Durability evaluation of existing concrete structures and durability design of precast elements applied in brazilian stadiums for the Football World Cup 2014.
Distribution of projects by origin of the resources in the first planning cycle in April 2012, in billions of brazilian reais

1 Euro = 3.16 Reals

State and municipal government
- Federal funding
- Federal resource
- Private resource

<table>
<thead>
<tr>
<th>Category</th>
<th>State and municipal government</th>
<th>Federal funding</th>
<th>Federal resource</th>
<th>Private resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stadiums</td>
<td>2.5</td>
<td>3.7</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Urban mobility</td>
<td>4.6</td>
<td>3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airports</td>
<td>7.4</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ports</td>
<td>0.9</td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total investments</td>
<td>12.0</td>
<td>7.1</td>
<td>11.1</td>
<td>7.1</td>
</tr>
</tbody>
</table>
The use of precast concrete in buildings is largely related to a way of building economic, durable, structurally safe and architectural versatility. The precast industry is continuously making efforts to meet the demands of society.

The most effective way to industrialize the construction sector is to transfer the work made in the site building to permanent and modern factories. The production in a factory makes production processes more efficient and rational with specialized workers, task repetition, high quality control, etc. Competitiveness and society are forcing the construction industry to update constantly, improving its efficiency and working conditions through the development and technological innovation of new constructive systems and processes.
Less construction time: less than half the time required for conventional framed construction on site. Because of the slowness of the traditional methods of cast in place concrete structures, the long construction delays are generally accepted. However, the current demand for a rapid return on investment is becoming more and more important: the decision to start the construction may be delayed until the last moment, but, once started, the initial schedule of the work must be fulfilled. In addition, the projects are becoming more complex, which is not favorable for conventional framed construction that needs to do in a short time. Setup can continue even in the winter, with a temperature of –20° c. Work on the construction site should stop as soon as the temperature reaches –5° c. The prefabrication process is independent of the adverse climate conditions and production continued normally in winter.
Prefabrication has greater economic potential, structural performance and durability than the traditional framed constructions on the site, because of the highly leveraged and optimized use of materials. This is achieved through the use of modern equipment and manufacturing procedures that are carefully crafted.

The prefabrication employs computer-controlled equipment for the preparation of concrete. Additives and additions are employed to achieve the mechanical performances, specific for each concrete class. The casting and setting of concrete are performed indoors, with optimized equipment. The water/cement ratio can be reduced to the minimum possible and the setting and curing are performed under controlled conditions. In addition, the effectiveness of the mixing is better than the molded concrete on site.
The high-performance concrete HPC (with superior resistance to 50 MPa) is well known in the prefabrication industry and many factories are already employing it on a daily basis. The greatest benefits of precast structures are related to structural efficiency that allows elements more slender and the optimized use of materials. Another positive feature is the increased durability against freezing and chemical agents. The biggest advantages are achieved by compressed elements, especially the columns.

For beams, the use of higher resistance for concrete allows the use of prestressing. This means the possibility of employing a greater number of prestressing cables and, consequently, a greater flexion capacity, great momento of cracking and higher service load.
Self compacted concrete is a new solution and quite promising for the prefabrication process. While the high resistance is focused on optimizing product performance (strength and durability), the self compacted concrete presents a beneficial impact to the production process, because it requires no vibration and therefore offers many advantages, such as: less noise during the molding process of precast elements; reduced pressure on the forms; greater speed and ease in the molding process, especially for thin and complicated sections, resulting in less air bubbles on the surface of the piece, being easy to pump. The development of this technique and its application has been growing quickly in the precast industry in Europe, and it is expected that in a few years, this procedure will be employed as a conventional technique on a daily basis.
12 ARENAS

Maracanã - 78.000
Rio de Janeiro

Estádio Nacional - 70.000
Brasília

Arena Corinthians - 68.000
São Paulo

Arena Castelão - 67.000
Fortaleza

Mineirão - 64.000
Belo Horizonte

Beira-Rio - 52.000
Porto Alegre

Arena Fonte Nova - 50.000
Salvador

Arena Pernambuco - 46.000
Recife

Arena da Amazônia - 44.000
Manaus

Arena das Dunas - 43.000
Natal

Arena Pantanal - 43.000
Cuiabá

Arena da Baixada - 41.000
Curitiba
Castelão Arena in Fortaleza
Pernambuco Arena in Recife
Corinthians Arena
Fall of the last segment of the steel structure of the coverage of the Arena Corinthians in November 2013.
As the concrete structure was precasted, there was energy dissipation of shock and damage were concentrated in the region of impact.
National Stadium in Brasília
Beira Rio Stadium in Porto Alegre
Amazônia Arena in Manaus
Fonte Nova Arena in Salvador
Maracanã Stadium in Rio de Janeiro
Maracanã Stadium before and after reform and adequacy (retrofit)
Original structures

- Assessment of the conservation status of concrete structures (structural and durability)
- Projects of rehabilitation of structures
- Works of adequacy to the needs for the World Cup (pre-cast)

Diagram:
- Concrete coverage
- Upper stand (seats)
- Clamped free beam
- Lower stand (seats)
Model Code for Service Life Design
fib Bulletin No. 34, 2006, pp. 116

1. General
2. Basis of design
3. Verification of Service Life Design
4. Execution and its quality management
5. Maintenance and condition control
Methodology

- Study of projects and old photographs
- Visual and photographic survey of the pathological manifestations
- Electromagnetic detection of reinforcements
- Use of ultrasound to check non-destructively:
  - presence of voids
  - discontinuities and inhomogeneities
  - estimation of elastic modulus and compressive strength
- Schmidit rebound hammer test
- Ohmic resistance and resistivity
- Electrochemical tests:
  - corrosion potential (Ecorr)
  - polarization resistance (corrosion density - icorr)
Methodology

- Dimensions, covering and reinforcement spacing
- Evaluation and measurement of the carbonation depth and presence of free and total chlorides
- Extraction of cylindrical concrete specimens (core)
  - Axial compressive strength
  - Modulus of elasticity
  - Content of chlorides
  - Empty index
  - Absorption
Methodology

- Extraction of reinforcement steel bar specimens
  - Graph: Tension X Deformation
    - Yield strength
    - Fracture strength
    - Maximum Stretching (elongation)
  - Bend test
  - Chemical composition
  - Metallography
Electrochemical evaluation of the Wall Beam

- 2000 Ωm, 4.44 kΩ, 0.013 μA/cm², -128 mV, 1.20 m
- 2000 Ωm, 3.13 kΩ, 0.065 μA/cm², -184 mV, 0.60 m
- 1300 Ωm, 1.32 kΩ, 0.380 μA/cm², -233 mV, 0.30 m
- 550 Ωm, 1.70 kΩ, 0.444 μA/cm², -368 mV, 0.15 m
- 130 Ωm

Notes:
- The values are likely related to resistances and currents measured at different depths in the wall.
Reinforcement completely corroded due to high porosity of concrete that functioned as a chamber of relief of tensions arising from the expansion of reinforcement in corrosion process.
Embrittlement of reinforcement due to intergranular corrosion
Removal of the lower stand (seats) for design reasons and meeting the requirements of FIFA
Removal of the concrete coverage and clamped free beam
Evolution of the works

January, 2011
Demolition of the clamped free beam west.
Evolution of the works

June 22, 2011

June 2011
Beginning of the withdrawal of the coverage with the use of crane with a capacity of 400 tons.

July 4, 2011
Evolution of the works

January 31, 2012
Execution of mixed structures (steel and concrete) in the region of the VIPs areas
Execution of concrete structures cast in place and precast of the bottom of the stands
Implementation of the foothills made with concrete molded in place to restrict horizontal movements of the stands.
Mixed structures (steel and concrete)
Compression ring mounting

April 2012
View of the compression ring placed on the head of the columns, which are fixed the support devices.
Support Device to transfer efforts from Compression Ring to the column. Were installed 56 mobiles Supports Devices (only compression is transferred) and 4 fixeds (compression and shear are transferred)
Complete coverage made with tensioned cables and composite membrane of teflon and fiberglass
New coverage with 68.40 meters in length
New foundations
type root piles foundation
Structures of new ramps molded on site
Pre-concrete slabs
Usually the engineers concentrate their efforts on quality, time and cost of construction, but the current change of paradigms of construction includes the concern with the environment. Most of the works that were made for the 2014 World Cup (Brazil) and works for the 2016 Olympics (Rio de Janeiro, Brazil) had been and are being certified by international institutions that deal with sustainability (e.g. LEED).
Present design procedures are predominantly based on strength principles, and the design is increasingly being refined to address durability requirements (resistance to chloride ingress, improved freezing and thawing resistance, etc.).

A certain level of durability, such as requirement for concrete cover to protect reinforcement under aggressive action from environment and industry is inherent with design calculation.

Reinforced concrete (RC) structures are designed in accordance with national or international codes and Standards.
Performance and assessment requirements for design standards on structural concrete
A.2 Examples of national standards “deemed to satisfy”

American Concrete Institute standards
Building Standards Requirements for Structural Concrete, ACI 318–08, 475 pp., American Concrete Institute, Farmington Hills, Michigan, 48331, USA.
Analysis and Design of Reinforced Concrete Bridge Structures, ACI 343R–95, 158 pp., American Concrete Institute, Farmington Hills, MI, 48331, USA.

A.2.2 European standards

A.2.3 Japanese standards
Standard Specifications for Concrete Structures, Japan Society of Civil Engineers, Tokyo, 160–0004, Japan, 2002:

A.2.4 Australian standards

A.2.5 Colombian standards
Colombian Code — National Structural Concrete Standards; included in NSR–98, Colombian Code for Earthquake Resistant Design and Construction.

A.2.6 Saudi Arabian standards

A.2.7 Brazilian standards

A.2.8 Egyptian standards
ECP 203, Egyptian Code for the Design and Construction of concrete Structures, limit states design method.”
Referências bibliográficas

Concrete Durability

Durability is the ability of a material or structure to withstand the conditions of service taken into account in the project during its lifetime, designed without significant deterioration.

In Model Code (FIB (CEB–FIP), Bulletin 34 – Model Code for Service Life Design), basic requirement is: "Concrete structures shall be designed, constructed and operated in such a way that, under the expected environmental influences, they maintain their safety, serviceability and acceptable appearance during an explicit or implicit period of time without requiring unforeseen high costs for maintenance and repair."
Project service life is the period of time during which the concrete structures designed are maintained. During this period of time the owner or user must meet the recommendations for use and maintenance procedures recommended by the designer and constructor.

The concept of service life design applies to the structure as a whole or its parts. Thus, certain parts of the structures may deserve special consideration with different service life value as, for example, support devices and movement joints.
- Damaged or missing movement joints and broken corners:
- Seepage, leaching of concrete reinforcement corrosion.
Crushing and deterioration of support devices

Fonte: Marcos Mitre

Pontes Paulo Guerra: Estado antes da recuperação (Carneiro, 2006)
Service life design (NBR 15575-1, 2013)

<table>
<thead>
<tr>
<th>System</th>
<th>Minimum Design Life (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>Structure</td>
<td>≥ 50</td>
</tr>
<tr>
<td>Internal floors</td>
<td>≥ 13</td>
</tr>
<tr>
<td>Vertical external sealing</td>
<td>≥ 40</td>
</tr>
<tr>
<td>Vertical internal sealing</td>
<td>≥ 20</td>
</tr>
<tr>
<td>Coverage</td>
<td>≥ 20</td>
</tr>
<tr>
<td>Sanitary system</td>
<td>≥ 20</td>
</tr>
</tbody>
</table>

Considering frequency and maintenance processes according to ABNT NBR 5674 and specified in the respective User Manual, operation and maintenance given to the user prepared in compliance with the ABNT NBR 14037.

### Classes of environmental aggressiveness (CEA)
NBR 6118 (2014)

<table>
<thead>
<tr>
<th>Classes of environmental aggressiveness</th>
<th>Aggressiveness</th>
<th>Overall classification of the type of environment of the purpose of design</th>
<th>Risk of deterioration of the structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Weak</td>
<td>Rural Submerged</td>
<td>Insignificant</td>
</tr>
<tr>
<td>II</td>
<td>Moderate</td>
<td>Urban(^a,,b)</td>
<td>Low</td>
</tr>
<tr>
<td>III</td>
<td>Strong</td>
<td>Marine(^a), Industrial(^a,,b)</td>
<td>High</td>
</tr>
<tr>
<td>IV</td>
<td>Very Strong</td>
<td>Industrial(^a,,b), Tidel/splash</td>
<td>Very high</td>
</tr>
</tbody>
</table>

\(^a\) A microclimate with a milder class of aggressiveness (one level above) may be accepted for dry indoor environments (living rooms, bedrooms, bathrooms, kitchens and laundry rooms in residential apartments and commercial developments or environments with concrete coated with mortar and paint).

\(^b\) A milder class of aggressiveness (one level above) may be accepted in: structures in regions with a dry climate, with relative humidity less than or equal to 65%, parts of the structure protected from rain in predominantly dry environments, or regions where it rarely rains.

\(^c\) Chemically aggressive environments, industrial tanks, electroplanting, bleaching in the pulp and paper industries, fertilizer warehouses, chemical industries.
Maracanã stadium

Classes of environmental aggressiveness II (Moderada) NBR 6118 (2007)
NORTH AND SOUTH UPPER STANDS

The upper region on the slab from the bleachers

VL
VT1
VT2
VT3

Lower region on the slab from the bleachers

Structures of bleachers evaluated
Conservation status of the lower region of the upper stands

Overview of the Upper Stands North and lower region of the stands, at the end of the structural balance (clamped free beam). This region is unprotected and subject to the action of weathering.
Conservation status of the lower region of the upper stands
### Content of chlorides - Stands

<table>
<thead>
<tr>
<th>Samples</th>
<th>Parameters</th>
<th>Chlorides (%) in mass concrete</th>
<th>Chlorides (%) in mass of binder</th>
<th>Binder (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP Nº 8; Stands section 9-10. Slab stands (Top point)</td>
<td></td>
<td>0.08</td>
<td>0.25</td>
<td>32.03</td>
</tr>
<tr>
<td>CP Nº 16; Stands section 439-44. Slab stands (Lowest point)</td>
<td></td>
<td>0.08</td>
<td>0.26</td>
<td>30.16</td>
</tr>
<tr>
<td>CP Nº 30; Standss section 51-52. Slab stands (Top point)</td>
<td></td>
<td>0.10</td>
<td>0.35</td>
<td>28.21</td>
</tr>
<tr>
<td>CP Nº 38; Stands section 21-22. Slab stands (Lowest point)</td>
<td></td>
<td>0.12</td>
<td>0.36</td>
<td>33.59</td>
</tr>
</tbody>
</table>
Condition of the Wall Beams
## Content of chlorides in the Wall Beams

<table>
<thead>
<tr>
<th>Samples</th>
<th>Parameters</th>
<th>Chlorides (%) in mass concrete</th>
<th>Chlorides (%) in mass of binder</th>
<th>Binder (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP Nº 06 - Wall beam (WB) 09-10 Stretch Grandstand, D (mm); 80 and H (mm); 197</td>
<td></td>
<td>0.01</td>
<td>0.040</td>
<td>24.85</td>
</tr>
<tr>
<td>CP Nº 14 - Wall beam (WB) 43-44 Stretch Grandstand, D (mm); 80 and H (mm); 300</td>
<td></td>
<td>0.01</td>
<td>0.036</td>
<td>28.42</td>
</tr>
<tr>
<td>CP Nº 25 - Wall beam (WB) 51-52 Stretch Grandstand, D (mm); 80 and H (mm); 220</td>
<td></td>
<td>0.01</td>
<td>0.034</td>
<td>29.61</td>
</tr>
<tr>
<td>CP Nº 26 - Wall beam (WB) 51-51 Stretch Grandstand, D (mm); 80 and H (mm); 390</td>
<td></td>
<td>0.02</td>
<td>0.115</td>
<td>17.43</td>
</tr>
<tr>
<td>CP Nº 36 - Wall beam (WB) 21-22 Stretch Grandstand, D (mm); 80 and H (mm); 130</td>
<td></td>
<td>0.01</td>
<td>0.052</td>
<td>19.36</td>
</tr>
<tr>
<td>CP Nº 37 - Wall beam (WB) 21-22 Stretch Grandstand, D (mm); 80 and H (mm); 90</td>
<td></td>
<td>0.01</td>
<td>0.039</td>
<td>25.90</td>
</tr>
</tbody>
</table>
## Requirements for concrete exposed to solutions containing sulphates

<table>
<thead>
<tr>
<th>Exposure conditions depending on the aggressiveness</th>
<th>Water soluble sulphate (SO₄⁻⁻) present in the soil % in mass</th>
<th>Water soluble sulphate (SO₄⁻⁻) present in the water ppm</th>
<th>Maximum water/cement ratio by weight for normal concrete*</th>
<th>Minimum fₜₐₜ for concrete with normal, aggregated or mild MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weak</td>
<td>0.00 to 0.10</td>
<td>0 to 150</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Moderate **</td>
<td>0.10 to 0.20</td>
<td>150 to 1500</td>
<td>0.50</td>
<td>35</td>
</tr>
<tr>
<td>Severe***</td>
<td>Above 0.20</td>
<td>Above 1500</td>
<td>0.45</td>
<td>40</td>
</tr>
</tbody>
</table>

* Low water/cement ratio or high resistance may be necessary for obtaining low permeability of concrete or corrosion protection or reinforcement protection to freezing and thawing processes

** Seawater

*** For severe conditions, aggression must be compulsorily used cements resistant to sulphates
Maximum content of chloride ions for protection of reinforcement of concrete structures

<table>
<thead>
<tr>
<th>Type of structure</th>
<th>Maximum content of chloride ions (Cl⁻) in concrete % on mass of cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prestressed concrete</td>
<td>0.05</td>
</tr>
<tr>
<td>Reinforced concrete exposed to chlorides in the conditions of service of the structure</td>
<td>0.15</td>
</tr>
<tr>
<td>Reinforced concrete in severe exposure conditions (dry and protected from humidity in the conditions of service of the structure)</td>
<td>0.40</td>
</tr>
<tr>
<td>Other types of construction with reinforced concrete</td>
<td>0.30</td>
</tr>
</tbody>
</table>

If a concrete with reinforcement is exposed to chlorides from chemicals agents of the thaw, salt, salt water, sea water or splashes or sprinkling of these three agents, the requirements of table 3 for the water/cement ratio and compressive characteristic resistance of concrete must be satisfied. It is not allowed the use of additives containing chlorides in its composition in prestressed or reinforced concrete structures.
### Author/Standards

<table>
<thead>
<tr>
<th>Use of concrete</th>
<th>Chloride content class&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Maximum content of Cl⁻ by mass of cement&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without prestressing steel or metal parts embedded, exception of elements of high corrosion resistance (stainless steel)</td>
<td>Cl 1.0</td>
<td>1.00%</td>
</tr>
<tr>
<td>With armour of steel or metal parts embedded</td>
<td>Cl 0.20</td>
<td>0.20%</td>
</tr>
<tr>
<td>Cl 0.40</td>
<td>0.40%</td>
<td></td>
</tr>
<tr>
<td>With protective steel armor</td>
<td>Cl 0.10</td>
<td>0.20%</td>
</tr>
<tr>
<td>Cl 0.20</td>
<td>0.10%</td>
<td></td>
</tr>
</tbody>
</table>

---

1. For a specific use of concrete, the class to be applied depends on the provisions valid at the place of use of the concrete.
2. When type I additions are used and taken into account for the cement content, chloride content is expressed as the percentage of chloride ions by mass of cement over the total mass of additions that are taken into account (in relation to the mass of binder).

### ACI 222R-01 (2001)

<table>
<thead>
<tr>
<th>Category</th>
<th>ASTM C 1152</th>
<th>ASTM C 1218</th>
<th>Smith (ACI 222.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prestressed concrete</td>
<td>0.08%</td>
<td>0.06%</td>
<td>0.06%</td>
</tr>
<tr>
<td>Reinforced concrete exposed to moisture conditions</td>
<td>0.15%</td>
<td>0.08%</td>
<td>0.08%</td>
</tr>
<tr>
<td>Reinforced concrete dry or protected from moisture</td>
<td>0.20%</td>
<td>0.15%</td>
<td>0.15%</td>
</tr>
<tr>
<td><strong>Author/Standards</strong></td>
<td>**Maximum content of chlorides (percent) ***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BS 8110: Part 1 – BSi (1997)</td>
<td>In 2003 has been replaced by the European Standard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Andrade (1992)</td>
<td>0.40%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thomas (1996)</td>
<td>0.2% - For concrete with 50% of fly ash 0.7% - For concretes without fly ash</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Type of structure</strong></td>
<td><strong>Maximum content of chloride ions in concrete % on mass of cement</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reinforced concrete exposed to chlorides in the conditions of service of the structure</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reinforced concrete in severe exposure conditions (dry and protected from humidity in the conditions of service of the structure)</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other types of construction with reinforced concrete</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Use of concrete</strong></td>
<td><strong>Maximum content of chloride ions mg/l in water for kneading</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prestressed concrete or Grout</td>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete reinforced</td>
<td>1,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple concrete (without reinforcement)</td>
<td>4,500</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Details of design that improve durability

Drainage

Architectural and structural shapes

Quality and thickness of the covering
Correlation between class of aggressiveness and quality of the concrete NBR 6118 (2014)

<table>
<thead>
<tr>
<th>Concrete a</th>
<th>Type b,c</th>
<th>Classes of aggressiveness (Table 6.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>Water/cement ratio by mass</td>
<td>CA</td>
<td>≤ 0.65</td>
</tr>
<tr>
<td></td>
<td>CP</td>
<td>≤ 0.60</td>
</tr>
<tr>
<td>Classes of concrete (NBR 8953)</td>
<td>CA</td>
<td>≥ C20</td>
</tr>
<tr>
<td></td>
<td>CP</td>
<td>≥ C25</td>
</tr>
</tbody>
</table>

a The concrete used in the execution of the structures must comply with the requirements established under NBR 12655.

b CA corresponds to reinforced concrete components and structural elements.

c CP corresponds to prestressed concrete components and structural elements.
Correlation between class of aggressiveness and qualify of the concrete (NBR 12655, 2012)

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Type</th>
<th>Classes of aggressiveness (Table 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>Water/cement ratio by mass</td>
<td>CA</td>
<td>≤ 0.65</td>
</tr>
<tr>
<td></td>
<td>CP</td>
<td>≤ 0.60</td>
</tr>
<tr>
<td>Classes of concrete (NBR 8953)</td>
<td>CA</td>
<td>≥ C20</td>
</tr>
<tr>
<td></td>
<td>CP</td>
<td>≥ C25</td>
</tr>
<tr>
<td>Cement consumption per cubic meter of concrete kg/m³</td>
<td>CA and CP</td>
<td>≥ 260</td>
</tr>
</tbody>
</table>

CA corresponds to reinforced concrete components and structural elements; CP corresponds to prestressed concrete components and structural elements.
## Requirements for concrete under special conditions of exposure (NBR 12655)

<table>
<thead>
<tr>
<th>Conditions of exposure</th>
<th>Maximum water/cement ratio for concrete with normal aggregate</th>
<th>Minimum value of $f_{ck}$ (for concrete with normal or lightweight aggregate) (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditions in which a concrete with low water permeability is required</td>
<td>0.50</td>
<td>35</td>
</tr>
<tr>
<td>Exposure to freezing and thawing processes in moist conditions or de-icing chemicals</td>
<td>0.45</td>
<td>40</td>
</tr>
<tr>
<td>Exposure to chlorides from de-icing chemicals, salts, salt water, sea water, or splashing or spraying of these agents.</td>
<td>0.40</td>
<td>45</td>
</tr>
</tbody>
</table>
Minimum coverings

In the current works, the value of $\Delta c$ must be lower than or equal to 10 mm. When there is an adequate quality control and strict tolerance limits of the variability during execution, can be adopted the value $\Delta c = 5$ mm, but the requirement of strict control should be made explicit in the design drawings. Permission is granted, then the reduction of nominal covering, prescribed in the next table, in 5 mm. The nominal and minimum covering are always referred to the surface of the external rebar, in general the outside face of the stirrup. The nominal coverings of a particular bar must always be:

a) $c_{nom} \geq \phi_{bar}$
b) $c_{nom} \geq \phi_{cable} = \phi \cdot n = \phi \cdot n$; $n =$ number of wires
c) $c_{nom} \geq 0.5 \phi$ of the sheath.

The maximum size characteristic of coarse aggregate used in the concrete cannot overcome in 20% the nominal thickness of coverings, namely:

$$d_{max} \leq 1.2 \ c_{nom}$$
## Correlation between class of environmental aggressiveness and normal covering for $\Delta_c = 10\text{mm}$ [1]

<table>
<thead>
<tr>
<th>Type of structure</th>
<th>Component or element</th>
<th>Classes of environmental aggressiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nominal cover mm</td>
</tr>
<tr>
<td>Reinforced concrete</td>
<td>Slab(^b)</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Bean/pillar</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Structural elements in contact with the ground(^d)</td>
<td>30</td>
</tr>
<tr>
<td>Prestressed concrete(^a)</td>
<td>Slab</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Bean/pillar</td>
<td>30</td>
</tr>
</tbody>
</table>

\(^a\)Nominal coverings of sheath, wires, cables and strand. The passive reinforcement covering must respect the covering for the concrete.

\(^b\)To the upper surface of slabs and beams that will be lined with mortar to subfloor, with final coatings, dry carpet and wood type, with finishing mortar and finishing, such as high performance flooring, ceramic floors, asphalt floors and others, the requirements of this table can be replaced by of 7.4.7.5, respecting a nominal coverings $\geq 15$ mm.

\(^c\)On surfaces exposed to aggressive environments, such as reservoirs, water treatment plants and sewage systems, sewage ducts, waste water channels and other works in chemical environments and intensely aggressive, must be met the aggressive class coatings IV

\(^d\)In the stretch of the pillars in contact with the soil along the Foundation elements, the armor must have nominal coverings $> 45$ mm.

For concrete strength class higher than the minimum required, the covering required in the table (7.2) can be reduced by up to 5 mm.

In the case of prefabricated structural elements the values relating to the covering of reinforcements (Table 7.2) must follow the provisions of ABNT NBR 9062.
Reduction of coverings in 5 mm beyond those established by NBR 6118 (2014) if $f_{ck} \geq 40$ MPa and $a/c \leq 0.45$, limiting the following values of coverings:

- Slabs in reinforced concrete: 15 mm;
- Other parts in reinforced concrete (beams/columns): 20 mm;
- Parts in prestressed concrete: 25 mm;
- Slender prestressed Parts (tiles/ribs): 15 mm;
- Alveolar Slabs prestressed: 20 mm.
Durability requirements related to cracking and reinforcement protection, depending on the environmental aggressiveness classes NBR 6118 (2014)

<table>
<thead>
<tr>
<th>Type of structural concrete</th>
<th>Environmental aggressiveness class (CAA) and type of prestressing</th>
<th>Requirements relating to the cracking</th>
<th>Combination of actions on the service use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple concrete</td>
<td>CEA I and CEA IV</td>
<td>None</td>
<td>--</td>
</tr>
<tr>
<td>Concrete reinforced</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CEA I</td>
<td>ELS-W $W_k \leq 0.4$ mm</td>
<td>Frequent combination</td>
</tr>
<tr>
<td></td>
<td>CEA II and CEA III</td>
<td>ELS-W $W_k \leq 0.3$ mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CEA IV</td>
<td>ELS-W $W_k \leq 0.2$ mm</td>
<td></td>
</tr>
<tr>
<td>Prestressed concrete level 1 (partial prestressing)</td>
<td>Pre-traction with CEA I or Post-traction with CEA I and II</td>
<td>ELS-W $W_k \leq 0.2$ mm</td>
<td>Frequent combination</td>
</tr>
<tr>
<td>Prestressed concrete level 2 (limited prestressing)</td>
<td>Pre-traction with CEA II or Post-traction with CEA III and IV</td>
<td>Check the two conditions below</td>
<td>Frequent combination</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ELS-F</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ELS-D&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Combination almost permanent</td>
</tr>
<tr>
<td>Prestressed concrete level 3 (full prestressing)</td>
<td>Pre-traction with CEA III and IV</td>
<td>Check the two conditions below</td>
<td>Rare combination</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ELS-F</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ELS-D&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Frequent combination</td>
</tr>
</tbody>
</table>

<sup>a</sup>The designer's criteria, the ELS-D may be replaced by ELS-DP with $a_p = 50$ mm (Figure 3.1)

Notes:
1. Definitions of ELS-W, F, and ELS ELS-D can be found in 3.2
2. For classes of environmental AAC aggressiveness-III and IV, requires that the wire non-members have special protection in the region of its anchors.
3. In the design of flat slabs and pre-stressed concrete mushroom, simply be answered the ELS-F to the frequent combination of actions, in all classes of environmental aggressiveness.
Special measures

In adverse exposure conditions, special measures must be taken to protection and conservation of type: application of water repellents and waterproofing paints on surfaces of concrete, mortars, ceramics or other on the concrete surface, galvanization of the reinforcement, cathodic protection of the reinforcement, corrosion inhibitor, fibers, silica fume and polimers in concrete composition.

Inspection and preventive maintenance

The set of projects relating to a work must be guided under an explicit strategy to facilitate procedures for inspection and preventive maintenance of the building.

The Manual of Use, Operation, Inspection and Maintenance must be produced.
Conclusions

- Specify relation water/cement, cement type, type and content of pozolânicas additions, size of aggregates, slump, maximum apertures of cracks, nominal minimum covering, without taking into account the tolerances due to execution ($\Delta c$), in addition to the compressive strength.

- Current and important works are specifying and controlling the resistivity, the permeability to air or water, chloride diffusion coefficient, among other parameters, to obtain durable concrete.

- The monitoring the changes of the original characteristics of concrete structures by means of sensors is a tool that contributes to the preventive and corrective maintenance activities to ensure the lifetime specified in the project.
Conclusions

We have standards that contribute to the design, implementation and maintenance of concrete structures, but...

Among the pathological manifestations more incidents are still the cracks, low or unexisting coverings and concrete execution failures (for example the honeycomb).

Need for training of customers, dealers, public administration bodies and bidders.

Holistic assessment of the structures is needed, jointing the environmental aggressiveness, microclimates and structural behavior.
The concrete was the winner of the Football World Cup 2014. Technical legacy left by the works of World Cup is immeasurable.
Thank you very much for your attention