordance with ASTM C 150.

4.1.3 High-alumina cement

High-alumina cement is only allowed for non-structural applications.

4.1.4 Test certificate

A Manufacturer's test certificate, indicating the particular batch number or fabrication date, etc. shall be submitted by the Supplier before or simultaneously during the delivery of the cement.

4.1.5 Transport and Storage

The cement shall be delivered to the site in three ply bags or in bulk carriers. Bags transported by sea shall be packed in plastic. The name and brand of the manufacturer, including batch number or fabrication date shall be plainly marked on the bags.

The cement shall be stored in such a way that the date of manufacturing is clearly visible so that it is used in sequence by the date of manufacture, oldest first.

The maximum height of storage of the bags shall be 2 m with a ventilated space between the floor and lowest bags. In tropical and subtropical areas the outside of the cement storage shall be painted in a reflected white colour.

A cement storage shall be provided with the following:

- concrete floor;
- waterproof walls and roof;
- ventilation in the building to prevent condensation;
- adequate drainage system;
- air-conditioning system to control the temperature between 0 °C and < 40°C.

The bulk cement shall be stored in a silo. The silo shall comply with the following:

- in hot climates the silo shall be painted in a reflective white colour;

- in all areas the temperature shall not exceed 40°C and/or shall be maintained frost-proof.

The cement shall be suitably protected during storage to avoid deterioration in quality.

Cement which has been in storage for more than 3 months from the date of manufacture shall be tested to verify that its quality is still in accordance with the standards referred to in (5.1.1) or (5.1.2).

The presence of lumps will lead to rejection of the cement. Cement older than 6 months shall not be used.

4.2 AGGREGATES

Coarse and fine aggregates shall comply with BS 882 or ASTM C 33 or approved equivalent.

The content of acid-soluble chlorides (expressed as Cl) should not exceed 0.06% by wt of fine aggregates and 0.03% by wt of coarse aggregates.

The content of acid-soluble sulphates (expressed as calculated SO_3 equivalent) shall not exceed 0.4% by wt of fine aggregates and 0.4% by wt of coarse aggregates.

The aggregates shall be tested for possible alkali reaction or other deleterious reactivity.

At all times, the aggregates shall be free of impurities and if not, the aggregates shall be washed mechanically with water (as specified in 5.4) to remove clay, silt and fine dust.

Note: Attention is drawn to the possibility of alkali reactive aggregates. Every effort shall be made to select non-reactive aggregates and make use where possible of proven reliable sources. This also applies to aggregates with lower chloride diffusion resistance.

4.3 REINFORCING MATERIAL

In general the reinforcing material work shall be in accordance with BS 4449, BS 4483, ENV 10080, ASTM A 615 and ASTM A 617.

Reinforcing material for general concrete work shall be hot rolled high yield deformed bars.

Reinforcing material for pre-stressed concrete in cryogenic environment shall be suitable for cryogenic temperatures and in accordance with BS 5896.

4.4 WATER

Only clean, fresh water free from harmful matter shall be used. It shall not contain chlorides (Cl) in excess of 500 mg/kg nor sulphates (SO_3) in excess of 500 mg/kg.

The water shall not contain dissolved solids in excess of 2000 mg/kg.

Furthermore the water shall not contain sugars, phosphates and harmful impurities (for instance oil).

The pH of the water shall be > 5.0.

Tests shall be carried out in accordance with BS 3148 and BS 2690.

In hot and cold climates the water shall be chilled or heated water respectively in accordance with CEB-FIP Model Code 1990.

4.5 CONCRETE MIXES

The concrete mix design shall take into account the type of foundations, structures, elements etc. for which it is intended.

Special attention shall be paid to possible bleeding after placing. Trial tests, including a bleeding test in accordance with ASTM C 232, shall be performed especially for large/thick horizontal slabs.

Special admixtures may be considered if bleeding cannot be controlled sufficiently by means of a standard mix design. In general a low slump in combination with proper grading and/or the use of an air entrainer may prevent bleeding. Reference is made to BS 5328-1, clause 7.2.

The required concrete mixes shall be designed in accordance with CEB-FIP Model Code or BS 5328 and BS 8110 or approved equivalent, with a designation of nominal maximum size of aggregate and workability.

Furthermore, the concrete mix shall be designed for durability taking full account of the environment to which it will be subjected.

The maximum total content of acid-soluble chlorides (expressed as Cl) shall not exceed the following limits:

	Cl (ion) content by weight of cement
- Pre-stressed concrete, Heat-cured concrete	0.06% wt
- Concrete made with sulphate-resisting Portland cement	0.15% wt
- Concrete made with ordinary Portland cement/Portland blast-furnace cement	0.30% wt

The maximum total content of acid-soluble sulphates (expressed as calculated SO_3 equivalent) shall not exceed 4.0% by wt of cement in the mix, including the sulphate present in the cement.

The concrete grades shall be selected on the following minimum characteristic strengths at 28 days:

Grade C20	Blinding concrete
Grade C30	All reinforced concrete structures except jetties
Grade C40	Pre-stressed concrete structures and reinforced concrete of marine structures

The maximum Water Cement Ratio (WCR) shall be as follows:

	WCR maximum
Grade 20	0.55
Grade 30	0.45
Grade 40	0.45

4.6 EXPOSURE CONDITIONS

The environments to which concrete is exposed in service can be classified into five levels of severity, i.e. dry, humid (without and with frost), humid in combination with de-icing agents, sea water (without and with frost) and aggressive (weak, moderate, severe or very severe).

Criteria for classification and subsequent requirements for concrete exposed to chemical attack (including recommendation for mix design related to a particular exposure class or condition) are given in Appendix 1.

5. FORM WORK

5.1 GENERAL

The form work shall comply with and be designed and constructed in accordance with BS 8110-1, clause 6.9 or CEB-FIB Model Code 1990.

Note: The choice of the materials to construct the form work shall depend on climatic conditions and the expected heat of hydration.

Design, calculation and execution of form work shall take into account climatic conditions, the expected heat of hydration and finishing of concrete surfaces.

All edges of exposed concrete members shall have a chamfer of approximately 25 mm.

5.2 REMOVAL

The form work shall be removed in accordance with BS 8110-1, clause 6.2.6.3 or CEB-FIB Model Code 1990.

A striking plan shall be produced, which anticipates climatic conditions, heat of hydration, strength development, load conditions and relevant curing methods.

6. REINFORCEMENT

6.1 CUTTING, BENDING AND WELDING

Reinforcing steel shall be cut, bent and welded in accordance with BS 8110-1, clause 7 and clause 8, or CEB Model-FIB Code.

Welding of reinforced steel should be avoided and if necessary the relevant welding standards shall be adopted, especially regarding welder qualifications and the recommendations of the reinforcement Manufacturer. Welding shall be included in the quality plan.

6.2 PLACING

Black annealed steel binding wire of 1.5 mm thickness shall be used for fixing the reinforcing material. The ends of the binding wire shall be tucked in to prevent corrosion spots in the concrete.

Spacers shall comply with the CEB-FIB Model Code 1990. Non-concrete spacer blocks shall not be used.

7. CONCRETE MEASURING, MIXING, PRODUCTION, TRANSPORTING AND WEATHER PROVISIONS

7.1 MEASURING , MIXING, PRODUCTION AND TRANSPORTING

The measuring, mixing, production and transporting of concrete shall be in accordance with CEB-FIB Model Code 1990 or BS 8110-1 clause 6 and BS 5328. Hand-mixing and re-tempering shall not be allowed.

Contractor shall provide full details of the batch plant(s) and devices, and shall produce trial mixes before start of permanent placing concrete, to prove that the specified concrete grade can be obtained.

Under no circumstances water shall be added to the mixer in transit to the site.

7.2 ADMIXTURES AND ADDITIONS

7.2.1 Admixtures

An admixture is defined as a product which is added in quantities generally less than or equal to 5% by mass of the cement before or during mixing or during an additional mixing operation, causing the required modifications to the normal properties.

Admixtures shall comply with CEB-FIB Model Code 1990 and testing shall comply with ASTM C 494.

All admixtures used to modify one or more characteristics of concrete shall be accompanied by a certificate from an approved institute, stating:

- exact range and method of application;
- physical and chemical composition;
- positive and negative side effects;
- a recommendation on the maximum allowable quantities (as a percentage of the mass of the cement) to achieve the particular requirement;
- proportioning and mixing.

The admixtures shall contain no chlorides. If a retarder and plasticizer are required only a dual-purpose additive should be used, as determined in the classification below.

The classification of admixtures shall comply with ASTM C 494. This classification is as follows:

type A	plasticizers
type B	retarders
type C	accelerators
type D	plasticizers with retarding action
type E	plasticizers with accelerating action
type F	superplasticizers
type G	superplasticizers with retarding action

The Contractor shall be responsible for any defective concrete that may result from the use of such admixtures. All information regarding the admixture(s), such as certificates, concrete mix trials, test results, etc. shall be made available to the Principal.

7.2.2 Additions

An addition is defined as a finely divided material that is added to the concrete in order to improve certain properties or to achieve special properties. Examples of additions are:

- latent hydraulic pumice and pulverised-fuel ash (pozzolanic material, used to reduce heat caused by hydration in mass concrete);
- silica fume (pozzolanic material used for high strength concrete);
- polymers (used for liquid tight floors and rapid repairs).

All additions used to modify or improve one or more characteristics of concrete shall be accompanied by a certificate from an approved institute, stating:

- exact range and method of application,
- physical and chemical composition,
- positive and negative side effects,
- a recommendation on the maximum allowable quantities (as a percentage of the mass of the cement) to achieve the particular requirement,
- proportioning and mixing.

The additions shall contain no chlorides. Trial mixing shall be executed to check their effectiveness.

The Contractor shall be responsible for any defective concrete that may result from the use of such additions. All information regarding the addition(s), such as certificates, concrete mix trials, test results, etc. shall be made available to the Principal.

7.3 EXTREME WEATHER PROVISIONS

Provisions for pouring concrete in extreme weather conditions shall be made with reference to the following standards:

For hot weather:

- ACI 305R

  and

- BS 8110-1 clause 6.2.5.

Note: In general concrete mixes with temperatures higher than 32 °C shall not be used. Measures to prevent temperatures rising above this limit in hot climates could include, for instance, the placing of concrete during the evening or at night, the use of special additives or the use of chilled water.

For cold weather:

- ACI 306R
  and
- BS 8110-1, clause 6.2.4.

7.4 HEAT OF HYDRATION

The heat of hydration shall not cause a temperature differential between the interior of the concrete and any outside face greater than 15 °C.

The temperature gradient in thick slabs and walls over 600 mm shall be verified by trials. If the temperature gradient is > 15 °C adequate measures shall be taken, for example cooling, form work insulation, application of low heat cement, retarder, pozzolanic material, etc. to reduce the heat of hydration.

8 CONCRETE PLACING

8.1 GENERAL

The placing of concrete shall be in accordance with the appropriate section of BS 8110-1 or CEB-FIB Model Code.

8.1.1 Placing by a pumping method

For placing by pumping the concrete mix shall be in accordance with CEB-FIB Model Code, Appendix D.11.6. A back up plan (including facilities) shall be in place to ensure the continuity of concrete placing in case the pump should fail.

8.1.2 Mixing time

The total time required for mixing, transportation and pouring of the concrete should in general not exceed 60 minutes. During this period the segregation of aggregates shall be prevented and the workability shall be maintained. A mixing, transportation and pouring schedule shall be produced.

8.1.3 Concrete placed in underwater constructions

Special precautions are required when concrete is placed in underwater constructions. A concrete placing plan shall be submitted by the construction Contractor, for approval by Principal, based on trials which demonstrate that the required quality and consistency of the concrete mix can be achieved.

8.1.4 Construction joints

Construction joints shall comply with BS 8110-1, clause 6.2.9 and kickers shall be cast monolithically with beams/slabs/foundations.

8.1.5 Placing and compacting of concrete

Placing and compacting of concrete shall comply with BS 8110-1, clause 6.2.2 or CEB-FIB Model Code.

8.2 FINISHING AND REPAIR

8.2.1 Finishing

Top surfaces of concrete in walls, beams, buttresses and floors shall be finished to the proper level and, if specified, to the required slopes. No holes or rough patches shall remain. Surfaces requiring subsequent plastering or tiling shall be rough-finished to provide a proper key for the finishing layer.

8.2.2 Setting

After initial setting of the concrete, any disturbance thereon (e.g. from walking, wheeling-over or vibration of the form work) shall be prevented until the concrete has sufficiently hardened.

Reinforcement, anchor bolts etc. projecting from the concrete shall not be disturbed during hardening of the concrete.

8.2.3 Repair

Touching up of concrete surfaces after the removal of form work is not permitted until they have been inspected and released in accordance with the quality procedures.

The repair method including materials and the extent of the repair works to remedy the imperfections of the concrete shall be specified and approved for each repair case and comply with the design requirements of the structure concerned.

9. CURING OF CONCRETE

Curing shall be carried out in accordance with BS 8110-1, clause 6.6 or CEB-FIB Model Code, Appendix D 12.

10. GROUTING

Grouting refers to all work to be carried out to properly fill the space between concrete surfaces and base plates of equipment, steel structures or concrete prefabricated elements with mortar in order to achieve adequate transfer of horizontal and vertical forces and to inject pre-stressed systems (tendons).

10.1 TYPES OF GROUT

10.1.1 Sand-cement grout

The use shall be limited to grouting of minor steel structures (e.g. instrument stands) only.

The grout shall be a mixture of one part of Portland cement and three parts of clean fine sand.

The grout shall have a minimum crushing strength of 20 N/mm^2 after 28 days and not less than 13 N/mm^2 at 7 days.

The sand aggregate shall comply with the relevant sections of BS 812 or equivalent code with respect to mechanical, physical and chemical properties, and be capable of freely passing a filter mesh of 1.5 mm.

10.1.2 Non-shrink grout

A grout is regarded as non-shrink if its volume is not less than the initial volume, after hardening for 28 days. During this period the test specimens shall have been completely protected against drying, evaporating, carbonation and exposure to temperatures outside the range 23 °C ± 3 °C.

The type and brand of non-shrink grout shall, after approval, be indicated on the drawings and/or specification for concrete work

Contractor shall supply the Manufacturer's data sheets and certificates.

The grout shall be free of chlorides and shall have a pouring consistency.

A metal-oxidising or gypsum-forming non-shrink grout shall not be used.

Non-shrink grout shall be applied under all major steel structures and stationary, rotating and reciprocating equipment. The selection of the type of grout for rotating and reciprocating equipment shall be in accordance with DEP 31.29.00.10-Gen.

In general one of the following types of non-shrink grout shall be used:

- cement-based non-shrink grout, with a minimum compressive strength of 75 N/mm^2;
- epoxy-based non-shrink grout, with a minimum compressive strength of 95 N/mm^2.

10.1.3 Grouting of pre-stressed systems (tendons)

Grouting of tendons shall be in accordance with CEB-FIB MODEL CODE 1990, Section 11.8 and the FIB Guide to Good practice "Grouting of tendons in pre-stressed concrete", 1900 or BS 8110-1, clause 8.9.

The injection grout shall have at least the same properties (compressive strengths, tensile strengths, adhesion etc.) as the specified concrete. The water/cement ratio shall not exceed 0.40.

The Contractor shall compile the type and composition (including test results and data sheets) of the injection grout.

A QA/QC procedure shall be provided by Contractor.

The ducts of the tendons shall be dried by air blowing. The air shall be free of oil and shall have a maximum relative humidity of 65%. The ducts of the tendons shall be filled with injection grout and checked for proper, complete filling. See also BS 4408 in this respect.

The pockets at the anchorage of the pre-stressed tendons shall be filled with concrete of at least the same properties as the structural concrete. A modified poured (repair) concrete or gunited concrete should be used. Surface preparation, such as removal of the laitance and the use of an approved bonding agent, shall be considered to ensure proper bonding.

10.2 SURFACE PREPARATION

10.2.1 General

a) Surface preparation of foundations for rotating/reciprocating equipment:

For surface preparation refer to para. 4 of DEP 31.29.00.10-Gen., Installation of rotating equipment.

Special attention shall be paid to the extent of the grouting. As mentioned in DEP 31.29.00.10-Gen., the foundation shall be sized so that grouting can be extended to 50 mm beyond the base/sole plate or the shims. If the size of concrete foundation is greater than the base/sole plate, form work shall be used to match the 50 mm.

b) Surface preparation of foundations for steel structures and stationary equipment:

The surface of the foundation under the base plate of the object to be grouted shall be chipped and brushed to remove the weak upper layer of the concrete, damaged concrete and any oil-soaked concrete areas. Prior to grouting, loose concrete or dust shall be removed, preferably by compressed air.

Before grouting commences the concrete surfaces shall be soaked with clean water for 24 hours, unless the grout Manufacturer specifies otherwise.

All grout mortar shall be machine mixed to an even consistency. Under no circumstances shall hand mixing be employed.

Adequate wedges and/or shim plates shall be used for levelling steel structures or stationary equipment, prior to grouting, to which the following shall apply:

- Shims under steel structures and equipment such as columns, vessels, heat exchangers, etc. shall be of a machined type and need not be removed. Machined type shims need the approval of the equipment Vendor .
- Wedges are restricted to minor steel structures, supports etc. and shall be removed.

10.2.2 Shims

The following shall apply for shims that will remain in place after grouting:

- The shim shall be embedded in a mortar bed such that the top of the shim is level in all planes.
- Shim plates shall be installed so that they will be fully embedded in and surrounded by the grout to be installed later; the minimum cover to shim sides shall be 50 mm.
- Load per shim pack shall not exceed 7 N/mm^2 under the worst loading condition. In this case the grout shall be considered as a filling material only when calculating the aforementioned bearing stress.

10.3 APPLICATION

10.3.1 Grouting of rotating/reciprocating equipment

For grouting of this equipment reference is made to DEP 31.29.00.10-Gen.

Exposed cement-based grout surfaces shall be coated (with an epoxy based product) if future contamination with lubricants is possible.

10.3.2 Grouting of steel structures and stationary equipment

The installation of the grout shall be carefully supervised.

Special attention shall be paid to prevent distortion of the item being grouted.

The placing of sand-cement grout mortar shall commence not later than 15 minutes after completion of the mixing. No grout mortar shall be used that has not been placed after 30 minutes from completion of mixing. Under no circumstances shall re-mixing or knocking up be allowed.

Proprietary grouts shall be mixed, placed and cured in strict accordance with the grout Manufacturer's instructions.

Vent holes should be drilled in base plates to avoid air pockets. The equipment Vendor should be consulted for approval.

The grout shall fill all voids between the base plate or sole plate and the foundation, and shall have full surface contact.

Cement-based grout shall be kept moist during the first 7 days after placing and shall be protected from sunshine and drying out by protective covering.

After hardening, wedges shall be removed and the resulting voids filled with grout.

The grout thickness shall be minimum 25 mm but shall not exceed 50 mm.

Grouting shall be extended 50 mm beyond the base/ sole plate if the concrete foundation is greater than the base/sole plate. Form work shall be used to match the 50 mm. The edge of the grout shall be provided with a chamfer of approximately 25 mm.

11. QUALITY PLAN

11.1 GENERAL

The Contractor shall submit a quality plan which shall comply with the CEB-FIB MODEL CODE, Section 12 and shall be based on ISO 9000 quality system requirements and BS 5328. The quality plan shall cover quality assurance and control and shall be divided into detailed design and production/execution plan. The quality plan shall be subject to audit by the Principal.

11.2 PRODUCTION/EXECUTION QUALITY PLAN

11.2.1 General

The Production/Execution Quality Plan shall cover all aspects related to production/execution requirements, such as performance of tests, trial mixes, availability of certificates/data sheets, reinforcement, sources of cement/aggregates/sand/water, workmanship, batch plant(s), storage, transport, handling etc.

11.2.2 Local Conditions Production/Execution

The quality plan shall cover all aspects related to local conditions, such as climatic conditions, back up facilities, spare parts, transport possibilities, storage facilities, quarries, local Suppliers/Manufactures, test facilities (field laboratory), etc. Trial concrete mixes shall be proven to perform under local conditions and with the equipment to be used during execution.

11.2.3 Testing and Reporting

An overview of the tests related to the quality plan are given in Appendix 3. A reporting system shall be part of the quality plan. The reporting system shall record all results obtained during testing, transporting, production, supplying, placing/pouring, finishing, curing, striking, etc. Weather conditions shall also be recorded. After completion rebound and/or ultrasonic measurements should be taken to control and verify the concrete quality against the compliance tests and required concrete quality if there is any doubt about the above records. The results should be recorded. Any deviation shall be reported, including the measurements to be taken.

12. CHEMICAL-RESISTANT CONSTRUCTIONS

Protection against chemicals, even very dilute solutions, shall be provided either by suitable chemical resistant bricks or tiles, refer DEP 30.48.60.33-Gen., or by a monolithic epoxy compound.

For details of chemical-resistant linings for concrete structures, reference is made to DEP 30.48.60.12-Gen. and DEP 30.48.60.22-Gen.

13. ANCHOR BOLTS, PIPE SLEEVES, BOLTS, ETC.

The design of the anchoring length of the anchor bolts shall be checked for maximum pull-out force. Anchor bolts, pipe sleeves, anchor rails, inserts, bolts, etc. shall be positioned accurately, and be firmly attached to the form work before the concrete is poured.

If slight adjustment in the position of anchor (holding-down) bolts is required, this shall be indicated on the base plate drawing supplied with the loading information, and it shall also be clearly indicated on the detail foundation drawing with the method(s) to be applied.

Installed anchor bolts, etc., shall be properly protected against damage and corrosion until the equipment/structure is permanently installed. The minimum concrete cover shall be 75 mm.

14. MAINTENANCE

Inspection should be carried out on concrete structures at regular intervals and the findings recorded to monitor their condition. This ensures that imperfections in concrete structures such as porous concrete, too little concrete cover or attack by aggressive environment is detected at an early stage.

The most common reasons for deterioration of concrete are carbonation and ingress of chlorides, both resulting in corrosion of reinforcement and spalling-off of the concrete. The reinforcement in the concrete is protected against corrosion because of the passivating layer, which is formed by the reaction of hydroxide and ferro ions on its surface. Carbonation, a process in which CO_2 in the air reacts with calcium hydroxide, leads to degradation of the passivating layer after which, in the presence of oxygen and moisture, corrosion may start. Penetration of chlorides into the concrete will also result in the degradation of the passivating layer with subsequent corrosion.

Note: Special attention shall be paid in hot climate areas (e.g. Middle East) because water evaporation from the soil can lead to chlorides being deposited at the soil/foundation interface ("chloride pumping"). Lining should be applied to prevent the water and chlorides seeping into the concrete.

When deterioration of concrete of structural elements is detected and the reason for it is established, early repair should be considered to avoid further deterioration of the attacked concrete and high cost in the long term. High repair costs and inconvenience during repair can be avoided by preventive maintenance, taking those measures (for instance the application of a lining or coating) at an early stage which will avoid or postpone the start of deterioration (mostly corrosion).

The time for implementation of these measures can be based on an estimate of the rate of carbonation and/or chloride ingress provided by the findings of the inspection records.

Particular attention shall be paid to the condition of concrete stacks. In general more than one plant is connected to this type of stack, resulting in almost continuous operation of the stack. This can lead to severe deterioration of linings and subsequently the concrete shaft because of original minor defects. For inspection and maintenance of concrete stacks refer to the CICIND Manual for Inspection and Maintenance of Brickwork and Concrete Chimneys and DEP 34.24.27.31 Gen.

15. REFERENCES

In this DEP, reference is made to the following publications:

NOTE: Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments, supplements or revisions thereto.

SHELL STANDARDS

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
Design of chemical-resistant linings for concrete structures	DEP 30.48.60.12-Gen.
Installation of chemical-resistant linings for concrete structures	DEP 30.48.60.22-Gen.
Requirements for chemical-resistant brick lining materials	DEP 30.48.60.33-Gen.
Installation of rotating equipment	DEP 31.29.00.10-Gen
Minimum requirements for structural design and engineering	DEP 34.00.01.30-Gen.
Site preparation and earthworks	DEP 34.11.00.11-Gen.
Geotechnical and foundation engineering	DEP 34.11.00.12-Gen.
Minimum requirements for design and engineering of buildings	DEP 34.17.00.32-Gen
Reinforced concrete stacks	DEP 34.24.27.31-Gen.

AMERICAN STANDARDS

Specification for deformed and plain billet-steel bars for concrete reinforcement (Metric)	ASTM A 615
Specification for axle-steel deformed and plain bars for concrete reinforcement	ASTM A 617
Specification for Concrete Aggregates	ASTM C 33
Test for Compressive Strength of Cylindrical Concrete Specimens	ASTM C 39
Test for Organic Impurities in Fine Aggregates for Concrete	ASTM C 40
Test for Effect of Organic Impurities in Fine Aggregate on Strength of Mortar	ASTM C 87
Test for Soundness of Aggregates by Use of Sodium Sulphate or Magnesium Sulphate	ASTM C 88
Test for Compressive Strength of Hydraulic Cement Mortars	ASTM C 109
Chemical Analysis of Hydraulic Cement	ASTM C 114
Test for Material Finer than 75 µm (No. 200) Sieve in Mineral Aggregates by Washing	ASTM C 117
Test for Lightweight Pieces in Aggregate	ASTM C 123
Test for Specific Gravity and Absorption of Coarse Aggregate	ASTM C 127
Test for Specific Gravity and Absorption of Fine Aggregate	ASTM C 128
Test for Resistance to Abrasion of Small Size	ASTM C 131

Coarse Aggregate by Use of the Los Angeles Machine	
Test for Sieve or Screen Analysis of Fine and Coarse Aggregates	ASTM C 136
Test for Unit Weight, Yield, and Air Content of concrete	ASTM C 138
Test for Clay Lumps and Friable Particles in Aggregates	ASTM C 142
Test for Slump of Portland Cement Concrete	ASTM C 143
Specification for Portland Cement	ASTM C 150
Test for Autoclave Expansion of Portland Cement	ASTM C 151
Test for Density of Hydraulic Cement	ASTM C 188
Test for Time of Setting of Hydraulic Cement by Vicat Needle	ASTM C 191
Test for Fineness of Portland Cement by Air Permeability Apparatus	ASTM C 204
Standard Test Methods for Bleeding of Concrete	ASTM C 232
Test for Potential Reactivity of Aggregates	ASTM C 289
Recommended Practice for Petrographic Examination of Aggregates for Concrete	ASTM C 295
Test for Resistance to Abrasion of Large Size Coarse Aggregate by Use of the Los Angeles Machine	ASTM C 535
Total Moisture content of Aggregate by Drying	ASTM C 566
Tests for Chloride Ion in Water and Waste Water	ASTM D 512
Tests for Sulphate Ion in Water and Waste Water	ASTM D 516
Tests for Particulate and Dissolved Matter in Water	ASTM D 881

Issued by
American Society for Testing and Materials
1916 Race St.
Philadelphia, Pa. 19103
USA

Building Code Requirements for Reinforced concrete	ACI 318
Hot weather concreting	ACI 305R
Cold weather concreting	ACI 306R

Issued by
American Concrete Institute
P.O. Box 19150, Redford Station
Detroit, Michigan 48219
USA

BRITISH STANDARDS

Specification for Portland cement	BS 12
Specification for Portland blast furnace cement	BS 146
Testing aggregates	BS 812
Specification for aggregates from natural sources for concrete (including granolithic)	BS 882
Methods of test for soils for civil engineering	BS 1377

purposes, Part 1, 2 and 3	
Waterproof building papers	BS 1521
Testing concrete	BS 1881
Methods of testing water used in industry	BS 2690
Methods of tests for water for making concrete	BS 3148
Specification for sulphate-resisting Portland cement	BS 4027
Recommendations for non-destructive methods for testing of concrete, Part 3 Gamma radiography of concrete.	BS 4408
Specification for carbon steel bars for the reinforcement of concrete	BS 4449
Steel fabric for the reinforcement of concrete	BS 4483
Concrete Part 1: Guide to specifying concrete	BS 5328 BS 5328-1: 1997
Code of practise for design of concrete structures for retaining aqueous liquids	BS 8007
Structural use of concrete	BS 8110: 1997
Methods of testing cement	BS 196
Determination of strength	BS EN 196-1
Testing aggregates - Method for the determination of alkali-silica reactivity - Concrete prism method	BS DD 218

Issued by
British Standards Institution
389 Chiswick High Road
London W4 4AL
UK

EUROPEAN STANDARDS

CEB-FIP Model Code 1990 (for concrete structures), Bulletin No. 213/214	CEB-FIP Model Code 1990

Issued by
Comité Euro-Internacional du Béton (CEB)
EPFL - Case Postale 88 - CH 1015
Lausanne
Switzerland

Steel for the reinforcement of concrete - Weldable ribbed reinforcing steel B 500 - Technical delivery conditions for bars, coils and welded fabric	ENV 10080

Issued by:
CEN Secrétariat Central
Rue de Stassart 36
B-1050 Brussels
Belgium
Copies can also be obtained from national standards organizations

INTERNATIONAL STANDARDS

Concrete hardness; determination of the depth of penetration of water under pressure	ISO/DIS 7031
Quality management and quality assurance standards	ISO 9000
Soil Quality - Determination of pH	ISO 10390

Issued by
International Organization for Standardization
PO Box 56,
CH-1211 Geneve 20,
Switzerland

16. BIBLIOGRAPHY

NOTE: The documents listed below are for information only and do not form an integral part of this DEP.

Recommended practice for the measuring, mixing and placing of concrete	ACI 304-73
Placing concrete by pumping methods	ACI 304.2R-71
Consolidation of concrete	ACI 309-72

Issued by
American Concrete Institute
P.O. Box 19150, Redford Station
Detroit, Michigan 48219
USA

Specification for batch type concrete mixers	BS 1305
Specification for high slag blast furnace cement	BS 4246
Specification for the performance of pre-stressing anchorage for post tension construction	BS 4447
Methods of testing cement	BS 4550
Concrete admixtures	BS 5075
Code of practice for the structural use of concrete for retaining aqueous liquids	BS 5337
Guide to assessment of concrete strength in existing structures	BS 6089
Maritime structures	BS 6349
Code of practice for protection of structures against water from the ground	BS 8102
Assessment of the composition of fresh concrete	DD 83

Issued by
British Standards Institution
389 Chiswick High Road
London W4 4AL
UK

CEB Design Guide for Durable Concrete Structures	CEB Bulletin No. 183

Issued by
Comité Euro-Internacional du Béton (CEB)
EPFL - Case Postale 88 - CH 1015
Lausanne
Switzerland

APPENDIX 1 AGGRESSIVITY OF THE ENVIRONMENT AND RECOMMENDATIONS FOR MIX DESIGN

1. TEST CRITERIA AND CLASSIFICATION

1.1 CLASSIFICATION

In order to classify the severity of chemical attack to concrete, the exposure classification shall be in accordance with Table 1.

Table 1 Exposure classification

Exposure class	Exposure/environmental conditions
1	Dry
2 (a and b)	Humid (without and with frost)
3	Humid in combination with de-icing agents
4 (a and b)	Sea water (without and with frost)
5 (a, b, c and d)	Aggressive (weak, moderate, severe or very severe)

The exposure classes follow in general the guidelines of the present national and international standards. Reference should be made to ENV 206 and CEB-Durable Concrete Structures, Design Guide. The relation between the exposure classes and the various aggressivity criteria is shown in tables 2, 3 and 4 in the following sections.

1.2 GROUND WATER

The aggressivity to concrete, depending on the concentration of chemicals present in water, is shown in Table 2, which gives the limiting values of deleterious substances in water of predominantly natural composition for the assessment of the severity of chemical attack. The values stated result from tests on groundwater as described in Appendix 2.

Table 2 Limiting values of deleterious substances in water

	Limiting values for the assessment of the deleterious substances in ground water			
	Degree of severity [1)]			
Criterion of exposure class	5a	5b	5c	5d
pH value	6.5 - 5.5	5.5 - 4.5	4.5 - 4.0	< 4
Carbonic acid dissolving lime in mg/l determined by marble test according to Heyer	15 - 30	30 - 60	60 - 100	> 100
Ammonium (NH_4^+) in mg/l	15 - 30	30 - 60	60 - 100	> 100
Magnesium (Mg^{2+}) in mg/l	100 - 300	300 - 1 500	1 500 - 3 000	> 3 000
Sulphate (SO_4^{2-}) in mg/l	200 - 600	600 - 3 000	3 000 - 6 000	> 6 000

NOTE 1: The degree of severity is valid for stationary or slowly moving water under moderate climatic conditions (e.g. Central Europe). For other locations (e.g. Middle East), where more severe environmental conditions exist, Table 2 shall be used only as a guide. It is dependent upon the highest degree of severity even if it is only reached by one of the five criteria listed in lines 1 to 5. If two or more values are found to lie in the upper quarter of a zone (in the case of the pH in the lower quarter) then the degree of severity is deemed to be raised by one step. This increase does not, however, apply to sea water.

1.3 SOIL

The aggressivity of soil to concrete is shown in Table 3.

Table 3 Aggressivity of soil to concrete

	Limiting values for the assessment of the deleteriousness of soils		
	Degree of severity (1)		
Criterion of exposure classes	5a	5b	5c/5d
pH value	> 5.5		
Sulphate (SO_4^{2-}) in mg per kg of air-dry soil	2 000 - 6 000	6 000 - 12 000	>12 000

NOTE 1: The degree of severity is valid for soils which are saturated at frequent intervals. It can be reduced with decreasing permeability of the soil. If the content of sulphur from sulphides exceeds 100 mg S^{2-} per kg air-dry soil (more than 0.01% S^{2-}) or if dumps of industrial waste products are concerned, the deleteriousness should be assessed by a soil consultant.
The chemical attack is expected to be more severe at higher temperatures and at higher pressures or if the concrete is additionally exposed to mechanical abrasion due to fast flowing water or to alternating freezing and thawing. The severity can be assumed to be lower if the water temperature is consistently low, or if the quantities of water are small and the water is almost motionless, as for example in soils with a permeability factor $k < 10^{-5}$ m/s.

2. REQUIREMENTS FOR CONCRETE EXPOSED TO CHEMICAL ATTACK

Depending on the aggressivity of ground water and soil, measures shall be taken to adequately protect the concrete against deterioration.

The resistance of concrete to chemical attack largely depends on the cement content, type of cement and impermeability of the hardened concrete.

To achieve an adequate level of impermeability, the water/cement ratio (W/C) shall be kept as low as practicable and shall not exceed the values stated in Table III. The concrete shall be carefully cured, preferably by wet curing for 7 days.

2.1 CHEMICAL ATTACK

In case of aggressive conditions it shall be proven on samples derived from trial mixes that the water penetration, determined in accordance with the "Rilem Method" as described in ISO/DIS 7031, is less than the values shown in Table 4.

Table 4 Water penetration

Degree of severity	W/C ratio	Minimum cement content aggr. $D_{nom.}$ = 40 mm (1)	Rilem test	Coating
3 and 4	< 0.50	300 kg/m^3	< 50 mm	No
5a	< 0.45	300 kg/m^3 (2)	< 50 mm	No
5b	< 0.45	350 kg/m^3 (3)	< 30 mm	No
5c	< 0.45	350 kg/m^3 (3)	< 30 mm	Yes (4)
5d	< 0.40	350 kg/m^3 (3)	< 30 mm	Yes (4)

NOTES:
1) For nominal maximum size of aggregate, D_{nom} = 20 mm, the cement content shall be increased by 10%. However, in no case shall the cement content be less than 280 kg/m^3 or more than 400 kg/m^3

2) If weak aggressivity is caused by the presence of sulphates, the limiting values shall be as follows:

SO_4^{-2} (mg/l)	W/C ratio	Type cement	Minimum cement density
200-400	< 0.50	OPC	330 kg/m^3
400-600	< 0.45	OPC	350 kg/m^3
	< 0.40	SRPC	350 kg/m^3

3) If moderate or severe aggressivity is caused by the presence of sulphates, the type of cement to be used shall be sulphate resisting Portland cement with a C_3A content of less than 5%.

4) In all cases of severe or very severe aggressivity the selection of the coating and/or lining systems shall be done by specialists and in consultation with the Principal.

2.2 CHLORIDE ATTACK

In order to protect the reinforcement against chloride attack the following measures shall be taken if concrete is exposed to a concentration of Cl > 100 mg/l.

Foundations and structures on land:

1) Cement content: ≥320 kg/m^3 by $D_{nom.}$ = 40 mm
2) Type of cement: blast furnace cement with a slag content of > 65%.
3) Water/cement ratio: < 0.40
4) Crack width in accordance with CEB-FIB MODEL CODE. For prestressed concrete the crack width shall be < 0.1 mm.

Structures in contact with or above sea water:

1) Cement content: 400 kg/m^3 by $D_{nom.}$ = 40 mm
2) Type of cement: blast furnace cement with a slag content of > 65% or Portland cement type II (ASTM C-150).
3) Water/cement ratio < 0.40
4) Crack width in accordance with CEB-FIB MODEL CODE 1990, section 7.4. For prestressed concrete the crack width shall be < 0.1 mm.

3. **REPORTING**

The Contractor shall seek advice of a soil consultant in the case of extreme environmental conditions (e.g. soils containing industrial wastes, heavy salt laden atmosphere, severe weathering regions).
A comprehensive report shall be submitted to the Principal. The report shall contain but not be limited to the following information:
1) Test results of chemical analysis of ground water and soils in accordance with DEP 34.11.00.10-Gen.
2) The concrete mix design and measures to be taken, based on the test results as mentioned under sub.1.

APPENDIX 2 INSPECTION AND REPAIR

1. INSPECTION

Various causes can lead to significant reduction in the designed life of a concrete structure or to unacceptable structural safety due to material deterioration. In order to assure that the integrity of concrete structures is maintained, regular inspection of the state of the structures will provide the required information to initiate measures for eventual repairs.
The implementation of inspection record systems which record the history of the various structures will help to decide whether structures can be left untreated or need surface treatment (preventive maintenance). The inspection can initially be carried out visually combined with the "rebound hammer".
If this inspection gives rise to doubt about strength or durability of a structure, this structure should be further investigated. In this stage the assistance of an expert is recommended especially in connection with the advice for a repair method.
The investigation may involve following test methods and their purposes.

1.1 TEST METHODS

a)	rebound hammer (NDT)	determination of strength
b)	ultrasonic (NDT)	determination of strength weak surface layers
c)	core drilling (DT)	determination of strength porosity (RILEM CPC 13.1)
		concrete composition (cement content, W/C ratio)
d)	phenolphthalein testing (DT)	determination of depth of carbonation in situ and lab
e)	dust sampling over various and depth (DT)	determination of chloride sulphate contents
f)	cover meter (NDT)	determination of cover on rebar
g)	X-ray investigation (NDT)	determination of position and diameter of rebar
h)	measuring of surface potential (NDT)	determination of non-visible corrosion on rebar
i)	sampling of soil and ground water	determination of aggressive components

NDT = non-destructive testing
DT = destructive testing

a, b, c) These three methods are often used in combination.

c) Conclusions can be drawn on the durability of the concrete depending on:

a. porosity;

b. maximum size of aggregates;

c. porosity of aggregates;

d. cement content;

e. water cement ratio.

d) To determine which part of the concrete has lost its pacifying ability, a solution of 1 gramme phenolphthalein to 1 litre ethanol shall be sprayed on the concrete; if the concrete colours pink, the concrete still has its pacifying ability.

e) Dust samples shall be taken using a drill of 25 mm diameter over depths 0 mm-30 mm, 30 mm-60 mm and 60 mm-100 mm. If the chloride content is greater than 0.15% or 0.3% of the cement content (SRPC or OPC respectively), there is a potential danger of rebar

corrosion. If the SO_3 content is greater than 4% of the cement content, there is a potential danger of sulphate attack.

i) *Tests on Ground water:*

1) pH value (ASTM D 1293)
2) Hardness (ASTM D 1126)
   a) Total hardness
   b) Carbonate hardness
   c) Non-carbonate hardness
3) Concentration of aggressive carbon dioxide (DIN 4030, Heyer test)
4) Concentration of sulphates (ASTM D 516)
5) Concentration of chlorides (ASTM D 512)
6) Concentration of magnesium (ASTM D 511)
7) Concentration of sulphides (DIN 4030)
8) Concentration of ammonium (ASTM D 1426)
9) Potassium permanganate consumption (ASTM D 2033)
10) Ca content (ASTM D 511)

Soil samples:

1) pH value of soil (ISO 10390)
2 Sulphate content (BS 1377)
3 Sulphide content (BS 1377)
4 Chloride content (BS 1377)

For sampling and tests on ground water and soil, see DEP 34.11.00.10-Gen.

1.2 CONCRETE DEFECTS

1.2.1 **General**

An inspection of a concrete structure may reveal the following defects:

1) Cracks 2) Deterioration 3) Surface deposits 4) Textural defects

1.2.2 **Definition of terms relating to durability and strength of concrete**

a) Cracks:

An incomplete separation into two or more parts limited to a certain depth or extending over the whole depth of a section.

- Cracks are classified by direction, width and depth and may be longitudinal, transverse, vertical, diagonal and random. Three width ranges are suggested as follows:

  fine : generally less than 0.1 mm;
  medium : between 0.1 mm and 0.3 mm;
  wide : over 0.3 mm.

- Pattern cracking: Cracks without a regular pattern resulting from a decrease in volume of the material near the surface, or from an increase in volume of the material below the surface, or both.

b) Deterioration:

Deterioration is any adverse change of normal mechanical, physical and chemical properties either on the surface or in the whole body of concrete.

- Disintegration: deterioration into small fragments or particles due to any cause.
- Pop-out: the breaking away of small portions of a concrete surface due to internal pressure which leaves a shallow, typically conical, depression.
- Scaling: local flaking or peeling away of the near-surface portion of concrete or mortar.
- Demoulding: adherence of concrete skin to the mould.
- Spall: a fragment, usually in the shape of a flake, detached from a larger mass by a blow, by the action of weather, fire, pressure (rear corrosion), or expansion within the large mass.
- Dummy area: area of concrete surface which resounds hollow when struck.

c) Surface deposits:

- Exudation: a liquid or viscous gel-like material discharged through a pore, crack or opening in the surface.
- Encrustation: a crust or coating, generally hard, formed on the surface of concrete or masonry construction.
- Stalactite: a downward pointing formation, hanging from the surface of concrete, shaped like an icicle.
- Dusting: the development of a powdered material at the surface of hardened concrete.
- Corrosion/Rust stains: disintegration of deterioration of concrete or reinforcement by chemical or electrochemical attack.

d) Textural defects:

- Sand streak: streak in surface of formed concrete caused by bleeding or over-vibration.
- Honeycomb: voids left in concrete due to failure of the mortar to effectively fill the spaces among coarse aggregate particles.

1.2.3 **Cause of defects**

Possible causes of defects are:

- impact;
- overloading;
- fire;
- structural movement;
- lack of durability of the concrete by e.g. incorrect cement content or type of cement;
- frost;
- chemical attack;
- electro-chemical attack;
- bad workmanship: insufficient compacting and concrete cover.

SUMMARY OF TYPES OF DEFECTS IN RELATION TO POSSIBLE CAUSES

POSSIBLE CAUSES	TYPE OF DEFECT														
	Cracking		Deterioration					Surface deposits						Textural defects	
	Cracks (deep)	Pattern cracking surface	Disinteg-ration	Pop-outs	Scaling	Spalling	Dummy	Exuda-tion	Encrus-tation	Stalac-tite	Dusting	Rebar corro-sion	Rust stains	Sand streak	Honey-combing
Chemical influences															
Carbonation												X	X		
Chloride attack												X	X		
Acids attack (soft water)					x				x	x					
Alkali aggregate reaction	x	x	x	x				x							
Sulphate attack			x	x											
Physical influences															
Fire	x	x		x		x									
Frost	x	x			x	x									
Leaching of lime									x	x					
Mechanical influences															
Overloading	x														
Differential settlements	x														
Impacts, explosions	x					x									
Execution															
Not properly vibrated							x								X
Not properly cured	x	x													
Too high w/c ratio												X	X	X	
Excessive withdrawal of mixing water		x									X			X	X
Engineering															
Too little concrete cover						x						X	X		
Too small rebar distances							x								X
Insufficient reinforcement	x														
Obstruction or deformation	x														

2. REPAIR METHODS

2.1 DEFECTS AND REPAIR METHODS

The repair methods are specified in sections 2.2, 2.3 and 2.5. The following table gives an indication of the relation between defect and most suitable repair method by referencing to the relevant sections.

- Cracks active	- seal off with sheet or use joint sealer
- Cracks not originated by corrosion and not active:	
a) deep cracks	- (2.3)
b) pattern cracking	- if cracks are limited to surface (2.4)
c) active cracks	- because of varying temperature gradients, fill up with elastic sealant
- Disintegration	- sulphate attack or alkali reaction from the inside: dependent on the severity or total replacement
- Pop-outs	- (2.2d) + (2.4)
- Scaling	- (2.4) In case of surface attack by acids or sulphates, depth of penetration to be established carefully, re-installation of concrete may be required, resulting in enlarged cross sections by means of (2.2) + (2.5)
- Spalling	- (2.2) (either a, b or c) + (2.4)
- Dummy area	- (2.2) (either a, b, c or d)
- Exudation	- (2.4)
- Encrustation	- (2.4)
- Stalactite	- If the formation of stalactites is the result of crack formation then (2.3), otherwise (2.4)
- Dusting	- (2.4) If dusting is caused by leaching of lime, determine depth of dusting (2.2) (either a, b or d)
- Rebar corrosion	- (2.2) (either a, b, c or d)
- Rust stains	- (2.2) (either a, b, c or d)
- Sand streak	- Depending on depth (2.2) (either a, b or d)
- Honeycombing	- Depending on extent (2.2) (either a, b or d)

2.2 REINSTATEMENT OF CONCRETE

Preparation before reinstatement of concrete:

In general loose particles shall be removed from the surface which has to be repaired; then the surface must be thoroughly cleaned and wetted with water before repairing.

If the defect is attributed to ingress of chlorides the deteriorated concrete shall be removed to 30 mm behind the existing rebar. In case of carbonation only the carbonated concrete

shall be removed. The rebar shall be thoroughly cleaned and treated with an anti-corrosive material.

The principal techniques for reinstatement of concrete are guniting, casting a new section, prepacking, and cement-based and resin-based mortar patching.

a) Guniting is the technique most likely to achieve a technically satisfactory repair. Concrete repair specialists have developed small equipment capable of carrying out local repair with gunite. Good compaction is achieved with guniting, but skill is needed to ensure that the compaction behind the reinforcement is good enough. Rebounding material can get trapped, giving a lean, "no fines" mix at this vulnerable position. Almost no form work is needed, overhead repair is possible and fast progress can be achieved. Guniting can be used both for reinstatement of spalled areas of concrete and for enlarging the cover generally over the area of a concrete element.

b) Casting a new face onto concrete members.

   This is most appropriate for walls or columns and in cases where exposure of steel is general rather than local and where increase in member size is required and possible. The minimum thickness that should be reinstated this way is normally 120 mm. The need for a high workability mix achieving low permeability in the final condition will require the use of 10 mm maximum size rounded aggregate with a super plasticizer in the mix. Shuttering and vibration techniques are critical.

c) Pre-packing.

   The method consists of placing well graded aggregates (maximum size 16 mm) between form work and pressure grouting of the voids between the aggregates with a sand cement mortar.

   It is a clean repair method, specially suitable for column repair in situations where guniting causes too much mess or is impossible due to lack of space.

d) Patching-up with non-shrink ready mixed cement based mortar suitable for local repair up to depths of approximately 40 mm, mainly for repairing of concrete of which the cover to rebar is damaged. No form work is required. A cement-rich mortar is essential.

   If only local repair is required, it is advantageous to apply resin based mortars.

   The mortars to be used are ready mixed dry pack. Often super plasticizers and/or polymers are added in the mixing water or in the dry premix.

2.3 INJECTION OF CRACKS

Cracks outside the acceptable limits (Appendix 1) may be injected with epoxy resin. Resins can be injected into relatively fine cracks (even as fine as 0.1 mm) using the techniques now available.

Restoration of full structural properties is possible provided that the causes of cracking have been removed. If not, further cracking is likely to occur adjacent to the old.

2.4 SURFACE TREATMENT

An overall surface treatment may be required, both to improve the appearance of the concrete and to assist in preventing further deterioration. This surface treatment may imply e.g. grit blasting, and local patching followed by the application of a coating.

2.5 COATINGS FOR MAINTENANCE AND REPAIR APPLICATIONS

A. Marine structures

The following coatings should be applied:

1. Underside of structures not directly exposed to sunlight

   a) Blown asphalt bitumen.

      Mixture of: - Mexphalte R 85/25 - 60 % by wt and high aromatic white spirit - 40 % by wt

      Surface preparation:

      1) Remove laitance from repaired concrete by light blast sweeping.

      2) Clean all existing surfaces by blasting.

      Application on repaired or existing concrete:

      1) For surface preparation, see above.

      2) Apply by brush or spray two layers of above blown asphalt bitumen mixture to a total dry film thickness of 300 µm.

   b) Flintkote (WATERPROOFING SEALER)

      Application on repaired concrete or existing concrete in accordance with Manufacturer's requirements:

      1) For surface preparation, see above.

      2) Apply by brush or spray priming layer (1 part of Flintkote to 5 parts water).

      3) Apply by brush or spray, two layers of Flintkote to a total dry film thickness of 750 µm.

2. Parts of structures exposed to sunlight

   For coating system, surface preparation and application refer to 1. above. Since this coating system is not resistant to sunlight, a finishing coat of two layers bituminous aluminium paint to a total dry film thickness of 70 µm shall be applied.

   Application over the blown asphalt bitumen layer after 1-2 weeks.

   Alternatively the coating system 1.b) Flintkote (WATERPROOFING SEALER) can be applied.

   If required for cosmetic reasons a finishing coat of the aforementioned bituminous aluminium paint can be applied after 3-4 weeks.

3. Parts of structures between mean low water level and high high water level, so-called splash zone.

   a) Two component, solventless epoxy coating which can be applied on wet concrete surface.

      Application on repaired or existing concrete:

      1) For surface preparation, see 1).

      2) Apply by brush or roller three layers to a total dry film thickness of 1 mm.

4. In general, concrete areas below "mean low water level" need no further protection by a coating.

B. Coatings for concrete plant structures

The following coatings should be applied:

a) Epoxy based

Application on repaired or existing concrete:

1) For surface preparation see below.

2) Apply by brush, roller or spray an epoxy-based priming layer.

3) Apply by brush, roller or spray two or more layers of epoxy-based paint to a total dry film thickness of 250-600 µm.

b) Polyurethane based

Application on repaired or existing concrete:

1) For surface preparation see below.

2) Apply by brush, roller or spray a polyurethane or other suitable priming layer.

3) Apply by brush, roller or spray two or more layers of polyurethane based paint to a total dry film thickness of 200 µm.

c) Silicate based

Application on repaired or existing concrete:

1) For surface preparation see below.

2) Apply by brush, roller or spray a silicone or siloxane based priming layer.

3) Apply by brush, roller or spray two or more layers of silicate based paints to a total dry film thickness of 200 µm.

Surface preparation:

1) Remove laitance from repaired concrete by light blast sweeping.

2) Clean all existing surfaces by blasting.

The choice of coating depends on the type and severity of aggressive environments to which the concrete is subjected.

For special applications such as basement walls, holding basins etc. specialist consultation is recommended.

APPENDIX 3 TESTS

		Test Description	European Standard (International Standard)	British Standard	American Standard	Frequency
Cement			ENV 197-1-2	BS 12 / BS 146	ASTM C150	
	Test 1	Chemical composition	EN 196-2-5-21		ASTM C114	A/E.D.
	Test 2	Compressive strength	EN 196-1	BS 12 / BS 146	ASTM C109	A/E.D.
		Fineness	EN 196-6	BS 12 / BS 146	ASTM C204	A/E.D.
		Setting time	EN 196-3 (ISO 9597)	BS 12 / BS 146	ASTM C191	A/E.D.
		Soundness	EN 196-3 (ISO 9597)	BS 12 / BS 146	ASTM C151	A/E.D.
	Test 3	Density		BS 12	ASTM C188	A
Aggregates				BS 882	ASTM C33	
	Test 4	Organic impurities		Standard colour solution test	ASTM C40	A/D.V.
	Test 5	Effect of organic impurities			ASTM C87	A/ If Required
	Test 6	Soundness			ASTM C88	A/O.M.
	Test 7	Chloride content		Analytical analysis		A/O.M.
	Test 8	SO_3 content		Analytical analysis		A/O.M.
	Test 9	Sieve analysis		BS 812	ASTM C136	A/D
	Test 10	10% fines value		BS 812		A/W/D.V.
	Test 11	Crushing value (ACV)		BS 812		A/W/D.V.
	Test 12	Impact value (AIV) or Los Angeles test		BS 812	ASTM C131 ASTM C 535	A/W/D.V.
	Test 13	Abrasion value (AAV) or Los Angeles Test		BS 812	ASTM C131 ASTM C 535	A/W/D.V.
	Test 14	Material < 75 µm		BS 812	ASTM C117	A/W/D.V.
	Test 15a	Potential alkali-silica reactivity			ASTM C289	A
	Test 15b	Potential alkali reactivity (in general, e.g. cement-aggregate combination, carbonate rocks)			ASTM C227 ASTM C586 ASTM C1260 ASTM C 1293	A
	Test 16	Clay lumps content		BS 812	ASTM C142	A/W/D.V.
	Test 17	Light weight pieces in aggregate (coal/lignite content)			ASTM C123	A/O.M.
	Test 18	Porosity:				
		Sand/aggregate		BS 812	ASTM C128	A/O.M.
		Course aggregate		BS 812	ASTM C127	A/O.M.
	Test 19	Water content in aggregates		BS 812	ASTM C566	D/D.V./S.W.C.

		Test Description	European Standard (International Standard)	British Standard	American Standard	Frequency
Water				BS 3148	ACI 318	
	Test 20	pH value		Analytic		A/W
	Test 21	Chem. analysis of water		Analytic		A/O.M./D.V.
	Test 22	Dissolved solids		BS 2690	ASTM D1881	A/T.M
	Test 23	Comparison setting time		BS 3148	ASTM C191	If Required
	Test 24	Comparison compressive strength		BS 3148	ASTM C109	If Required
Reinforcement				BS 4449	ASTM A 617 ASTM A 615	
	Test 25	Purchase / delivery: a) Tensile test b) Bend test		BS 4449 BS 7777	ASTM A 617 ASTM A 615	A//E.D A/E.D.
Concrete mix				BS 8110		
	Test 26	Slump test		BS 1881	ASTM C143	D.P.
	Test 27	Mix density and cement content		BS 1881	ASTM C138	E.P. (TWICE)
	Test 28	Air content		BS 1881	ASTM C138	E.P. (TWICE)
	Test 29	Chloride content		Calculated total Cl from individual constituents	ASTM C1152 ASTM C1218	A/O.M.
	Test 30	SO_3 content		Calculated total SO_3 from individual constituents		A/O.M.
	Test 31	Compression tests on cubes/cylinders		BS 1881	ASTM C39	According BS 5328, part 1, Table 15 and E.P.
Temperature				BS 5328, Part 4	ASTM C94	
	Test 32	The temperature of all constituents of the mix and the mix proper shall be recorded.				D.P.

Legend

A	For approval before work commences	E.D.	Each Delivery	T.M.	Twice per Month
D	Daily	E.P.	Each Pouring	W	Weekly
D.P.	During Pouring	O.M.	Once per Month		
D.V.	Daily Visual	S.W.C.	at Sudden Weather Change		

All relevant tests shall be repeated in case of change of quarry/Manufacturer/Supplier. The above tests should be part of the quality plan.