



Exploration & Production

GENERAL SPECIFICATION

CIVIL WORKS

GS EP CIV 301

Design of reinforced and prestressed concrete

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1. Scope

This specification defines the minimum requirements applicable to the design of reinforced and prestressed concrete structures.

Nonetheless certain equipment and/or works may present particular requirements. In such a case the COMPANY reserves the right to modify General Specifications or supplement them with Particular Specifications.

2. Reference documents

The reference documents listed below form an integral part of this General Specification. Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published at the EFFECTIVE DATE of the CONTRACT.

Where there are national regulations, their particular requirements, and those of the standards or codes to which they refer, must be applied, supplementing or amending the provisions of this document.

If there are no mandatory national regulations, international regulations, standards and codes shall be applied.

If there are no applicable international standards and codes, the national standards and codes shall be chosen from those listed below according to the projects in hand and shall be defined in the job specification.

In the absence of a specific exemption, duly justified by the CONTRACTOR and agreed by the COMPANY, codes and standards of different origins may not be used in whole or in part.

If certain points in these regulations need to be clarified, the CONTRACTOR shall describe and justify the changes and/or additions to be made so that they can be adapted to the nature and environment of the structure. Such proposals shall be considered acceptable only when they have been examined and approved by the COMPANY.

A definitive list of regulations, standards and codes proposed by the CONTRACTOR shall be taken from the reference documents defined in this specification and the project's job specification.

Only the main standards are mentioned; the CONTRACTOR shall be responsible for compliance with any secondary standards. The list provided in this document should not be regarded as exhaustive.

Unless otherwise indicated in specific contractual conditions, for all documents cited for reference and their addenda, the latest issue applies.

Standards

International standards and codes

Reference	Title
ISO 128	Technical drawings. General principles of presentation
ISO 3766	Construction drawings. Simplified representation of concrete reinforcement
ISO 4066	Construction drawings. Bar scheduling

Reference	Title
ISO 4157-1	Construction drawings. Designation systems. Part 1 : buildings and parts of buildings
ISO 4157-2	Construction drawings. Designation systems. Part 2 : room names and numbers
ISO 4157-3	Construction drawings. Designation systems. Part 3 : room identifiers
ISO 4172	Technical drawings. Construction drawings. Drawings for the assembly of prefabricated structures
ISO 6284	Construction drawings. Indication of limit deviations
ISO 7437	Technical drawings. Construction drawings. General rules for execution of production drawings for prefabricated structural components
ISO 7518-	Technical drawings. Construction drawings. Simplified representation of demolition and rebuilding
ISO 7519	Technical drawings. Construction drawings. General principles of presentation for general arrangement and assembly drawings
ISO 8560	Technical drawings. Construction drawings. Representation of modular sizes, lines and grids
ISO 9431	Construction drawings. Spaces for drawing and for text, and title blocks on drawing sheets
ISO 11091	Construction drawings - Landscape drawing practice
ISO 13567-1	Technical product documentation - Organization and naming of layers for CAD - Part 1 : overview and principles
ISO 13567-2 -	Technical product documentation - Organization and naming of layers for CAD - Part 2 : concepts, format and codes used in construction documentation
IBC	International Building Code

European standards and codes

Reference	Title
EN 206-1	Concrete - Part 1 : specification, performance, production and conformity
EN 1990	Eurocode - Basis for Design
EN 1991-1-1	Eurocode 1 - Actions on structures - Part 1-1 : general actions - Densities, self weight, imposed loads for buildings
EN 1991-1-2	Eurocode 1 : actions on structures - Part 1-2 : general actions - Actions on structures exposed to fire
EN 1991-1-3	Eurocode 1 - Actions on structures - Part 1-3 : general actions - Snow loads
EN 1991-1-4	Eurocode 1 : actions on structures - Part 1-4 : general actions - Wind actions
EN 1991-1-5	Eurocode 1 : actions on structures - Part 1-5 : general actions - Thermal actions
EN 1991-1-6	Eurocode 1 : actions on structures - Part 1-6 : general actions - Actions during execution
EN 1991-1-7	Eurocode 1 : Actions on structures - Part 1-7 : general actions - Accidental actions
EN 1991-2	Eurocode 1 - Actions on structures - Part 2 : traffic loads on bridges
EN 1991-3	Eurocode 1 - Actions on structures - Part 3 : actions induced by cranes and machinery
EN 1991-4	Eurocode 1 - Actions on structures - Part 4 : silos and tanks
EN 1992-1-1	Eurocode 2 : Design of concrete structures - Part 1-1: General rules and rules for buildings
EN 1992-1-2	Eurocode 2 - Design of concrete structures - Part 2 : concrete bridges - Design and detailing rules
EN 1992-2	Eurocode 2 - Design of concrete structures - Part 2 : concrete bridges - Design and detailing rules
EN 1992-3	Eurocode 2 - Design of concrete structures - Part 3 : liquid retaining and containment structures
XP ENV 1992-1-5	Eurocode 2 : design of concrete structures - Part 1-3 : general rules - Structures with unbonded and external prestressing tendons
XP ENV 1992-1-6	Eurocode 2 : design of concrete structures - Part 1-6 : general rules - Plain concrete structures
XP ENV 1992-2	Design of concrete structures - Part 2 : concrete bridges
EN 1994-1-1	Eurocode 4 - Design of composite steel and concrete structures - Part 1-1 : general rules and rules for buildings

Reference	Title
EN 1994-1-2	Design of composite steel and concrete structures - Part 1-2: General - Structural fire design
EN 1994-1-2	Eurocode 4 : design of composite steel and concrete structures and national application document - Part 1-2 : general rules - Structural fire design
EN 1994-2	Eurocode 4 - Design of composite steel and concrete structures - Part 2 : general rules for bridges
EN 1997-1	Eurocode 7 : geotechnical design - Part 1 : general rules
EN 1997-2	Eurocode 7 : geotechnical design - Part 2 : ground investigation and testing
EN 1998-1	Eurocode 8 - Design of structures for earthquake resistance - Part 1 : general rules, seismic actions and rules for buildings
EN 1998-2	Eurocode 8 - Design of structures for earthquake resistance - Part 2 : bridges
EN 1998-3	Eurocode 8 - design of structures for earthquake resistance - Part 3 : assessment and retrofitting of buildings
EN 1998-4	Eurocode 8 : design of structures for earthquake resistance - Part 4 : silos, tanks and pipelines
EN 1998-5	Eurocode 8 - Design of structures for earthquake resistance - Part 5 : foundations, retaining structures and geotechnical aspects
EN 1998-6	Eurocode 8 - Design of structures for earthquake resistance - Part 6 : towers, masts and chimneys

French standards and codes

Reference	Title
XP A 35-014	Reinforcing steels - Plain, indented or ribbed stainless steel bars and coils
NF A 35-015	Concrete reinforcing steels. Weldable round bars
NF A 35-016	Concrete reinforcing steels. Weldable ribbed bars and coils of grade FeE500. Fabric made of these reinforcements
NF A 35-017	Concrete reinforcing steels. Non weldable ribbed bars and wire rods
NF A 35-19-1	Concrete reinforcing steels. Reinforcing steels made of weldable indented wires. Part 1 : bars and coils
NF A 35-19-2	Concrete reinforcing steels. Reinforcing steels made of weldable indented wires. Part 2 : welded fabric
NF A 35-020-1	Steel products. End coupling or anchoring devices for high adherence steel for concrete reinforcement. Part 1 : requirements for mechanical performances
NF A 35-020-2	Steel products - End coupling and anchoring steel devices for high adherence steel for concrete reinforcement - Part 2 : test methods
NF A 35-021	Steels for concrete. Weldable wires used for the fabrication of reinforcing steels
NF A 35-024	Steels for concrete. Fabric composed of wires with a diameter lower than 5 mm
XP A 35-025	Steel products - Hot-dip galvanised bars and coils for reinforced concrete - Wire intended for manufacture of hot-dip galvanised concrete reinforcing steels
NF A 35-027	Steel products for reinforced concrete - Reinforcements
NF A 35-30	Steel products. Bars with improved bond for concrete poles, supports for over head lines
XP A 35-031	Concrete reinforcing steels. Weldable ribbed bars of diameter over 40 mm
NF A 35-035	Steel products - Hot-dip zinc or zinc-aluminium coated prestressing smooth wires and 7-wire strands
XP A 35-037-1	Steel products - Protected and sheathed high strength steel strands - Part 1 : general requirements
XP A 35-037-2	Steel products - Protected and sheathed high strength steel strands - Part 2 : requirements for sliding protected and sheathed strands (type P)
XP A 35-037-3	Steel products - Protected and sheathed high strength steel strands - Part 3 : requirements for adherent protected sheathed strands (type SC)

Reference	Title
XP A 35-045-1	Steel products - Prestressing steels - Part 1 : general requirements
XP A 35-045-2	Steel products - Prestressing steels - Part 2 : wire
XP A 35-045-3	Steel products - Prestressing steels - Part 3 : strand
NF P 02-001	Conventional, signs, architectural drawings. Architectural, building and civil engineering drawings. General principles. Presentation principles
NF P 02-005	Architectural, building and civil engineering drawings. Dimensioning
NF P 02-006	Architectural, building and civil engineering drawings. Sizes and folding
NF P 06-001	Bases for design of structures. Working loads for buildings
NF P 06-002	Rules NV 65 - Rules defining the effects on buildings of snow and winds and appendices
NF P 06-004	Bases for design of structures. Permanent and service loads due to gravity
NF P 06-005	Bases for design of structures. Notations. General symbols
NF P 06-006	N 84 rules. Bases for design of structures. Working loads for buildings
NF P 06-013	Earthquake resistant construction rules. Earthquake resistant rules applicable to buildings, called PS 92
NF P 06-014	Earthquake resistant construction rules. Earthquake resistant construction of individual houses and of related buildings
NF P 18-201 (DTU 21)	Execution of concrete works. Technical specifications
NF P 18-210 (DTU 23.1)	Concrete walls. Technical specifications
NF P 18-702	Rules BAEL 91, revised 99 - Technical rules for the design of reinforced concrete structures according to the limit states method
NF P 18-703	Rules BPEL 91 - Technical rules for the design of prestressed concrete according to the limit states method
Règles FB (P 92-701)	Method for calculation of anticipated behaviour of concrete structures subjected to fire

American standards and codes

Reference	Title
ACI 117	Standard tolerances of construction and materials
ACI 201.1R	Guide for making a condition survey of concrete in service
ACI 201.2R	Guide to durable concrete
ACI 224R	Control of cracking in concrete structures

Reference	Title
ACI 224.1R	Causes, evaluation and repair of cracks in concrete structures
ACI 224.2R	Cracking of concrete members in direct tension
ACI 301	Specification for structural concrete
ACI 305.1	Specification for Hot Weather Concreting
ACI 305R	Hot weather concreting
ACI 306.1	Standard Specification for Cold Weather Concreting
ACI 306R	Cold weather concreting
ACI 315	Details and detailing of concrete reinforcement
ACI 318	Building code requirements for structural concrete
ACI 350	Environmental Engineering Concrete Structures and Commentary
ACI 360R	Design of Slabs on Grade
ACI 543R	Design, manufacture, and installation of concrete piles
ASCE 7	Minimum Design Loads for Buildings and Other Structures
ASCE 7	Minimum Design Loads for Buildings and Other Structures- Including Supplement
ASTM A185	Standard specification for steel welded wire fabric, plain, for concrete reinforcement
ASTM A416	Standard specification for steel strand, uncoated seven-wire for prestressed concrete
ASTM A421	Standard specification for uncoated stress relieved steel wire for prestressed concrete
ASTM A615	Standard specification for deformed and plain billet-steel bars for concrete reinforcement
IBC	International Building Code

British standards and codes

Reference	Title
BS 476	Fire test on building materials and structures
BS 4449	Steel for the reinforcement of concrete - Weldable reinforcing steel - Bar, coil and decoiled product
BS 4482	Steel wire for the reinforcement of concrete products — Specification
BS 4483	Steel Fabric for the Reinforcement of Concrete - Specification
BS 6100	Glossary of building and civil engineering terms
BS 6399-1	Loading for Buildings - Part 1: Code of Practice for Dead and Imposed Loads

Reference	Title
BS 6399-2	Loading for Buildings - Part 2: Code of Practice for Wind Loads
BS 6399-3	Loading for Buildings Part 3: Code of Practice for Imposed Roof Loads
BS 8004	Code of practice for foundations
BS 8007	Code of practice for design of concrete structures for retaining aqueous liquids
BS 8110-1	Structural use of concrete Part 1: Code of practice for design and construction
BS 8110-2	Structural Use of Concrete - Part 2: Code of Practice for Special Circumstances
BS 8110-3	Structural Use of Concrete Part 3: Design Charts for Singly Reinforced Beams, Doubly Reinforced Beams and Rectangular Columns

Professional Documents

Reference	Title
ACI SCM-11	Design and construction of concrete slabs on grade
FIP	FIP Recommendations Acceptance and Application of Post-Tensioning Systems
NAVFAC DM-7	Design manual: soil mechanics, foundations, and earth structures
Portland Cement Association	Concrete pavement design for roads and streets carrying all traffic
Post-Tensioning Institute	Design and construction of post-tensioned slabs
TM 5-809-12	Concrete floor slabs on grade subjected to heavy loads
TM 5-822-6	Engineering and design: rigid pavements for roads, streets, walks and open storage areas
Wire Reinforcement Institute	Design procedure for industrial slabs

Regulations

Reference	Title
Not applicable	

Codes

Reference	Title
Not applicable	

Other documents

Reference	Title
Not applicable	

Total General Specifications

Reference	Title
GS EP CIV 201	Design and construction of roads and stabilized areas
GS EP CIV 300	Reinforced and prestressed concrete
GS EP CIV 401	Minimum requirements for building design and construction
GS EP CIV 500	Special foundations
GS EP GEO 102	Onshore geotechnical soil survey

3. Applicability

This general specification is applicable for the design of reinforced and prestressed concrete structures. The Engineering CONTRACTOR shall take into account particular recommendations according to the applicability areas.

4. General principles for design

4.1 Design criteria

The durability of part or of the whole structure within its specific environmental conditions shall be guaranteed for permitting normal operational use during the whole project lifetime duration. This shall be achieved through proper design and construction, as well as adequate maintenance.

Design shall as well guarantee that the durability of the structure and its performances are by no means affected by any damage that may occur, provided relevant maintenance measures are taken.

In view of achieving adequate structural durability, the Engineering CONTRACTOR shall take into account different interdependent factors as follows:

- The current expected use of the structure and its forecast future use
- The required performance criteria
- The expected effects resulting from environment
- Composition, characteristics and performances of materials

- The choice of a structural system
- The shape of structural elements and their means of construction
- The quality of workmanship and the quality control level
- Specific protection means
- The maintenance during the expected project lifetime, as defined by Particular Specifications.

The effects of environmental conditions on the durability of the structure shall be taken into consideration from the beginning of the project in order to allow for proper means for protection of materials and products. The assessment of damages caused to materials may be evaluated by calculations, tests or may be based on experience derived from past constructions, or any combination of these.

4.2 Design data

Structural design shall be based on the following data:

4.2.1 Geotechnical data

A geotechnical survey shall be performed prior to the structural design.

The report shall contain sufficient description of field and laboratory investigation, subsurface conditions, typical test data, basic assumptions, recommendations, and final design.

The following outline shall be used as a guide:

- A general description of the site, indicating principal topographic features in the vicinity. A plan map that shows the surface contours, the location of the proposed structures, and the location of all boreholes shall be included
- A description of the general and local geology of the site, including the results of the geological studies
- The results of field investigations, including logs of all borings, locations of and pertinent data from piezometers, and a general description of subsurface materials, based on the borings. The boring logs should indicate how the borings were made, type of sampler used, split-spoon penetration resistance, and other field measurement data
- Groundwater conditions, including data on seasonal variations in groundwater level and results of field pumping tests, if performed
- A general description of laboratory tests performed, range of test values, and detailed test data on representative samples
- A generalized geologic profile used for design, showing properties of subsurface materials and design values of shear strength for each critical stratum. The profile may be described or shown graphically
- Basic assumptions for loadings and the computed factors of safety for bearing capacity calculations
- Basic assumptions, loadings, and results of settlement analyses.

The objectives of foundation investigations are to determine the stratigraphy and nature of subsurface materials and their expected behavior under structure loadings and to allow savings in design and construction costs.

The investigation shall reveal adverse subsurface conditions that could lead to construction difficulties, excessive maintenance, or possible failure of the structure.

The scope of investigations depends on the nature and complexity of sub-surface materials and the size, requirements for, and cost of the structure.

4.2.2 Material data

The structures and members are composed of concrete reinforced with steel bars and/or prestressed with steel wire, strand or bars.

Common concrete compressive strength for structural members ranges from 20 to 40 MPa, measured either on cubic or cylindrical samples, as defined by the relevant code.

The class of concrete for pre-stressed construction should be at least $f_{ck}40$ in accordance with [EN 1992-1-1](#) Table 3.1 (i.e. C40/50 according to [EN 206](#)).

Concrete should conform to the requirements of [EN 206-1](#) regarding constituents, testing, durability, concrete quality, mixing and placing.

The concrete should be designed to have acceptable properties for the following:

- waterproof;
- fire resistance;
- behaviour at cryogenic temperature if it s required;
- durability.

Durability aspects of each structure should be evaluated against [EN 1992-1-1](#) Clause 4. The exposure class of the primary container has to be working out in accordance with [EN 1992-1-1](#) Clause 4.

Where uncracked concrete properties are to be adopted, the strain history of the concrete needs to be tracked from first placement. The potential for early-age thermal cracking, drying shrinkage and internal cracking due to heat of hydration, effects should be included in this assessment.

The reinforcing steel should comply with [EN 1992-1-1](#).

Reinforcing bars design is based on their yield strength, which is commonly taken between 240 and 500 MPa.

Pre-stressing steel, anchors and ducts should be in accordance with [EN 1992-1-1](#). Strand for pre-stressing systems should comply with [FIP](#) recommendations for the approval, supply and acceptance of steels for pre-stressing tendons. Stress relaxation of the strands should be Class "very low", i.e. not more than 2.5% of failure after 1,000 hours at ambient temperature from an initial stress 70% of failure. Mechanical properties should be assessed in accordance with [FIP](#) assessment of mechanical properties of structural materials for project applications.

In any case, design shall be based on materials strengths which available or obtainable on site.

The Particular Specifications shall define applicable strength.

4.2.3 Loading data

Loads applied to the structure are distributed in the following categories:

4.2.3.1 Dead load

Dead load refers to the weight of integral materials and equipment (including the structure's own weight) supported in, or on, a structure and intended to remain permanently in place.

In case of lack of precise information, the following default values for construction material shall be used:

- Plain concrete: 2 200 daN/m³
- Reinforced concrete: 2 500 daN/m³
- Steel: 7 850 daN/m³
- Soil (dry): 1 800 daN/m³

The weight of partitions is considered to be dead load. The actual weight of partitions, as shown on the architectural plans for a building is to be used in the design.

In office buildings or in other occupancies where partitions are likely to be subject to rearrangement or alteration, the minimum allowance for the weight of partitions shall be a uniform load equivalent of 1.00 kN/m².

Design live loads may be omitted from the strip of floor area under each partition.

Dead load shall take into account the weight of building service equipment, including: plumbing, stacks, piping, heating and air conditioning equipment, electrical equipment, elevators, elevator machinery, flues, and similar fixed equipment.

4.2.3.2 Live load

Live loads include all loads (vertically down, vertically up, and lateral) incident to the occupancy and use of a structure.

Live loads may consist of uniform or concentrated loads.

Live load reduction may be used as specified by the relevant code.

Handrails shall be designed to withstand lateral thrust.

4.2.3.3 Environmental load

This load consists mainly of snow load, sand load, wind pressure and suction, earthquake load, soil pressure on subsurface portions of the structure, loads from possible ponding of rainwater on flat surfaces, and forces caused by temperature differentials.

This load is dependent on local climatic and seismic conditions. They shall be defined in Particular Specifications.

Snow or sand load applies to exposed areas of buildings (roof) and structures (platforms). Design shall take into account unbalanced conditions of loading because of wind and sunlight, which tend to reduce load on some areas, and increase load on others.

The design wind pressure is determined from the wind speed, by using the formulas given in the relevant code.

The design loading shall include effects of pressure and suction.

The design of tall and slender structures such as towers and stacks shall investigate the effects of wind-induced vibration.

If analysis results indicate that unacceptable levels of vibrations can occur, then helical strakes, dynamic vibrations absorbers shall be adopted.

Whenever possible, seismic forces shall be computed by using equivalent static forces as allowed by the relevant codes.

As an alternative, they may be found for a particular structure by means of elastic or inelastic dynamic analysis, taking into account ground acceleration and mass, stiffness and damping characteristics of the construction.

4.3 Minimum requirements

Technical and economical optimisation of the design of the works shall be pursued, in view of the environmental conditions, the construction means and their implementation on site.

4.4 Structure durability

The design life for the project shall be for 365 days per annum for a service life greater than 30 years unless particular specifications.

The proximity of the sea shall be taken into account to provide protection of the civil works. The structure shall be protected against any corrosion due to chloride ingress in the concrete and the steel structure shall be protected against corrosion in accordance with the general specifications.

In order to reduce maintenance cost and increasing productivity, the status of the plant assets must be known. The Contractor shall provide a survey and maintenance strategy of assets based on a risk analysis taking into account the ageing of infrastructures. The Company should be aware how the quality of their infrastructure (tank, pipe, berth, etc.) can evolve, and hence, anticipate better plan maintenance operations.

The design of individual components of the facilities may include a strategy for planned obsolescence and replacement, where a single equipment lifetime of 30 years is not feasible or optimum. In instances where such a replacement philosophy is adopted, the initial design shall include demonstration of how replacement will be optimally achieved.

5. Design documents

Design documents shall include the following:

5.1 Calculation notes

Typical contents of a calculation note shall be the following:

- Table of contents
- List of revisions
- Purpose of the calculation note
- Sketches of the structure

- Assumptions:
 - Loads
 - Load cases
 - Load combinations
 - Criteria to be complied with
- References to documents used (codes, standards, notes, etc.)
- General description of the calculation method, including formulas, sign conventions, etc. When a computer code is used, the following additional information shall be provided:
 - Purpose of the code
 - Theoretical basis and calculation principles
 - Description of the model
 - Input data
 - Output results
 - Computer lists attached as appendices to the note (these lists shall never constitute the note by themselves)
- Stress or displacement calculations
- Analysis of results
- Conclusions

5.2 Combinations of Actions

Structure should be designed for the Ultimate Limit State (ULS) and Serviceability Limit State (SLS) combination of actions.

- ULS - includes all action conditions. This design state should be assessed to determine concrete section adequacy in accordance with the strength requirements of EN 1992 using appropriate material strength partial safety factors and partial action factors (see Table 3.1 and Table 3.2).
- SLS – includes construction, normal operating, and spill conditions. This design state should be assessed to determine structure displacements and crack widths for durability and liquid tightness of the concrete wall for the spill condition.

The normal actions referred to above should be combined in accordance with [EN 1990 Annex A](#) and [EN 1992](#) such that all possible combinations which can occur during construction, testing, cool down, normal operation and warming-up of the project, are incorporated in the design. Only one accidental action should be combined with the appropriate combination of normal actions in any individual case.

All relevant action combinations should be considered and proposed by the Designer.

Partial action and materials factors should be applied in accordance with [EN 1992](#).

The effects of the range of differential settlements, creep, shrinkage and maximum and minimum ambient temperatures should be included in the analyses.

5.3 Drawings

Apart from all information necessary to build the structure, drawings shall include the following information:

- Units used
- Co-ordinates system
- Type of concrete
- Concrete facing
- Construction tolerances
- Scales: scale shall range from 1/100 for general view (1/50 for reinforcement drawings) to 1/10 for details
- Construction joints
- Development and splicing length

The drawings shall be accurate enough to completely define the works to be performed.

6. Particular design requirements

The design and calculations of reinforced concrete structures shall be based on the relevant codes and standards defined in the Particular Specifications. The application of the pre-stressed concrete may be used only for the following structures:

- LNG/LPG storage tanks
- Bridge and culvert
- Piles
- Other structures outside the process area where the risk of fire is absent or limited.

6.1 Foundation piles

Foundation piles shall be provided in the following cases:

- Soil bearing capacity is not sufficient to withstand loads from the foundation
- Expected settlements exceed the project requirements.

They shall be designed to take both horizontal and vertical loads applied on top.

Piles develop their carrying capacity as a combination of friction along their length and end bearing.

The geotechnical survey shall serve as a basis to estimate the pile capacity from these effects.

When piles are used in groups, they shall be separated by a distance at least equal to three times the diameter of the largest pile. On top of that, the effect of close proximity of piles shall be considered by taking into account the proper reduction coefficient applied to the nominal capacity.

The stresses developed during the installation shall be taken into account so as to ensure that the strength of the in-place pile is sufficient to transmit the load imposed on it with the adequate factor of safety against failure.

The piles shall be properly designed to bear the applied loads :

- Vertical load: this is the main loading to which the pile is submitted. Possibility of tension in the piles shall also be investigated
- Horizontal load: lateral forces on piles may be caused by the effect of wind or earthquake on the structure, as well as effect of tides, currents, or impacts of ships
- Eccentric vertical load: as the vertical load applied to the pile is seldom a simple axial load, the effect of a moment on top of the pile shall either be investigated or an effective restraint of the pile caps be provided.
- Impact of frozen soil or permafrost.

6.2 Shallow foundation

Shallow foundations include strip, pad and raft foundation.

This type of foundation is in most of cases suitable for buildings.

The center of the foundation shall be arranged vertically under the center of gravity of the loading. If this is not be possible, the effects on the structure of rotation and settlements shall be investigated.

The design of a strip or pad footing shall be performed according to one of the following methods:

- A strut-and-tie analysis in which the vertical load is transferred through the foundation to the soil by means of concrete struts. This method is valid for footings subject to soil reaction close to a uniform distribution. The reinforcement is then designed to anchor the struts. In such a case, horizontal reinforcement is sufficient
- A beam-type analysis in which the effect of flexure and shear in the footing is investigated and reinforcement designed accordingly. In that case, due to the difficulty and cost of placing vertical reinforcement, an optimisation of the thickness of the footing might be required in order to ensure that the concrete alone has sufficient capacity to undertake shear force.

When considering a structure founded on several footings lying on different types of foundation soil, attention shall be paid to the possibility of differential settlement.

Measures shall be taken to minimise the settlements and the effect of these shall be considered in the design of the supported structure.

Foundations and structures subject to temperature effects shall be designed for any temperature difference that may occur.

6.3 Slab on grade

Slabs on grade are concrete slabs poured on top of a soil layer.

They are subjected to the following loads:

- Wheel load, defined by the axle load, distance between wheels, tire contact area and frequency of load
- Concentrated load, defined by the magnitude of load, area of contact and distribution of load

- Strip load (distributed over a narrow area), defined by the magnitude of load, width and length of loaded area
- Uniform load (distributed over a wide area), defined by the magnitude of load, width and length of loaded area
- Construction load, mainly due to wheel or concentrated loads applied during construction
- Environmental load (thermal expansion, contraction, drying shrinkage), including effect of expansive soil
- Load induced by differential settlement.

Slabs shall be designed for the most critical combination of these loading conditions, considering the magnitude of load, contact area and load distribution.

The design parameters to be considered are the following:

- Slab thickness
- Concrete strength
- Sub-grade thickness
- Distribution of joints.

The design of slabs on grade shall be performed using approved methods, such as:

- Portland Cement Association (PCA) design method
- Wire Reinforcement Institute (WRI) design method
- Corps of Engineers (COE) design method.

Alternative design methods may be used after approval from the COMPANY.

6.4 Pedestals

Pedestals are short columns supporting equipment and lying on a strip or pad foundation or a pile cap.

As such, they shall be designed for the critical combination of vertical load and moment.

Reinforcement is then designed to resist the tensile stresses in the pedestal.

Minimum reinforcement to be provided shall be based on the requirements for a short column.

6.5 Columns

Columns are compression members commonly divided into two categories:

- Short columns
- Slender columns

The limit between these categories shall depend on the code used for the project.

Columns shall be designed to resist the effects of normal forces and flexure.

The design of slender columns shall take into consideration the effects of lateral deflections.

As a minimum, columns shall be reinforced with 4 bars located in the corners of the concrete section, with ties to prevent longitudinal bars from buckling.

6.6 Beams

Beams are members resisting effects of flexure and shear.

Reinforcing bars shall be placed on the tension side, as close to extreme tension fiber as is compatible with proper corrosion protection of the steel.

Design of beams shall also comply with the allowable deflection requirements.

6.7 Slabs

Slabs are flat horizontal members supported on their edges.

Design of one-way slabs shall take into consideration requirements for beams.

Design of two-way slabs shall take advantage of bi-directional behaviour.

In any case, the slab shall be reinforced in both direction, either by using the required reinforcement given by calculation, or by placing a minimum amount of reinforcement, as required by the applicable code.

6.8 Retaining walls

Retaining walls are used to hold back masses of earth.

Various types of retaining walls may be considered:

- Gravity walls
- Cantilever walls
- Counterfort Buttress walls

Retaining walls shall be checked for stability, which requires:

- Sliding check: the horizontal component of earth pressure is to be resisted by friction between concrete and soil
- Overturning check: the overturning moment is to be resisted by the stability component generated by the vertical component of earth pressure (weight)
- Soil bearing pressure check: soil pressure induced by the loads from the wall and earth must be below the allowable pressure.

The concrete design of the retaining wall shall be performed accordingly, with respect to the applied load, i.e. considering the structure made of slabs, beams, etc.

Special attention shall be paid to the drainage of water behind the wall as water pressure may create significant additional pressure,

6.9 Foundations for machinery

Vibrations are induced in structures by reciprocating and rotating equipment, rapid application and subsequent removal of a load, or by other means.

Vibrations take place in flexural, extensional, or torsional modes, or any combination of the three.

Resonance occurs when the frequency of an applied dynamic load coincides with a natural frequency of the supporting structure. In this condition, vibration deflections increase progressively to dangerous proportions.

Resonance shall be prevented by ensuring, in the design, that the natural frequency of a structure and the frequency of load application do not coincide.

The design of such foundations shall take into consideration the reaction of underlying soil to vibratory loading and the determination of the natural frequencies of the foundation-soil system.

It shall take into account foundation material properties and interaction with foundation.

The geometry and mass of the foundation shall be selected based on proper analysis satisfying imposed restrictions on foundation movements (lateral, vertical and torsional or a combination of these) resulting from dynamic loads due to machine operation, as provided by the MANUFACTURER.

Foundations for heavy vibratory machinery are likely to require isolation from the surrounding structure, floors, and foundations.

Depending on conditions, adequate isolation may be achieved by leaving an open space between the machine base and surrounding structure.

This method still requires evaluation of whether vibrations can be transmitted to the structure through the foundations.

If unacceptable vibrations are induced in the surrounding structures, use of insulating pads or springs may be required.

6.10 Liquid-retaining structures

Special precautions shall be taken regarding the liquid tightness. All these structures shall be water tested.

6.11 Cryogenic structures

Special precautions shall be taken regarding the temperatures and thermal actions. Thermal effects during testing, cool-down, normal and abnormal operation and warming should be considered. Normal thermal actions are deformation-based and as such should only be considered for Serviceability Limit States.

6.12 Anchor bolts

The maximum pull-out force shall be considered for the design of the anchoring length of the anchor bolts.

The design shall be checked for the most severe combination of pull-out/shear forces. The reinforcement around the anchor bolts shall comply with the relevant codes and standards defined in the Particular Specifications.