PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE

ESCUELA DE INGENIERIA

# UNDERSTANDING PERFORMACE OF CONCRETE USING NATURAL POZZOLANS AGAINST CORROSION

**FERNANDO JAVIER BUSTOS RODRÍGUEZ**

Thesis submitted to the Office of Research and Graduate Studies in partial fulfillment of the requirements for the Degree of Master of Science in Engineering (or Doctor in Engineering Sciences)

Advisor:

**MAURICIO LOPEZ C.**

Santiago de Chile, September, 2011

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A mis Padres, hermana, familiares y amigos, que nunca han dejado de apoyarme.

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## TABLE OF CONTENTS

Pág.

# LIST OF TABLES

## LIST OF FIGURES

Pág.

# RESUMEN

Estructuras de hormigón armado durables pueden hacer una contribución a la sustentabilidad al evitar la pérdida de recursos innecesariamente. La corrosión de las barras de acero embebidas en el hormigón es una de las principales preocupaciones e implica el ingreso de diferentes elementos que pueden iniciarla. Esto hace que la permeabilidad del recubrimiento sea la propiedad de interés y un completo entendimiento de ella es necesario. Para entender el desempeño de estructuras de hormigón armado en términos de su durabilidad se midió la resistencia a compresión, permeabilidad al aire, absorción capilar, permeabilidad ión cloruro, profundidad de corrosión, ingreso de cloruros y potencial de corrosión. Se observó que estructuras consideradas nuevas no tienen necesariamente un mejor desempeño que estructuras antiguas. Además, para establecer de buena manera el daño presente en una estructura se necesitan comparar diferentes indicadores, sin embargo, la resistencia a la compresión no es uno de ellos. Se demuestra que la absorción capilar y permeabilidad a los iones cloruros no es influenciada por presencia de carbonatación. La permeabilidad del hormigón es influenciada por el uso de puzolanas naturales como material cementicio suplementario y diferentes cantidades de agregado. El uso de puzolanas naturales reduce la permeabilidad al aire y a los iones cloruro en un 84 y 66% respectivamente, pero incrementa la absorción capilar más de dos veces. Se demuestra que la zona de interfase agregado-pasta (dependiente del contenido de agregado) tiene una importante influencia en la permeabilidad. Un incremento en el contenido de agregado en volumen de 0.64 a 0.69 y de 0.69 a 0.75 incrementa la permeabilidad al aire en un 35 y 91% respectivamente.



**Palabras claves:** durabilidad, permeabilidad, corrosión, puzolanas naturales, interfase

## ABSTRACT

Reinforced concrete structure being durable can make a contribution in sustainability, avoiding the waste of resources unnecessarily. Corrosion of steel bars embedded in concrete is of great concern and imply the ingress of different components to induce it. This makes permeability of cover the property of interest and a whole understanding of it is necessary. To understand the performance of concrete structures in terms of it durability compressive strength, air permeability, sorptivity, chloride ion permeability, carbonation depth, chloride ingress and potential of corrosion were measured. It is noticed that structures considered as new do not have a better performance than old ones. Also, a good damage assessment needs comparing different measurements but compressive strength is not related to it. It is demonstrated that sorptivity and chloride ion permeability results are not influenced by carbonation. Permeability of concrete is influenced by use of natural pozzolans as supplementary cementitious materials and different amount of aggregates. Use of natural pozzolans reduces air and chloride ion permeability by 84 and 66% respectively but increase sorptivity rate more than two times. The interfacial-transition-zone (dependent of the aggregate content) is probed to have an important influence in permeability. An increase in the aggregate content by volume from 0.64 to 0.69 and from 0.69 to 0.75 increases the air permeability in 35 and 91% respectively.

**Keywords:** durability, permeability, corrosion, natural pozzolans, ITZ

# 1. INTRODUCTION

## 1.1. Reinforced concrete durability context and relevance

One of the most important challenges in construction nowadays is sustainability. Construction industry consumes high amounts of materials and energy sources and has an important impact in environment: the extraction of fine and coarse aggregate implies to modify the conditions of a hill or a bank of river. Clinker production, the main cement component, is one of the biggest sources of carbon dioxide emissions (Mehta & Monteiro, 2006), producing a tone of carbon dioxide per ton of clinker and its production requires high levels of energy (1700 Jules per gram of clinker). This is not friendly with the environment; therefore, something must be done in order to attenuate the negative impacts.

Durability of materials is another concern of construction industry. The lack of durability of construction materials implies structures will not have the design performance along its service life, needing more maintenance and rehabilitation, as shown in Figure 1.

However, it is not clear how structures need to be specified to be durable. For instance, over-specification is both wasteful of resources and unfair to the client while under-specification leads to premature and costly repair work (Richardson, 2004), and none of the alternatives are sustainable. Further, materials deterioration can make a structure not able to resist structural solicitations during its service life which is also pose as a sustainability concern. Thus, durability of materials, especially reinforced concrete durability has acquired a main role nowadays as way to get a sustainable concrete construction; however, specifications for durable concrete are still a challenge.

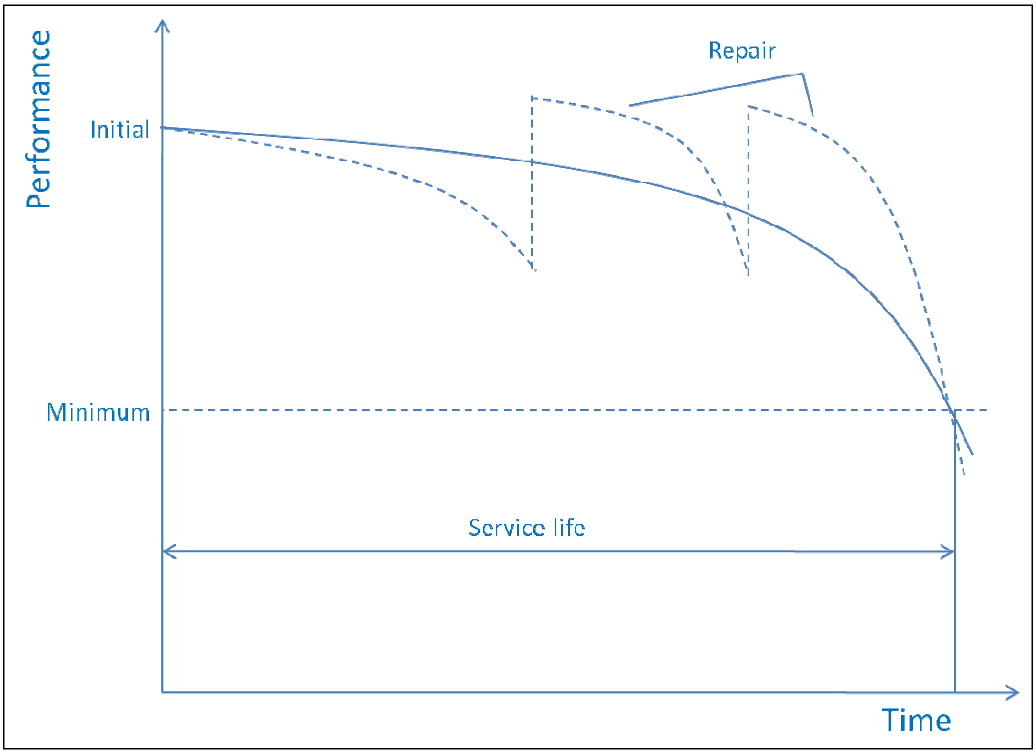


Figure 1: Relationship between concrete performance and service life (CEB, 1997)

Richardson (2004) proposed that the main challenge for concrete professionals in XXI century is specification and achievement of durable concrete. The infrastructure investment as well as conservation and reposition cost could be decreased if infrastructure would have an acceptable performance during its lifetime, but it is not always the case.

As regards to durability of concrete, reinforced concrete corrosion is now the greatest cause of different infrastructure and building durability failures around the world (Richardson, 2004), therefore requires special attention. Long-term studies showing chlorides penetration and corrosion of steel bars in concrete are rarely found (Uddin Mohammed, Hamada, & Yamaji, 2004); and it is lower in concrete with blended cement with high content of natural pozzolans (most used in Chilean construction industry).

Also environmental conditions do not follow a steady regimen; hence, it is even more difficult to improve concrete structures performance affected by the environmental conditions by just improving materials characteristics (CEB, 1997) and considering a steady regimen as test method does. However, the understanding of deterioration processes and its parameters involved is needed to relate different factors affecting durability.

A whole understanding of factors affecting durability and relations between them is shown in the Comite Euro-International Du Beton (1997). In this scheme, durability is linked with performance and all parameters affecting each one are listed.

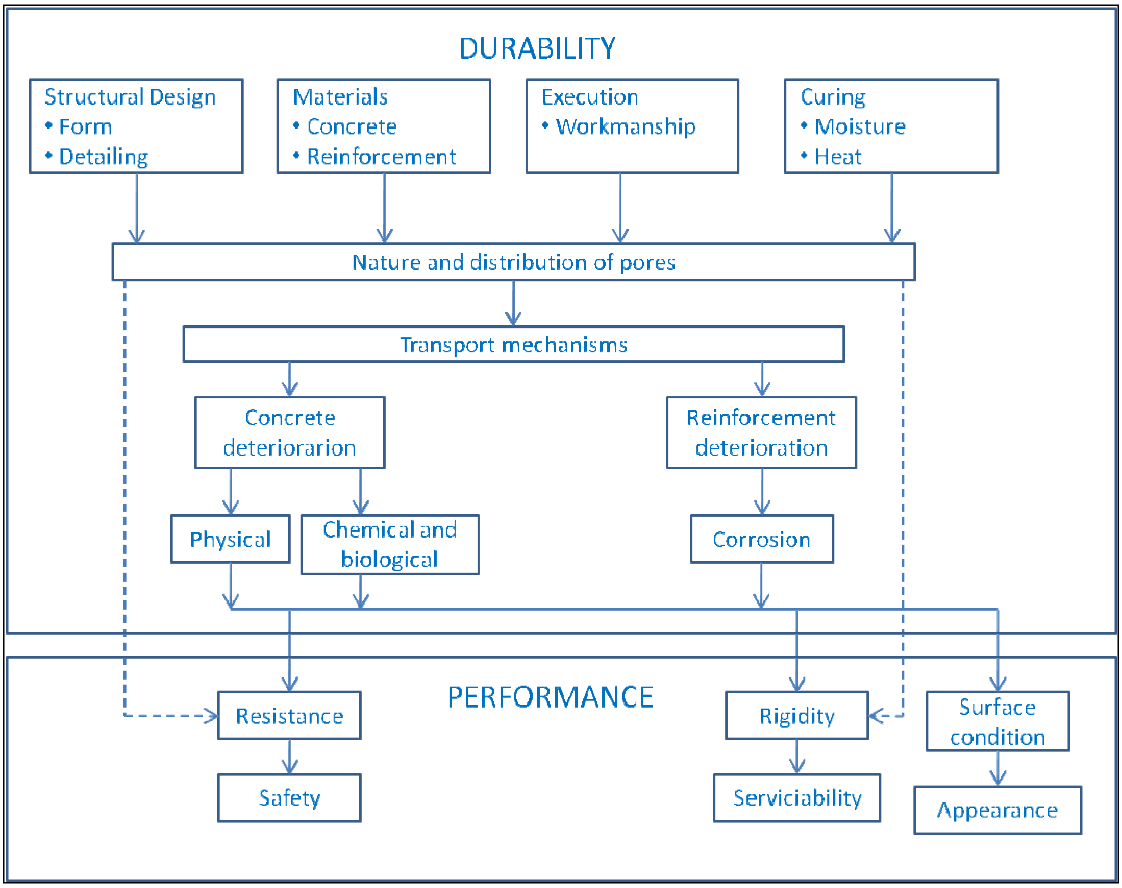


Figure 2: Relationship between durability and performance (CEB, 1997)

The first step to understand the structure durability is analyzing the steps involving its construction, since the structural design and materials selection and the execution in field and curing treatment applied. Above determine pore structure and it distribution and this in turn will explains transport mechanisms present during the structure service life. As each deterioration process implies the ingress of agents, the transport mechanisms will determine the ease of deterioration development.

Finally, structural performance is dependent by mechanical properties like concrete resistance and rigidity and reductions on these compromise the safety and serviceability.

Therefore, long term studies are still necessary and environmental effects should be considered to understand different scenarios and processes of deterioration related to durability of concrete.

Some of the most important pathologies in reinforced concrete are alkali-silica reaction, freeze/thaw cycles, sulfate attack, carbonation, chloride ingress, and corrosion of reinforcement.

Since corrosion of reinforcement is a deterioration process affecting the steel bars and it can be induced by carbonation and/or chloride ingress, it will be considerate in a separate section.

## 1.2. Concrete Pathologies

### 1.2.1. Alkali-silica reaction

Although aggregates in concretes are considered to be inert, under certain conditions siliceous components in aggregates react with sodium and potassium hydroxides in the alkaline pore solution of concrete, forming a gel that can expand upon wetting increasing pressure due the expansion of hardened concrete (Richardson, 2004). Such pressure may crack the concrete if tensile strength is exceeded.

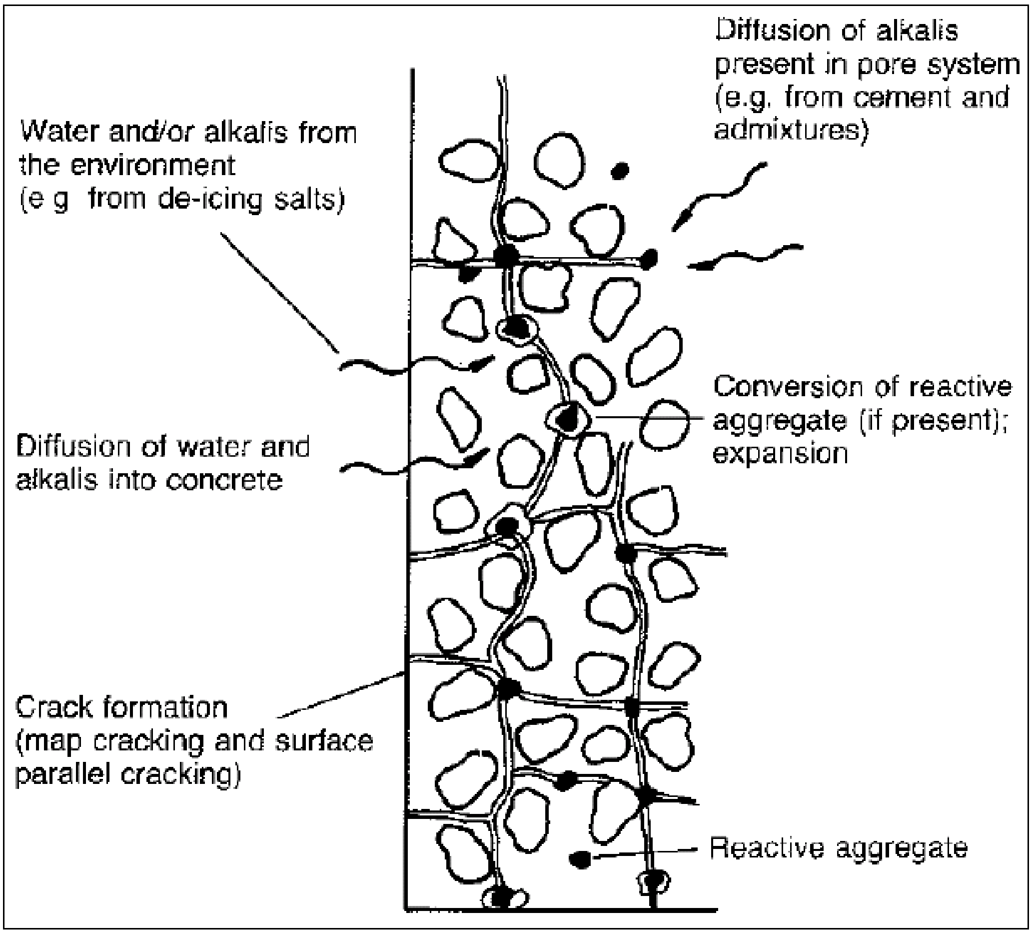


Figure 3: Effect of Alkali-Silica reaction (CEB, 1997)

### 1.2.2. Freeze/thaws cycles

In solid state, water occupies a volume 9% greater than liquid water. So, if water in concrete pores froze an expansion will occur that will generate internal pressures. Cracks may form which fill of water upon thawing, allowing new expansion and further cracking upon the next freeze cycle.

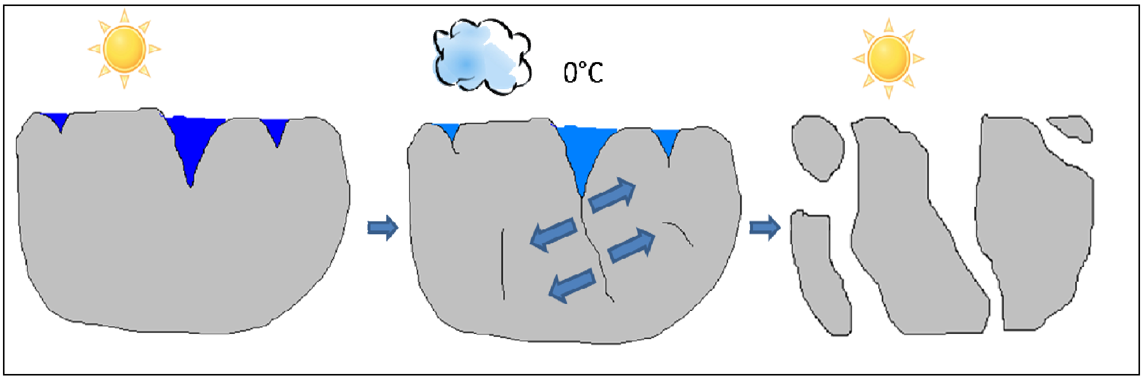


Figure 4: Freeze/thaw effect (CEB, 1997)

### 1.2.3. Sulfate attack

Sulfate attack is characterized by the chemical reaction of sulfate ions with the aluminates components of cement, forming mainly ettringite and to a lesser extent gypsum. The resulting compounds cause expansion of concrete, leading to cracking with an irregular pattern (CEB, 1997).

All previous pathologies imply cracking, so they will facilitate the further ingress (access) of damaging agents.

## 1.3. Reinforcement Corrosion

Corrosion of metals is an electrochemical process whereby a metal undergoes a reaction with oxygen and moisture in the environment to form a compound. Mehta & Montero (2006) consider that corrosion cells may be generated by having two dissimilar metals embedded in concrete, when exits significant variations in surface of the steel or when appears differences in concentration of dissolved ions, such as alkalis and chlorides, in the vicinity of the reinforcement.

Concrete possesses high pH (between 12 and 13) due to the calcium hydroxides form upon hydration of cement present in the pore liquid phase. Reinforcement begin to corrode in fresh concrete through a reaction between iron andwater, forming corrosion products consisting of $Fe_2O_3$ or $Fe_3O_4$ which prevents the dispersal of ferrous ions and is a conductor of electricity (Richardson, 2004). This corrosion products forms a layer on the surface of the reinforcement and became it in a "passive" state. This "passive" state prevents corrosion by avoiding contact between steel bars and oxygen and moisture. The passive film may be broken down in time through carbonation or chloride ingress reaching the steel (Richardson, 2004), enabling chemical reactions to produce corrosion.

When the passive layer is broken down, corrosion occurs in the voids that contains water by reactions of ferrous ions (from anodic reaction) with hydroxide ions (from cathodic reaction), producing ferrous hydroxide which will react with oxygen and water again to produce ferric hydroxide (El-Reedy, 2008). Chemical reactions are shown next.

$$Fe \rightarrow Fe^{2+} + 2e^-$$

$$2e^- + H_2O + ½\ O2 \rightarrow 2OH^-$$

$$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$$

$$4Fe(OH_2) + O_2 + 2H_2O \rightarrow 4Fe(OH)_3$$

$$2Fe(OH)_3 \rightarrow Fe_2O_3.H_2O + 2H_2O$$

Iron hydroxides react with oxygen and water molecules forming oxides with lower density, occupying more volume. As it was seen in other concrete pathologies, this increase of volume creates pressures exceeding tensile strength, which generates cracking and delamination in concrete surface.

Figure 5: Reinforced concrete column showing delamination due reinforcement corrosion

Corrosion occurs if concrete's moisture is high enough to act as an electrolyte and the concrete cover has to be permeable to allow the ingress of oxygen and elements that may destroy the passive film on the reinforcement, i.e. carbon dioxide and/or chlorides. Hence, it is of interest to understand how carbonation and chloride ingress allow the occurrence of corrosion.

### 1.3.1. Carbonation

Carbonation is a chemical reaction between carbon dioxide ($CO_2$) present in air with calcium hydroxide ($Ca(OH)_2$) present in the hydrated cement paste. $Ca(OH)_2$ gives the alkaline nature to concrete, having a pH between 12 and 13. The reaction occurs in presence of moisture and involves the production of calcium carbonate ($CaCO_3$), decreasing the surrounding pore fluid pH at 8-9 (Richardson, 2004).

The high pH of concrete without carbonation creates the passivation of steel; therefore reinforcement corrosion will not start in this state. However, when pH drops, reinforcement is vulnerable to corrosion.

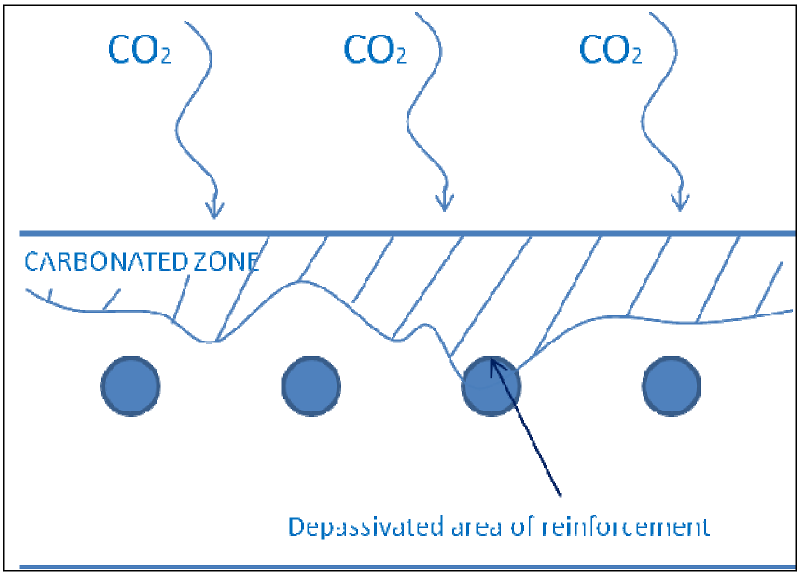


Figure 6: Carbonated front in concrete (Richardson, 2004)

Carbonation rate depends on the diffusivity and permeability of concrete; if concrete is more permeable $CO_2$ diffuse easily. However, as calcium hydroxide ($Ca(OH)_2$) reacts with $CO_2$ forming calcium carbonate ($CaCO_3$), which has greater volume, porosity of carbonated concrete is reduced (Neville, 2000) affecting permeability of concrete.

$$Ca(OH)_2 + CO_2 \rightarrow Ca^{2+} + 2OH^-$$
$$Ca^{2+} + 2OH^- + CO_2 \rightarrow CaCO_3 + H_2O$$

Further, as $CO_2$ reacts with $Ca(OH)_2$, the lower calcium hydroxide content, the less amount of $CO_2$ needed to remove the remaining $Ca(OH)_2$ to produce $CaCO_3$ (Neville, 2000; Richardson, 2004). In this context, blended cements are more susceptible to carbonation and so do concretes with low cement contents.

Additionally, calcium carbonate and hydrated silica can be formed when carbon dioxide is combined with calcium oxide (CaO) present in un-hydrated and calcium silicate hydrate.

$$3CaO.SiO_2 + 3CO_2 + yH_2O \rightarrow SiO2.yH_2O + 3CaCO_3$$
$$2CaO.SiO_2 + 2CO_2 + yH_2O \rightarrow SiO2.yH_2O + 2CaCO_3$$

Also, there are many mathematical models to predict the rate of carbonation, accepting that the square root of time provides a good basis. The square root of time relationship is stated as follow:

$$x = k\sqrt{t},$$

where x = depth of carbonation, t = time and a factor "k". Sophisticated models improve the factor "k", establishing that is dependent of the water-to-cement ratio, diffusivity carbon dioxide concentration, exposure conditions, among others.

### 1.3.2. Chloride ingress

The passivity of reinforcement depends on the stability of the alkaline nature of the concrete. An excessive level of chlorides makes the protection afforded by the passive layer around the steel bars ineffective. When critical level is exceeded, chloride induced corrosion may occur (Richardson, 2004) in a small area affected acting as the anode.

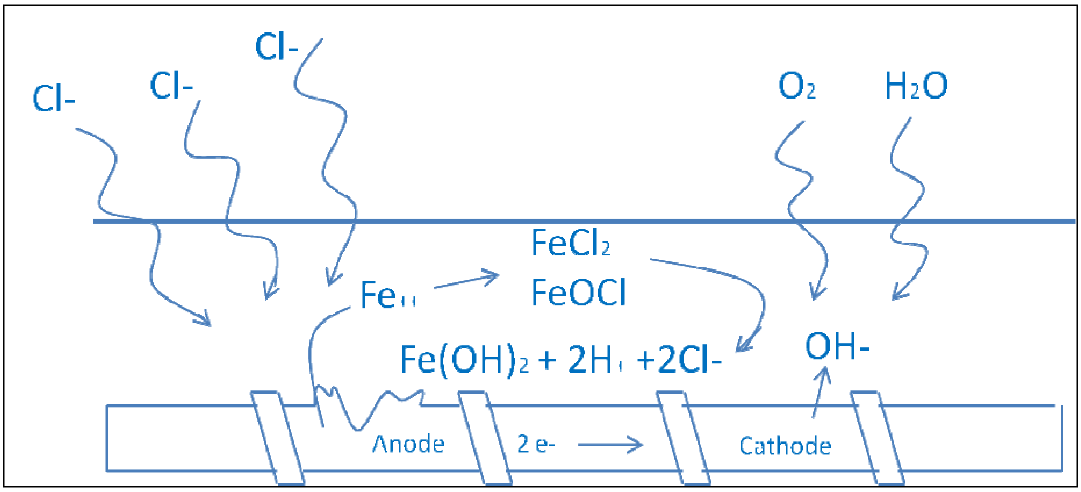


Figure 7: Corrosion in chloride environment

Chemical reaction goes as follow:

$$2Fe \rightarrow 2Fe^{2+} + 4e^{-}$$

$$2Fe^{2+} + 4Cl^{-} \rightarrow 2FeCl_2$$

$$2FeCl_2 + 4H_2O \rightarrow 2Fe(OH)_2 + 4H^{+} + 4Cl^{-}$$

$$2FeOCl + 2H_2O \rightarrow 2Fe(OH)_2 + 2Cl^{-}$$

There are model to predict the chloride ingress too, they are governed by Fick´s second law of diffusion.

Both, carbonation and chlorides ingress facilitates corrosion and are dependent of the ease at which carbon dioxide and chlorides penetrates concrete.

In this context, as occurrence of corrosion implies ingress of different elements at the level of reinforcement, permeability is of great concern. Concrete cover needs to be impermeable enough to avoid the ingress of these elements, and thick enough to prevent reaching the reinforcement at early ages. Moreover, cement content, cement type and environment are of consideration to facilitate or delay reinforcement corrosion.

### 1.4. Factors controlling durability

From above, chemical and physical processes affecting durability of concrete depend on the transport of elements that enable that processes (if they are not in concrete). For the case of corrosion, what is matter of interest in this research, the elements involved are oxygen, water, carbon dioxide and chlorides.
The rate at which particles and fluids pass through the concrete depends mainly on the permeability of concrete (Carcasses & Ollivier, 1999; Mehta & Monteiro, 2006). Permeability depends on many factors such as pore structure and its connectivity, transport mechanisms, environmental aggressiveness among others (Neville, 2000).

#### 1.4.1. Pore structure

The water filled spaces in fresh concrete become filled by hydration products forming a gel with greater bulk volume than unhydrated cement grains (Richardson, 2004) that makes hardenedconcrete more impermeable. The different spaces created between crystals of hydrated products are the pore structure, and it is classified depending on its pore radius range. Richardson (2004) and CEB (1997) classified the pores as gel pores (or micropores) if its diameter is between 1 and 8nm, in capillary pores between 0.01 and 5µm and air voids in a range from 100µm (entrained air) to 2mm (entrapped air).

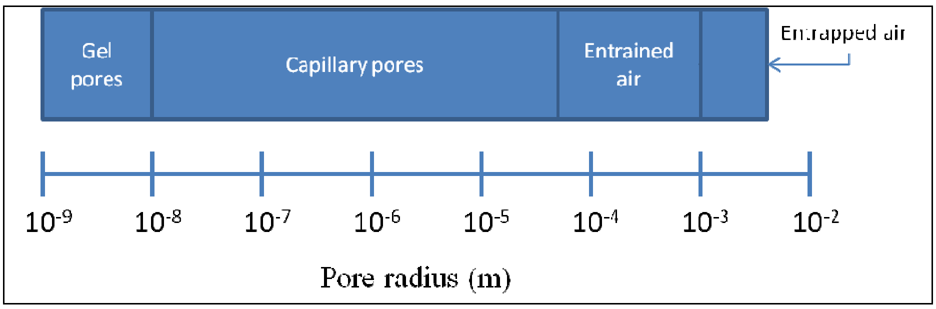


Figure 8: Pore types (Richardson, 2004)

Even though the size pores is relevant, its distribution also has great influence. If a concrete "A" has more volume of gel pores than capillary pores compared with a concrete "B", concrete "A" should be less impermeable (assuming that all other factors remain constant).Hence, the pore network of the bulk paste, as well as the interface between aggregate and cement paste, are matter of concern. Pore network means that pores are connected; the more connected and less tortuous they are, high levels of permeability will be obtained.

### 1.4.2. Permeability

The permeability of concrete is influenced by permeability of the cement paste, especially the quality of paste in cover concrete structures and at the interface with aggregate particles (Richardson, 2004).

If concrete is considered as a material with different phases, its permeability will be influenced by permeability of each phase. In a three-phase model, the phases involved are: cement paste, aggregates and interfacial transition zone (ITZ) (Mehta & Monteiro, 2006; Carcasses & Ollivier, 1999).

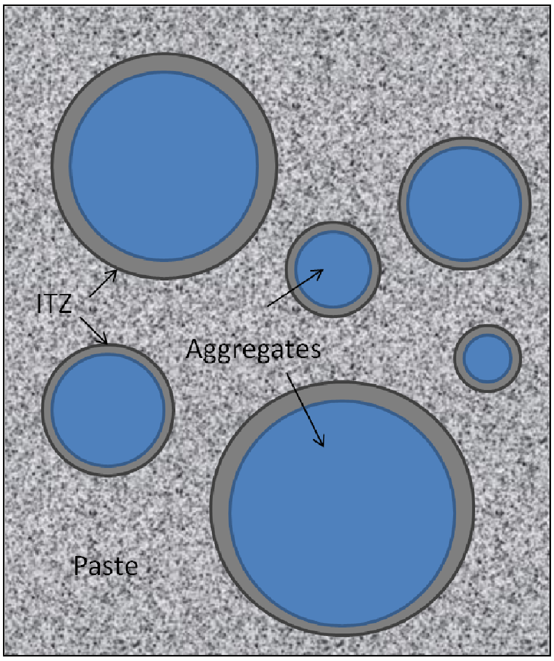


Figure 9: ITZ representation

Permeability of hardened cement paste is mainly dependent on water-to-binder ratio (w/b). As w/b is the main factor influencing mechanical properties such as compressive strength, many people specify compressive strength to ensure durability, which is a big mistake (Mehta & Monteiro, 2006; Neville, 2000).

High w/b produce a high capillary porosity, due to weak and less dense chemical bonds in the hydration process. Mixing water is indirectly responsible for this (Mehta & Monteiro, 2006), since it determines total and unfilled space in the cement paste microstructure after water has been consumed either by cement hydration or by evaporation, resulting in large and well-connected capillary pores when too much water is added. In theory, all capillary voids could be filled with a w/b low enough (Richardson, 2004); however, in practice this is rarely achieved because full hydration is not possible.

With respect to aggregates, its permeability depends on their own characteristics; for example, for porous and permeable aggregates, hydration products can penetrate external pores decreasing permeability to that of cement paste or ITZ. For non-porous aggregates the tortuosity (as many paths that are generated by including an aggregate) of the pore structure increases importantly decreasing intrinsic permeability to values lower than that of cement paste or ITZ (Carcasses & Ollivier, 1999).

If aggregates are considered as impermeable (at least with very low permeability), it can be assumed that more aggregate present in concrete will decrease permeability. Nevertheless, permeability does not decrease because cement paste located at the aggregate surface (ITZ) is more porous, permeable, and weaker compared to bulk cement paste. Therefore, an increase in the aggregate content increases this detrimental effect of the ITZ. One of the reasons of ITZ being weaker is that a thin water film is formed around large aggregate particles increasing w/b locally (Mehta & Monteiro, 2006). ITZ is addressed deeper in Chapter 3.2

Besides w/b, curing and consolidation has an influence in permeability of concrete (CEB, 1997). An adequate curing process decrease permeability of concrete surface by providing better hydration in the zone exposed to environmental condition, reducing the porosity and pore connectivity.

### 1.4.3. Transport mechanisms

The main transport mechanisms in concrete are: gas and water diffusion, ionic diffusion, absorption and liquid flow under pressure (Richardson, 2004).

When transport of gas trough concrete is result of a concentration gradient rather than pressure differences, the transport mechanisms would be diffusion (Neville, 2000); molecules move from areas of high concentration to areas of low concentration. Diffusing molecules move randomly and independently from each other, having constant collisions (Richardson, 2004) what makes that only a fraction of those molecules cross a given section.

The ionic diffusion, as that present in sulfates and chlorides, follows a similar pattern to gas diffusion, but in addition to a concentration gradient, saturated conditions are needed.

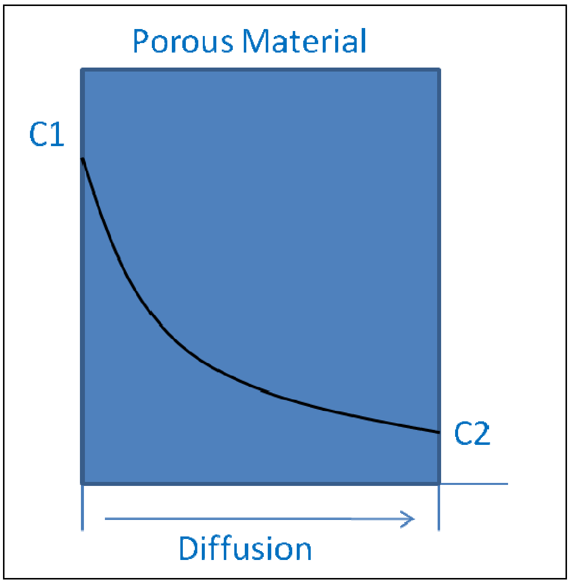


Figure 10: Diffusion principle

Absorption is referred to the ingress of a fluid into the spaces within the concrete by capillary action (Neville, 2000; Richardson, 2004), because is related to the pore structure and not necessarily depends on permeability. This transport mechanism takes place when the concrete surface is affected by rain or splash water and is partially unsaturated.

Finally, the liquid flow under pressure appears when an element is under a hydrostatic head produced by a column of water, for example. Saturation is not needed for it existence but will have great importance if the element is saturated.

In un-immersed structures, gas diffusion takes place predominantly. If rain starts, capillary pores will catch water particles by absorption, making more dificult the gas diffusion. This will continue until concrete surface get saturated with water, where water and ionic diffusion may take place. If the structure, or part of it, is immersed, the liquid flow under pressure will dominate.

### 1.4.4. Environmental aggressiveness

Agents involved in any concrete pathology are immersed in the environment surrounding the structure, and its concentration will determine the risk of triggering a deterioration process. Also the structure can be exposed to the environment at different levels, such as mild, moderate and severe. Different categories for environmental pollution and potential to develop corrosion of atmospheres are given in ISO 9223.

To estimate the durability risk and to incorporate it at the design stage, an evaluation guide for a given structure in a given environment was developed. According to Comite Euro – International Du Beton (CEB, 1997) the factors that have dominant influence in determining the aggressiveness of a particular environment are the presence of aggressive substances in moisture, moisture and temperature.

As was mentioned in Chapter 1.2, some substances causing deterioration process are oxygen, carbon dioxide, chlorides, sulphates, alkalis, among others. The higher concentration of any of these agents, at a same level of relative humidity and temperature, the higher is the risk of start a deterioration process or make it more severe.

Water is present in all deterioration processes and it is found in moisture (in un-immersed structures) and can be measured by the relative humidity. Richardson (2004) state that rate of carbonation is highest in the range of 50 to 75 percent of relative humidity (RH). For reinforcement corrosion concrete moisture is more important than moisture in the environment; 80 percent of RH is critical, below this level there is insufficient water and over it, is saturated; therefore no oxygen is present to react.

Finally, as deterioration processes involve chemical reactions, they will be accelerated by increasing the temperature. Hence, average temperatures and variations of it will determine the ease at which the chemical reactions are produced.

## 1.5. Supplementary cementitious materials

A review through the most relevant issues involved in durability of concrete has been made, now is time to make an approach of how improve it.

One way to obtain a more durable concrete is using supplementary cementitious materials (SCM). This occurs because SCM particles are finer than Portland cement, improving the particle packing and with an adequate good curing, SCM reduce permeability of concrete (Neville, 2000), improving its durability.

The use of SCM improves durability of concrete, providing additional benefits such as improvement in workability, reduction of the heat of hydration, reduction in permeability, increase in ultimate strength, increase in resistance to sulphate attack and reduction in alkali-silica expansion (Rodríguez-Camacho & Uribe-Afif, 2002; Uzal & Turanli, 2003; Papadakis & Tsimas, 2002).

A method that helps to reduce the impact of cement industry on energy and carbon-dioxide emissions is to produce blended Portland cements containing less than 95 percent Portland clinker (Mehta & Monteiro, 2006), giving another path to get a sustainable concrete construction. Also, among the SCM, natural pozzolans have gain more attention because they might be widely available. Some clays and volcanic ashes and do not depend on the presence of other industries such as silica fume, fly ash and ground granulated blast furnace slag.

As any other SCM with high $SiO_2$ contents, natural pozzolans react with calcium hydroxide produced by the hydrating Portland cement, forming new calcium silica hydrates (C-S-H) (Neville, 2000), having a great impact in concrete performance (CEB, 1997) by improving concrete mechanical properties, such as compressive strength and concrete physical properties such as permeability.

### 1.6. Context in Chile

Why is all of this relevant to Chile? According to Infrastructure Committee Report, Chile (2010), infrastructure deficit reaches USD 22,700 million, while infrastructure investment is USD 24,100 million and the minimum conservation and reposition cost is about USD 723 million. In this context, there is a significant amount of money that could be invested in other projects with national interest, being durability of concrete one way to make a contribution in this but durability specification have an outstanding debt.

Blended cement (OPC with natural pozzolans) is the most used cement in Chile. Its production and internal consumption are growing up. According to Minería Chilena (2006) cement local production arise 4.7 million tons, representing a per capita consumption of 274 kilograms of cement. It has increased because the Chilean economy have had a sustained growth and natural events, like the earthquake on February of 2010, has triggered an explosive cement demand due to reconstruction needs.

Also, this growth in cement production means an increase in carbon dioxide emissions. This may become another problem of national interest, unless appropriate measures are applied, which gives another plus to durability concerns.

All of this implies that construction of durable structures needs to be done to avoid future maintenance and reconstruction due bad performance among structure service life.

# 2. RESEARCH CONTEXT

## 2.1. Hypothesis

The hypotheses of this research are:

- Permeability, porosity, and chemical composition of concrete using blended cements (OPC + natural pozzolans) have an adequate performance in terms of it durability, independently of the environmental conditions of exposure.
- An adequate design of the concrete mixture (constituent's material selection and their proportion) determines its permeability, and the use of natural pozzolans are as important as amount of ITZ in controlling permeability.

## 2.2. Objectives

According to the first hypothesis, the main objective is characterizing the structures in terms of it durability. The specific objectives are:

(1) Evaluate the most appropriate test(s) to evaluate durability of reinforced concrete.

(2) To determine the effect of carbonation in permeability of concrete.

It is considered a specific objective to determine the most appropriate test(s) to evaluate durability of reinforced concrete.

For the second hypothesis the main objective is to establish a relationship between concretes design parameters explaining it permeability. The specific objectives are:

(1) To determine the effect in sorptivity (capillary absorption), air permeability and chloride ion permeability.

(2) To determine the amount of ITZ, by estimating the aggregate surface, that minimizes the values of sorptivity, air permeability and chloride ion permeability.

(3) To establish if using natural pozzolans is more important than the amount of ITZ to decrease the values of sorptivity, air permeability and chloride ion permeability.

### 2.3. Experimental methodology

In order to reach the best understanding of the performance of concrete made with blended cement (OPC + natural pozzolans), in Chile, three complementary approaches were considered:

The first approach consisted of evaluating different structures in terms of its mechanical properties, permeability and deterioration. This was applied to eight structures in two different environments: urban (characterized by high CO2 concentrations), and marine (characterized by high chloride contents). In each environment, a structure ranging between 5 to 50 years in age was considered.. The structures selected are shown in Table 1.

Table 1: Selected structures

| | Urban Environment | Marine Environment |
|---|---|---|
| Young structures (5 – 15 years old) | • Education Faculty, PUC<br>• History and Geography, PUC | • Sports center, UV<br>• Architectural Faculty, UV |
| Old structures (20 – 50 years old) | • Mechanical Engineering Department PUC<br>• Electrical Engineering Department PUC | • Retaining wall, España Avenue, Valparaíso<br>• Velodrome ChileDeportes, Valparaíso |

Unfortunately, there was not enough information on the projects (specifications) and results from quality control available; therefore, the second step was to evaluate their mechanical properties, permeability, and deterioration.

The second approach consisted of building four concrete walls , two in Santiago and two in Valparaíso, using water to binder ratio (w/b) of 0.6 and 0.4 and with cement content of 270 kg/m$^3$ a 400 kg/m$^3$ respectively to each w/b; which correspond to the minimum and a relatively high cement content allowed in Chile. Also, steel reinforcement was disposed having three different covers: 1.5, 2.5 and 5 cm, to determine cover effectiveness in each environment. The steel bars used were 18 mm in diameter.

The objective is to perform a long-term monitoring (app 40 years) in order to determine the environmental aggressiveness and its effect in mechanical properties, permeability and deterioration processes. So far, only results at 28 and 90 days have been taken.

These two approaches were part of FONDEF project D07i1076 called "Definition and Implementation of a Durability Specification System for Reinforced Concrete Structures". Only part of the results from structures tests and walls built are analyzed because the whole analysis is protected as results of FONDEF project D07i1076. Results are summarized in Appendix 1 and 2 respectively.

Finally, the third approach consisted on conducting research aimed to understand the effect of the use of natural pozzolans as SCM, and the amount of ITZ present in permeability of concrete.. It is generally accepted that permeability of concrete decreases when using natural pozzolans; however, the effect of ITZ it is not clearly understood yet.

The experimental methodology is summarized in Figure 11.

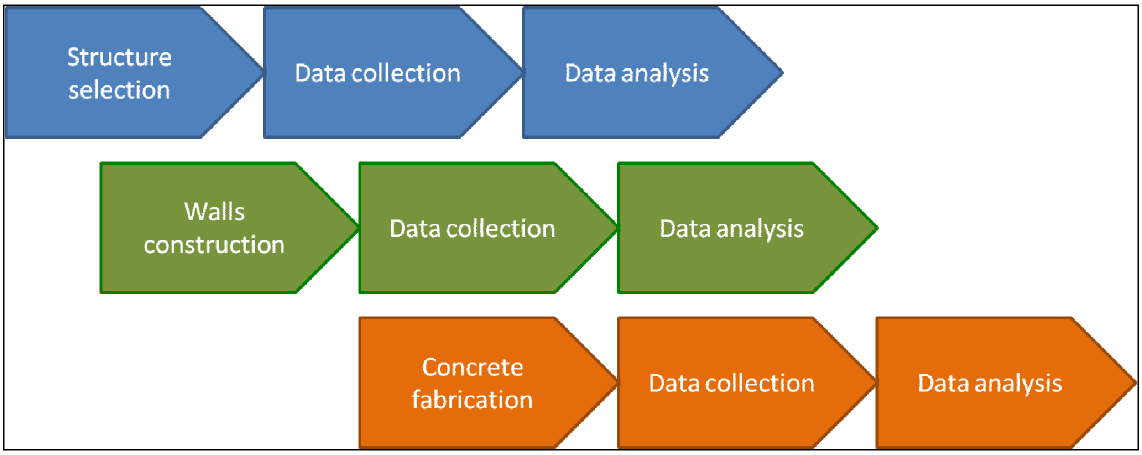


Figure 11: Experimental methodology

# 3. PERFORMANCE EVALUATION OF EXISTING STRUCTURES

## 3.1. Structures selection

The concrete specimens used were structural elements (columns, beams and walls) of structures located in two cities of Chile: Santiago, with yearly averages temperatures and relative humidity rates of 16.8°C and 61.2 respectively (Troconis et al., 2009) and Valparaíso, a coastal location where the chosen elements where at 600m or less from the sea, under yearly averages temperatures and relative humidity rates of 14.8°C and 82% respectively (Wikipedia, 2008). These cities were selected because they represent: a zone with a high concentration of $CO_2$, expecting corrosion induced by carbonation, and a zone severally affected by chlorides.

Considering that a specific aggressive environment have different effects in the deterioration processes depending on the exposure period, the selected structures were classified in two ranges: “young” structures (YS), between 5 and 15 years of age and “old” structures (OS), between 20 and 50 years of age. A total of eight structures were selected, four under urban conditions and four under marine conditions with two YS and two OS in each case. This also allowed for studying the effect of the age of construction, considering that nowadays less cement is used compared to that in the past (Neville, 2001)..

In each structure, west and south fronts were tested, representing the worst scenarios of environment exposure, compared to north and east face. The west face was selected because it has a wet and dry cycle during the day; it was wet in the morning due to morning frost and shadow, and dry from noon to sunset because of the sun path. Additionally, in marine environments, the west front faces the wind and so high exposure to chlorides. In the other hand, the south face in chile is usualy moist because sun never hits it.

### 3.2. Reinforced concrete structures characterization

In the context of FONDEF project D07i1076, in each structural element, sixteen concrete cores were extracted according to NCh 1171/1.

The different tests were separated in three categories in terms of the property measured.

Table 2: Methods of assessment used

| *Physical and mechanical properties assessment* | *Durability assessment* | *Damage assessment* |
|---|---|---|
| • Compressive Strength | • Air permeability | • Carbonation depth |
| • Splitting tensile strength | • Chloride permeability | • Chloride penetration |
| • Esclerometric Index | • Sorptivity | • Chloride profile |
| • Ultrasonic pulse velocity | • Porosity | • Corrosion Potential |
| • Internal Humidity | • Initial Surface Absorption Test | • Corrosion Rate |
| • Rate of Hydration | | • Resistivity |

In Chapter 3.2 results shows compressive strength, carbonation depth, chlorides penetration depth, corrosion potential and rate of corrosion as a deterioration index; and air permeability, chloride ion permeability and sorptivity (capillary absorption) as durability index.

Only compressive strength was considered as mechanical property and it was measured on cores according to ASTM C39 / C39M - 10.

Carbonation depth was measured by applying phenolphthalein to concrete cores. The uncolored zone represents de zone affected by carbonation as is shown in Figure XX.

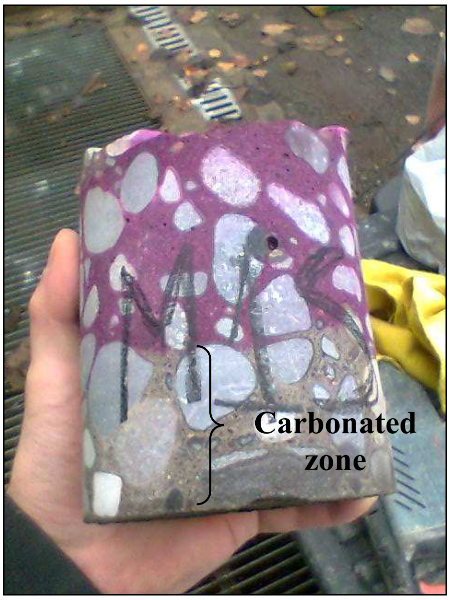


Figure 12: Concrete simple with phenolphthalein

Chlorides penetration depth was measured by applying silver nitrate at 0.1N (Otsuki, Nagataki, & Nakashita, 1992) to one half of a concrete core obtained by from the spliting test.

Corrosion potential and rate of corrosion was measured using GeCor-8 equipment, which used the $Cu/CuSO_4$ electrode recommended by ASTM C876. The test consists of determining the potential difference between steel bars and the concrete surface in contact with the electrode. A reinforcement grid is made prior to apply the test and a map by testing potential corrosion in several points. Corrosion rate was tested in zones with great risk, detected by corrosion potential.

When an important section of the wall had high corrosion potentials the average result is shown, but when there are a few points with corrosion potentials of consideration, just those values are presented.


Figure 13: GeCor 8 equipment

Air permeability was measured on concrete cover at three heights, and six measures were taken at each height, according to SN EN 206-1, 2003 (Swiss standard).

The test method consists of estimating air permeability by applying a known vacuum and measuring the air influx from within concrete. Saturated or partially saturated pores will affect the air permeability; therefore, the results need to be corrected by moisture (Torrent). Moisture was estimated by measuring concrete electrical resistivity. Figures 14 and 15 shows the air permeability test principle, and equipment, espectively.

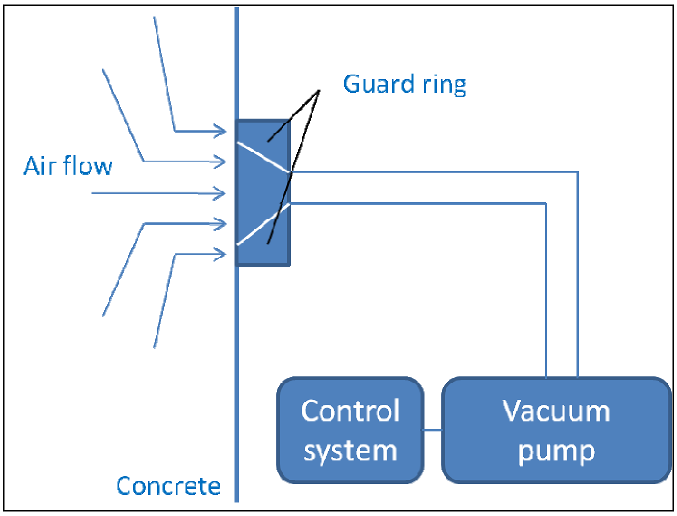


Figure 14: Air permeability testing principle

Figure 15: Permea-Torr equipment

Chloride ion permeability was measured on 100x50-mm cylinder samples according to ASTM C1202-05. In this test, an electrical potential of 60 V is maintained across the flat ends of the saw-cut cylinder (previously conditioned), during 6 hours. One end is immersed in a NaCl solution and the other end is immersed in a NaOH solution. Chloride ions travel across the specimens and the current is measured periodically. At the end of the test, the total charge passed, in coulombs, is calculated, and the permeability of concrete is obtained.

Sorpitivity was measured on 100 x 50-mm cylinder samples according to ASTM C1585-04. The test consists of measuring the change in mass over time of a concrete specimen, previously conditioned. One flat side of the specimen is in contact with water and a change of mass is produced by capillary absorption. Water loss is prevented by sealing the side and the top surface of the specimens. Figure 16 shows a schematic of the test.

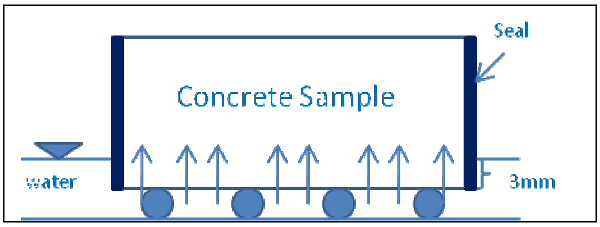


Figure 16: Sorptivity test

Data collected during the first 6 hours of the test corresponds to the "initial absorption" while that collected between 1 to 7 days correspond to the "secondary absorption". Results are plotted as the cumulative change in mass divided by the exposed area and density of water, versus the square root of time.

This method calculates the slope of the initial absorption and the secondary absorption, each one independently. As each stage represents different effects (i.e., capillary absorption for the initial and diffusion for the secondary), a unique coefficient is calculated from the intersection of the two slopes.

### 3.3. Compressive Strength

Compressive strength is the mechanical property most used to specify concrete structures.

Concrete used in the structural elements tested are within the range commonly used in Chilean construction industry, as shown in Figure 17.

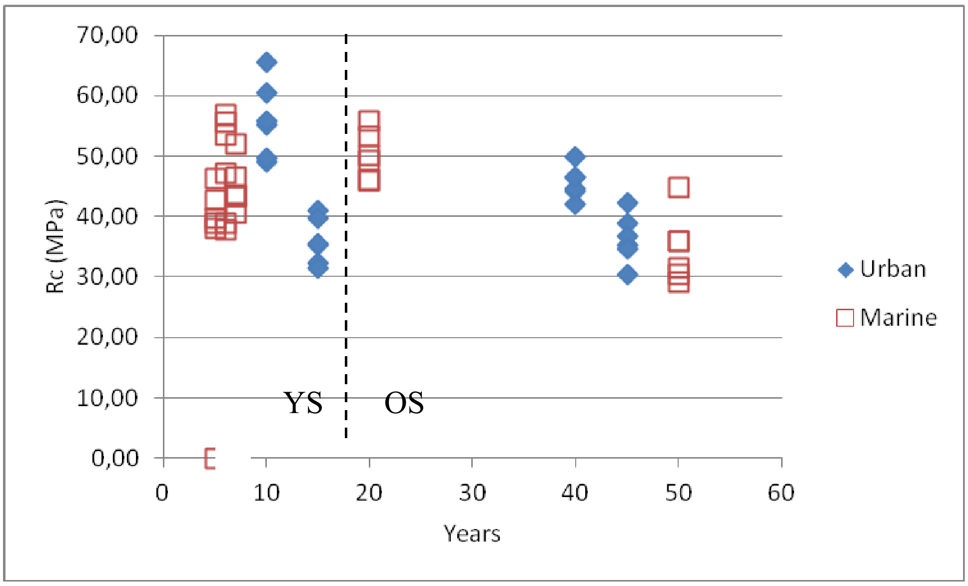


Figure 17: Structures compressive strength

According to these values, concrete structures should have a good performance in terms of it durability as was believed in the past (Neville, 2001).

### 3.4. Durability Assessment

Because it is not expected that concrete durability is assured just by a certain compressive strength, , other tests must be applied to get a whole understanding about the durability state of a structure.

From values shown in Figure 18 for air permeability, there are no significant differences at any age ranges and exposure conditions.

The above is attributable to high sensibility to cracks and micro-cracks presence (i.e. cracks from thermal strains, shrinkage strains) of the equipment used, even when the intention was avoid them. Therefore, it is not considered as a good index to evaluate structures, but can be adequate for testing concrete at early ages (see Chapter 3.2).

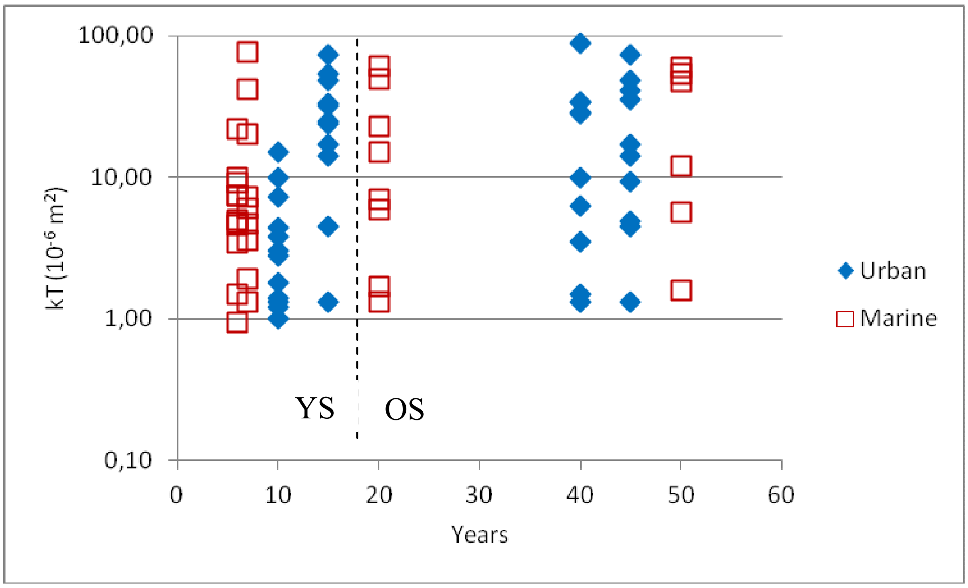


Figure 18: Air permeability (log scale) vs. years of exposure

Chloride ion permeability (see Figure 19), decreases with time reaching its minimum value over 20 years of age, becoming relatively constant, independently the conditions of exposure.

Although the rate of hydration plays an important role in explaining the decrease in permeability with time, other factors such as mixture design and exposure conditions might have an effect on the results.

According to the age, OS concretes have great performance in terms of its chloride ion permeability. These concretes have less amount of cement and are more finely graduated.

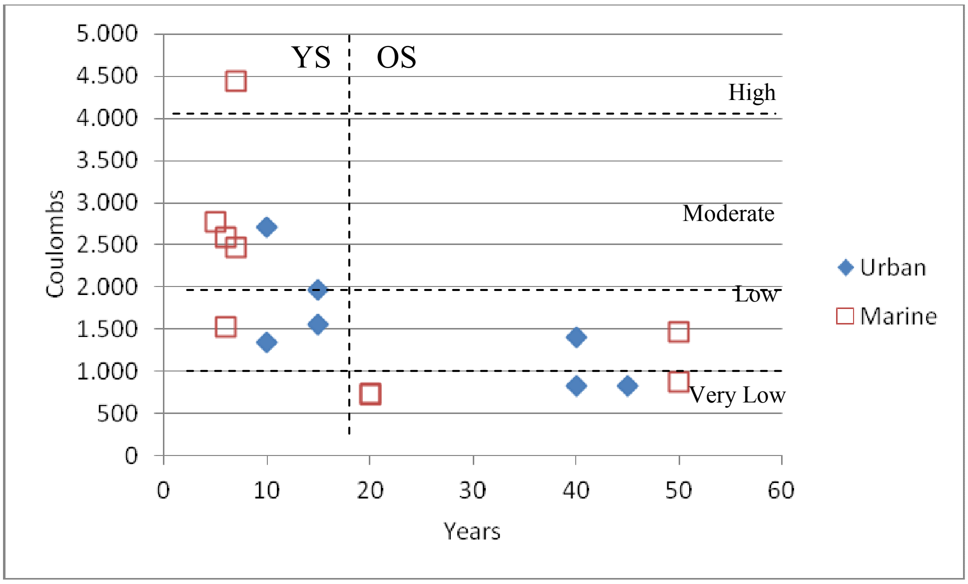


Figure 19: Chloride ion permeability vs. years of exposure

In terms of sorptivity values, they did not follow any appreciable pattern as Figure 20 shows. Capillary pores are of great concern in this test (Castro, Bentz, & Weiss, 2011) and since concrete surface condition varies from sample to sample (due different exposure conditions aggressiveness), results will not be comparable if they do not have a common surface treatment.

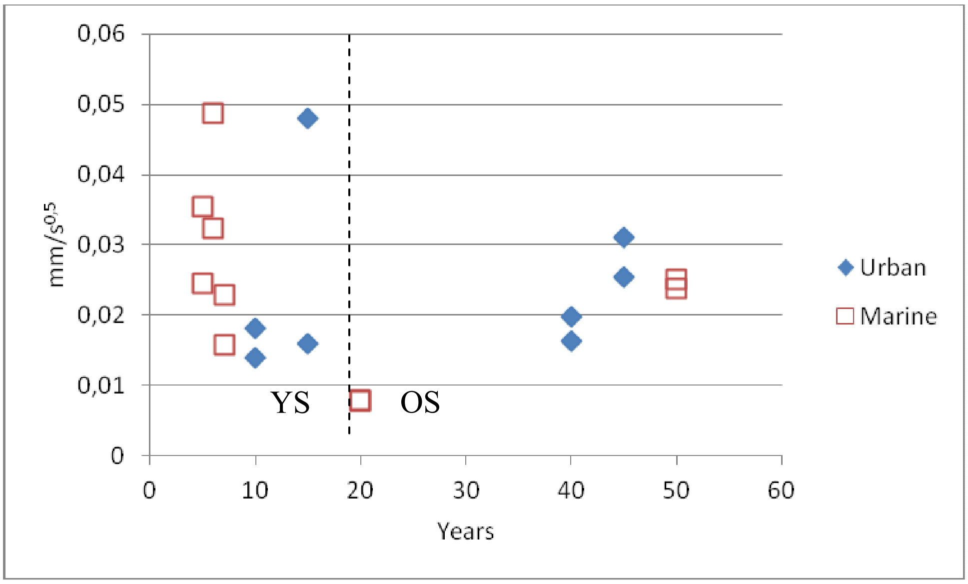


Figure 20: Sorptivity vs. years of exposure

### 3.5. Deterioration Assessment

An analysis of different concrete properties is necessary to establish the real corrosion risk of the structures, by measuring carbonation depth, chloride ingress depth, corrosion potential and rate of corrosion.

It is not enough to measure just the depth of carbonation or depth and chloride penetration because the time needed to reach that depth it is also of interest; therefore, the coefficient of diffusion should be measured. It is accepted that this coefficient depends on the square root of time and can be estimated using the following equation:

$$K = X\,(t_0)^{-0,5} \quad (mm/year^{0,5}) \qquad (1),$$

where X is the chloride penetration or carbonation depth and $t_0$ is the age in years.

The values obtained for this property are summarized in Table 3. The categories used to evaluate the results are shown in Appendix 3.

Table 3: Deterioration assessment results

| | Cl penetration coefficient (mm/year$^{0,5}$) | Carbonation coefficient (mm/year0,5) | Corrosion Potencial (mV) | Rate of corrosion (µA/cm$^2$) |
|---|---|---|---|---|
| Old structures | 7.45 | 4.21 | -239.9 | 0 |
| | 1.80 | 4.42 | -373.5 | 0.010 |
| | 2.00 | 4.55 | -27.9 | 0.000 |
| | 1.01 | 3.94 | -486.7 | 0.010 |
| | 3.42 | 3.08 | -244.5 | 0.001 |
| | 4.39 | 3.22 | -594.11 | 0.002 |
| | 3.32 | 3.39 | -256.1 | 0.170 |
| | 5.57 | 3.48 | -448 | 0.007 |
| Young structures | 7.41 | 5.31 | -575.5 | 0 |
| | 4.55 | 5.40 | -559.2 | 0 |
| | 3.99 | 3.48 | -28.3 | 0.017 |
| | 5.08 | 4.98 | -638.2 | 0.000 |
| | 8.84 | 7.45 | | 0.100 |
| | 6.67 | 6.87 | | 0.100 |
| | 9.01 | 6.50 | -658.55 | 0.545 |
| | 5.61 | 2.48 | 26.65 | 0.184 |

Results show very low values of corrosion potential, under -350mV, considered high risks of corrosion. Also, structures with these values of corrosion potential have high values of diffusion coefficient, and in some of them have reached the reinforcement. Even when these results make the possibility of corrosion occurrence more feasible, rate of corrosion shows very low values.

The rate of corrosion values presented confinement problems at the moment of the test; hence they are not considered. Therefore, high diffusion coefficients with corrosion potential values under -350mV are considered as relevant when a deterioration assessment is made.

Also the categorization of the structures in terms their age seems to affect the diffusion coefficient. This fact is related to the cement content and its composition used in different periods of time, and is further discussed in the Chapter 3.1.5.

Finally, from the corrosion potential maps, zones with values of consideration are detected at medium or low heights. Hence, it is relevant to ensure durability condition at these points.

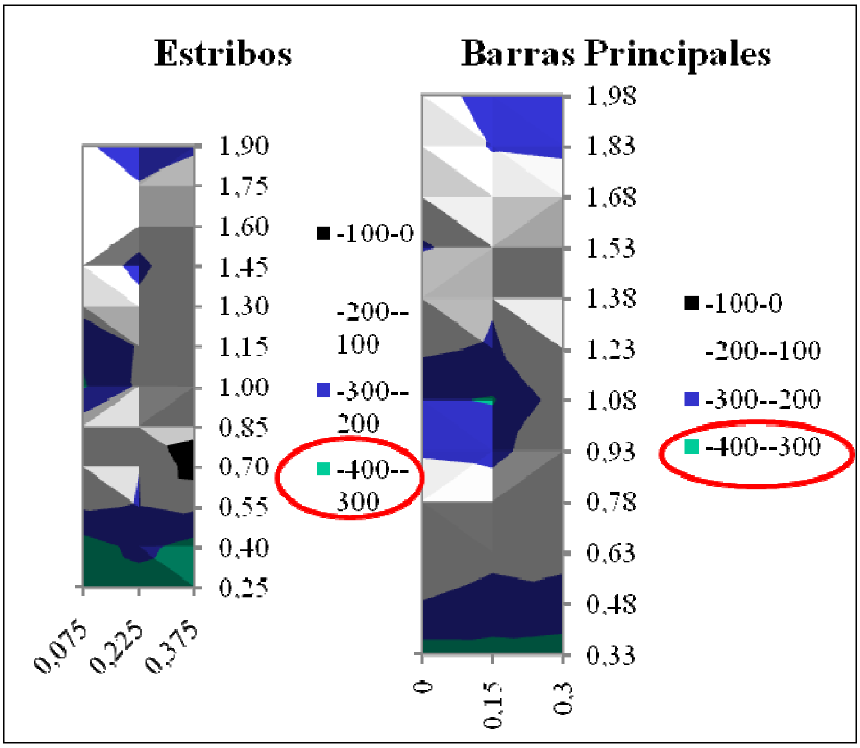


Figure 21: Examples of corrosion potential maps

### 3.6. Carbonation effect in permeability of concrete

As was explained before, carbonation affects durability of reinforced concrete, destroying the layer at bars surface lowering its pH. This is an indirect way to promote deterioration of concrete and it is a concern only if reinforcement exits. The question is, does carbonation affect any concrete property by its own? It was mentioned in Chapter 1.3 that carbonation reduces the pore size of concrete, decreasing its permeability at surface level of a structure.

To understand the performance of concrete with blended cement used in Chile (OPC + natural pozzolans), air, water (by sorptivity) and chloride ion permeability were measured in samples extracted from the structures, and results were related to carbonation depth.

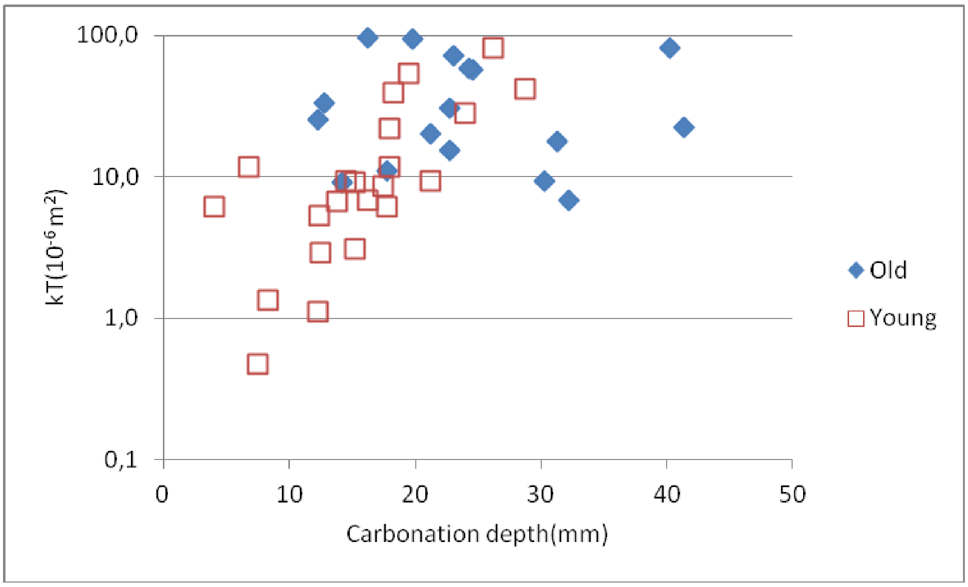


Figure 22: Air permeability (log scale) vs. carbonation

All the OS had a similar performance in terms of it air permeability. They are in the same range, independently of the carbonation present. However YS increase its air permeability as carbonation depth rises. However, since an overlapping exits between OS and YS values above kT = $10x10^{-6}$ $m^2$, air permeability do not reach limit, this means air permeability does not become constant at any carbonation depth. An explanation of this rise in concrete differences among time, doses has change as well as cement composition, which implies different responses to deterioration processes.

Nowadays, cements are more finely ground and the chemical composition has more tricalcium silicate, making hydration process faster (Neville, 2001) and enabling to use less cement content than before the 80´s. According this, less cement content allows faster carbonation, because less carbon dioxide is needed to become calcium hydroxide in calcium carbonate.

If we consider that water-to-binder ratio (w/b) is one of the main factor affecting carbonation, more than cement content (Neville, 2000); comparing a concrete from the past with one from the present, both with the same strength, it will result that the concrete from the present will have less cement content resulting in a high w/b. This could be another reason why YS are more affected by carbonation than OS if we assume that every element tested has a similar strength.

These arguments do not apply to high strength concretes because they use an important amount of cement, which is not the case of structures tested.

In terms of sorptivity and chloride ion permeability, the performance of YS it is not better than OS.

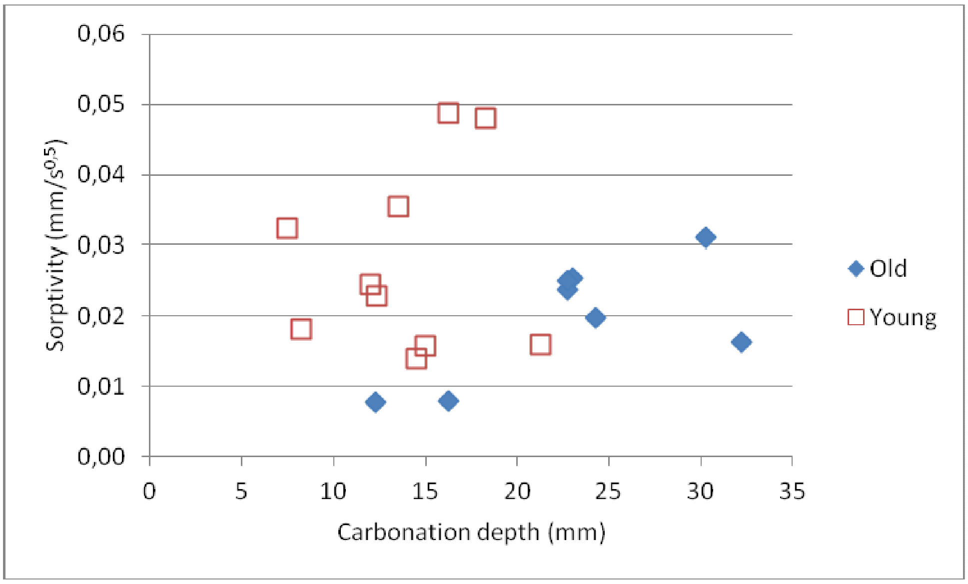


Figure 23: Sorptivity vs. carbonation

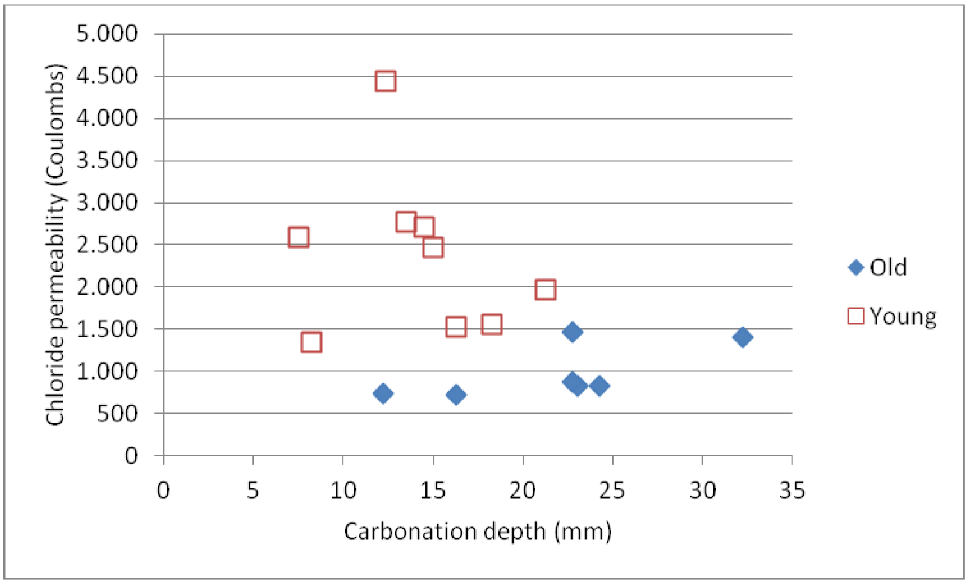


Figure 24: Chloride ion permeability vs. carbonation

These results may have two possible explanations: carbonation products occupies more volume; therefore, a more compact surface is obtained in OS, decreasing permeability, and/or, less cement content in YS implies more water per unit of cement; hence, more capillary pores are generated at early ages, decreasing the permeability (Mills, 1987).

To establish if carbonation has a significant effect in permeability of concrete, samples extracted with a length higher than 100mm were cut in half order to obtain two specimens: an outer region affected by carbonation and an inner region no affected (no carbonation depth over 50mm were detected). Sorptivity and chloride ion permeability were tested in each sample and a statistical analysis was made.

Table 4: Permeability results with and without carbonation

| | Chloride ion permeability | | Sorptivity | |
|---|---|---|---|---|
| | Outer | Inner | Outer | Inner |
| Old structures | 887.8 | 1716.1 | 0.031 | 0.028 |
| | 1409.9 | 1430.4 | 0.025 | 0.031 |
| | 824.9 | 632.6 | 0.016 | 0.033 |
| | 878.7 | | 0.02 | 0.027 |
| | 1469.8 | | 0.024 | 0.015 |
| | 724.7 | | 0.025 | 0.022 |
| | 746.5 | 351.2 | 0.008 | |
| New structures | 1555.9 | 1518.6 | 0.008 | 0.005 |
| | 1964.4 | 3824.7 | 0.048 | 0.04 |
| | 1352.9 | 1148.3 | 0.016 | 0.027 |
| | 2706.7 | 1927.3 | 0.018 | 0.01 |
| | 1535.9 | | 0.014 | 0.009 |
| | 2593.7 | | 0.049 | 0.036 |
| | 2772.0 | 1917.0 | 0.032 | 0.019 |
| | 4442.3 | 1132.5 | 0.025 | 0.024 |
| | 2471.3 | 1101.5 | 0.035 | 0.017 |
| | | | 0.023 | 0.011 |
| | | | 0.016 | 0.012 |

Results are presented as relative percentage of outer zones in the next Figure.

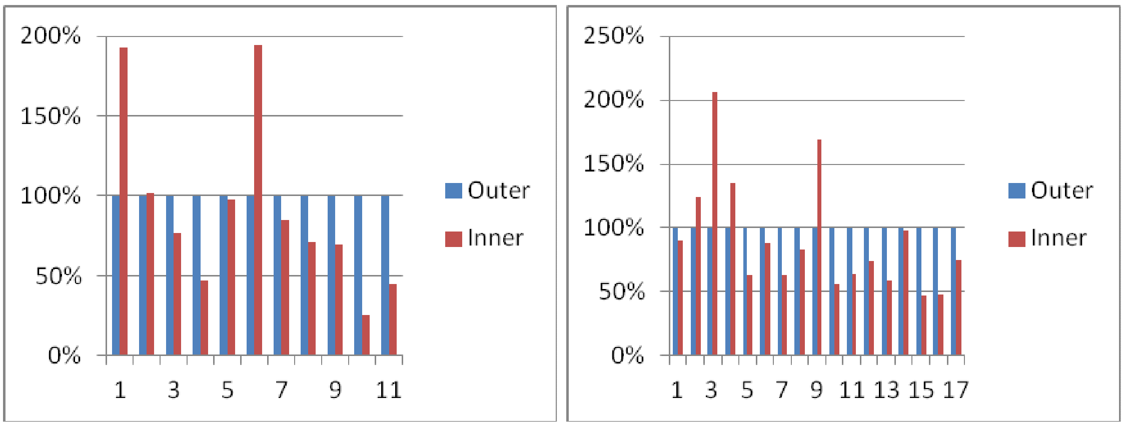


Figure 25: Carbonation effect in chloride ion permeability and sorptivity

Results show no significant differences between the two samples of the same concrete. Carbonation does not affect sorptivity and chloride permeability with a 95% of confidence level; comparing different ages, environments.

# 4. LONG-TERM MONITORING

## 4.1. Walls scheme

The walls where built and disposed in field according the next planes. Figure 26 also shows the measurement plan trough time.

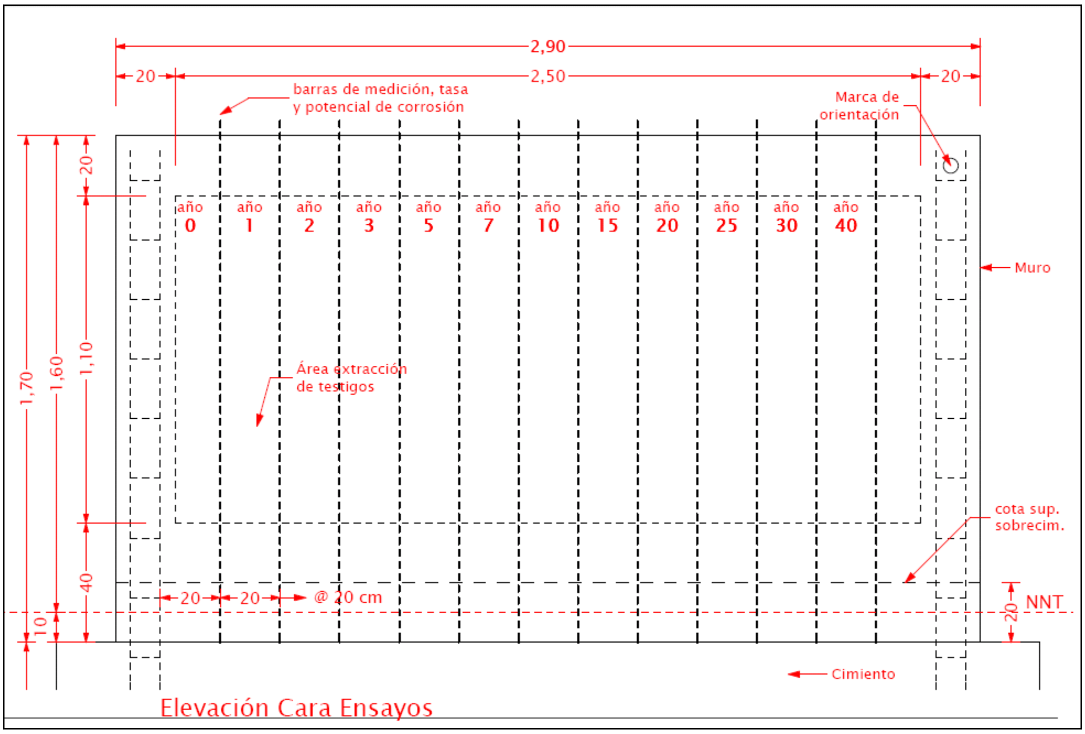


Figure 26: Wall elevation and measurement plan

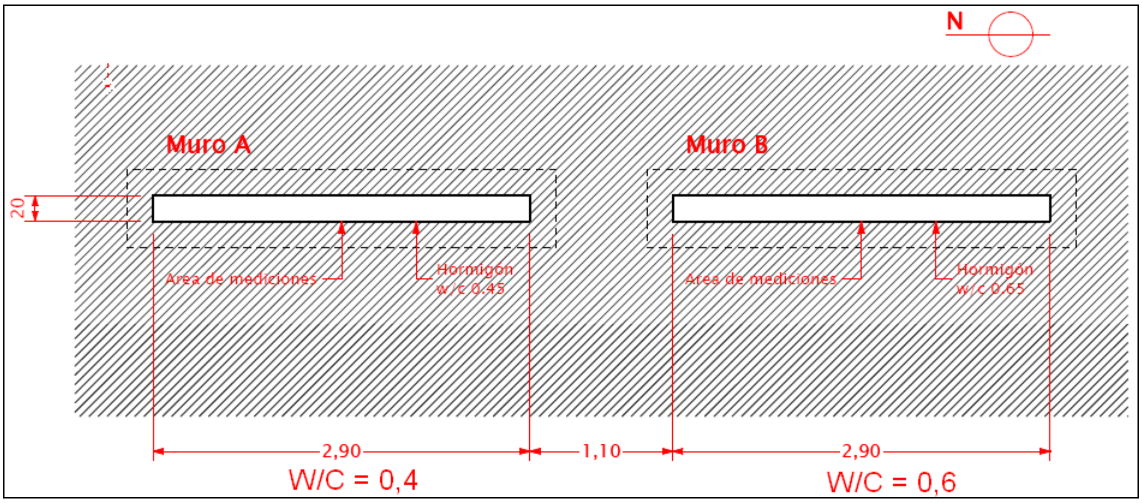


Figure 27: Walls position in field

### 4.2. Materials and Mixtures

"Blind" cement (OPC with natural pozzolans) was used in the mixtures. The coarse aggregate had a saturated surface dry (SSD) density of 2673 kg/m3 and absorption of 1.1%, and the fine aggregate has a SSD density of 2767kg/m3 and absorption of 1.0%. Mixture design is summarized in the next Table:

Table 5: Concrete mixtures design (amounts in kg per cubic meter of concrete)

| Concrete Material | Wall 1 Weight (kg) | Wall 2 Weight (kg) |
|---|---|---|
| Cement | 400 | 270 |
| Water | 160 | 162 |
| Coarse Aggregate | 927 | 985 |
| Fine Aggregate | 927 | 985 |
| Superplasticizer | 2.8 | 2.43 |
| w/b | 0.4 | 0.6 |
| Aggregate content by volume | 0.68 | 0.72 |
| Paste content by volume | 0.32 | 0.28 |

## 4.3. Cementitious materials

Oxides analysis, specific weight and Blaine fineness was made for both, OPC and blended cement. The results are summarized in Table 6.

Table 6: Cement characterization

| | Blind cement |
|---|---|
| $SiO_2$ (%) | 29.8 |
| CaO (%) | 47.3 |
| $Fe_2O_3$ (%) | 1.8 |
| $Al_2O_3$ (%) | 4.4 |
| $SO_3$ (%) | 2.67 |
| MgO (%) | 1.4 |
| Losing on ignition (%) | 3.2 |
| Insoluble residue (%) | 22.6 |
| Specific gravity | 2.91 |
| Specific surface (cm2/gr) | 4607 |

The relatively high insoluble residue in the blended cement represents the natural pozzolans.

### 4.4. Results summary and analysis

So far, mechanical properties, air permeability, sorptivity and chloride ion permeability results at 28 and 90 days have been taken and are summarized in the next Table:

Table 7: Walls measurement at 28 and 90 days

| | Field Measurement | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Santiago | | | | Valparaíso | | | |
| w/c | 0.4 | | 0.6 | | 0.4 | | 0.6 | |
| Test | Value | Age | Value | Age | Value | Age | Value | Age |
| Air permeability ($10^{-16}$ $m^2$) | 0,6 | 28 | 9.8 | 28 | 0.78 | 28 | 4.69 | 58 |
| | 14.36 | 90 | 33.88 | 90 | | | | |
| | 11.25 | 190 | 15.73 | 190 | | | | |
| Sorptivity (mm/$s^{0.5}$) | 0.012 | 90 | 0.017 | 90 | | | | |
| Chloride ion permeability (Coulombs) | 533 | 97 | 1701 | 97 | 625 | 90 | 3427 | 90 |
| Compressive Strength (MPa) | 56.7 | 28 | 30.3 | 28 | 62.5 | 28 | 35.5 | 28 |
| Splitting tensile strength (MPa) | 4.88 | 28 | 3.3 | 28 | 3.6 | 28 | 3.4 | 28 |

| | Laboratory Measurement | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Santiago | | | | Valparaíso | | | |
| w/c | 0,4 | | 0,6 | | 0,4 | | 0,6 | |
| Test | Value | Age | Value | Age | Value | Age | Value | Age |
| Compressive Strength (MPa) | 45.4 | 4 | 18.7 | 4 | | | | |
| | 52.2 | 7 | 22.5 | 7 | | | | |
| | 56.4 | 28 | 27.8 | 28 | 68.4 | 28 | 35.6 | 28 |
| | 59.1 | 90 | 36.1 | 90 | 78.1 | 90 | | 90 |
| Splitting tensile strength (MPa) | 3.8 | 28 | 1.7 | 28 | 2.5 | 28 | 3.2 | 28 |
| | 4.6 | 90 | 5.6 | 90 | | | | |
| Elastic Modulus (MPa) | 28.8 | 28 | 21.9 | 28 | 29.4 | 28 | 27.4 | 28 |
| | 30.8 | 90 | 26.5 | 90 | 32,9 | 90 | 30.7 | 90 |

Comparing mechanical properties, there are no significant differences between field and laboratory conditions. Nevertheless, even when materials and mixture design where the same for walls built in Santiago and Valparaiso, mechanical property values are higher in Valparaiso for laboratory and field conditions which means that execution plays and important role in achieve a target value.

Air permeability grows with time and its impact is w/b dependent. With a w/b of 0.4, air permeability increases 24 times from 28 to 90 days, while with a w/b of 0.6, the increase is 3.5 times. For all ages, wall with w/b of 0.4 shows less air permeability than the wall with w/b of 0.6, but differences are closer at 90 days.

Sorptivity results shows no big differences between different w/b in Santiago at 90 days.

Chloride ion permeability seems to be more sensitive to different w/b. Also, with a w/b of 0.4 there are no big differences between the two environmental conditions but with w/b of 0.6 the differences may be of consideration.

Even when important differences are detected between the two environmental conditions in terms of mechanical properties, air permeability, sorptivity and chloride ion permeability do not follow the same pattern.

Corrosion potential was also measured and results are shown in Table xx:

Table 8: Corrosion potential at different covers

| | Covering (mm) | 1,5 | 2,5 | 5,0 | 1,5 | 2,5 | 5,0 | 1,5 | 2,5 | 5,0 | 1,5 | 2,5 | 5,0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Corrosion Potential (mV) | | | | | | | | | | | |
| Santiago | w/b = 0.6 | -62 | -75 | -86 | -71 | -76 | -71 | -68 | -77 | -65 | -62 | -58 | -69 |
| | w/b = 0.4 | -75 | -80 | -87 | -79 | -90 | -84 | -86 | -88 | -86 | -77 | -83 | -104 |
| Valparaiso | w/b = 0.6 | 73 | 57 | 7 | -36 | 11 | -49 | -2 | -29 | -52 | -48 | 22 | 15 |
| | w/b = 0.4 | -36 | -80 | 721 | -76 | -47 | -34 | -21 | -104 | 48 | -36 | 14 | -15 |

At 90 days, none wall shows corrosion potential values of consideration. Electrical resistivity was also measured, values are too high to consider any risk, so it is possible to establish that corrosion process have not started yet.

# 5. REDUCING CONCRETE PERMEABILITY BY USING NATURAL POZZOLANS AND REDUCING AGGREGATE-TO-PASTE RATIO

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## 5.1. Abstract

Durability of reinforced concrete structures is mainly achieved with a low-permeability concrete. Permeability of concrete depends on both permeability of the bulk paste and that of its interfacial transition zone (ITZ). Even though permeability of bulk cement paste can be adequately controlled, the effect of ITZ on the permeability of concrete is not well understood yet and can be a key to improving the durability of concrete. This paper shows that minimizing permeability of concrete requires minimizing permeability of the bulk paste by using a supplementary cementing material (SCM) such as natural pozzolans (NP) and minimizing ITZ by reducing aggregate content. This was done by comparing performance of concrete mixtures made with ordinary portland cement (OPC) and blended cement (OPC+NP) at the same water-to-binder ratio (w/b) and by comparing performance of concrete mixtures with different aggregate contents (different amount of ITZ) at the same w/b. All of this was performed through testing of mechanical properties, air permeability, sorptivity (capillary absorption), chloride ion permeability, and aggregate specific surface.

Results shows that NP in concrete reduced air permeability by 84% and chloride ion permeability by 66%, but increased sorptivity by 50 to 140%. ITZ has an important effect in every property tested; especially in air permeability where sensitive reduction of more than a 90% was achieved at every age. ITZ effect seems to be as important as using SCM´s in reducing permeability of concrete.

**Keywords**: Durability, natural pozzolans, SCM, permeability, chlorides.

## 5.2. Introduction

### 5.2.1. Relevance of Durability

Sustainability one of the most important challenges that construction industry faces nowadays, and it is still not clear how to specify structures for sustainability. Over-specification is both wasteful and unfair to the client while under-specification leads to premature and costly repair work (Richardson, 2004), and neither of these practices are sustainable. Further, deterioration of materials makes structures unsafe which also poses a sustainability concern. Durability of materials, specifically that of reinforced concrete, has gained a main role in advancing sustainable construction by increasing safety and reducing maintenance and rehabilitation of structures (Shen, Li Hao, Wing-Yan Tam, & Yao, 2007). Nevertheless, specifications for durable concrete are still a challenge.
Compressive strength is the main, and most of the time the only, property used to specify hardened concrete. Therefore, traditionally mixture designs focus on achieving the specified strength without considering other concrete properties affecting durability. Although compressive strength and durability depend on similar factors, achieving one of them does not guarantee achieving the other, so special care needs to be taken to achieve both. Since there is no a recipe to ensure durability (Neville, 2001), there is the need to investigate different ways to improve concrete durability without affecting compressive strength.
Even when some designers are more aware of the importance of evaluating durability of structures to ensure the mechanical properties during service life and to estimate the

actual cost of the structure (Mehta & Monteiro, 2006), contractors usually do not have a thorough knowledge about how to ensure durability. The problem becomes more complex because the information from durability tests is fragmented and cannot be easily synthesized to understand durability from a broad point of view (Mehta, 1991).

Four deleterious agents have been identified as critical to concrete durability because their potential to produce corrosion in reinforced concrete. They are: water, chlorides, carbon dioxide, and oxygen. Thus, the ease with which these agents enter into and move through concrete, referred to as permeability (Neville, 2004), needs to be measured to assess concrete durability. Concrete permeability testing cannot be replaced by using the many probabilistic models developed to explain concrete deterioration, as proposed by Ferreira (2010) and Kliukas et al. (2004), despite their recent considerable improvements.

### 5.2.2 Supplementary Cementing Materials (SCM) in durability of concrete

The addition of SCMs is an effective way to decrease the permeability of concrete (CEB, 1997; Mehta & Monteiro, Concrete: Microstructure, Properties and Materials, 2006; Neville, 2004). Silica fume and fly ash are among the most widely used SCMs, but natural pozzolans has proven to greatly impact concrete performance (CEB, 1997).

Pozzolans are natural or artificial materials containing silica in a reactive form (Neville, 2004). Pozzolans react with the calcium hydroxide, derived from cement hydration, and water forming new calcium silicate hydrates (C-S-H) that increase compressive strength and reduce permeability.

The use of SCMs have proven to improve durability of concrete and provide additional benefits such as improvement in workability, reduction of the heat of hydration, reduction in permeability, increase in ultimate strength, increase in resistance to sulphate attack, and reduction in alkali-silica reaction (Rodríguez-Camacho & Uribe-Afif, 2002; Uzal & Turanli, 2003; Papadakis & Tsimas, 2002) .

Among many types of SCMs, natural pozzolans have gain more attention lately because they might be widely available, such as some clays and volcanic ashes. These materials do not depend on other industries, unlike SCMs such as silica fume, fly ash and ground granulated blast furnace slag.

As other SCMs, the use of natural pozzolans modifies concrete microstructure, improving concrete properties such as strength and permeability (Colak, 2002; Sabir, Wild, & Bai, 2001). Even more, the improvement in permeability appears to be very significant when compared to that in strength (Lopez & Castro, 2010).

### 5.2.3 Factors affecting permeability

Permeability of concrete depends on the permeability of the cement paste, aggregate, and interfacial transition zone (ITZ). However, according to many (for example, (Richardson, 2004), permeability of concrete is predominantly controlled by the permeability of cement paste and that of ITZ. For porous and permeable aggregates, hydration products can penetrate superficial pores "sealing" the aggregate and restricting the overall permeability to that of the cement paste or ITZ. For non-porous aggregates the tortuosity of the pore structure increases drastically, decreasing intrinsic permeability to values lower than that of cement paste or ITZ (Carcasses & Ollivier, 1999).

Water-to-binder ratio by weight (w/b) appears to be the main factor controlling permeability of cement paste (CEB, 1997; Neville, 2004), since it determines the initial space between unhydrated cement and the porosity and ultimately depercolation of pore structure (Powers, Copeland, & Mann, 1959; Powers, 1960).

Mixing water is indirectly responsible for the permeability of hydrated cement paste (Mehta & Monteiro, 2006), since it determines total and unfilled space in the cement paste microstructure after water has been consumed either by cement hydration or by evaporation. Thus, lower mixing water contents will decrease permeability of cement paste. On the other hand, very high cement contents do not necessarily decrease permeability; there seems to be an optimum cement content for decreasing permeability (Zhang & Gjorv, 1991), since increasing cement content makes concrete more prone to heating and thermal cracking.

Microcracks, normally present in the ITZ, increase permeability of concrete above that of the corresponding cement paste. From this perspective, ITZ effects on permeability become more important as aggregate volume increases (Carcasses & Ollivier, 1999).

The relevance of the ITZ on permeability of concrete is not only explained by microcracks, but also by differences in microstructure with the bulk cement paste. For instance, it has been established that the thin water film formed around large aggregate particles increases w/b locally producing a weaker and more permeable zone with respect to bulk cement paste (Mehta & Monteiro, 2006). For instance, Bourdette et al. (1995), measured very high porosity at the ITZ concluding that it plays an important role in the ion diffusion process. Additionally, another study focused on cement paste and mortars (Tumidajski, 1996), observed that the conductivity of the system decreases more or less linearly with an increase in the volume fraction of the aggregates. Accounting the dilution effect of aggregates, Tumidajski concluded that the ITZ had very little effect on the electrical conductivity of the overall system for an aggregate-to-mortar ratio over 0.1. Oppositely, Ping et al. (1991), used the same technique to obtain results suggesting that the ITZ had an important effect on both the electrical conductivity and permeability.

Another study (Mills, 1987) concluded that for a given strength and workability (i.e., constant w/b), permeability decreases as cement content decreases because the initial amount of mixing water determines the total porosity of the system. Such results may be explained based on the low w/b and superplasticizer that make ITZ microstructure very similar to that of the bulk paste (Carcasses & Ollivier, 1999).

One possible explanation to the opposing conclusions above is that the effect of the aggregate on concrete transport properties cannot be solely evaluated by simply accounting for the dilution effect; according to Carcasses et al. (1999), from the model developed by Garboczi et al., dilution, tortuosity and the intrinsic influence of porous ITZ appears to be all important in determining permeability of concrete. This is consistent with the conclusions obtained previously (Bourdette, Ringot, & Ollivier, 1995); that is, tortuosity of ITZ tends to have greater influence on the transport properties than the connectivity of the ITZ.

Igusa (Carcasses & Ollivier, 1999), using a three-phase model demonstrated that permeability of ITZ is higher than that of bulk cement paste by estimating the following properties for ITZ: thickness of 20 microns, conductivity being 6 times greater than that of cement paste, and porosity being 1.7 times greater than that of cement paste.

Ping et al. (1991), using quartz and limestone aggregate, determined that the thickness of ITZ decreases when reducing the maximum size of the aggregate. The ITZ using both types of aggregate was less dense than that of the bulk paste, but when using limestone, there was a critical particle size value below which ITZ becomes denser than the bulk paste. This was significant for aggregate sizes below 0.19 mm.

Overall, it can be stated that the use of natural pozzolans can be beneficial in decreasing permeability of cement paste and concrete, but controlling the permeability and amount of ITZ could be even more beneficial. Thus, assessing the amount of ITZ is necessary to estimate or understand its effect on permeability of concrete and to obtain a mixture design for low permeability.

### 5.3. Research Significance

SCMs are widely used as a cement replacement nowadays and their influence on durability has been extensively studied. However, there are few studies using natural pozzolans, despite their widespread use as an SCM in many countries. This paper assesses the effect of natural pozzolans on durability of concrete by measuring sorptivity and permeability to air and chloride ions; In addition, it assesses the effects of ITZ on the durability of concrete by using different aggregate-to-paste ratios, at the same w/b. Stereology was used to determine the specific surface of aggregate, and estimate the potential amount of ITZ, to ultimately describe the effect of ITZ in permeability of concrete. It was of interest to determine the relative importance of the effect of natural pozzolans and ITZ.

### 5.4. Experimental Method

The experimental program considered the fabrication of four mixtures for assessing the influence of natural pozzolans and ITZ on the permeability of concrete. Permeability was evaluated using three different methods: Sorptivity (capillary absorption) controlled by water permeability, air permeability, and chloride ion permeability. This approach aimed to assess permeability of concrete in both: i) in an unsaturated pore system where capillary absorption (sorptivity) and gas diffusion (air permeability) may dominate, and ii) in a saturated pore system, at normal pressure, where chloride ion diffusion is the predominant transport mechanism (Zhang & Gjorv, 1991). ITZ, on the other hand, was assessed based on the surface density of the aggregate by using stereology and microscopy.

### 5.4.1. Materials and Mixtures

OPC and blended cement (OPC with natural pozzolans) were used in the trial mixtures. The coarse aggregate had a saturated surface dry (SSD) density of 2585 kg/m3 and absorption of 1.4%, and the fine aggregate has a SSD density of 2810 kg/m3 and absorption of 1.1%.

The effect of natural pozzolans in permeability was assessed by comparing the performance of two concrete mixtures; C1 and C2. Both had the same mixture proportions, w/b of 0.5, with the only difference being the cement type: C1 used OPC and C2 used blended cement consisting of 62% OPC and 38% natural pozzolans. The effect of ITZ in permeability was assessed by comparing the performance of three mixtures: C2, C3, and C4. All of them with the same blended cement, w/b of 0.5, with the only difference being the aggregate-to-paste ratios by volume (a/cp): C2 had a a/cp of 2.57 (335 $kg/m^3$ of cement), C3 had a a/cp of 3.35 (270 $kg/m^3$ of cement), and C4 had a a/cp of 1.94 (400 $kg/m^3$ of cement). Mixture designs are summarized in Table 9.

Table 9: Concretes mixture design (amounts in kg per cubic meter of concrete)

| Concrete<br>Material | C1 Weight (kg) | C2 Weight (kg) | C3 Weight (kg) | C4 Weight (kg) |
|---|---|---|---|---|
| Cement | 335 | 335 | 270 | 400 |
| Water | 167.5 | 167.5 | 135 | 200 |
| Coarse Aggregate | 1130 | 1109 | 1202 | 1024 |
| Fine Aggregate | 753 | 739 | 801 | 682 |
| Superplasticizer | 2.35 | 3.02 | 0.35 | 0.52 |
| w/b | 0.5 | 0.5 | 0.5 | 0.5 |
| Aggregate content by volume | 0.71 | 0.69 | 0.75 | 0.64 |
| Paste content by volume | 0.29 | 0.31 | 0.25 | 0.36 |

### 5.4.2 Test Methods

Compressive strength, splitting tensile strength, modulus of elasticity, sorptivity, air permeability and chloride ion permeability were measured at different ages. The surface density of the aggregate for all mixtures was measured from an unbiased stereology technique.

Compressive strength was measured on 100 x 200-mm cylinders according to ASTM C39 / C39M - 10 at the age of 4, 7, 28, 90 and 150 days. Splitting tensile strength was also measured on 100 x 200-mm cylinder according to ASTM C496 / C496M – 04e1 at the age of 28, 90 and 150 days. Modulus of elasticity was measured on 150x300-mm cylinders according to ASTM C469 / C469M – 10 at the age of 28, 90 and 150 days.

Sorpitivity was measured on 100 x 50-mm cylinders according to ASTM C1585-04 at age of 28 and 90 days. The test consists of measuring the change in mass with time of a concrete specimen, previously dried at 50 ± 2°C and 80% relative humidity. One flat side of the specimen is exposed to water which produces a change of mass by capillary absorption. Water loss is prevented by sealing the other sides and of the specimens by a plastic bag to avoid water evaporation. Fig. 28 shows a schematic of the test.

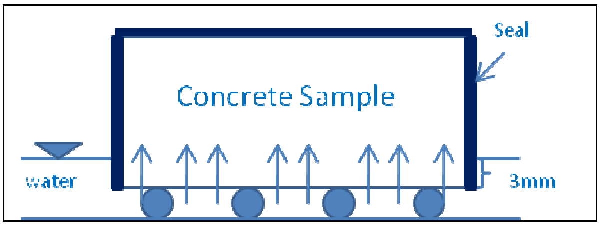


Figure 28: Schematic of sorptivity test

Data collected during the first 6 hours of the test correspond to the "initial absorption" while that collected between 1 to 7 days correspond to the "secondary absorption". Results are plot as the cumulative change in mass divided by exposed area and density of water (Y axis), versus the square root of time (X axis). The slopes of the initial and secondary absorption are calculated. As each stage represents different mechanisms (i.e., capillary absorption for the initial and diffusion for the secondary), a single coefficient is calculated from the intersection of the two slopes. According Castro et al. (2011), sorptivity results were normalized by paste content and by aggregate absorption because the important effect they have in the test.

It is important to note that sorptivity can be considered as an index for estimating potential durability of concrete (Hazaree, Wang, Ceylan, & Gopalakrishnan, 2010; Pereira de Oliveira, de Castro Gomes, Gon, & Gonilho Pereira, 2006).

Air permeability was measured on 200-mm cubes according to SN EN 206-1, 2003 (Swiss standard) at age of 28, 90, and 150 days. Six measurements (one on each face) were taken on each specimen.

The test method consists of estimating air permeability by applying vacuum and measuring the air influx from within concrete. The perpendicular flow of air through concrete at the level of the surface is ensured by a guard ring that prevents air from the exterior affecting the measurement. Saturated or partially saturated pores will affect the air permeability, so the results need to be corrected by moisture (Torrent). In order to measure air permeability in a unsaturated pore system, specimens were removed from the fog room and kept at 50% RH and 23°C to air dry the superficial pores two days before testing. Fig. 29 shows a schematic of the test.

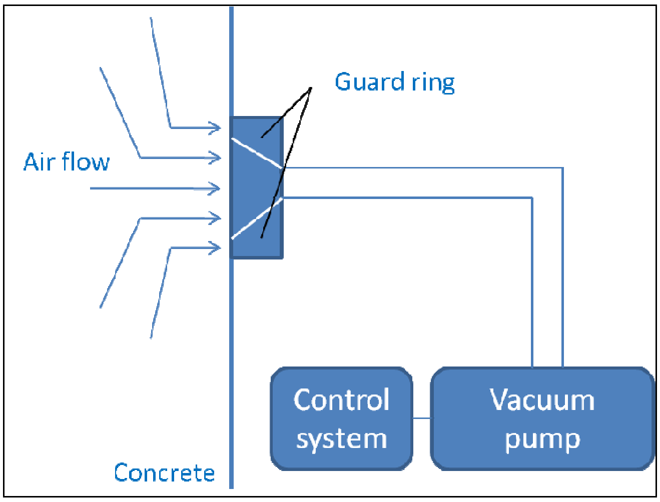


Figure 29: Schematic of air permeability test

It is important to note that air permeability has become the preferred method for specifying and measuring durability of concrete in Switzerland.

Chloride ion permeability was measured on 100x50-mm cylinders according to ASTM C1202-05 at the age of 35 and 97 days. In this method, an electrical potential of 60 V is maintained across the flat ends of saw-cut cylinders (previously conditioned), during 6 hours. One end is immersed in a NaCl solution and the other in a NaOH solution. Chloride ions travel across the specimens and the current is measured periodically. At the end of the 6 hours, the total charge passed, in coulombs, is calculated, and the permeability of concrete is obtained. Fig. 30 shows a schematic of the test.

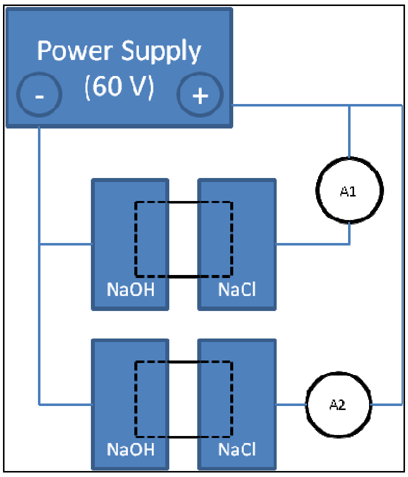


Figure 30: Schematic of chloride ion permeability test

ITZ was assessed through measuring aggregate surface by means of stereology parameters, specifically "surface density". The estimation of surface density was made from vertical uniform random (VUR) sections using an unbiased stereology technique based on cycloids. Cycloids were used because they are considered isotropic lines on vertical uniform random sections in 3D space (Howard & Reed, 2005).

Surface density is then estimated from:

$$Sv\,(Y,ref) = \frac{2 \times \sum_{i=1}^{n} I_i}{\frac{l}{p} \times \sum_{i=1}^{n} P_i} \quad (1)$$

Where $I_i$ is the number of intersections, $P_i$ the points hitting the reference space and l/p is the length of test line per grid point at the level of the tissue, corrected for linear magnification (Howard & Reed, 2005; Zhang & Han, 2004).

Surface density of the aggregate was also estimated based on their particle size distribution (sieve analysis) and assuming spherical particles.

## 5.5. Results and Discussion

### 5.5.1. Cementitious materials

Oxides analysis, specific weight and Blaine fineness was made for both, OPC and blended cement. The results are summarized in Table 10.

Table 10: Cements characterization

| | Ordinary Portland Cement | Blended cement (62% OPC+ 38% natural pozzolans) |
|---|---|---|
| $SiO_2$ (%) | 19.4 | 33.6 |
| CaO (%) | 63.3 | 39.1 |
| $Fe_2O_3$ (%) | 2.9 | 1.6 |
| $Al_2O_3$ (%) | 6.4 | 4.0 |
| $SO_3$ (%) | 2.66 | 2.62 |
| MgO (%) | 0.8 | 1.1 |
| Losing on Ignition (%) | 1.4 | 3.4 |
| Insoluble Residue (%) | 0.8 | 33.5 |
| Specific gravity | 3.15 | 2.82 |
| Specific Surface ($cm^2$/gr) | 4697 | 4876 |

Blended cement had a considerably higher $SiO_2$ content and lower specific gravity than OPC because of the inclusion of natural pozzolans. Content of CaO, $Fe_2O_3$, and $Al_2O_3$, are all lower in blended cement than in OPC. The relatively high insoluble residue in the blended cement represents the natural pozzolans. Blaine fineness is similar in both cements.

Natural pozzolans present in the cement used for C2, C3 and C4, had a volcanic origin and could be classified as a Type-N pozzolan according to ASTM C618 (2008). It corresponded to a volcanic glass known as rhyolite pumicite. The chemical compositions of NP and OPC used in this investigation are shown in Table 11.

Table 11: Chemical composition of natural pozzolans (Espinoza, Paul & Lopez, 2010)

| SiO2 (%) | Al2O3 (%) | Fe2O3 (%) | CaO (%) | MgO (%) | K2O (%) |
|---|---|---|---|---|---|
| 69.2 | 13.2 | 1.7 | 2.7 | 0.8 | 3.0 |
| SO3 (%) | Na2O (%) | TiO2 (%) | P2O5 (%) | LOI (%) | |
| 0.1 | 3.9 | 0.2 | 0.1 | 4.36 | |

The chemical composition of the natural pozzolans used in this investigation suggests an almost negligible hydraulic activity (2.7% of CaO content), and a relatively high pozzolanic activity due to its 69.2% of $SiO_2$.

### 5.5.2. Concrete mixtures

Average results for compressive strength, splitting tensile strength and modulus of elasticity at different ages are shown in Table 12, and average sorptivity, air permeability and chloride ion permeability, are shown in Table 13.

Table 12: Mechanical properties of mixtures under investigation

| Concrete | Age (days) | Compressive Strength (MPa) | Splitting Tensile Strength (MPa) | Modulus of Elasticity (GPa) |
|---|---|---|---|---|
| C1 | 4 | 25.6 | - | - |
| | 7 | 32.1 | - | - |
| | 28 | 34.2 | 3.8 | 24.8 |
| | 90 | 39.5 | 3.3 | 29.6 |
| | 150 | 45.0 | 3.8 | 28.4 |
| C2 | 4 | 17.5 | - | - |
| | 7 | 20.7 | - | - |
| | 28 | 26.3 | 3.0 | 23.5 |
| | 90 | 31.2 | 2.9 | 27.8 |
| | 150 | 35.0 | 3.2 | 26.8 |
| C3 | 4 | 12.2 | - | - |
| | 7 | 14.7 | - | - |
| | 28 | 21.7 | 1.4 | 23.9 |
| | 90 | 25.4 | 2.4 | 25.7 |
| | 150 | 27.2 | 3.9 | 26.4 |
| C4 | 4 | 19.5 | | |
| | 7 | 22.7 | - | - |
| | 28 | 29.9 | 2.5 | 26.7 |
| | 90 | 37.7 | 3.6 | 29.1 |
| | 150 | 45.5 | 4.5 | 27.9 |

Table 13: Durability properties of mixtures under investigation

| | Sorptivity coeficcient mm/$s^{0.5}$ | | | Air permeability $10^{-6}$ m2 | | | Chloride ion permeability Coulombs | | |
|---|---|---|---|---|---|---|---|---|---|
| | 28 days | 90 days | 150 days | 28 days | 90 days | 150 days | 28 days | 90 days | 150 days |
| C1 | 0.00913 | 0.00316 | 0.0052 | 1.102 | 0.399 | 0.109 | 4315 | 4437 | |
| C2 | 0.01218 | 0.00663 | 0.0106 | 0.135 | 0.065 | 0.045 | 1522 | 1705 | |
| C3 | 0.01590 | 0.01048 | 0.01315 | 0.983 | 1.223 | 0.500 | 2990 | 1432 | 908 |
| C4 | 0.00985 | 0.00542 | 0.00975 | 0.087 | 0.042 | 0.030 | 2327 | 781 | 898 |

### 5.5.3. Effect of natural pozzolans

The effect of the natural pozzolans in mechanical properties and permeability is analysed by comparing the performance of C1 with OPC and C2 with blended cement using the three proposed methods for characterizing permeability.

5.5.3.1. Compressive strength

Figure 31 shows the compressive strength obtained for each of the mixtures under study.

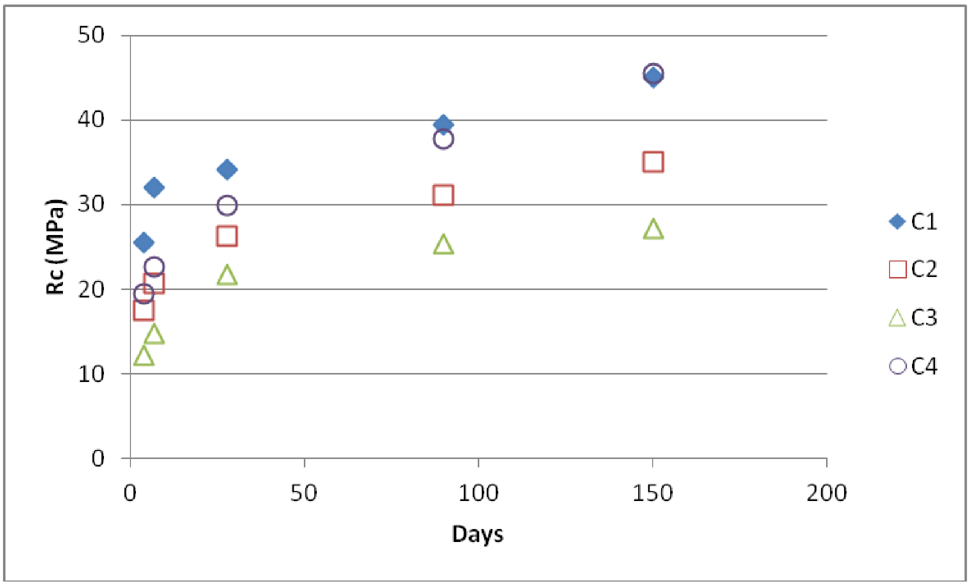


Figure 31: Strength gain of C1, C2, C3 and C4 concrete mixtres

When comparing C1 with OPC and C2 with blended cement with natural pozzolans, it can be concluded that the use of OPC provides higher compressive strength than the blended cement under investigation for all ages considered in this investigation. The maximum difference of 11.3 MPa was obtained at 7 days of age representing 55% of the strength of C2. At 150 days of age, the difference was 10 MPa and represented 28%

of the strength of C2. That is, the relative difference between C1 and C2 decreased over time suggesting that the pozzolanic reaction of the natural pozzolans contributed to increased strength of C2 over time. Mixtures C3 and C4 also presented lower compressive strength than C1 at almost all ages with the main difference being that the difference in compressive strength between C1 and C3 increased with time and between C1 and C4 decreased with time; in fact 150-day compressive strength of C1 and C4 were almost the same.

The differences in splitting tensile strength between mixtures with OPC (C1) and bended cement (C2, C3, and C4) are in most cases below 1.0 MPa and all decreases between 28 and 150 days of age.

Modulus of elasticity showed small differences between mixtures with OPC (C1) and bended cement (C2, C3, and C4) being most below 2.0 GPa (7%).

5.5.3.2 Sorptivity

Fig. 32 presents the results for sorptivity coefficient normalized by the respective volume of paste content and aggregate absorption according to Castro et al. (2011) at 28 and 90 days of age. Results suggest that concrete containing natural pozzolans (C2) present a higher sorptivity coefficient than concrete with OPC. Even though it has been demonstrated that the pozzolanic reaction of natural pozzolans produce more calcium silicate hydrates and create a more refined pore structure, this is not reflected in capillary absorption of water at 90 days of age as shown previously (Lopez & Castro, 2010).

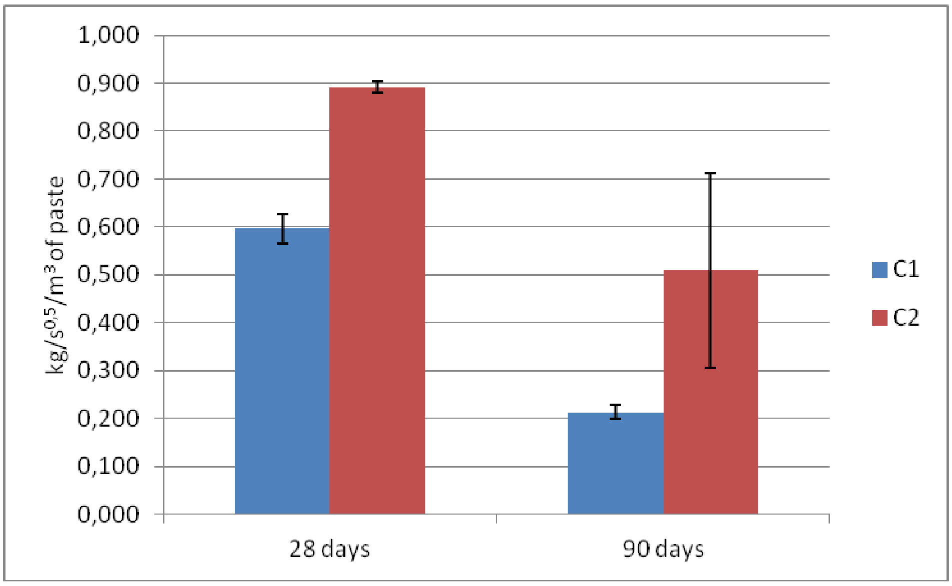


Figure 32: Sorptivity change in time of C1 and C2 concrete mixture normalized by paste content volume

Both concrete mixtures showed a decrease in sorptivity between 28 and 90 days of age; however, C1 with OPC decreased more importantly relatively to C2 with natural pozzolans making the difference between them more important with age. Additionally, variability in sorptivity of C1 with OPC was lower than that of C2 with natural pozzolans.

5.5.3.3. Air permeability

The results for air permeability in logarithmic scale versus the age at testing are shown in Figure 33, and Table 14 presents the standard deviation.

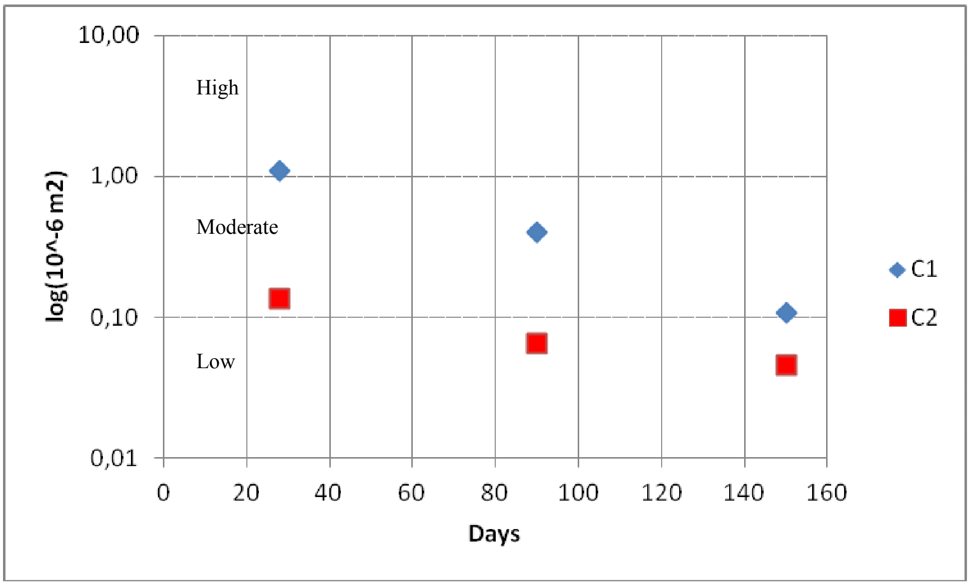


Figure 33: Air permeability change in time of C1 and C2 concrete mixture

Table 14: Standard deviation of air permeability

| Age | 28 | 90 | 150 |
|---|---|---|---|
| dv C1 | 0.39 | 0.62 | 0.13 |
| dv C2 | 0.10 | 0.06 | 0.06 |

Both concrete mixtures, C1 and C2, showed constant decrease in air permeability with time. Since air permeability is shown in logarithmic scale, the decrease in permeability between 28 and 150 days was 88 and 84% for C1 and C2, respectively..

Initially (i.e., 28 days of age), C2 with natural pozzolans showed an air permeability of about one tenth than that of C1 with OPC. However, C1 showed an important decrease between 28 and 150 days reaching an air permeability of approximately 2 times of that of C2. It is important to consider that C2 showed significantly lower variability than C1 which suggest a more uniform pore structure.

5.5.3.4 Chloride ion permeability

Since the use of SCM, such as natural pozzolans, can have a very significant effect on the chemistry of the pore solution affecting the electrical conductivity of concrete (Shi, 2004), the comparison between chloride ion permeability of C1 and C2, might not represent solely a change in microstructure but also an effect of the testing method.

The test of the samples presented problems that could not give representative results, so they were omitted. Nevertheless, a previous study (Lopez & Castro, 2010) made with the same constituents, and test equipment showed beneficial effects with the inclusion of natural pozzolans in chloride ion permeability. In that study a mixture similar to C1 had a chloride ion permeability of 4315 and 4437 coulombs at 28 and 90 days, respectively while a mixture similar to C2 had a chloride ion permeability of 1522 and 1705 coulombs at 28 and 90 days, respectively.

### 5.5.4. Effect of ITZ

The effect of ITZ on compressive strength and permeability is analysed by comparing the performance of C2, C3, and C4 concretes all with the same constituents, but different aggregate-to-paste ratio; i.e., different ITZ content.

ITZ was assumed to be proportional to the surface density of the aggregate of concrete. A first approach to estimate the aggregate surface was made assuming aggregates particles as spheres. As aggregate particles are trapped in a sieve in its minimum dimension, an aggregate particle was represented by a sphere inscribed at its minimum dimension. The amount of particles of each size was calculated based on the sieve analysis and the actual mixture design.

In order to determine the goodness of this approach, an unbiased stereology technique was applied to micrographs obtained using optical microscopy. Two different magnifications were used, 18x and 54x, in order to establish the best for measuring the surface density of the aggregate (Sv) according to equation (1). Four micrographs were used from each concrete mixture to assess Sv at each magnification.

Fig. 34 shows micrographs from C2, C3 and C4 with 18x of magnification.

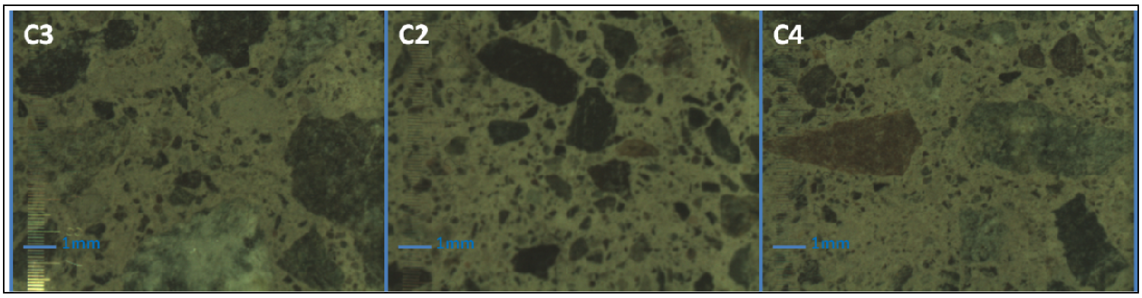


Figure 34: Micrographs from C2, C3 and C4 concrete mixtures

Sv calculated using equation (1) and the respective result with the "spherical approximation" are shown in Table 15. The order used to display the results starts with the mixture with more aggregate content (C3) and finished with that with less aggregate content (C4).

Table 15: Aggregate surface density

| | Technique | Magnification | C3 | C2 | C4 |
|---|---|---|---|---|---|
| Sv($m^{-1}$) | Microscopy | 54 | 11770 | 10339 | 9426 |
| dv | | | 1.2 | 1.5 | 1.3 |
| Sv($m^{-1}$) | Microscopy | 18 | 3328 | 4623 | 3895 |
| dv | | | 0.2 | 0.6 | 0.7 |
| Sv($m^{-1}$) | Spheres | 54 | 716.0 | 675.6 | 637.2 |
| Sv($m^{-1}$) | Spheres | 18 | 745.0 | 703.0 | 663.1 |

Since the visible aggregate particle size varies with magnification, the values obtained using stereology might also vary with magnification. It was established that the visible range at 18x magnification started at 0.11 mm while that for 54x magnification started at 0.028 mm.

The large difference between Sv estimated using stereology and the spherical approximation indicates that the latter is not conservative since underestimated Sv and so does the amount of ITZ. This underestimate is mainly due to the fact that the crushed aggregate used in this investigation do not have a round and regular shape, so their actual surface is much higher than that estimated by the spheres. Furthermore, the spheres are inscribed in the minimum size of the aggregate.

A comparison between spheres approximation and stereology with micrographs was also made, inscribing circumferences in the minimum size of aggregate particles and then applying stereology with cycloids, as show Fig. 35.

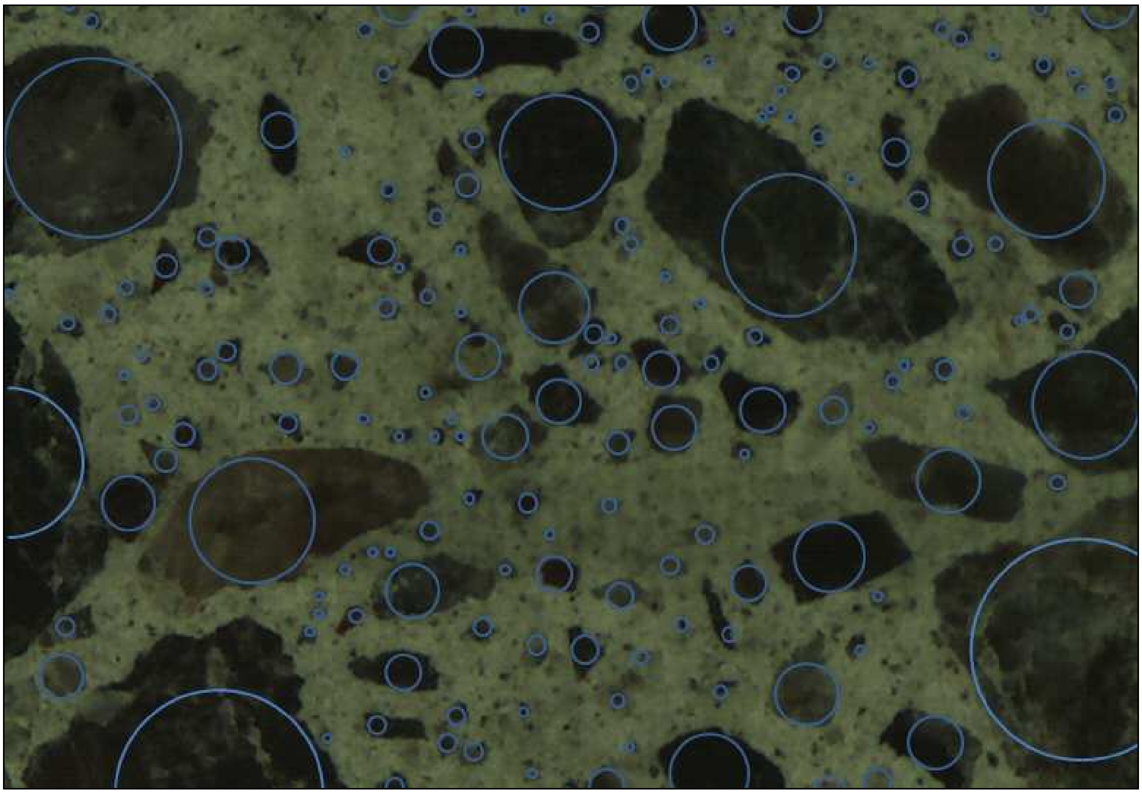

Figure 35: Comparison between spherical approximation and stereology

The analysis showed that considering aggregate being spheres under estimate aggregate surface density by at least 44%.

When comparing the stereology results from each magnification, it can be concluded that only the results from 54x followed the expected trend of increasing Sv with the increase of aggregate content. Thus, Sv obtained at 54x was used to represent the amount of ITZ and to evaluate the ITZ effect on permeability.

5.5.4.1. Compressive Strength

Figure 36 presents the compressive strength obtained in mixtures C2, C3, and C4 versus Sv as calculated using stereology technique and a magnification of 54x. Table 16 presents the standard deviation obtained in the test.

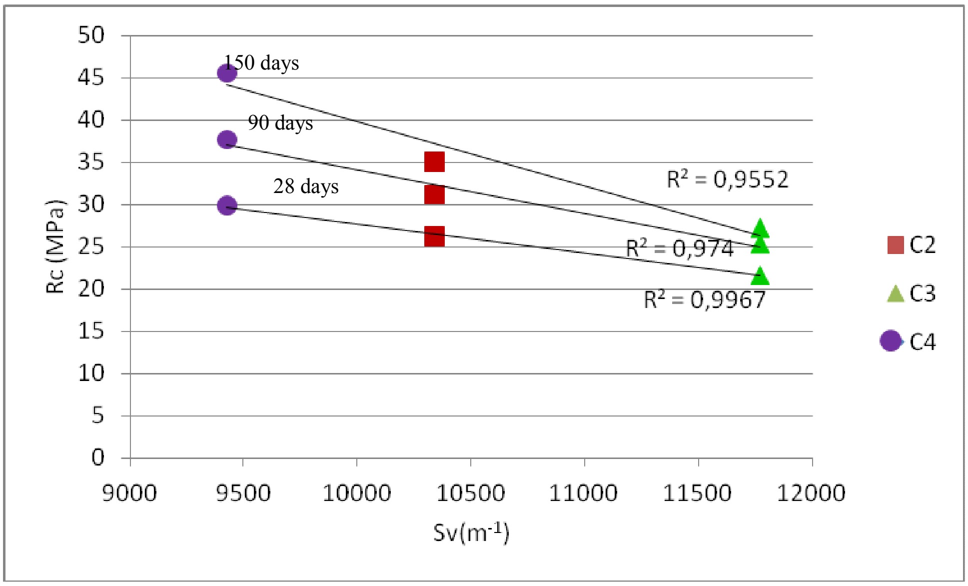


Figure 36: Compressive strength vs. surface density of aggregate (Sv)

Table 16: Standard deviation of compressive strength

| Age | 28 | 90 | 150 |
|---|---|---|---|
| C3 | 0.97 | 0.89 | 0.61 |
| C2 | 0.09 | 0.78 | 2.56 |
| C4 | 0.87 | 0.52 | 0.00 |

The effect of the Sv (and amount of ITZ) on compressive strength is very pronounced as shown in Fig. 9. Compressive strength decreases as Sv increases; and this reduction seems to approximate to a linear relationship for all ages and more pronounced as compressive strength increases. That is, as age and compressive strength increases, the drop in strength with Sv shows a steeper slope.

5.5.4.2. Sorptivity

It is clear that high Sv (and amount of ITZ) leads higher capillary absorption of water while low Sv has low capillary absorption (see Fig. 11). Also, reduction of sorptivity coefficient with age is not constant for all mixtures, high Sv has a greater reduction in sorptivity coefficient that low Sv between 28 and 90 days. Since all concrete mixtures have the same w/b (i.e., with similar pore structure and permeability of the bulk paste) and measurements were normalized by paste content and aggregate absorption, it is concluded that ITZ has a main role in determining sorptivity coefficient of concrete. Table 17 presents the standard deviation obtained in the test.

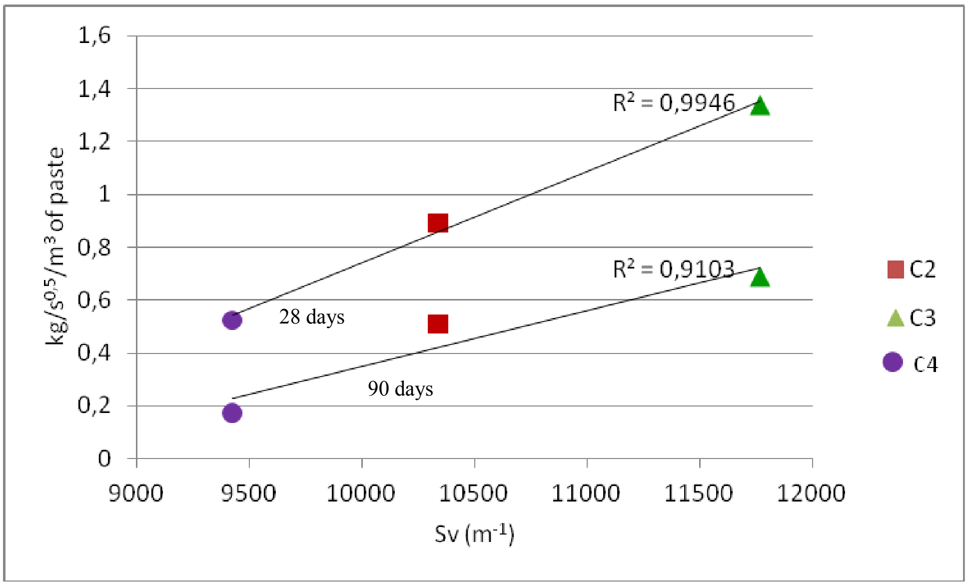


Figure 37: Sorptivity vs. surface density of aggregate (Sv)

Table 17: Standard deviation of sorptivity

| Age | 28 | 90 |
|---|---|---|
| C3 | 0.3980 | 0.0917 |
| C2 | 0.0116 | 0.2025 |
| C4 | 0.0067 | 0.1764 |

5.5.4.3. Air permeability

Sv (and amount of ITZ) has a pronounced effect on air permeability; it is clear that high Sv leads higher air permeability while low Sv has low air permeability (see Figure 38). However, such effect does not seem to be linear since an increase in 10% in Sv between C4 and C2 led to an increase in air permeability of 35%, and an increase in 12% in Sv between C2 and C3 led to an increase in air permeability of 91%. Table 18 presents the standard deviation obtained in the test.

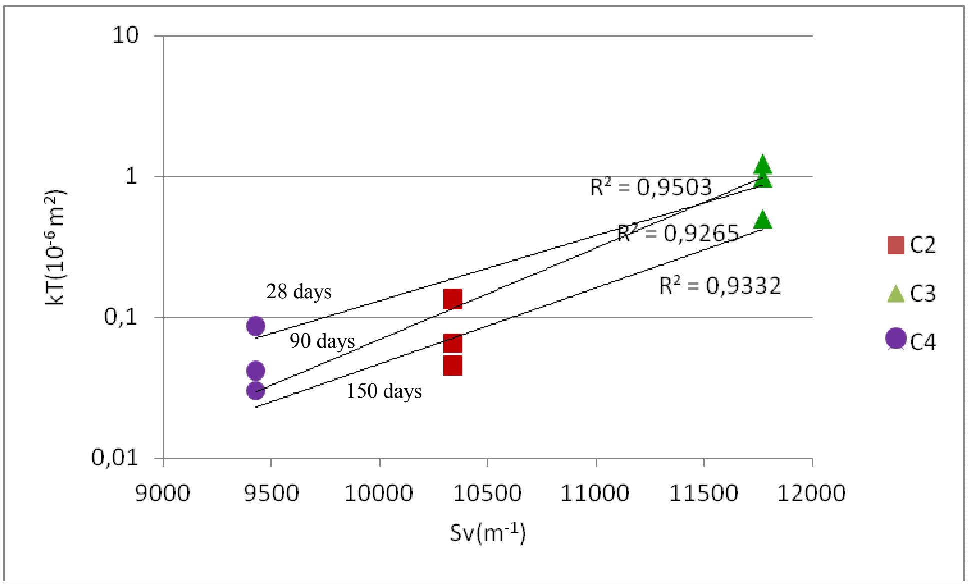


Figure 38: Air permeability (log scale) vs. surface density of aggregate (Sv)

Table 18: Standard deviation of air permeability

| Age | 28 | 90 | 150 |
|---|---|---|---|
| C3 | 1.45 | 1.28 | 0.87 |
| C2 | 0.10 | 0.06 | 0.06 |
| C4 | 0.06 | 0.04 | 0.03 |

5.5.4.4 Chloride ion permeability

The effect of Sv (and amount of ITZ) is important in chloride ion permeability; as Sv increases, chloride ion permeability increases too (Fig. 39). This effect seems to be similar at different ages. Since the results chloride ion permeability of C2 were not included, it is not possible to determine if the effect of Sv on chloride ion permeability is linear or no not. Table 19 presents the standard deviation obtained in the test.

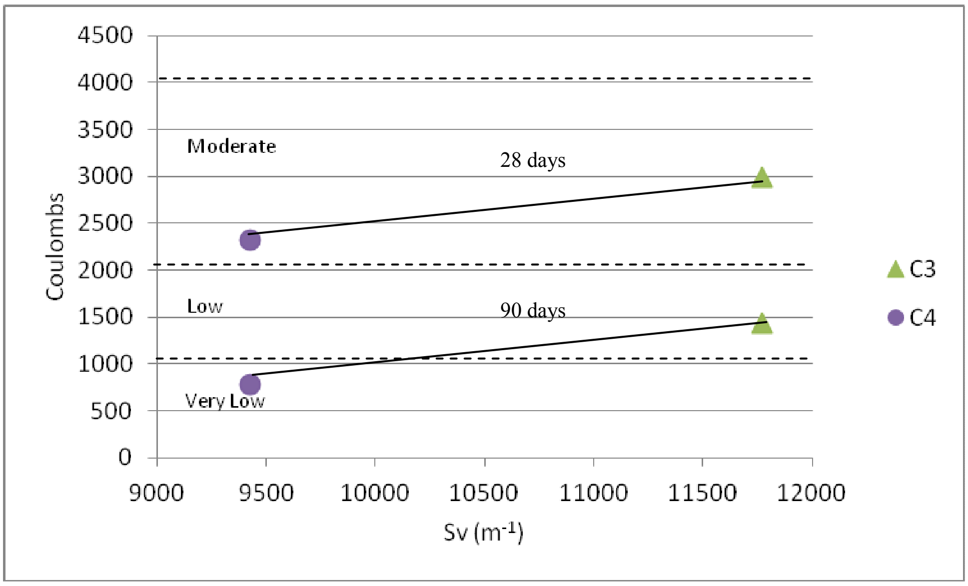


Figure 39: Chloride ion permeability vs. surface density of aggregate (Sv)

Table 19: Standard deviation of chloride ion permeability

| Age | 28 | 90 |
|---|---|---|
| C3 | 256.7 | 5.1 |
| C4 | 391.1 | 0.8 |

5.5.4.5. Comparative analysis

It is also of interest determine which factor (natural pozzolans or amount of ITZ) has the greater effect on concrete permeability. C1, concrete mixture with OPC was chosen as the control mixture for analysing the effect of the natural pozzolans, and C3, concrete mixture with the lowest amount of ITZ, was chosen as the control mixture for analysing the effect of ITZ. Figure 40 shows the relative effect of each factor on compressive strength.

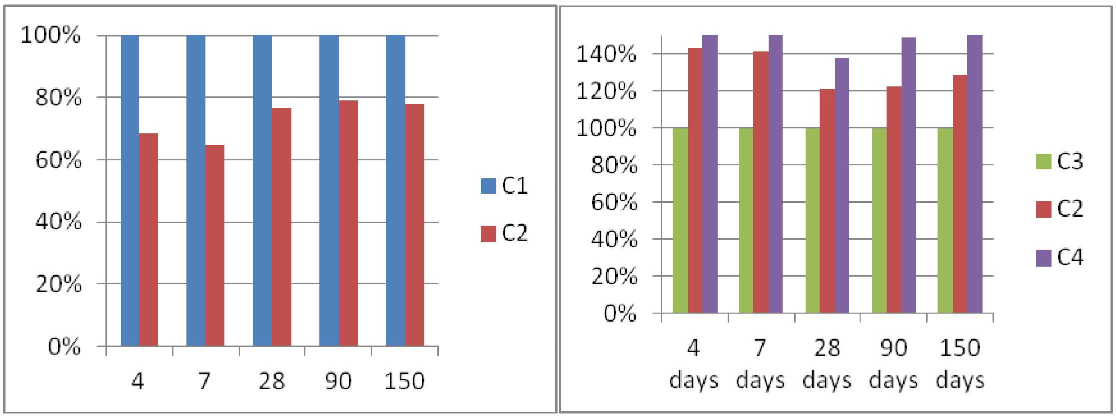


Figure 40: Effect of the use of natural pozzolans and change in amount of ITZ in compressive strength

For compressive strength, the efficiency of concrete with blended cement (68% OPC + 38% of natural pozzolans) ranged between 65 and 79% of that obtained for concrete with OPC only (C2 versus C1). It should be pointed out that there is an improvement in the efficiency of mixtures with blended cement after the first week, but it seems to stabilize after 28 days. On the other hand, the efficiency of concrete with more ITZ (Sv=11770 $m^{-1}$) was approximately 65% of that obtained for concrete with less ITZ (Sv=9426 $m^{-1}$) (C3 versus C4), and no clear improvement was observed at later ages. The effects of using blended cement with 38% of natural pozzolans or increasing the amount of ITZ by 44% seem to be on the same order of magnitude.

Fig. 41 shows the relative effect of the use of natural pozzolans and amount of ITZ on sorptivity coefficient.

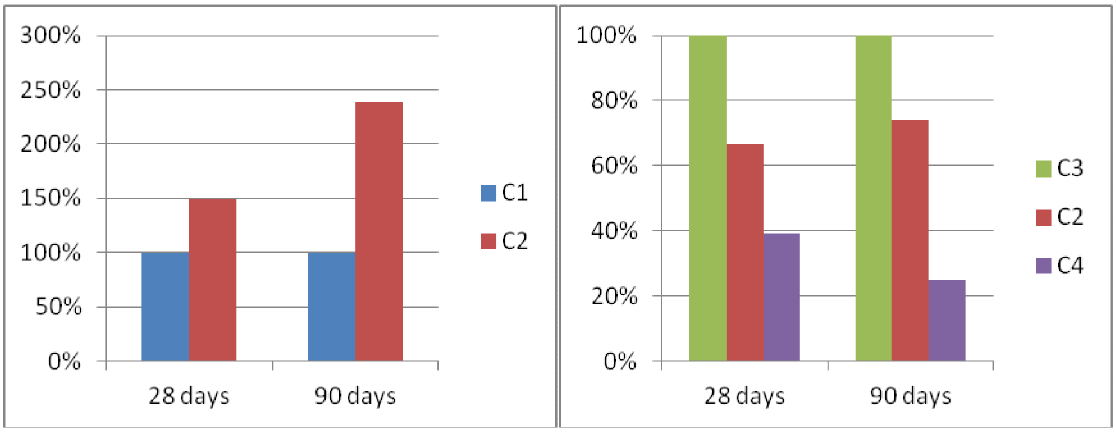


Figure 41: Effect of the use of natural pozzolans and change in amount of ITZ in sorptivity

When the amount of paste is considered in the measurements, concrete with blended cement (68% OPC+ 38% natural pozzolans) had a greater sorptivity coefficient than that of concrete with OPC only (C1 versus C2). The increase in sorptivity coefficient ranged between 50 and 140% at 28 and 90 days of age, respectively when natural pozzolans were considered. On the other hand, the decrease in ITZ decreased sorptivity coefficient by 60 and 75% at 28 and 90 days of age, respectively (C3 versus C4). Since sorptivity coefficient of C1 (without natural pozzolans) was similar to that of C4 (with natural pozzolans and lower ITZ), it can be concluded that using blended cement with

38% of natural pozzolans or decreasing the amount of ITZ by 20% have a similar effect in magnitude on sorptivity coefficient of concrete.

Fig. 15 shows the relative effect of the use of natural pozzolans and amount of ITZ on air permeability.

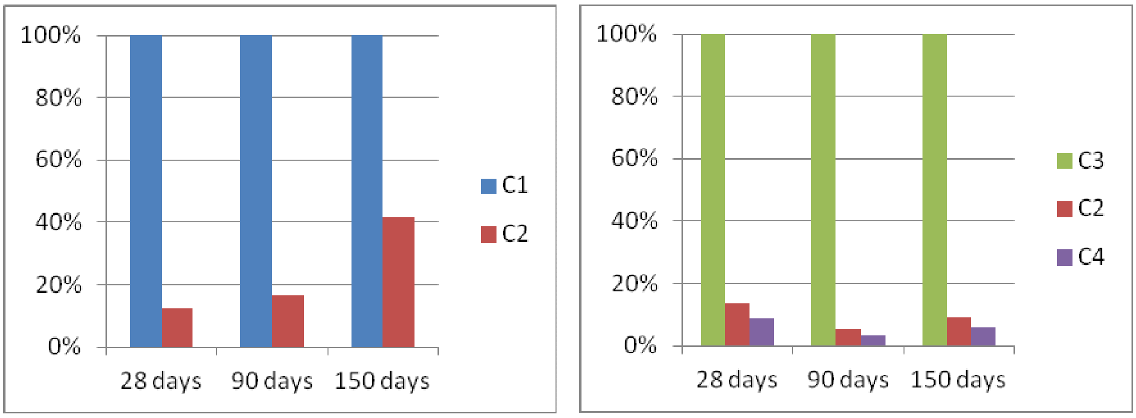


Figure 42: Effect of the use of natural pozzolans and change in amount of ITZ in air permeability

Air permeability showed a greater sensitivity to the factor under study than compressive strength and sorptivity coefficient. Oppositely to what was observed for sorptivity coefficient, concrete with blended cement (68% OPC+ 38% natural pozzolans) had much lower air permeability than that of concrete with OPC only (C1 versus C2). The use of blended cement decreased air permeability by 27%. On the other hand, the increase in ITZ greatly increased air permeability by 94% (C3 versus C4). In this case, using blended cement with 38% of natural pozzolans or increasing the amount of ITZ by 44% had opposite effects on concrete performance.

Overall, it can be stated that the use of blended cement with natural pozzolans has an opposite effect in compressive strength than in air permeability.

Additionally, the effect of the amount of ITZ is of much more impact on air permeability than in compressive strength. Fig. 16 compares the variation in compressive strength and air permeability for all four mixtures under investigation.

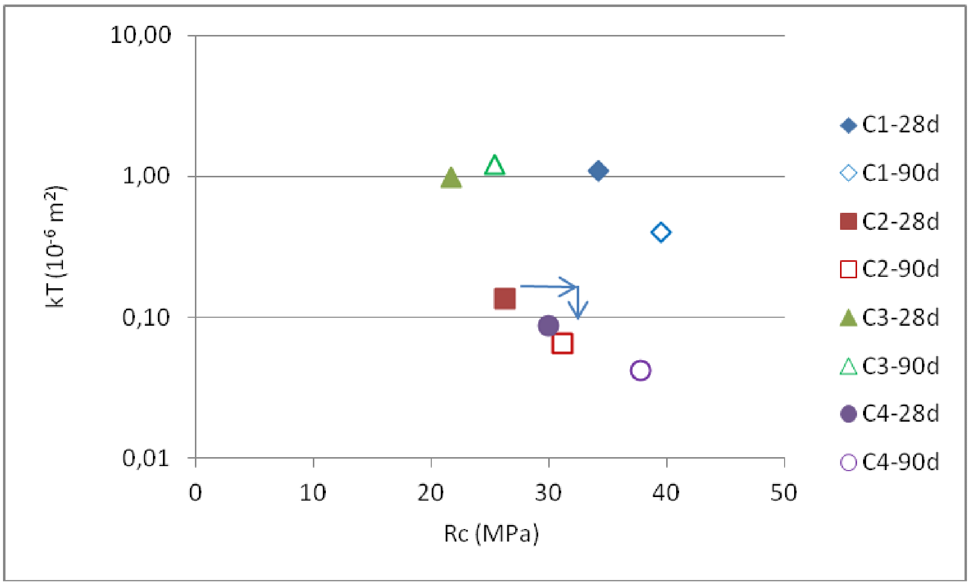


Figure 43: Compressive strength vs. air permeability (log scale)

Compressive strength and air permeability are greatly affected by the type of cement and amount of ITZ as shown by the wide range in both variables in Fig. 16. Compressive strength varied from 20 to 40 MPa and air permeability from 0.05 to 1.1 x $10^{-6}$ $m^2$ for mixtures under investigation in despite of all having a w/b at 0.5. It is concluded that the type of cement and amount of ITZ are as important as w/b in determining compressive strength and air permeability.

Compressive strength and air permeability are not directly dependent on one another. For instance, C1 at 90 days had a compressive strength of 40 MPa and air permeability of 0.8 x $10^{-6}$ $m^2$, and C2 at 28 days a compressive strength of 25 MPa and air permeability of 0.2 x $10^{-6}$ $m^2$; the effect in air permeability is greater than the effect in compressive strength. Thus, specifying a high strength concrete does not mean that air permeability, and ultimately, durability are adequate.

## 5.5. Concluding Remarks

Environmental and economic issues have increased the interest of creating more durable buildings and infrastructure. Concrete may greatly contribute to this goal by reducing its permeability.

This research aimed to determine the effect of using blended cement (OPC + natural pozzolans) and varying the amount of ITZ in reducing the permeability of concrete.

The use of blended cement with natural pozzolans decreased air permeability and chloride ion permeability by 84 and 66% respectively, but increased sorptivity coefficient between 28 and 90 days of age by 50 and 140%.

An increase in the amount of ITZ, represented by surface density of the aggregate, decreased compressive strength and increased sorptivity coefficient and chloride ion permeability, but the increase in air permeability is significantly sensible achieving 90% of reduction at every age.

Permeability, and particularly air permeability, seems to be very sensitive to changes in the amount of ITZ even at constant w/b and cement type. It is concluded that considering ITZ, represented by surface density of the aggregate, becomes important in controlling permeability of concrete.

The surface density from the stereological approach is an accurate alternative for assessing ITZ in concrete since the amount of ITZ does not linearly depend on aggregate content and it is not well represented by assuming aggregate particles as spheres. Furthermore, an appropriate magnification for the micrographs must be chosen.

Even though compressive strength and permeability are affected by the use of natural pozzolans and changes in the amount of ITZ, those effects vary importantly. This means that an increase in strength does not necessarily imply a decrease in permeability, so minimizing permeability for a durable concrete is not equivalent to maximizing its compressive strength.

An adequate mixture design is very important in achieving a durable concrete. Mixtures with lower aggregate content will have lower permeability and better durability. Also, the use of SCMs, such as natural pozzolans, might not be enough to reduce permeability of concrete if concrete includes a large amount of aggregate (i.e., ITZ).

### 5.6 Acknowledgements

Authors greatly acknowledge the support given by the FONDEF (Fund for scientific and technological development) through Project D07I1076, especially to the Director Carlos Videla and Associate Director Patricia Martínez. Additionally, authors also thank the support from Dictuc S.A., Instituto del Cemento y del Hormigón de Chile (ICH), and Universidad de Valparaíso.

## 6. CONCLUSIONS

From the testing of concrete structures, it was found that adequate compressive strength does not imply adequate performance in terms of it durability.

In terms of performance characterization of existent structures, old structures seems to have a better performance in terms of it durability, independently of exposure conditions, even when they have lower values for compressive strength, air permeability, sorptivity coefficients and chloride ion permeability values are similar or better than values for new structures. Also, even when corrosion potential are of concern for both ages classification, diffusion coefficients are better for old structures.

Related to test methods, air permeability test was not suitable for assessing permeability on existing structures due it dispersion in results. Since its behavior in laboratory is good enough, air permeability test seems to be sensitivity to cracks and micro-cracks present most of time in existing structures' cover, but it needs to be demonstrated.

In terms of sorptivity test, although it is influenced by several factors that were not known at the moment of measurement, when a comparison between concretes from a same mix is made, it could be a good index.

Chloride ion permeability seems to be the most acceptable test to evaluate existent structures. However, a reduction in voltage applied is suggested in order to minimize the rise of temperature among the test, what increase conductivity importantly.

Carbon dioxide and chloride coefficient diffusion are good index of damage and quality of concrete and can be very useful to estimate the real risk of presence of corrosion.

Carbonated layer at concrete surface do not influence sorptivity and chloride ion diffusion significantly, so measuring such properties on carbonated structures is representative of concrete performance without carbonation

From initial results taken in walls for long-term study, it is noticed that execution process plays an important role in achieved a determine objective. Even when significant differences were detected in mechanical property results between Santiago and Valparaiso, permeability values did not follow the same pattern. Also, it is noticed that w/b plays and important role too in permeability performance.

Use of natural pozzolans as well as different amounts of aggregates plays an important role in permeability of concrete. Although the effect of use different amounts of aggregates seems to be of great importance, this can not be generalized since just one w/b was analized. Nevertheless, using natural pozzolans and low amounts of aggregate can improve performance of concrete importantly.

The use of blended cement with natural pozzolans decreased air permeability and chloride ion permeability but, increase sorptivity between 28 and 90 days of age by 50 and 140%. This unexpected increase in sorptivity coefficient does not necessarily mean higher permeability or a more interconnected pore structure in concrete containing NP. The measured increase in sorptivity coefficient might be a consequence of lower internal relative humidity of concrete with NP before testing. This needs to be further investigated.

An increase in ITZ amount, represented by surface density of the aggregate, decreased compressive strength and increase sorptivity, air permeability, and chloride ion permeability significantly.

Permeability, and particularly air permeability, seems to be very sensitive to changes in the amount of ITZ even at constant w/b and cement type. It is concluded that considering ITZ, represented by surface density of the aggregate becomes important in controlling permeability of concrete.

Even though compressive strength and permeability are affected by the use of natural pozzolans and change in ITZ amount, those effect vary importantly. This means that an increase in strength not necessarily implies a decrease in permeability, so minimizing permeability for a durable concrete is not equivalent to maximize its compressive strength.

It is noticed that a mixture design is very important to achieve a durable concrete. Mixtures with less aggregate content will have a great performance. Also, the use of natural pozzolans can be insufficient to reduce permeability of concrete if there is an important amount of aggregate. Therefore, concretes with Portland cement and different aggregate content are needed to determine it.

Considering that some properties have been considered important in establish an adequate performance, specification in terms of it durability seems to be necessary.

More investigation of the effect of natural pozzolans is still necessary. Concretes with Portland cement have to be done with different aggregate content.

The effect of w/b deserves more investigation too because in this research just one w/b (0.5) was used. This is also noticed from the preliminary results from walls measurements because differences in terms of concrete performance are detected.

Estimation of aggregate surface must be improved because differences with reality may be important. Bigger magnification and more image prosecution are necessary.

Finally, more measurement in existing concrete structures are needed to calibrate models and estimate the real performance more accurately.

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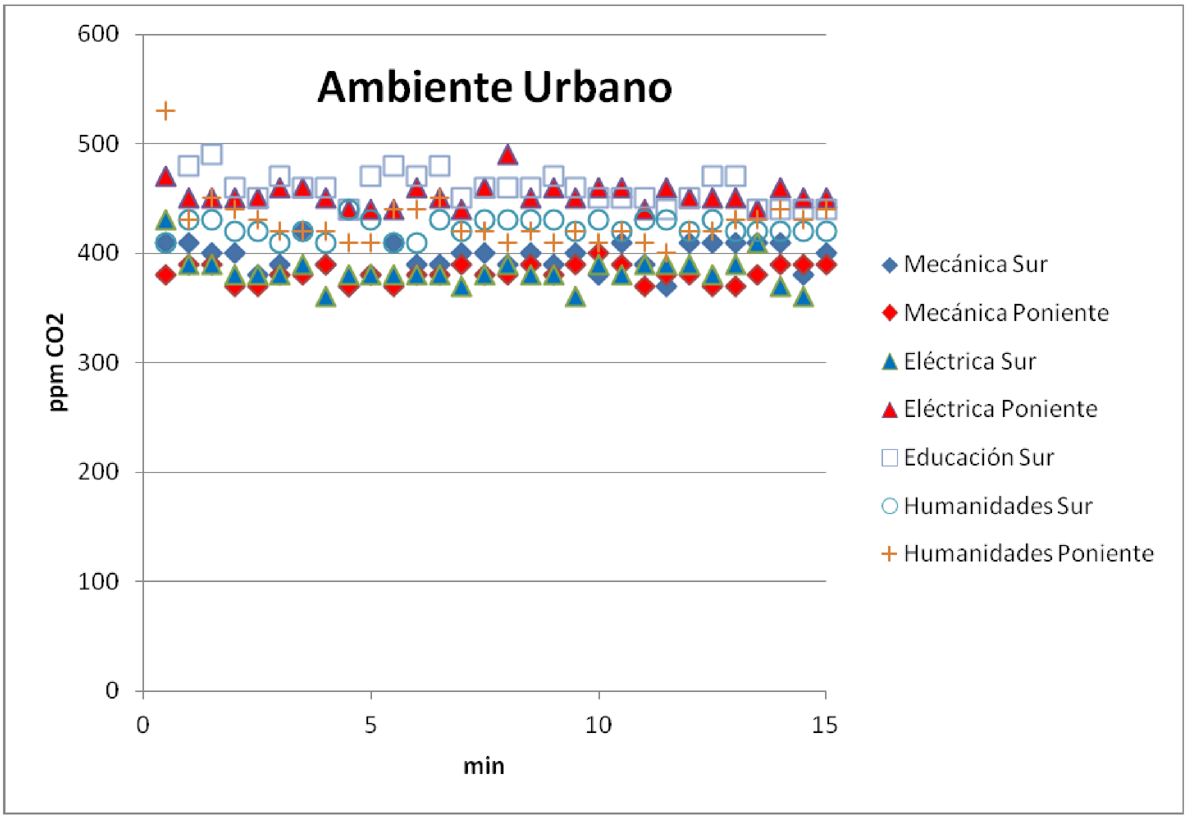
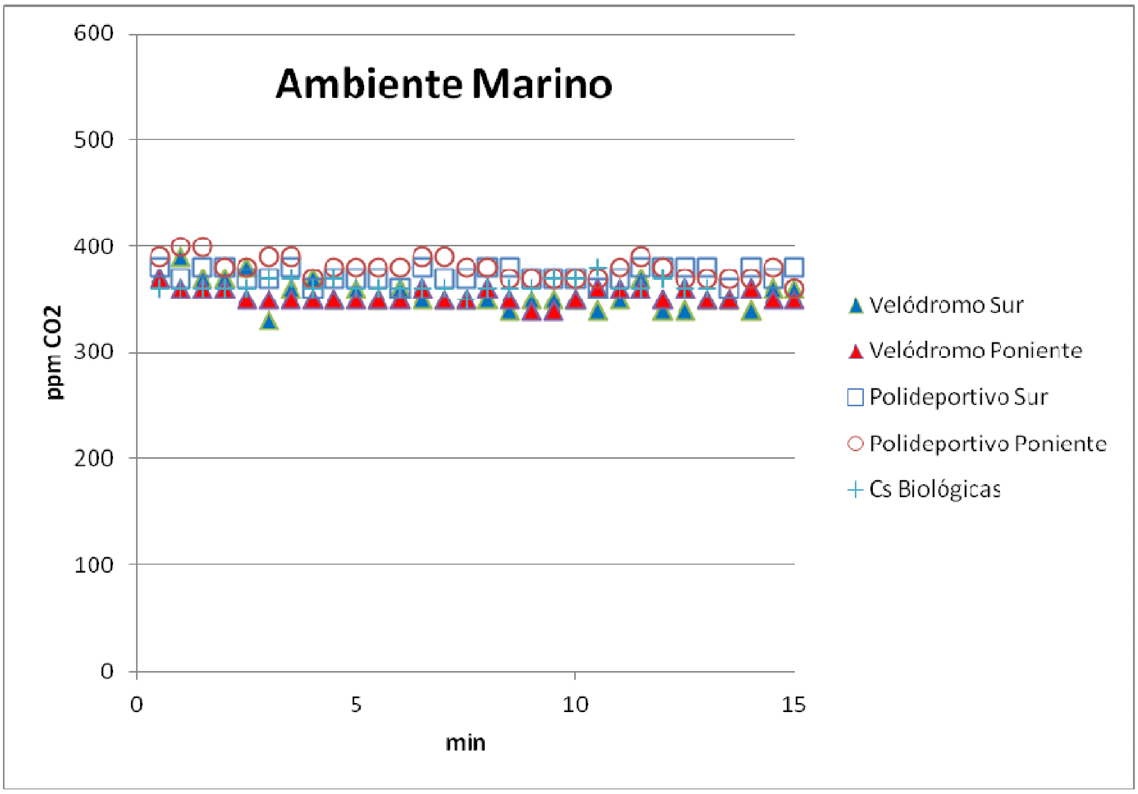
# APPENDICES

# APPENDIX A: STRUCTURE TESTING

Carbon dioxide measurements



# Resistivity

Mecánica
Método Wenner

| | Fachada Poniente | | | | | | Fachada Sur | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Punto | M1 | | M2 | | M3 | | M1 | | M2 | | M3 | |
| Distancia entre electrodos (cm) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Resistencia eléctrica B (kΩ) | 180 | 350 | 920 | 1100 | 1100 | 720 | 200 | 31 | 350 | 240 | 1000 | 850 |
| Resistividad B (kΩ*cm) | 3393 | 6597 | 17341,6 | 20734,5 | 20734,5 | 13572 | 3770 | 584,3 | 6597 | 4524 | 18850 | 16022 |
| Riesgo corrosión | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO |

Eléctrica
Método Wenner

| | Fachada Poniente | | | | | | Fachada Sur | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Punto | M1 | | M2 | | M3 | | M1 | | M2 | | M3 | |
| Distancia entre electrodos (cm) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Resistencia eléctrica B (kΩ) | 74 | 870 | 160 | 1100 | 85 | 1500 | 90 | 99 | 370 | 270 | 57 | 80 |
| Resistividad B (kΩ*cm) | 1395 | 16399 | 3015,93 | 20734,5 | 1602,212 | 28274 | 1696 | 1866 | 6974 | 5089 | 1074,4 | 1508 |
| Riesgo corrosión | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO |

Educación
Método Wenner

| | Fachada Poniente | | | | | | Fachada Sur | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Punto | M1 | | M2 | | M3 | | M1 | | M2 | | M3 | |
| Distancia entre electrodos (cm) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Resistencia eléctrica B (kΩ) | 850 | 1100 | 1100 | 1100 | 1100 | 1100 | 24 | 27 | 95 | 350 | 190 | 200 |
| Resistividad B (kΩ*cm) | 16022 | 20735 | 20735 | 20735 | 20734,51 | 20735 | 452,4 | 508,9 | 1791 | 6597 | 3581 | 3770 |
| Riesgo corrosión | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO |

Humanidades
Método Wenner

| | Fachada Poniente | | | | | | Fachada Sur | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Punto | M1 | | M2 | | M3 | | M1 | | M2 | | M3 | |
| Distancia entre electrodos (cm) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Resistencia eléctrica B (kΩ) | 180 | 103 | 160 | 240 | 140 | 660 | 630 | 480 | 695 | 700 | 760 | 320 |
| Resistividad B (kΩ*cm) | 3392,9 | 1942 | 3016 | 4524 | 2638,938 | 12441 | 11875 | 9048 | 13100 | 13195 | 14326 | 6032 |
| Riesgo corrosión | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO |

Polideportivo

Método Wenner

| | Fachada Poniente | | | | | | Fachada Sur | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Punto | M1 | | M2 | | M3 | | M1 | | M2 | | M3 | |
| Distancia entre electrodos (cm) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Resistencia eléctrica B (kΩ) | 56 | 150 | 330 | 260 | 230 | 260 | 2 | 4,5 | 9 | 10,8 | 14 | 15 |
| Resistividad B (kΩ*cm) | 1056 | 2827 | 6220,35 | 4900,88 | 4335,398 | 4900,9 | 37,7 | 84,82 | 169,6 | 203,6 | 263,89 | 282,7 |
| Riesgo corrosión | POCO | POCO | POCO | POCO | POCO | POCO | )DERA | )DERA | )DERA | POCO | POCO | POCO |

Muros Contención

Método Wenner

| | Fachada Derecha | | | | | | Fachada Izquierda | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Punto | M1 | | M2 | | M3 | | M1 | | M2 | | M3 | |
| Distancia entre electrodos (cm) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Resistencia eléctrica B (kΩ) | 100 | 45 | 81 | 64 | 87 | 50 | 59 | 88 | 65 | 36 | 50 | 96 |
| Resistividad B (kΩ*cm) | 1885 | 848,2 | 1526,81 | 1206,37 | 1639,911 | 942,48 | 1112 | 1659 | 1225 | 678,6 | 942,48 | 1810 |
| Riesgo corrosión | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO |

Método Wenner

| | Fachada Poniente | | | | | | Fachada Sur | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Punto | M1 | | M2 | | M3 | | M1 | | M2 | | M3 | |
| Distancia entre electrodos (cm) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Resistencia eléctrica B (kΩ) | 20 | 100 | 180 | 50 | 940 | 25 | 37 | 16 | 80 | 55 | 24 | 47 |
| Resistividad B (kΩ*cm) | 376,99 | 1885 | 3393 | 942,5 | 17718,6 | 471,2 | 697,4 | 301,6 | 1508 | 1037 | 452,4 | 885,9 |
| Riesgo corrosión | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO |

Auditorium

Método Wenner

| | Fachada Poniente | | | | | | Fachada Sur | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Punto | M1 | | M2 | | M3 | | M1 | | M2 | | M3 | |
| Distancia entre electrodos (cm) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Resistencia eléctrica B (kΩ) | 99 | 45 | 110 | 80 | 100 | 70 | 13 | 11 | 14 | 40 | 24 | 59 |
| Resistividad B (kΩ*cm) | 1866,1 | 848,2 | 2073 | 1508 | 1884,956 | 1319 | 245 | 207,3 | 263,9 | 754 | 452,4 | 1112 |
| Riesgo corrosión | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO | POCO |

## Ultrasonic pulse velocity

Mecánica

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 22-06-2010 | 22-06-2010 | 22-06-2010 | 22-06-2010 | 22-06-2010 | 22-06-2010 |
| Hora | | | | | | |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Transmisión onda directa | | | | | | |
| Transmisión onda semi directa | | | | | | |
| Transmisión onda indirecta | X | X | X | X | X | X |
| Espesor capa carbonatada (mm) | | | | | | |
| Superficie pulida (Si o No) | No | No | No | No | No | No |
| Distancia electrodos (m) | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 |
| | | | | | | |
| Tiempo transiente 1(µs) | 45,9 | 65,1 | 58,4 | 38,5 | 70,7 | 51,6 |
| Tiempo transiente 2(µs) | 46,2 | 61,9 | 58,2 | 37,2 | 71 | 51,1 |
| Tiempo transiente 3(µs) | 44 | 63,3 | 58,2 | 38,4 | 70,9 | 50,9 |
| Tiempo transiente 4(µs) | 45,1 | 64,1 | 58,3 | 38,7 | 71,2 | 50,6 |
| Tiempo transiente 5(µs) | 46,3 | 63,8 | 58,1 | 37,1 | 71,4 | 49,8 |
| Tiempo transiente 6(µs) | 45,7 | 64,3 | 57,6 | 38,6 | 70,9 | 51,1 |
| Tiempo transiente 7(µs) | 46 | 63,5 | 58 | 37,2 | 71,3 | 50,6 |
| Tiempo transiente 8(µs) | 45,9 | 63,6 | 58,1 | 38,1 | 71,4 | 50,3 |
| Tiempo transiente 9(µs) | 45,8 | 61,1 | 57,7 | 37,3 | 71,2 | 49,7 |
| Tiempo transiente 10(µs) | 46,3 | 63,6 | 58,2 | 38,4 | 71,6 | 50,4 |
| Promedio tiempo transiente (µs) | 45,72 | 63,43 | 58,08 | 37,95 | 71,16 | 50,61 |
| Promedio VPU (m/s) | 4374,453 | 3153,082 | 3443,526 | 5270,092 | 2810,568 | 3951,788 |
| Desviación estándar tiempo (µs) | 0,699 | 1,154 | 0,253 | 0,665 | 0,280 | 0,593 |
| Coeficiente de variación (%) | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| Calidad del hormigón | DURABLE | ALTA | ALTA | DURABLE | NORMAL | ALTA |

Eléctrica

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 22-06-2010 | 22-06-2010 | 22-06-2010 | 22-06-2010 | 22-06-2010 | 22-06-2010 |
| Hora | | | | | | |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Transmisión onda directa | | | | | | |
| Transmisión onda semi directa | | | | | | |
| Transmisión onda indirecta | X | X | X | X | X | X |
| Espesor capa carbonatada (mm) | | | | | | |
| Superficie pulida (Si o No) | No | No | No | No | No | No |
| Distancia electrodos (m) | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 |
| Tiempo transiente 1(µs) | 115,6 | 90,2 | 113,7 | 77,9 | 98,2 | 103,1 |
| Tiempo transiente 2(µs) | 87,9 | 90,4 | 114,7 | 75 | 98,1 | 103,9 |
| Tiempo transiente 3(µs) | 90,5 | 89,3 | 120 | 76,4 | 97,5 | 104,2 |
| Tiempo transiente 4(µs) | 89,4 | 89,9 | 115,2 | 78,2 | 97,4 | 104,3 |
| Tiempo transiente 5(µs) | 90,5 | 89,1 | 114,7 | 82 | 97,8 | 104,4 |
| Tiempo transiente 6(µs) | 85,3 | 87,1 | 116,2 | 74,1 | 98,2 | 104,2 |
| Tiempo transiente 7(µs) | 87,8 | 88,3 | 117,1 | 77,1 | 96,4 | 103,1 |
| Tiempo transiente 8(µs) | 85,4 | 88,5 | 116,5 | 74,5 | 97,5 | 104,5 |
| Tiempo transiente 9(µs) | 87,6 | 87,7 | 114,2 | 76,1 | 97,3 | 104,1 |
| Tiempo transiente 10(µs) | 90,1 | 87,3 | 115,4 | 74,7 | 95,8 | 103,9 |
| Promedio tiempo transiente (µs) | 91,01 | 88,78 | 115,77 | 76,6 | 97,42 | 103,97 |
| Promedio VPU (m/s) | 2197,561 | 2252,760 | 1727,563 | 2610,966 | 2052,967 | 1923,632 |
| Desviación estándar tiempo (µs) | 8,846 | 1,191 | 1,822 | 2,375 | 0,783 | 0,497 |
| Coeficiente de variación (%) | 0,004 | 0,001 | 0,001 | 0,001 | 0,000 | 0,000 |
| Calidad del hormigón | NORMAL | NORMAL | DEFICIENTE | NORMAL | NORMAL | DEFICIENTE |

Educación

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 07-07-2010 | | | 22-06-2010 | 22-06-2010 | 22-06-2010 |
| Hora | | | | | | |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Transmisión onda directa | | | | | | |
| Transmisión onda semi directa | | | | | | |
| Transmisión onda indirecta | X | X | X | X | X | X |
| Espesor capa carbonatada (mm) | | | | | | |
| Superficie pulida (Si o No) | No | No | No | No | No | No |
| Distancia electrodos (m) | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 |
| Tiempo transiente 1(μs) | 78 | 68,2 | 66,8 | 46,5 | 56,3 | 69,5 |
| Tiempo transiente 2(μs) | 77,5 | 67,5 | 66,7 | 46,8 | 56,1 | 72 |
| Tiempo transiente 3(μs) | 76,1 | 65,3 | 66,8 | 46,7 | 56,1 | 71,1 |
| Tiempo transiente 4(μs) | 75,4 | 66,7 | 66,6 | 45,6 | 55,9 | 70,4 |
| Tiempo transiente 5(μs) | 75,9 | 65,5 | 66,7 | 45,8 | 56,2 | 67,2 |
| Tiempo transiente 6(μs) | 77,8 | 65,4 | 66,8 | 45,5 | 55,3 | 67,5 |
| Tiempo transiente 7(μs) | 77,3 | 64,7 | 66,4 | 45,1 | 56,4 | 67,1 |
| Tiempo transiente 8(μs) | 76,2 | 64,5 | 66,9 | 44,9 | 56,7 | 68,2 |
| Tiempo transiente 9(μs) | 76,1 | 63,9 | 66,5 | 45,8 | 56,6 | 66,5 |
| Tiempo transiente 10(μs) | 74,8 | 64,1 | 66,9 | 45,2 | 56,8 | 67,9 |
| Promedio tiempo transiente (μs) | 76,51 | 65,58 | 66,71 | 45,79 | 56,24 | 68,74 |
| Promedio VPU (m/s) | 2614,037 | 3049,710 | 2998,051 | 4367,766 | 3556,188 | 2909,514 |
| Desviación estándar tiempo (μs) | 1,077 | 1,448 | 0,166 | 0,674 | 0,438 | 1,890 |
| Coeficiente de variación (%) | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Calidad del hormigón | NORMAL | ALTA | NORMAL | DURABLE | ALTA | NORMAL |

Humanidades

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 22-06-2010 | 22-06-2010 | 22-06-2010 | 22-06-2010 | 22-06-2010 | 22-06-2010 |
| Hora | | | | | | |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Transmisión onda directa | | | | | | |
| Transmisión onda semi directa | | | | | | |
| Transmisión onda indirecta | X | X | X | X | X | X |
| Espesor capa carbonatada (mm) | | | | | | |
| Superficie pulida (Si o No) | No | No | No | No | No | No |
| Distancia electrodos (m) | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 |
| Tiempo transiente 1(µs) | 49,9 | 49,6 | 47 | 61,1 | 56,8 | 54,5 |
| Tiempo transiente 2(µs) | 50 | 49,5 | 46,9 | 61 | 56,9 | 59,1 |
| Tiempo transiente 3(µs) | 49,7 | 49,2 | 47,1 | 60,7 | 54,5 | 58,7 |
| Tiempo transiente 4(µs) | 49,8 | 49,1 | 46,8 | 60,9 | 54,7 | 56,6 |
| Tiempo transiente 5(µs) | 49,6 | 49,3 | 46,9 | 61,1 | 56,4 | 57,9 |
| Tiempo transiente 6(µs) | 49,7 | 49,4 | 46,7 | 61,9 | 56,3 | 57,4 |
| Tiempo transiente 7(µs) | 49,6 | 50,1 | 46,1 | 61,2 | 56,5 | 57,1 |
| Tiempo transiente 8(µs) | 49,3 | 50,3 | 46,3 | 60,5 | 57 | 56,2 |
| Tiempo transiente 9(µs) | 49,4 | 50,6 | 45,9 | 61,3 | 56,8 | 55,4 |
| Tiempo transiente 10(µs) | 49,5 | 50,5 | 45,8 | 61,4 | 56,2 | 55,3 |
| Promedio tiempo transiente (µs) | 49,65 | 49,76 | 46,55 | 61,11 | 56,21 | 56,82 |
| Promedio VPU (m/s) | 4028,197 | 4019,293 | 4296,455 | 3272,787 | 3558,086 | 3519,887 |
| Desviación estándar tiempo (µs) | 0,217 | 0,562 | 0,481 | 0,387 | 0,890 | 1,508 |
| Coeficiente de variación (%) | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| Calidad del hormigón | DURABLE | DURABLE | DURABLE | ALTA | ALTA | ALTA |

Polideportivo

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 29-07-2010 | | | 29-07-2010 | | |
| Hora | | | | | | |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Transmisión onda directa | | | | | | |
| Transmisión onda semi directa | | | | | | |
| Transmisión onda indirecta | X | X | X | X | X | X |
| Espesor capa carbonatada (mm) | | | | | | |
| Superficie pulida (Si o No) | No | No | No | No | No | No |
| Distancia electrodos (m) | 0,15 | 0,15 | 0,15 | 0,15 | 0,15 | 0,15 |
| | | | | | | |
| Tiempo transiente 1(µs) | 62,2 | 52,5 | 60,7 | 84,6 | 90,3 | 117,2 |
| Tiempo transiente 2(µs) | 61,4 | 52,3 | 60,2 | 84,4 | 89,6 | 117,1 |
| Tiempo transiente 3(µs) | 60,7 | 51,2 | 59,7 | 84,2 | 89,7 | 117,4 |
| Tiempo transiente 4(µs) | 59,4 | 51,3 | 59,3 | 84,6 | 89,3 | 117,1 |
| Tiempo transiente 5(µs) | 59,9 | 51,4 | 59,4 | 84,5 | 88,7 | 117,2 |
| Tiempo transiente 6(µs) | 60,1 | 49,4 | 59,2 | 84,7 | 87,9 | 117 |
| Tiempo transiente 7(µs) | 59,7 | 48,7 | 58,9 | 84,1 | 87,6 | 116,8 |
| Tiempo transiente 8(µs) | 59,9 | 48,7 | 59,1 | 83,8 | 87,3 | 117,2 |
| Tiempo transiente 9(µs) | 59,9 | 48,3 | 59,4 | 83,4 | 86,7 | 117,1 |
| Tiempo transiente 10(µs) | 59,7 | 48,5 | 59,2 | 83,6 | 86,5 | 117,3 |
| Promedio tiempo transiente (µs) | 60,29 | 50,23 | 59,51 | 84,19 | 88,36 | 117,14 |
| Promedio VPU (m/s) | 2487,975 | 2986,263 | 2520,585 | 1781,684 | 1697,601 | 1280,519 |
| Desviación estándar tiempo (µs) | 0,884 | 1,666 | 0,551 | 0,456 | 1,343 | 0,165 |
| Coeficiente de variación (%) | 0,000 | 0,001 | 0,000 | 0,000 | 0,001 | 0,000 |
| Calidad del hormigón | NORMAL | NORMAL | NORMAL | DEFICIENTE | DEFICIENTE | DEFICIENTE |

Chiledeportes

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | | | | | | |
| Hora | | | | | | |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Transmisión onda directa | | | | | | |
| Transmisión onda semi directa | | | | | | |
| Transmisión onda indirecta | X | X | X | X | X | X |
| Espesor capa carbonatada (mm) | | | | | | |
| Superficie pulida (Si o No) | No | No | No | No | No | No |
| Distancia electrodos (m) | 0,18 | 0,18 | 0,18 | 0,18 | 0,18 | 0,18 |
| Tiempo transiente 1(µs) | 47,5 | 63,5 | 64,9 | 48,9 | 52,3 | 49,2 |
| Tiempo transiente 2(µs) | 47 | 63,4 | 62,4 | 47 | 52,9 | 48 |
| Tiempo transiente 3(µs) | 46,3 | 65,3 | 65 | 46,6 | 53,1 | 46,5 |
| Tiempo transiente 4(µs) | 46,3 | 51,1 | 66,6 | 46,7 | 53 | 48,7 |
| Tiempo transiente 5(µs) | 46,2 | 49,3 | 66,1 | 46,5 | 53,5 | 49,6 |
| Tiempo transiente 6(µs) | 39 | 52,6 | 60,7 | 46,8 | 53,5 | 46,5 |
| Tiempo transiente 7(µs) | 45,7 | 62,1 | 61,7 | 46,5 | 53,3 | 48,7 |
| Tiempo transiente 8(µs) | 45,7 | 49,4 | 61,2 | 48,7 | 52,7 | 53,5 |
| Tiempo transiente 9(µs) | 46,2 | 49,9 | 69,3 | 48,6 | 53,2 | 51,1 |
| Tiempo transiente 10(µs) | 45,3 | 49,1 | 68,4 | 48,4 | 53,4 | 50,8 |
| Promedio tiempo transiente (µs) | 45,52 | 55,57 | 64,63 | 47,47 | 53,09 | 49,26 |
| Promedio VPU (m/s) | 3954,306 | 3239,158 | 2785,084 | 3791,869 | 3390,469 | 3654,080 |
| Desviación estándar tiempo (µs) | 2,378 | 7,006 | 3,038 | 1,033 | 0,381 | 2,142 |
| Coeficiente de variación (%) | 0,001 | 0,002 | 0,001 | 0,000 | 0,000 | 0,001 |
| Calidad del hormigón | ALTA | ALTA | NORMAL | ALTA | ALTA | ALTA |

Muro Contención

| | Lado Derecho | | | Lado Izquierdo | | |
|---|---|---|---|---|---|---|
| Fecha | 11-11-2010 | | | 11-11-2010 | | |
| Hora | | | | | | |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Transmisión onda directa | | | | | | |
| Transmisión onda semi directa | | | | | | |
| Transmisión onda indirecta | X | X | X | X | X | X |
| Espesor capa carbonatada (mm) | | | | | | |
| Superficie pulida (Si o No) | No | No | No | No | No | No |
| Distancia electrodos (m) | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 |
| Tiempo transiente 1(µs) | 54,1 | 60,4 | 73,6 | 60,1 | 52,5 | 57,6 |
| Tiempo transiente 2(µs) | 54 | 59 | 73 | 60,2 | 51,2 | 57,3 |
| Tiempo transiente 3(µs) | 54 | 45,3 | 74,3 | 59,9 | 51 | 56,3 |
| Tiempo transiente 4(µs) | 54 | 58,5 | 74,4 | 59,6 | 51,1 | 57 |
| Tiempo transiente 5(µs) | 53,9 | 54,3 | 73,8 | 58,6 | 50,9 | 57,5 |
| Tiempo transiente 6(µs) | 49,6 | 29 | 73,9 | 59,5 | 52,7 | 57,3 |
| Tiempo transiente 7(µs) | 54,3 | 50,6 | 73,5 | 59,6 | 52,4 | 81,5 |
| Tiempo transiente 8(µs) | 54,6 | 50,8 | 73,7 | 60,1 | 52,1 | 56,7 |
| Tiempo transiente 9(µs) | 54,5 | 14,3 | 73,5 | 59,7 | 52,3 | 56,5 |
| Tiempo transiente 10(µs) | 55,1 | 48,6 | 73,6 | 59,4 | 52,4 | 57,5 |
| Promedio tiempo transiente (µs) | 53,81 | 47,08 | 73,73 | 59,67 | 51,86 | 59,52 |
| Promedio VPU (m/s) | 3716,781 | 4248,088 | 2712,600 | 3351,768 | 3856,537 | 3360,215 |
| Desviación estándar tiempo (µs) | 1,525 | 14,664 | 0,406 | 0,467 | 0,717 | 7,736 |
| Coeficiente de variación (%) | 0,000 | 0,003 | 0,000 | 0,000 | 0,000 | 0,002 |
| Calidad del hormigón | ALTA | DURABLE | NORMAL | ALTA | ALTA | ALTA |

Esclerometric index

**Mecánica**

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 14-06-2010 | | | 14-06-2010 | | |
| Hora | | | | | | |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Posición esclerómetro | orizont | orizont | orizont | orizont | orizont | orizontal |
| Rugosidad superficial (lisa o áspera) | Áspera | Áspera | Áspera | Áspera | Áspera | Áspera |
| Condición superficial (seca o húmeda) | Seca | Seca | Seca | Seca | Seca | Seca |
| Superficie carbonatada (si o no) | Si | Si | Si | Si | Si | Si |
| Superficie pulida (si o no) | No | No | No | No | No | No |
| Rebote 1 | 53 | 44 | 36 | 56 | 49 | 38 |
| Rebote 2 | 48 | 41 | 39 | 49 | 46 | 36 |
| Rebote 3 | 56 | 40 | 42 | 56 | 52 | 42 |
| Rebote 4 | 54 | 38 | 50 | 51 | 50 | 36 |
| Rebote 5 | 51 | 47 | 31 | 54 | 50 | 42 |
| Rebote 6 | 47 | 48 | 39 | 50 | 44 | 43 |
| Rebote 7 | 54 | 40 | 45 | 47 | 48 | 47 |
| Rebote 8 | 49 | 40 | 48 | 56 | 50 | 36 |
| Rebote 9 | 54 | 46 | 50 | 56 | 50 | 47 |
| Rebote 10 | 52 | 44 | 45 | 55 | 44 | 41 |
| MIN | 47 | 38 | 31 | 47 | 44 | 36 |
| MAX | 56 | 48 | 50 | 56 | 52 | 47 |
| Promedio Rebote | 51,88 | 42,75 | 43 | 53,38 | 48,38 | 40,63 |
| Resistencia estomada (Mpa) | 66 | 48 | 48 | 69 | 59,5 | 44 |
| Desviación estándar rebote | 2,97 | 3,46 | 6,28 | 3,43 | 2,75 | 4,24 |
| Desviación estándar Mpa | 11,32 | 10,78 | 7,59 | 10,81 | 11,56 | 9,92 |
| Coeficiente variación (%) | 0,05 | 0,07 | 0,13 | 0,05 | 0,05 | 0,10 |

**Polideportivo**

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 29-07-2010 | | | 29-07-2010 | | |
| Hora | | | | | | |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Posición esclerómetro | orizont | orizont | orizont | orizont | orizont | orizont |
| Rugosidad superficial (lisa o áspera) | Lisa | Lisa | Lisa | Lisa | Lisa | Lisa |
| Condición superficial (seca o húmeda) | Seca | Seca | Seca | Seca | Seca | Seca |
| Superficie carbonatada (si o no) | Si | Si | Si | Si | Si | Si |
| Superficie pulida (si o no) | No | No | No | No | No | No |
| Rebote 1 | 40 | 50 | 43 | 54 | 52 | 45 |
| Rebote 2 | 42 | 41 | 40 | 47 | 52 | 48 |
| Rebote 3 | 43 | 44 | 40 | 48 | 51 | 53 |
| Rebote 4 | 42 | 43 | 35 | 49 | 52 | 48 |
| Rebote 5 | 40 | 50 | 42 | 50 | 51 | 48 |
| Rebote 6 | 45 | 46 | 43 | 56 | 50 | 45 |
| Rebote 7 | 41 | 44 | 42 | 47 | 56 | 42 |
| Rebote 8 | 52 | 42 | 40 | 47 | 46 | 44 |
| Rebote 9 | 40 | 43 | 36 | 50 | 53 | 44 |
| Rebote 10 | 36 | 41 | 41 | 46 | 52 | 44 |
| MIN | 36 | 41 | 35 | 46 | 46 | 42 |
| MAX | 52 | 50 | 43 | 56 | 56 | 53 |
| Promedio Rebote | 41,63 | 44,13 | 40,5 | 49 | 51,63 | 45,75 |
| Resistencia estomada (Mpa) | 44 | 51 | 44 | 60 | 65 | 53 |
| Desviación estándar rebote | 4,20 | 3,31 | 2,74 | 3,27 | 2,51 | 3,18 |
| Desviación estándar Mpa | 9,96 | 10,95 | 11,57 | 10,99 | 11,83 | 11,09 |
| Coeficiente variación (%) | 0,10 | 0,06 | 0,06 | 0,05 | 0,04 | 0,06 |

**Educación**

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 07-07-2010 | | | 15-06-2010 | | |
| Hora | | | | | | |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Posición esclerómetro | orizont | orizont | orizont | orizont | orizont | orizontal |
| Rugosidad superficial (lisa o áspera) | Lisa | Lisa | Lisa | Lisa | Lisa | Lisa |
| Condición superficial (seca o húmeda) | Seca | Seca | Seca | Seca | Seca | Seca |
| Superficie carbonatada (si o no) | Si | Si | Si | Si | Si | Si |
| Superficie pulida (si o no) | No | No | No | No | No | No |
| Rebote 1 | 33 | 30 | 39 | 41 | 49 | 42 |
| Rebote 2 | 36 | 35 | 35 | 44 | 42 | 38 |
| Rebote 3 | 36 | 37 | 39 | 41 | 51 | 38 |
| Rebote 4 | 36 | 34 | 37 | 44 | 51 | 37 |
| Rebote 5 | 35 | 36 | 40 | 42 | 45 | 38 |
| Rebote 6 | 36 | 35 | 37 | 48 | 42 | 40 |
| Rebote 7 | 36 | 37 | 40 | 47 | 43 | 39 |
| Rebote 8 | 34 | 39 | 37 | 40 | 42 | 43 |
| Rebote 9 | 37 | 33 | 39 | 44 | 50 | 40 |
| Rebote 10 | 35 | 30 | 43 | 46 | 48 | 41 |
| MIN | 33 | 30 | 35 | 40 | 42 | 37 |
| MAX | 37 | 39 | 43 | 48 | 51 | 43 |
| Promedio Rebote | 35,5 | 34,63 | 38,5 | 43,63 | 46,25 | 39,5 |
| Resistencia estomada (Mpa) | 34,5 | 33 | 39,8 | 49,4 | 54,6 | 41,7 |
| Desviación estándar rebote | 1,17 | 2,95 | 2,22 | 2,71 | 3,89 | 1,96 |
| Desviación estándar Mpa | 13,26 | 11,34 | 12,14 | 11,60 | 10,31 | 12,42 |
| Coeficiente variación (%) | 0,03 | 0,09 | 0,06 | 0,05 | 0,07 | 0,05 |

**Chiledeportes**

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 29-07-2010 | | | 29-07-2010 | | |
| Hora | | | | | | |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Posición esclerómetro | orizont | orizont | orizont | orizont | orizont | orizont |
| Rugosidad superficial (lisa o áspera) | Lisa | Lisa | Lisa | Lisa | Lisa | Lisa |
| Condición superficial (seca o húmeda) | Seca | Seca | Seca | Seca | Seca | Seca |
| Superficie carbonatada (si o no) | Si | Si | Si | Si | Si | Si |
| Superficie pulida (si o no) | No | No | No | No | No | No |
| Rebote 1 | 48 | 54 | 45 | 47 | 42 | 38 |
| Rebote 2 | 50 | 53 | 46 | 44 | 48 | 40 |
| Rebote 3 | 50 | 53 | 46 | 47 | 40 | 39 |
| Rebote 4 | 54 | 52 | 42 | 41 | 42 | 43 |
| Rebote 5 | 48 | 52 | 48 | 38 | 33 | 40 |
| Rebote 6 | 55 | 47 | 51 | 43 | 38 | 34 |
| Rebote 7 | 50 | 46 | 54 | 38 | 44 | 37 |
| Rebote 8 | 48 | 54 | 46 | 42 | 45 | 34 |
| Rebote 9 | 48 | 48 | 48 | 40 | 42 | 36 |
| Rebote 10 | 48 | 47 | 43 | 46 | 42 | 48 |
| MIN | 48 | 46 | 42 | 38 | 33 | 34 |
| MAX | 55 | 54 | 54 | 47 | 48 | 48 |
| Promedio Rebote | 49,5 | 50,75 | 46,63 | 42,63 | 41,88 | 38,38 |
| Resistencia estomada (Mpa) | 61 | 63,6 | 55,2 | 47,5 | 46 | 39,7 |
| Desviación estándar rebote | 2,60 | 3,20 | 3,57 | 3,41 | 4,06 | 4,25 |
| Desviación estándar Mpa | 11,72 | 11,06 | 10,66 | 10,84 | 10,11 | 9,90 |
| Coeficiente variación (%) | 0,04 | 0,05 | 0,06 | 0,07 | 0,09 | 0,11 |

**Eléctrica**

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 16-06-2010 | | | 14-06-2010 | | |
| Hora | | | | | | |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Posición esclerómetro | orizont | orizont | orizont | orizont | orizont | orizontal |
| Rugosidad superficial (lisa o áspera) | Lisa | Lisa | Lisa | Lisa | Lisa | Lisa |
| Condición superficial (seca o húmeda) | Seca | Seca | Seca | Seca | Seca | Seca |
| Superficie carbonatada (si o no) | Si | Si | Si | Si | Si | Si |
| Superficie pulida (si o no) | No | No | No | No | No | No |
| Rebote 1 | 58 | 55 | 52 | 54 | 54 | 54 |
| Rebote 2 | 54 | 60 | 46 | 47 | 52 | 52 |
| Rebote 3 | 48 | 56 | 49 | 56 | 55 | 54 |
| Rebote 4 | 58 | 50 | 44 | 49 | 52 | 56 |
| Rebote 5 | 55 | 50 | 43 | 50 | 50 | 46 |
| Rebote 6 | 54 | 46 | 50 | 42 | 54 | 52 |
| Rebote 7 | 55 | 44 | 48 | 53 | 53 | 41 |
| Rebote 8 | 59 | 49 | 45 | 55 | 53 | 57 |
| Rebote 9 | 55 | 52 | 53 | 43 | 53 | 53 |
| Rebote 10 | 56 | 48 | 46 | 57 | 40 | 51 |
| MIN | 48 | 44 | 43 | 42 | 40 | 41 |
| MAX | 59 | 60 | 53 | 57 | 55 | 57 |
| Promedio Rebote | 55,63 | 50,75 | 47,5 | 50,88 | 52,63 | 52,25 |
| Resistencia estomada (Mpa) | 73,7 | 63,6 | 57 | 63,8 | 67,3 | 66,7 |
| Desviación estándar rebote | 3,08 | 4,85 | 3,37 | 5,32 | 4,30 | 4,79 |
| Desviación estándar Mpa | 11,20 | 9,22 | 10,88 | 8,69 | 9,85 | 9,29 |
| Coeficiente variación (%) | 0,04 | 0,08 | 0,06 | 0,08 | 0,06 | 0,07 |

**Engendro**

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 09-08-2010 | | | 09-08-2010 | | |
| Hora | | | | | | |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Posición esclerómetro | orizont | orizont | orizont | orizont | orizont | orizont |
| Rugosidad superficial (lisa o áspera) | Lisa | Lisa | Lisa | Lisa | Lisa | Lisa |
| Condición superficial (seca o húmeda) | Seca | Seca | Seca | Seca | Seca | Seca |
| Superficie carbonatada (si o no) | Si | Si | Si | Si | Si | Si |
| Superficie pulida (si o no) | No | No | No | No | No | No |
| Rebote 1 | 44 | 42 | 42 | 44 | 40 | 42 |
| Rebote 2 | 42 | 43 | 46 | 44 | 41 | 42 |
| Rebote 3 | 47 | 41 | 45 | 44 | 45 | 42 |
| Rebote 4 | 44 | 42 | 47 | 46 | 40 | 41 |
| Rebote 5 | 45 | 42 | 47 | 41 | 42 | 44 |
| Rebote 6 | 44 | 45 | 45 | 42 | 40 | 43 |
| Rebote 7 | 44 | 44 | 44 | 42 | 40 | 40 |
| Rebote 8 | 42 | 40 | 43 | 46 | 42 | 40 |
| Rebote 9 | 44 | 42 | 47 | 42 | 40 | 40 |
| Rebote 10 | 42 | 41 | 43 | 43 | 46 | 42 |
| MIN | 42 | 40 | 42 | 41 | 40 | 40 |
| MAX | 47 | 45 | 47 | 46 | 46 | 44 |
| Promedio Rebote | 43,63 | 42,13 | 45 | 43,38 | 41,25 | 41,5 |
| Resistencia estomada (Mpa) | 49,4 | 46,5 | 52 | 49 | 45 | 45,4 |
| Desviación estándar rebote | 1,55 | 1,48 | 1,85 | 1,71 | 2,22 | 1,35 |
| Desviación estándar Mpa | 12,86 | 12,94 | 12,53 | 12,68 | 12,14 | 13,07 |
| Coeficiente variación (%) | 0,03 | 0,03 | 0,04 | 0,03 | 0,05 | 0,03 |

**Humanidades**

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 15-06-2010 | | | 15-06-2010 | | |
| Hora | | | | | | |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Posición esclerómetro | orizont | orizont | orizont | orizont | orizont | orizontal |
| Rugosidad superficial (lisa o áspera) | Lisa | Lisa | Lisa | Lisa | Lisa | Lisa |
| Condición superficial (seca o húmeda) | Seca | Seca | Seca | Seca | Seca | Seca |
| Superficie carbonatada (si o no) | Si | Si | Si | Si | Si | Si |
| Superficie pulida (si o no) | No | No | No | No | No | No |
| Rebote 1 | 51 | 51 | 49 | 50 | 46 | 48 |
| Rebote 2 | 50 | 51 | 53 | 46 | 49 | 47 |
| Rebote 3 | 50 | 46 | 54 | 47 | 47 | 50 |
| Rebote 4 | 50 | 51 | 51 | 48 | 48 | 44 |
| Rebote 5 | 49 | 55 | 50 | 50 | 49 | 46 |
| Rebote 6 | 52 | 56 | 54 | 48 | 53 | 46 |
| Rebote 7 | 52 | 48 | 55 | 45 | 48 | 44 |
| Rebote 8 | 50 | 52 | 58 | 51 | 50 | 49 |
| Rebote 9 | 49 | 52 | 53 | 52 | 46 | 48 |
| Rebote 10 | 49 | 52 | 54 | 46 | 50 | 44 |
| MIN | 49 | 46 | 49 | 45 | 46 | 44 |
| MAX | 52 | 56 | 58 | 52 | 53 | 50 |
| Promedio Rebote | 50,13 | 51,5 | 53 | 48,25 | 48,38 | 46,5 |
| Resistencia estomada (Mpa) | 62,2 | 65 | 68,2 | 58,5 | 58,7 | 55 |
| Desviación estándar rebote | 1,14 | 2,91 | 2,60 | 2,36 | 2,12 | 2,17 |
| Desviación estándar Mpa | 13,30 | 11,38 | 11,72 | 11,99 | 12,25 | 12,19 |
| Coeficiente variación (%) | 0,02 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 |

**Muro Contención**

| | Lado Derecho | | | Lado Izquierdo | | |
|---|---|---|---|---|---|---|
| Fecha | 11-11-2010 | | | 11-11-2010 | | |
| Hora | | | | | | |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Posición esclerómetro | orizont | orizont | orizont | orizont | orizont | orizont |
| Rugosidad superficial (lisa o áspera) | Lisa | Lisa | Lisa | Lisa | Lisa | Lisa |
| Condición superficial (seca o húmeda) | Seca | Seca | Seca | Seca | Seca | Seca |
| Superficie carbonatada (si o no) | Si | Si | Si | Si | Si | Si |
| Superficie pulida (si o no) | No | No | No | No | No | No |
| Rebote 1 | 56 | 58 | 57 | 54 | 60 | 56 |
| Rebote 2 | 50 | 55 | 57 | 57 | 57 | 61 |
| Rebote 3 | 50 | 56 | 57 | 53 | 61 | 58 |
| Rebote 4 | 59 | 52 | 56 | 52 | 57 | 58 |
| Rebote 5 | 60 | 56 | 56 | 59 | 58 | 56 |
| Rebote 6 | 59 | 56 | 54 | 57 | 61 | 56 |
| Rebote 7 | 51 | 55 | 58 | 52 | 61 | 54 |
| Rebote 8 | 58 | 58 | 60 | 52 | 60 | 54 |
| Rebote 9 | 56 | 57 | 58 | 56 | 57 | 52 |
| Rebote 10 | 58 | 56 | 55 | 52 | 61 | 52 |
| MIN | 50 | 52 | 54 | 52 | 57 | 52 |
| MAX | 60 | 58 | 60 | 59 | 61 | 61 |
| Promedio Rebote | 55,88 | 56,13 | 56,75 | 54,13 | 59,38 | 55,5 |
| Resistencia estomada (Mpa) | 74,3 | 74,8 | 76,3 | 70,5 | 81,9 | 73,5 |
| Desviación estándar rebote | 3,92 | 1,73 | 1,69 | 2,63 | 1,83 | 2,83 |
| Desviación estándar Mpa | 10,27 | 12,67 | 12,71 | 11,69 | 12,56 | 11,47 |
| Coeficiente variación (%) | 0,05 | 0,02 | 0,02 | 0,04 | 0,02 | 0,04 |

## Carbonation depth

**Mecánica**

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 19-06-2010 | 19-06-2010 | 19-06-2010 | 19-06-2010 | 19-06-2010 | 19-06-2010 |
| Hora | | | | | | |
| Código testigo | M1P | M2P | M3P | M1S | M2S | M3S |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Diámetro armadura (mm) | 8 | 8 | 8 | 8 | 8 | 8 |
| Espesor recubrimiento (mm) | 28 | 28 | 28 | 25 | 25 | 25 |
| Edad estructura (años) | 45 | 45 | 45 | 45 | 45 | 45 |
| Profundidad mínima 1 (mm) | 0 | 25,5 | 35,6 | 13 | 17,1 | 35,8 |
| Profundidad mínima 2 (mm) | 6,4 | 19,4 | 31 | 0 | 12 | 19,6 |
| Profundidad máxima 1 (mm) | 39 | 44,4 | 44,5 | 44,4 | 34,4 | 59 |
| Profundidad máxima 2 (mm) | 11,3 | 31,8 | 50 | 40,8 | 28,6 | 51 |
| Profundidad promedio Xco2 (mm) | 14,18 | 30,28 | 40,28 | 24,55 | 23,03 | 41,35 |
| Kco2 (mm/año^0.5) | 2,11 | 4,51 | 6,00 | 3,66 | 3,43 | 6,16 |
| Tiempo en alcanzar armadura (años) | 175,58 | 38,49 | 21,75 | 46,66 | 53,05 | 16,45 |
| Resistencia carbonatación | ALTA | MODERADA | BAJA | MODERADA | MODERADA | BAJA |

**Eléctrica**

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 03-07-2010 | | | 03-07-2010 | | |
| Hora | 12:00-14:00 | | | 12:00-14:00 | | |
| Código testigo | EL1P | EL2P | EL3P | EL1S | EL2S | EL3S |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Diámetro armadura (mm) | 10 | 10 | 10 | 10 | 10 | 10 |
| Espesor recubrimiento (mm) | 24 | 24 | 24 | 20 | 20 | 20 |
| Edad estructura (años) | 40 | 40 | 40 | 40 | 40 | 40 |
| Profundidad mínima 1 (mm) | 0 | 30 | 28 | 26 | 0 | 0 |
| Profundidad mínima 2 (mm) | 16 | 31 | 28 | 28 | 27 | 24 |
| Profundidad máxima 1 (mm) | 39 | 34 | 37 | 30 | 33 | 26 |
| Profundidad máxima 2 (mm) | 36 | 34 | 32 | 33 | 37 | 35 |
| Profundidad promedio Xco2 (mm) | 22,75 | 32,25 | 31,25 | 29,25 | 24,25 | 21,25 |
| Kco2 (mm/año^0.5) | 3,59709084 | 5,09917273 | 4,94105884 | 4,62483108 | 3,83426166 | 3,35992001 |
| Tiempo en alcanzar armadura (años) | 44,5163628 | 22,1525149 | 23,59296 | 18,7011469 | 27,2079923 | 35,432526 |
| Resistencia carbonatación | MODERADA | MODERADA | MODERADA | MODERADA | MODERADA | MODERADA |

**Educación**

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 03-07-2010 | | | 03-07-2010 | | |
| Hora | 15:00-16:00 | | | 13:30-14:45 | | |
| Código testigo | ED1P | ED2P | ED3P | ED1S | ED2S | ED3S |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Diámetro armadura (mm) | 8 | 8 | 8 | 8 | 8 | 8 |
| Espesor recubrimiento (mm) | 27 | 27 | 27 | 30,5 | 30,5 | 30,5 |
| Edad estructura (años) | 15 | 15 | 15 | 15 | 15 | 15 |
| Profundidad mínima 1 (mm) | 9 | 15 | 21 | 13 | 18 | 24 |
| Profundidad mínima 2 (mm) | 19 | 17 | 19 | 12 | 16 | 24 |
| Profundidad máxima 1 (mm) | 21 | 18 | 24 | 17 | 28 | 27 |
| Profundidad máxima 2 (mm) | 29 | 23 | 32 | 19 | 23 | 30 |
| Profundidad promedio Xco2 (mm) | 19,5 | 18,25 | 24 | 15,25 | 21,25 | 26,25 |
| Kco2 (mm/año^0.5) | 5,03487835 | 4,71212974 | 6,19677335 | 3,93753307 | 5,48672641 | 6,77772086 |
| Tiempo en alcanzar armadura (años) | 28,7573964 | 32,8316757 | 18,984375 | 60 | 30,9010381 | 20,2503401 |
| Resistencia carbonatación | MODERADA | MODERADA | BAJA | MODERADA | MODERADA | BAJA |

**Humanidades**

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 03-07-2010 | | | 03-07-2010 | | |
| Hora | 9:30-11:30 | | | 9:30-11:30 | | |
| Código testigo | H1P | H2P | H3P | H1S | H2S | H3S |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Diámetro armadura (mm) | 10 | 10 | 10 | 10 | 10 | 10 |
| Espesor recubrimiento (mm) | 29 | 29 | 29 | 24 | 24 | 24 |
| Edad estructura (años) | 12 | 12 | 12 | 12 | 12 | 12 |
| Profundidad mínima 1 (mm) | 10 | 3 | 18 | 10 | 10 | 16 |
| Profundidad mínima 2 (mm) | 12 | 4 | 16 | 11 | 9 | 16 |
| Profundidad máxima 1 (mm) | 14 | 12 | 7 | 21 | 20 | 21 |
| Profundidad máxima 2 (mm) | 13 | 14 | 9 | 19 | 19 | 17 |
| Profundidad promedio Xco2 (mm) | 12,25 | 8,25 | 12,5 | 15,25 | 14,5 | 17,5 |
| Kco2 (mm/año^0.5) | 3,5362704 | 2,38156986 | 3,60843918 | 4,4022958 | 4,18578945 | 5,05181486 |
| Tiempo en alcanzar armadura (años) | 67,2519783 | 148,275482 | 64,5888 | 29,7210427 | 32,8751486 | 22,5697959 |
| Resistencia carbonatación | MODERADA | ALTA | MODERADA | MODERADA | MODERADA | MODERADA |

**Polideportivo**

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 29-07-2010 | 29-07-2010 | 29-07-2010 | 29-07-2010 | 29-07-2010 | 29-07-2010 |
| Hora | | | | | | |
| Código testigo | PL1P | PL2P | PL3P | PL1S | PL2S | PL3S |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Diámetro armadura (mm) | 10 | 10 | 10 | 10 | 10 | 10 |
| Espesor recubrimiento (mm) | 51 | 51 | 51 | 23 | 23 | 23 |
| Edad estructura (años) | 6 | 6 | 6 | 6 | 6 | 6 |
| Profundidad mínima 1 (mm) | 8 | 9 | 16 | 0 | 4 | 4 |
| Profundidad mínima 2 (mm) | 4 | 16 | 17 | 5 | 7 | 6 |
| Profundidad máxima 1 (mm) | 22 | 21 | 16 | 5 | 7 | 8 |
| Profundidad máxima 2 (mm) | 21 | 19 | 22 | 6 | 12 | 9 |
| Profundidad promedio Xco2 (mm) | 13,75 | 16,25 | 17,75 | 4,00 | 7,50 | 6,75 |
| Kco2 (mm/año^0.5) | 5,61 | 6,63 | 7,25 | 1,63 | 3,06 | 2,76 |
| Tiempo en alcanzar armadura (años) | 82,54 | 59,10 | 49,53 | 198,38 | 56,43 | 69,66 |
| Resistencia carbonatación | MODERADA | BAJA | BAJA | ALTA | MODERADA | ALTA |

**Velódromo**

| | Fachada Poniente | | | Fachada Sur | | |
|---|---|---|---|---|---|---|
| Fecha | 29-07-2010 | | | 29-07-2010 | | |
| Hora | 16:30-18:15 | | | 14:30-16:00 | | |
| Código testigo | ChD1P | ChD2P | ChD3P | ChD1S | ChD2S | ChD3S |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Diámetro armadura (mm) | 8 | 8 | 8 | 8 | 8 | 8 |
| Espesor recubrimiento (mm) | 12 | 12 | 12 | 36 | 36 | 36 |
| Edad estructura (años) | 50 | 50 | 50 | 50 | 50 | 50 |
| Profundidad mínima 1 (mm) | 7 | 7 | 7 | 0 | 11 | 4 |
| Profundidad mínima 2 (mm) | 22 | 12 | 14 | 17 | 17 | 12 |
| Profundidad máxima 1 (mm) | 23 | 33 | 19 | 45 | 31 | 14 |
| Profundidad máxima 2 (mm) | 37 | 39 | 41 | 41 | 32 | 49 |
| Profundidad promedio Xco2 (mm) | 22,25 | 22,75 | 20,25 | 25,75 | 22,75 | 19,75 |
| Kco2 (mm/año^0.5) | 3,14662518 | 3,21733585 | 2,86378246 | 3,64159992 | 3,21733585 | 2,79307179 |
| Tiempo en alcanzar armadura (años) | 14,5436182 | 13,9113634 | 17,558299 | 97,7283439 | 125,20227 | 166,127223 |
| Resistencia carbonatación | MODERADA | MODERADA | ALTA | MODERADA | MODERADA | ALTA |

**Muro Contención Poniente**

| | Lado Der | | | Lado Izq | | |
|---|---|---|---|---|---|---|
| Fecha | 11-11-2010 | | | 11-11-2010 | | |
| Hora | | | | | | |
| Código testigo | MC1D | MC2D | MC3D | MC1I | MC2I | MC3I |
| Punto | M1 | M2 | M3 | M1 | M2 | M3 |
| Diámetro armadura (mm) | 20 | 20 | 20 | 20 | 20 | 20 |
| Espesor recubrimiento (mm) | 55 | 55 | 55 | 55 | 55 | 55 |
| Edad estructura (años) | 20 | 20 | 20 | 20 | 20 | 20 |
| Profundidad mínima 1 (mm) | 10 | 14 | 8 | 11 | 8 | 12 |
| Profundidad mínima 2 (mm) | 9 | 10 | 12 | 18 | 11 | 13 |
| Profundidad máxima 1 (mm) | 27 | 16 | 15 | 23 | 14 | 14 |
| Profundidad máxima 2 (mm) | 25 | 25 | 16 | 25 | 16 | 17 |
| Profundidad promedio Xco2 (mm) | 17,75 | 16,25 | 12,75 | 19,25 | 12,25 | 14 |
| Kco2 (mm/año^0.5) | 3,96902066 | 3,63361046 | 2,85098667 | 4,30443086 | 2,73918327 | 3,13049517 |
| Tiempo en alcanzar armadura (años) | 192,025392 | 229,112426 | 372,164552 | 163,265306 | 403,165348 | 308,673469 |
| Resistencia carbonatación | MODERADA | MODERADA | ALTA | MODERADA | ALTA | MODERADA |

Chloride ingress

| Testigo | 1 | 2 | 3 | 4 | 5 | 6 | Promedio (mm) |
|---|---|---|---|---|---|---|---|
| MP | 47,89 | 53,63 | 48,27 | 50,51 | 51,29 | 48,32 | 49,99 |
| MS | 10,43 | 13,29 | 10,62 | 9,74 | 16,32 | | 12,08 |
| ELP | 11,89 | 22,18 | 11,13 | 13,55 | 4,44 | | 12,64 |
| ELS | 22,54 | 1,06 | 3,57 | 6,65 | 3,39 | 1,19 | 6,40 |
| EDP | 29,82 | 30,18 | 28,7 | 27,84 | 28,46 | 27,26 | 28,71 |
| EDS | 18,21 | 14,2 | 16,74 | 16,69 | 20,05 | 19,86 | 17,63 |
| HP | 16,5 | 12,06 | 10,58 | 10,68 | 11,3 | 14,64 | 12,63 |
| HS | 17,51 | 19,88 | 16,86 | 14,33 | 13,46 | 14,34 | 16,06 |
| | | | | | | | |
| ChP | 12,43 | 14,38 | 12,65 | 26,67 | 44,01 | 34,89 | 24,17 |
| ChS | 51,61 | 50,51 | 33,12 | 4,04 | 17,91 | 29,13 | 31,05 |
| MCI | 11,54 | 20,12 | 16,75 | 16,45 | 13,95 | 10,31 | 14,85 |
| MCD | 15,38 | 21,17 | 17,82 | 22,6 | 25,82 | 46,79 | 24,93 |
| AMP | 28,34 | 10,32 | 24,62 | 26,4 | 27,55 | 23,04 | 23,38 |
| AMS | 21,76 | 16,65 | 15,95 | 19,74 | 17,34 | 14,42 | 17,64 |
| PLP | 25,26 | 20,13 | 19,32 | 21,25 | 23,31 | 23,17 | 22,07 |
| PLS | 19,3 | 12,3 | 11,84 | 2,08 | 10,99 | 26 | 13,75 |

Compressive strength

| Fecha Ensayo | 21-07-2010 | | | | | | 21-07-2010 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Código testigo** | **M1P** | **M2P** | **M3P** | **M1S** | **M2S** | **M3S** | **EL1P** | **EL2P** | **EL3P** | **EL1S** | **EL2S** | **EL3S** |
| Carga Rotura (kN) | 308 | 339 | 230 | 274 | 290 | 264 | 407 | 350 | 335 | 372 | 359 | 371 |
| Tensión de Rotura (Mpa) | 38,4 | 42,3 | 28,7 | 34,2 | 36,2 | 33,0 | 50,8 | 43,7 | 41,8 | 46,4 | 44,8 | 46,3 |
| Resistencia Cilíndrica (Mpa) | 33,2 | 36,5 | 24,8 | 29,7 | 31,2 | 29,0 | 44,0 | 38,3 | 36,4 | 40,7 | 38,8 | 40,7 |
| Resistencia Cúbica estimada (Mpa) | 38,2 | 41,6 | 29,8 | 34,7 | 36,5 | 33,9 | 48,8 | 43,3 | 41,3 | 46,0 | 43,9 | 46,0 |
| | 6,084185626 | | | 1,288756638 | | | 3,888580889 | | | 1,161005665 | | |
| | 36,5 | | | 35,0 | | | 44,5 | | | 45,3 | | |
| Fecha Ensayo | 21-07-2010 | | | | | | 21-07-2010 | | | | | |
| **Código testigo** | **ED1P** | **ED2P** | **ED3P** | **ED1S** | **ED2S** | **ED3S** | **H1P** | **H2P** | **H3P** | **H1S** | **H2S** | **H3S** |
| Carga Rotura (kN) | 235 | 266 | 233 | 306 | 298 | 263 | 514 | 425 | 430 | 471 | 372 | 384 |
| Tensión de Rotura (Mpa) | 29,3 | 33,2 | 29,1 | 38,2 | 37,2 | 32,8 | 64,2 | 53,0 | 53,7 | 58,8 | 46,4 | 47,9 |
| Resistencia Cilíndrica (Mpa) | 26,9 | 29,6 | 26,0 | 35,3 | 34,1 | 30,0 | 59,4 | 49,3 | 49,8 | 54,3 | 43,1 | 43,8 |
| Resistencia Cúbica estimada (Mpa) | 31,9 | 34,6 | 31,0 | 40,2 | 38,9 | 35,1 | 59,4 | 54,2 | 54,8 | 54,3 | 48,2 | 48,8 |
| | 1,881224463 | | | 2,662432574 | | | 2,839007735 | | | 3,352055551 | | |
| | 32,5 | | | 38,1 | | | 56,1 | | | 50,4 | | |
| Fecha Ensayo | | | | | | | | | | | | |
| **Código testigo** | **ChD1P** | **ChD2P** | **ChD3P** | **ChD1S** | **ChD2S** | **ChD3S** | **PL1P** | **PL2P** | **PL3P** | **PL1S** | **PL2S** | **PL3S** |
| Carga Rotura (kN) | 352 | 261 | 220 | 267 | 203 | 219 | 362 | 274 | 286 | 444 | 450 | 418 |
| Tensión de Rotura (Mpa) | 43,9 | 32,6 | 27,5 | 34,0 | 25,8 | 27,9 | 46,1 | 34,9 | 36,4 | 55,4 | 57,3 | 53,2 |
| Resistencia Cilíndrica (Mpa) | 39,6 | 30,6 | 25,3 | 30,7 | 24,3 | 26,5 | 42,0 | 32,8 | 33,9 | 50,5 | 52,2 | 48,5 |
| Resistencia Cúbica estimada (Mpa) | 44,8 | 35,9 | 30,4 | 35,9 | 29,2 | 31,6 | 47,1 | 37,8 | 38,9 | 55,6 | 56,9 | 53,6 |
| | 7,269833719 | | | 3,385310348 | | | 5,09706811 | | | 1,668982159 | | |
| | 37,0 | | | 32,2 | | | 41,3 | | | 55,4 | | |

| Fecha Ensayo | 07-01-2011 | | | | | | 07-01-2011 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Código testigo** | **EN1S** | **EN2S** | **EN3S** | **EN1P** | **EN2P** | **EN3P** | **MC1I** | **MC2I** | **MC3I** | **MC1D** | **MC2D** | **MC3D** |
| Carga Rotura (kN) | 380 | | 342 | 309 | 317 | 300 | 385 | 348 | 346 | 475 | 385 | 500 |
| Tensión de Rotura (Mpa) | 47,4 | 0,0 | 42,7 | 38,6 | 39,6 | 37,4 | 47,1 | 42,6 | 42,3 | 58,1 | 47,1 | 62,4 |
| Resistencia Cilíndrica (Mpa) | 40,9 | | 37,6 | 34,0 | 34,9 | 33,0 | 45,3 | 40,9 | 40,7 | 55,8 | 44,8 | 53,2 |
| Resistencia Cúbica estimada (Mpa) | 46,3 | | 42,7 | 39,0 | 39,8 | 38,0 | 50,2 | 46,1 | 45,8 | 55,8 | 49,3 | 53,2 |
| | 2,50092717 | | | 0,869491273 | | | 2,453768035 | | | 3,302549994 | | |
| | 44,5 | | | 38,9 | | | 47,4 | | | 52,8 | | |

| Fecha Ensayo | 27-01-2011 | | | | | |
|---|---|---|---|---|---|---|
| **Código testigo** | **AMP1** | **AMP2** | **AMP3** | **AMS1** | **AMS2** | **AMS3** |
| Carga Rotura (kN) | 323 | 338 | 363 | 400 | 319 | 303 |
| Tensión de Rotura (Mpa) | 40,3 | 42,2 | 45,3 | 49,9 | 39,8 | 37,8 |
| Resistencia Cilíndrica (Mpa) | 38,3 | 38,4 | 41,3 | 47,0 | 38,2 | 35,6 |
| Resistencia Cúbica estimada (Mpa) | 43,4 | 43,6 | 46,4 | 51,9 | 43,3 | 40,5 |
| | 1,699688617 | | | 5,953251479 | | |
| | 44,5 | | | 45,3 | | |

# Air permeability

Mecánica

| | Poniente | | | | | | Sur | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fecha | | | | | | | | | | | | |
| Altura medición (m) | M1 | | M2 | | M3 | | M1 | | M2 | | M3 | |
| ΔPieff (mbar) | 23 | 22,4 | 21,9 | 21 | 13,8 | 21,1 | 128,7 | 57,1 | 22,6 | 286,6 | 46 | 21,8 |
| Tiempo de ensayo (seg) | 105 | 255 | 150 | 105 | 75 | 75 | 75 | 75 | 150 | 75 | 75 | 120 |
| L (mm) | 108 | 47 | 66 | 98 | 151 | 233 | 60 | 60 | 68 | 60 | 60 | 84 |
| kT (10^(-16)m2) | 17 | 1,3 | 4,5 | 14 | 48 | 114 | 73 | 41 | 5 | 139 | 35 | 9 |
| kT form(10^(-16)m2) | 0,00519 | 0,00062 | 0,00048 | 0,00076 | 0,00153 | 0,00384 | 0,01071 | 0,04974 | 0,00131 | 0,01288 | 0,00141 | 0,00078 |
| kT eff (10^(-16)m2 | 17 | 1,3 | 4,5 | 14 | 48 | 114 | 73 | 41 | 4,9 | 139 | 35 | 9,3 |
| Permeabilidad al aire | MUY ALTA | ALTA | ALTA | MUY ALTA | MUY ALTA | MUY ALTA | MUY ALTA | MUY ALTA | ALTA | MUY ALTA | MUY ALTA | ALTA |

Eléctrica

| | Poniente | | | | | | Sur | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fecha | 10-01-2011 | | | | | | 10-01-2011 | | | | | |
| Altura medición (m) | M1 | | M2 | | M3 | | M1 | | M2 | | M3 | |
| ΔPieff (mbar) | 22,1 | 10,8 | 23,5 | 24,4 | 23,6 | 44,5 | 21 | 545,8 | 10,7 | 164,8 | 21,6 | 44,5 |
| Tiempo de ensayo (seg) | 240 | 75 | 120 | 180 | 270 | 75 | 75 | 75 | 75 | 75 | 135 | 75 |
| L (mm) | 48 | 118 | 91 | 64 | 48 | 60 | 232 | 60 | 117 | 60 | 73 | 60 |
| kT (10^(-16)m2) | 1,5 | 29 | 10 | 3,5 | 1,3 | 34 | 113 | 250 | 28 | 89 | 6,3 | 34 |
| kT form (10^(-16)m2) | 0,00316 | 0,00145 | 0,00431 | 0,00034 | 0,00254 | 0,00092 | 0,03053 | 0,04365 | 0,00335 | 0,00888 | 0,0093 | 0,01732 |
| kT eff(10^(-16)m2 | 1,5 | 29 | 10 | 3,5 | 1,3 | 34 | 113 | 250 | 28 | 89 | 6,3 | 34 |
| Permeabilidad al aire | ALTA | MUY ALTA | MUY ALTA | ALTA | ALTA | MUY ALTA | MUY ALTA | MUY ALTA | MUY ALTA | MUY ALTA | ALTA | MUY ALTA |

Educación

| | Poniente | | | | | | Sur | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fecha | | | | | | | | | | | | |
| Altura medición (m) | M1 | | M2 | | M3 | | M1 | | M2 | | M3 | |
| ΔPieff (mbar) | 17 | 40,9 | 26,7 | 14,6 | 40,4 | 26,6 | 23 | 22,4 | 21,9 | 21 | 13,8 | 21,1 |
| Tiempo de ensayo (seg) | 75 | 75 | 75 | 75 | 75 | 75 | 105 | 255 | 150 | 105 | 75 | 75 |
| L (mm) | 187 | 60 | 60 | 160 | 60 | 60 | 108 | 47 | 66 | 98 | 151 | 233 |
| kT (10^(-16)m2) | 74 | 33 | 25 | 54 | 32 | 24 | 17 | 1,3 | 4,5 | 14 | 48 | 114 |
| kT form (10^(-16)m2) | 0,00254 | 0,00124 | 0,00106 | 0,00164 | 0,00122 | 0,00103 | 0,0389 | 0,00799 | 0,00461 | 0,00239 | 0,00888 | 0,01381 |
| kT eff(10^(-16)m2 | 74 | 33 | 25 | 54 | 32 | 24 | 17 | 1,3 | 4,5 | 14 | 48 | 114 |
| Permeabilidad al aire | MUY ALTA | MUY ALTA | MUY ALTA | MUY ALTA | MUY ALTA | MUY ALTA | MUY ALTA | ALTA | ALTA | MUY ALTA | MUY ALTA | MUY ALTA |

Humanidades

| | Poniente | | | | | | Sur | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fecha | | | | | | | | | | | | |
| Altura medición (m) | M1 | | M2 | | M3 | | M1 | | M2 | | M3 | |
| ΔPieff (mbar) | 23,4 | 22,8 | 23 | 23,3 | 22 | 22,6 | 21,5 | 22,7 | 22 | 22,9 | 23,4 | 22,9 |
| Tiempo de ensayo (seg) | 300 | 270 | 255 | 270 | 180 | 180 | 150 | 225 | 105 | 165 | 135 | 120 |
| L (mm) | 45 | 46 | 48 | 47 | 57 | 59 | 65 | 51 | 103 | 64 | 79 | 88 |
| kT (10^(-16)m2) | 1 | 1,2 | 1,4 | 1,3 | 2,8 | 3 | 4,4 | 1,8 | 15 | 3,8 | 7,2 | 10 |
| kT form (10^(-16)m2) | 0,00103 | 0,002 | 0,00141 | 0,0009 | 0,00239 | 0,00053 | 0,00069 | 0,00054 | 0,00125 | 0,00057 | 0,00075 | 0,00216 |
| kT eff(10^(-16)m2) | 1 | 1,2 | 1,4 | 1,3 | 2,8 | 3 | 4,4 | 1,8 | 15 | 3,8 | 7,2 | 10 |
| Permeabilidad al aire | ALTA | ALTA | ALTA | ALTA | ALTA | ALTA | ALTA | ALTA | MUY ALTA | ALTA | ALTA | MUY ALTA |

Velódromo

| | Poniente | | | | | | Sur | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fecha | 20-12-2010 | | | | | | 20-12-2010 | | | | | |
| Altura medición (m) | M1 | | M2 | | M3 | | M1 | | M2 | | M3 | |
| ΔPieff (mbar) | 90 | 15,4 | 24,7 | 25,4 | 506,6 | 24 | 351 | 197,9 | 345 | 98,2 | 22,7 | 17,3 |
| Tiempo de ensayo (seg) | 75 | 75 | 135 | 225 | 75 | 135 | 75 | 75 | 75 | 75 | 105 | 75 |
| L (mm) | 940 | 155 | 74 | 50 | 60 | 72 | 60 | 207 | 356 | 60 | 96 | 60 |
| kT (10^(-16)m2) | 1761 | 47 | 60 | 1,6 | 5376 | 5,7 | 147 | 8721 | 251 | 54 | 12 | 175 |
| kT form(10^(-16)m2) | 0,65738 | 0,01667 | 0,0058 | 0,00485 | 0,02642 | 0,02003 | 0,08629 | 2,04536 | 0,05414 | 0,0328 | 0,03189 | 0,07502 |
| kT eff (10^(-16)m2 | 1761 | 47 | 60 | 1,6 | 5376 | 5,7 | 147 | 8721 | 251 | 54 | 12 | 175 |
| Permeabilidad al aire | MUY ALTA | MUY ALTA | MUY ALTA | ALTA | MUY ALTA | ALTA | MUY ALTA | MUY ALTA | MUY ALTA | MUY ALTA | MUY ALTA | MUY ALTA |

Polideportivo

| | Poniente | | | | | | Sur | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fecha | 20-12-2010 | | | | | | 20-12-2010 | | | | | |
| Altura medición (m) | M1 | | M2 | | M3 | | M1 | | M2 | | M3 | |
| ΔPieff (mbar) | 24,3 | 23,2 | 23,4 | 23,6 | 21,2 | 24,1 | 21,7 | 21,6 | 22,9 | | 22,8 | 10,6 |
| Tiempo de ensayo (seg) | 120 | 165 | 120 | 150 | 120 | 180 | 120 | 135 | 285 | | 223 | 75 |
| L (mm) | 89 | 62 | 86 | 68 | 78 | 70 | 77 | 67 | 42 | | 48 | 106 |
| kT (10^(-16)m2) | 9,9 | 3,4 | 9,1 | 4,6 | 7,4 | 4,8 | 7,4 | 5 | 0,94 | | 1,5 | 22 |
| kT form (10^(-16)m2) | 0,01225 | 0,00249 | 0,00198 | 0,0017 | 0,00253 | 0,00175 | 0,29054 | 0,10327 | 0,01992 | 0 | 0,01671 | 0,07209 |
| kT eff(10^(-16)m2) | 9,9 | 3,4 | 9,1 | 4,6 | 7,4 | 4,8 | 7,4 | 5 | 0,94 | 0 | 1,5 | 22 |
| Permeabilidad al aire | ALTA | ALTA | ALTA | ALTA | ALTA | ALTA | ALTA | ALTA | MEDIA | MUY BAJA | ALTA | MUY ALTA |

Muro Contención

| | Derecha | | | | | | Izquierda | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fecha | 06-01-2011 | | | | | | 06-01-2011 | | | | | |
| Altura medición (m) | M1 | | M2 | | M3 | | M1 | | M2 | | M3 | |
| ΔPieff (mbar) | 24,9 | 23,1 | 22,7 | 474,8 | 17,2 | 23,4 | 10,7 | 588,1 | 23 | 86,9 | 193,6 | 34,3 |
| Tiempo de ensayo (seg) | 135 | 105 | 210 | 75 | 75 | 135 | 75 | 75 | 240 | 75 | 75 | 75 |
| L (mm) | 60 | 104 | 50 | 60 | 177 | 74 | 109 | 60 | 47 | 60 | 202 | 356 |
| kT (10^(-16)m2) | 6,9 | 15 | 1,7 | 191 | 61 | 5,9 | 23 | 235 | 1,3 | 49 | 8241 | 250 |
| kT form (10^(-16)m2) | 0,00558 | 0,01932 | 0,0031 | 0,05791 | 0,02223 | 0,01021 | 0,0188 | 0,0474 | 0,00332 | 0,04741 | 0,63373 | 0,04501 |
| kT eff(10^(-16)m2) | 6,9 | 15 | 1,7 | 191 | 61 | 5,9 | 23 | 235 | 1,3 | 49 | 8241 | 250 |
| Permeabilidad al aire | ALTA | MUY ALTA | ALTA | MUY ALTA | MUY ALTA | ALTA | MUY ALTA | MUY ALTA | ALTA | MUY ALTA | MUY ALTA | MUY ALTA |

Aula Magna Arq

| | Poniente | | | | | | Sur | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fecha | 18-01-2011 | | | | | | 18-01-2011 | | | | | |
| Altura medición (m) | 0,2 | | 1,2 | | 1,98 | | 0,3 | | 1,2 | | 2,03 | |
| ΔPieff (mbar) | 24,1 | 10 | 24,1 | 23 | 19,2 | 21,2 | 14,3 | 23,3 | 22,4 | 22,2 | 23,1 | 10 |
| Tiempo de ensayo (seg) | 165 | 75 | 150 | 135 | 75 | 120 | 75 | 210 | 75 | 240 | 75 | 75 |
| L (mm) | 64 | 101 | 69 | 74 | 198 | 77 | 146 | 52 | 106 | 46 | 239 | 20 |
| kT (10^(-16)m2) | 3,6 | 20 | 4,7 | 6 | 77 | 7,3 | 42 | 1,9 | 232 | 1,3 | 113 | 101 |
| kT form (10^(-16)m2) | 0,00389 | 0,02276 | 0,00408 | 0,00645 | 0,02208 | 0,00824 | 0,12025 | 0,02434 | 0,29578 | 0,00539 | 0,1145 | 0,04369 |
| kT eff(10^(-16)m2) | 3,6 | 20 | 4,7 | 6 | 77 | 7,3 | 42 | 1,9 | 232 | 1,3 | 113 | 101 |
| Permeabilidad al aire | ALTA | MUY ALTA | ALTA | ALTA | MUY ALTA | ALTA | MUY ALTA | ALTA | MUY ALTA | ALTA | MUY ALTA | MUY ALTA |

## Corrosion potential

**Polideportivo Sur**

| Estribos | | | | Barras Ppales | | | | |
|---|---|---|---|---|---|---|---|---|
| 20-12-2010 | | | | 20-12-2010 | | | | |
| Medida | Altura | Barra 1 | Barra 2 | Medida | Altura | Barra 1 | Barra 2 | Barra 3 |
| | medición | mV | mV | | medición | mV | mV | mV |
| | (m) | | | | (m) | | | |
| Nº | | 0,075 | 0,225 | Nº | | 0 | 0,15 | 0,3 |
| 1 | 0,25 | 46,8 | -93,2 | 1 | 0,35 | 39,5 | 58,6 | -2,5 |
| 2 | 0,50 | -32,1 | -61,2 | 2 | 0,60 | 67,5 | -102,7 | -161,7 |
| 3 | 0,75 | 68,9 | 58,7 | 3 | 0,85 | 49,3 | 44,7 | 31,1 |
| 4 | 1,00 | 64,8 | 61,1 | 4 | 1,10 | 61,1 | 61,4 | 53 |
| 5 | 1,25 | 52,1 | 48,7 | 5 | 1,35 | 61,8 | 52,3 | 64,5 |
| 6 | 1,50 | 30,4 | 36,7 | 6 | 1,60 | 49,8 | 35,6 | 62,9 |
| 7 | 1,75 | -56,5 | 24,8 | 7 | 1,85 | -45,8 | -31,2 | 6,7 |
| 8 | 2,00 | 38,4 | 47,5 | 8 | 2,10 | -22,8 | 6,4 | -1,1 |
| 9 | 2,15 | 27,7 | 26,9 | 9 | 2,25 | 52,8 | 25,6 | 57,4 |
| 10 | 2,30 | | | 10 | 2,40 | 63,5 | 29,5 | 40,4 |

**Muro Contención Izq**

| Estribos | | | | Barras Ppales | | | | |
|---|---|---|---|---|---|---|---|---|
| 06-01-2011 | | | | 06-01-2011 | | | | |
| Medida | Altura | Barra 1 | Barra 2 | Medida | Altura | Barra 1 | Barra 2 | Barra 3 |
| | medición | mV | mV | | medición | mV | mV | mV |
| | (m) | | | | (m) | | | |
| Nº | | 0,075 | 0,255 | Nº | | 0 | 0,18 | 0,36 |
| 1 | 0,23 | -246,7 | -256,1 | 1 | 0,32 | -221,3 | -267,5 | -193,2 |
| 2 | 0,41 | -195,8 | -168,2 | 2 | 0,50 | -163,2 | -192,7 | -164,9 |
| 3 | 0,59 | -128,4 | -90,7 | 3 | 0,68 | -108,2 | -103,6 | -73,7 |
| 4 | 0,77 | -96,5 | -83,2 | 4 | 0,86 | -83,2 | -108,7 | -63,3 |
| 5 | 0,95 | -93,8 | -98,7 | 5 | 1,04 | -106,4 | -101,7 | -69,8 |
| 6 | 1,13 | -114,1 | -89,5 | 6 | 1,22 | -103,7 | -80,4 | -82,7 |
| 7 | 1,31 | -80,5 | -109,3 | 7 | 1,40 | -69,9 | -84,7 | -107,3 |
| 8 | 1,49 | -68,9 | -83,5 | 8 | 1,58 | -65,4 | -67,2 | -73,3 |
| 9 | 1,67 | -56 | -68,5 | 9 | 1,76 | -55,1 | -61,3 | -67,4 |
| 10 | 1,85 | -55,8 | -65,7 | 10 | 1,94 | -58,6 | -62,1 | -63,3 |
| 11 | 2,03 | -62,3 | -65,9 | 11 | 2,12 | -62,1 | -64,9 | -62,7 |
| 12 | 2,21 | -66,3 | -62,9 | 12 | 2,30 | | | |

**Muro Contención Der**

| Estribos | | | | Barras Ppales | | | | |
|---|---|---|---|---|---|---|---|---|
| 06-01-2011 | | | | 06-01-2011 | | | | |
| Medida | Altura | Barra 1 | Barra 2 | Medida | Altura | Barra 1 | Barra 2 | Barra 3 |
| | medición | mV | mV | | medición | mV | mV | mV |
| | (m) | | | | (m) | | | |
| Nº | | 0,075 | 0,225 | Nº | | 0 | 0,15 | 0,3 |
| 1 | 0,20 | -234,9 | -409,7 | 1 | 0,28 | -448,2 | -264,9 | -276,8 |
| 2 | 0,35 | -190,3 | -202,3 | 2 | 0,43 | -147,7 | -142,1 | -153,8 |
| 3 | 0,50 | -142,9 | -152,5 | 3 | 0,58 | -132,8 | -141,5 | -161,6 |
| 4 | 0,65 | -135 | -138,4 | 4 | 0,73 | -133,1 | -135,2 | -151,4 |
| 5 | 0,80 | -138,9 | -142,1 | 5 | 0,88 | -136,2 | -158,9 | -148,8 |
| 6 | 0,95 | -175,1 | -147,9 | 6 | 1,03 | -175,6 | -141,4 | -142,7 |
| 7 | 1,10 | -137,6 | -126,1 | 7 | 1,18 | -133,4 | -115,7 | -127,7 |
| 8 | 1,25 | -109,7 | -110,3 | 8 | 1,33 | -106,1 | -104,9 | -122,3 |
| 9 | 1,40 | -100,2 | -103,7 | 9 | 1,48 | -94,2 | -100,3 | -111,9 |
| 10 | 1,55 | -100,3 | -96,8 | 10 | 1,63 | -97,1 | -100,2 | -107,3 |
| 11 | 1,70 | -98,4 | -101,9 | 11 | 1,78 | -105,3 | -99,5 | -113,2 |
| 12 | 1,85 | -103,2 | -106,9 | 12 | 1,93 | | | |

| **Velódromo Poniente** | | | | | | |
|---|---|---|---|---|---|---|
| **Estribos** | | | **Barras Ppales** | | | |
| 20-12-2010 | | | 20-12-2010 | | | |
| **Medida** | **Altura medición (m)** | **Barra 1 mV** | **Medida** | **Altura medición (m)** | **Barra 1 mV** | **Barra 2 mV** |
| **Nº** | | *0,075* | **Nº** | | *0* | *0,15* |
| 1 | ***0,20*** | *-199* | 1 | ***0,28*** | *-197,9* | *-244,5* |
| 2 | ***0,35*** | *-138,8* | 2 | ***0,43*** | *-176,5* | *-183,1* |
| 3 | ***0,50*** | *-140,1* | 3 | ***0,58*** | *-159,9* | *-103,7* |
| 4 | ***0,65*** | *-126* | 4 | ***0,73*** | *-164,6* | *-87,8* |
| 5 | ***0,80*** | *-85,5* | 5 | ***0,88*** | *-115,1* | *-9* |
| 6 | ***0,95*** | *-141,3* | 6 | ***1,03*** | *-112,6* | *-80,2* |
| 7 | ***1,10*** | *-192,7* | 7 | ***1,18*** | *-134,6* | *-192,2* |
| 8 | ***1,25*** | | 8 | ***1,33*** | *-57,7* | *-181,3* |

Sorptivity

**Mecánica**

| **Código testigo** | **M5PE** | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,052 | | |
| Área (m2) | 0,008 | | 1,023353 |
| Wo (kg) | 0,988 | | |
| Wn (kg) | 1,02335341 | | |
| tn (s) | 21543,154 | | |
| m (s/m^2) | 7967142,635 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,031 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 8,754 | porosidad efectiva | |

| **Fecha** | **Tiempo Ac (s)** | **Tiempo Ac (min)** | **Tiempo Ac (hr)** | **t^0,5 (s^0,5)** | **Peso (g)** | **Peso (kg)** |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 987,600 | 0,9876 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 991,8 | 0,9918 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 994,4 | 0,9944 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 996,3 | 0,9963 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 1000,4 | 1,0004 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 1005,3 | 1,0053 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 1010,6 | 1,0106 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 1014,8 | 1,0148 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 1017,3 | 1,0173 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 1019,9 | 1,0199 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 1020,8 | 1,0208 |
| 14-07-2010 | 86400 | 1440 | 24 | 293,9 | 1024,1 | 1,0241 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 15-07-2010 | 172800 | 2880 | 48 | 415,7 | 1024,7 | 1,0247 |
| 16-07-2010 | 259200 | 4320 | 72 | 509,1 | 1025,3 | 1,0253 |
| 17-07-2010 | 345600 | 5760 | 96 | 587,9 | 1025,5 | 1,0255 |

| Código testigo | M5PI | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,04 | | |
| Área (m2) | 0,008 | | 0,779466 |
| Wo (kg) | 0,753 | | |
| Wn (kg) | 0,779466222 | | |
| tn (s) | 14614,343 | | |
| m (s/m^2) | 9133964,223 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,028 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 8,475 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 752,840 | 0,75284 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 757,4 | 0,7574 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 760,1 | 0,7601 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 763,2 | 0,7632 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 766,4 | 0,7664 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 770,5 | 0,7705 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 774 | 0,774 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 776,7 | 0,7767 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 778,5 | 0,7785 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 779,3 | 0,7793 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 779,5 | 0,7795 |
| | 86400 | 1440 | 24 | 293,9 | 780,1 | 0,7801 |
| | 172800 | 2880 | 48 | 415,7 | 780,6 | 0,7806 |
| | 259200 | 4320 | 72 | 509,1 | 780,9 | 0,7809 |
| | 345600 | 5760 | 96 | 587,9 | 780,9 | 0,7809 |

| Código testigo | M5SE | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,051 | | |
| Área (m2) | 0,008 | | 1,017661 |
| Wo (kg) | 0,988 | | |
| Wn (kg) | 1,017661481 | | |
| tn (s) | 22550,876 | | |
| m (s/m^2) | 8670079,271 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,025 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 7,475 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 987,720 | 0,98772 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 990,1 | 0,9901 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 993,8 | 0,9938 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 996,1 | 0,9961 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 998,9 | 0,9989 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 1002,8 | 1,0028 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 1006,9 | 1,0069 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 1009,7 | 1,0097 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 1012 | 1,012 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 1013,9 | 1,0139 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 1015,2 | 1,0152 |
| | 86400 | 1440 | 24 | 293,9 | 1018,1 | 1,0181 |
| | 172800 | 2880 | 48 | 415,7 | 1018,7 | 1,0187 |
| | 259200 | 4320 | 72 | 509,1 | 1018,9 | 1,0189 |
| | 345600 | 5760 | 96 | 587,9 | 1019,1 | 1,0191 |

| Código testigo | M5SI | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,053 | | |
| Área (m2) | 0,008 | | 1,019509 |
| Wo (kg) | 0,988 | | |
| Wn (kg) | 1,019509342 | | |
| tn (s) | 16368,489 | | |
| m (s/m^2) | 5827158,605 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,031 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 7,526 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 988,180 | 0,98818 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 994,2 | 0,9942 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 998,5 | 0,9985 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 1000,9 | 1,0009 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 1004,1 | 1,0041 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 1008 | 1,008 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 1012,2 | 1,0122 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 1014,8 | 1,0148 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 1016,6 | 1,0166 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 1018 | 1,018 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 1018,9 | 1,0189 |
| | 86400 | 1440 | 24 | 293,9 | 1019,9 | 1,0199 |
| | 172800 | 2880 | 48 | 415,7 | 1020,3 | 1,0203 |
| | 259200 | 4320 | 72 | 509,1 | 1020,6 | 1,0206 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 345600 | 5760 | 96 | 587,9 | 1020,7 | 1,0207 |

**Eléctrica**

| Código testigo | EL5PE |
|---|---|
| Diámetro (m) | 0,1 |
| Altura (m) | 0,052 |
| Área (m2) | 0,008 |
| Wo (kg) | 0,965 |
| Wn (kg) | 0,984925776 |
| tn (s) | 24714,604 |
| m (s/m^2) | 9140016,285 |
| k (kg/m^2 s^0,5) | 0,01628 |
| εe (s/m2) | 4,921 |

0,984926

resistencia a la penetración de agua
coeficiente de absorción capilar
coef ASTM mm/ s^0,5
porosidad efectiva

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 964,830 | 0,96483 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 967,1 | 0,9671 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 968,7 | 0,9687 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 969,8 | 0,9698 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 972,5 | 0,9725 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 975,2 | 0,9752 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 977,4 | 0,9774 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 979,2 | 0,9792 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 980,7 | 0,9807 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 981,6 | 0,9816 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 982,2 | 0,9822 |
| | 86400 | 1440 | 24 | 293,9 | 990,1 | 0,9901 |
| | 172800 | 2880 | 48 | 415,7 | 999,1 | 0,9991 |
| | 259200 | 4320 | 72 | 509,1 | 1003,1 | 1,0031 |
| | 345600 | 5760 | 96 | 587,9 | 1003,9 | 1,0039 |

| Código testigo | EL5PI |
|---|---|
| Diámetro (m) | 0,1 |
| Altura (m) | 0,052 |
| Área (m2) | 0,008 |
| Wo (kg) | 0,977 |
| Wn (kg) | 1,014521907 |
| tn (s) | 21073,656 |
| m (s/m^2) | 7793511,896 |
| k (kg/m^2 s^0,5) | 0,033 |
| εe (s/m2) | 9,205 |

1,014522

resistencia a la penetración de agua
coeficiente de absorción capilar
coef ASTM mm/ s^0,5
porosidad efectiva

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 976,930 | 0,97693 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 981 | 0,981 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 982,9 | 0,9829 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 984,2 | 0,9842 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 987,5 | 0,9875 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 992,6 | 0,9926 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 999,3 | 0,9993 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 1004,8 | 1,0048 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 1008,9 | 1,0089 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 1011,4 | 1,0114 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 1013,5 | 1,0135 |
| | 86400 | 1440 | 24 | 293,9 | 1014,9 | 1,0149 |
| | 172800 | 2880 | 48 | 415,7 | 1015,1 | 1,0151 |
| | 259200 | 4320 | 72 | 509,1 | 1015,3 | 1,0153 |
| | 345600 | 5760 | 96 | 587,9 | 1015,6 | 1,0156 |

| Código testigo | EL5SE | |
|---|---|---|
| Diámetro (m) | 0,1 | |
| Altura (m) | 0,051 | |
| Área (m2) | 0,008 | 1,005243 |
| Wo (kg) | 0,977 | |
| Wn (kg) | 1,005242891 | |
| tn (s) | 34272,826 | |
| m (s/m^2) | 13176788,04 | resistencia a la penetración de agua |
| k (kg/m^2 s^0,5) | 0,01975 | coeficiente de absorción capilar |
| εe (s/m2) | 7,168 | porosidad efectiva |

coef ASTM mm/ s^0,5

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 976,530 | 0,97653 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 981 | 0,981 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 982,7 | 0,9827 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 984,1 | 0,9841 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 985,8 | 0,9858 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 988,6 | 0,9886 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 992 | 0,992 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 994,2 | 0,9942 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 996,1 | 0,9961 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 997,5 | 0,9975 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 998,5 | 0,9985 |
| | 86400 | 1440 | 24 | 293,9 | 1005,6 | 1,0056 |
| | 172800 | 2880 | 48 | 415,7 | 1005,9 | 1,0059 |
| | 259200 | 4320 | 72 | 509,1 | 1006,1 | 1,0061 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 345600 | 5760 | 96 | 587,9 | 1006,4 | 1,0064 |

| Código testigo | EL5SI | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,053 | | |
| Área (m2) | 0,008 | | 0,996687 |
| Wo (kg) | 0,967 | | |
| Wn (kg) | 0,996686633 | | |
| tn (s) | 19945,701 | | |
| m (s/m^2) | 7100641,074 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,027 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 7,235 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 966,570 | 0,96657 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 970 | 0,97 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 973,2 | 0,9732 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 975,2 | 0,9752 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 977,7 | 0,9777 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 982 | 0,982 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 986,9 | 0,9869 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 990,1 | 0,9901 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 992,9 | 0,9929 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 994,5 | 0,9945 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 995,6 | 0,9956 |
| | 86400 | 1440 | 24 | 293,9 | 997 | 0,997 |
| | 172800 | 2880 | 48 | 415,7 | 997,2 | 0,9972 |
| | 259200 | 4320 | 72 | 509,1 | 997,5 | 0,9975 |
| | 345600 | 5760 | 96 | 587,9 | 997,6 | 0,9976 |

**Educación**

| Código testigo | ED5PE | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,051 | | |
| Área (m2) | 0,008 | | 0,971709 |
| Wo (kg) | 0,929 | | |
| Wn (kg) | 0,971708838 | | |
| tn (s) | 12587,514 | | |
| m (s/m^2) | 4839490,375 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,048 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 10,560 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 929,410 | 0,92941 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 934,6 | 0,9346 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 936,2 | 0,9362 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 940,1 | 0,9401 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 947 | 0,947 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 954,3 | 0,9543 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 963,8 | 0,9638 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 969,1 | 0,9691 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 971,5 | 0,9715 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 971,8 | 0,9718 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 971,9 | 0,9719 |
| | 86400 | 1440 | 24 | 293,9 | 972,8 | 0,9728 |
| | 172800 | 2880 | 48 | 415,7 | 973,5 | 0,9735 |
| | 259200 | 4320 | 72 | 509,1 | 974,2 | 0,9742 |
| | 345600 | 5760 | 96 | 587,9 | 974,5 | 0,9745 |

| Código testigo | ED5PI | |
|---|---|---|
| Diámetro (m) | 0,1 | |
| Altura (m) | 0,051 | |
| Área (m2) | 0,008 | 0,975452 |
| Wo (kg) | 0,931 | |
| Wn (kg) | 0,975452203 | |
| tn (s) | 20092,467 | |
| m (s/m^2) | 7724900,775 | resistencia a la penetración de agua |
| k (kg/m^2 s^0,5) | 0,040 | coeficiente de absorción capilar — coef ASTM mm/ s^0,5 |
| εe (s/m2) | 11,178 | porosidad efectiva |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 930,680 | 0,93068 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 939,6 | 0,9396 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 943 | 0,943 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 945,2 | 0,9452 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 948,7 | 0,9487 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 953,8 | 0,9538 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 960,7 | 0,9607 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 965,9 | 0,9659 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 969,7 | 0,9697 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 972,4 | 0,9724 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 974,3 | 0,9743 |
| | 86400 | 1440 | 24 | 293,9 | 976,1 | 0,9761 |
| | 172800 | 2880 | 48 | 415,7 | 976,6 | 0,9766 |
| | 259200 | 4320 | 72 | 509,1 | 977 | 0,977 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 345600 | 5760 | 96 | 587,9 | 977,3 | 0,9773 |

| Código testigo | ED5SE | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,052 | | |
| Área (m2) | 0,008 | | 0,960941 |
| Wo (kg) | 0,919 | | |
| Wn (kg) | 0,961 | | |
| tn (s) | 109665,551 | | |
| m (s/m^2) | 40556786,70 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,016 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 10,159 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 919,450 | 0,91945 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 923,4 | 0,9234 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 924,8 | 0,9248 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 925,7 | 0,9257 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 927 | 0,927 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 930,5 | 0,9305 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 934,8 | 0,9348 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 937,4 | 0,9374 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 939,2 | 0,9392 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 940,8 | 0,9408 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 941,6 | 0,9416 |
| | 86400 | 1440 | 24 | 293,9 | 952,5 | 0,9525 |
| | 172800 | 2880 | 48 | 415,7 | 961,6 | 0,9616 |
| | 259200 | 4320 | 72 | 509,1 | 962,9 | 0,9629 |
| | 345600 | 5760 | 96 | 587,9 | 963,3 | 0,9633 |

| Código testigo | ED5SI | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,053 | | |
| Área (m2) | 0,008 | | 0,961957 |
| Wo (kg) | 0,921 | | |
| Wn (kg) | 0,961957112 | | |
| tn (s) | 37292,770 | | |
| m (s/m^2) | 13276172,992 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,027 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 9,791 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 921,200 | 0,9212 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 926,8 | 0,9268 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 929,1 | 0,9291 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 930,7 | 0,9307 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 932,7 | 0,9327 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 936,5 | 0,9365 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 941,6 | 0,9416 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 945 | 0,945 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 947,7 | 0,9477 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 949,6 | 0,9496 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 951,3 | 0,9513 |
| | 86400 | 1440 | 24 | 293,9 | 962,3 | 0,9623 |
| | 172800 | 2880 | 48 | 415,7 | 962,8 | 0,9628 |
| | 259200 | 4320 | 72 | 509,1 | 963,2 | 0,9632 |
| | 345600 | 5760 | 96 | 587,9 | 963,4 | 0,9634 |

**Humanidades**

| **Código testigo** | **H5PE** | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,053 | | |
| Área (m2) | 0,008 | | 0,9809 |
| Wo (kg) | 0,945 | | |
| Wn (kg) | 0,980900153 | | |
| tn (s) | 64557,597 | | |
| m (s/m^2) | 22982412,726 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,018 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 8,670 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 944,810 | 0,94481 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 947,5 | 0,9475 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 947,9 | 0,9479 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 948,5 | 0,9485 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 949,1 | 0,9491 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 950,5 | 0,9505 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 953 | 0,953 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 956,3 | 0,9563 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 960,2 | 0,9602 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 963,5 | 0,9635 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 966,8 | 0,9668 |
| | 86400 | 1440 | 24 | 293,9 | 980,9 | 0,9809 |
| | 172800 | 2880 | 48 | 415,7 | 981,4 | 0,9814 |
| | 259200 | 4320 | 72 | 509,1 | 981,8 | 0,9818 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 345600 | 5760 | 96 | 587,9 | 981,9 | 0,9819 |

| **Código testigo** | **H5PI** | |
|---|---|---|
| Diámetro (m) | 0,1 | |
| Altura (m) | 0,053 | |
| Área (m2) | 0,008 | 0,983864 |
| Wo (kg) | 0,971 | |
| Wn (kg) | 0,983864324 | |
| tn (s) | 28740,845 | |
| m (s/m^2) | 10231699,796 | resistencia a la penetración de agua |
| k (kg/m^2 s^0,5) | 0,010 | coeficiente de absorción capilar — coef ASTM mm/ s^0,5 |
| εe (s/m2) | 3,136 | porosidad efectiva |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 970,810 | 0,97081 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 973,3 | 0,9733 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 974,1 | 0,9741 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 974,6 | 0,9746 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 975,2 | 0,9752 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 976,6 | 0,9766 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 978,1 | 0,9781 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 979,3 | 0,9793 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 980,4 | 0,9804 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 980,8 | 0,9808 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 981,3 | 0,9813 |
| | 86400 | 1440 | 24 | 293,9 | 986,1 | 0,9861 |
| | 172800 | 2880 | 48 | 415,7 | 988,9 | 0,9889 |
| | 259200 | 4320 | 72 | 509,1 | 990,7 | 0,9907 |
| | 345600 | 5760 | 96 | 587,9 | 991,8 | 0,9918 |

| **Código testigo** | **H5SE** | |
|---|---|---|
| Diámetro (m) | 0,1 | |
| Altura (m) | 0,051 | |
| Área (m2) | 0,008 | 0,977114 |
| Wo (kg) | 0,933 | |
| Wn (kg) | 0,977114464 | |
| tn (s) | 159353,595 | |
| m (s/m^2) | 61266280,420 | resistencia a la penetración de agua |
| k (kg/m^2 s^0,5) | 0,014 | coeficiente de absorción capilar — coef ASTM mm/ s^0,5 |
| εe (s/m2) | 10,988 | porosidad efectiva |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 933,100 | 0,9331 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 936,8 | 0,9368 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 937,4 | 0,9374 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 938,1 | 0,9381 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 939,5 | 0,9395 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 940,2 | 0,9402 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 941,3 | 0,9413 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 942,2 | 0,9422 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 943,1 | 0,9431 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 943,9 | 0,9439 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 946,1 | 0,9461 |
| | 86400 | 1440 | 24 | 293,9 | 970,1 | 0,9701 |
| | 172800 | 2880 | 48 | 415,7 | 977,2 | 0,9772 |
| | 259200 | 4320 | 72 | 509,1 | 977,8 | 0,9778 |
| | 345600 | 5760 | 96 | 587,9 | 977,9 | 0,9779 |

| **Código testigo** | **H5SI** | |
|---|---|---|
| Diámetro (m) | 0,1 | |
| Altura (m) | 0,051 | |
| Área (m2) | 0,008 | 0,975548 |
| Wo (kg) | 0,954 | |
| Wn (kg) | 0,975548281 | |
| tn (s) | 95741,018 | |
| m (s/m^2) | 36809310,915 | resistencia a la penetración de agua |
| k (kg/m^2 s^0,5) | 0,009 | coeficiente de absorción capilar |
| εe (s/m2) | 5,425 | porosidad efectiva |

coef ASTM mm/ s^0,5

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 13-07-2010 | 0 | 0 | 0 | 0 | 953,820 | 0,95382 |
| 13-07-2010 | 300 | 5 | 0,08 | 17,3 | 958 | 0,958 |
| 13-07-2010 | 600 | 10 | 0,17 | 24,5 | 958,9 | 0,9589 |
| 13-07-2010 | 900 | 15 | 0,25 | 30 | 959,5 | 0,9595 |
| 13-07-2010 | 1800 | 30 | 0,5 | 42,4 | 961,4 | 0,9614 |
| 13-07-2010 | 3600 | 60 | 1 | 60 | 962,7 | 0,9627 |
| 13-07-2010 | 7200 | 120 | 2 | 84,9 | 964,8 | 0,9648 |
| 13-07-2010 | 10800 | 180 | 3 | 103,9 | 966,4 | 0,9664 |
| 13-07-2010 | 14400 | 240 | 4 | 120 | 967,8 | 0,9678 |
| 13-07-2010 | 18000 | 300 | 5 | 134,2 | 968,9 | 0,9689 |
| 13-07-2010 | 21600 | 360 | 6 | 147 | 969,9 | 0,9699 |
| | 86400 | 1440 | 24 | 293,9 | 978,8 | 0,9788 |
| | 172800 | 2880 | 48 | 415,7 | 983,3 | 0,9833 |
| | 259200 | 4320 | 72 | 509,1 | 984,6 | 0,9846 |
| | 345600 | 5760 | 96 | 587,9 | 985,3 | 0,9853 |

**Polideportivo**

| **Código testigo** | **PL5PE** |
|---|---|
| Diámetro (m) | 0,1 |
| Altura (m) | 0,053 |
| Área (m2) | 0,008 |
| Wo (kg) | 0,975 |
| Wn (kg) | 1,0136 |
| tn (s) | 10404,000 |
| m (s/m^2) | 3703809,185 |
| k (kg/m^2 s^0,5) | 0,049 |
| εe (s/m2) | 9,388 |

~

1,01355

resistencia a la penetración de agua
coeficiente de absorción capilar
porosidad efectiva

coef ASTM mm/ s^0,5

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 12-10-2010 | 0 | 0 | 0 | 0 | 974,520 | 0,97452 |
| 12-10-2010 | 300 | 5 | 0,08 | 17,3 | 978,2 | 0,9782 |
| 12-10-2010 | 600 | 10 | 0,17 | 24,5 | 982,65 | 0,98265 |
| 12-10-2010 | 900 | 15 | 0,25 | 30 | 985,75 | 0,98575 |
| 12-10-2010 | 1800 | 30 | 0,5 | 42,4 | 992,58 | 0,99258 |
| 12-10-2010 | 3600 | 60 | 1 | 60 | 999,54 | 0,99954 |
| 12-10-2010 | 7200 | 120 | 2 | 84,9 | 1007,25 | 1,00725 |
| 12-10-2010 | 10800 | 180 | 3 | 103,9 | 1010,73 | 1,01073 |
| 12-10-2010 | 14400 | 240 | 4 | 120 | 1012,4 | 1,0124 |
| 12-10-2010 | 18000 | 300 | 5 | 134,2 | 1013,4 | 1,0134 |
| 12-10-2010 | 21600 | 360 | 6 | 147 | 1013,1 | 1,0131 |
| 13-10-2010 | 86400 | 1440 | 24 | 293,9 | 1012,9 | 1,0129 |
| 14-10-2010 | 172800 | 2880 | 48 | 415,7 | 1008,7 | 1,0087 |
| 15-10-2010 | 259200 | 4320 | 72 | 509,1 | 1008,5 | 1,0085 |
| 16-10-2010 | 345600 | 5760 | 96 | 587,9 | | 0 |

| **Código testigo** | **PL5PI** |
|---|---|
| Diámetro (m) | 0,1 |
| Altura (m) | 0,05 |
| Área (m2) | 0,008 |
| Wo (kg) | 0,933 |
| Wn (kg) | 0,967130794 |
| tn (s) | 14400,000 |
| m (s/m^2) | 5760000,000 |
| k (kg/m^2 s^0,5) | 0,036 |
| εe (s/m2) | 8,656 |

0,967131

resistencia a la penetración de agua
coeficiente de absorción capilar
porosidad efectiva

coef ASTM mm/ s^0,5

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 12-10-2010 | 0 | 0 | 0 | 0 | 933,140 | 0,93314 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 12-10-2010 | 300 | 5 | 0,08 | 17,3 | 936 | 0,936 |
| 12-10-2010 | 600 | 10 | 0,17 | 24,5 | 939,14 | 0,93914 |
| 12-10-2010 | 900 | 15 | 0,25 | 30 | 943,79 | 0,94379 |
| 12-10-2010 | 1800 | 30 | 0,5 | 42,4 | 949,12 | 0,94912 |
| 12-10-2010 | 3600 | 60 | 1 | 60 | 954,68 | 0,95468 |
| 12-10-2010 | 7200 | 120 | 2 | 84,9 | 960,42 | 0,96042 |
| 12-10-2010 | 10800 | 180 | 3 | 103,9 | 962,7 | 0,9627 |
| 12-10-2010 | 14400 | 240 | 4 | 120 | 965,1 | 0,9651 |
| 12-10-2010 | 18000 | 300 | 5 | 134,2 | 966,8 | 0,9668 |
| 12-10-2010 | 21600 | 360 | 6 | 147 | 967,2 | 0,9672 |
| 13-10-2010 | 86400 | 1440 | 24 | 293,9 | 967,7 | 0,9677 |
| 14-10-2010 | 172800 | 2880 | 48 | 415,7 | 967,9 | 0,9679 |
| 15-10-2010 | 259200 | 4320 | 72 | 509,1 | 968,2 | 0,9682 |
| 16-10-2010 | 345600 | 5760 | 96 | 587,9 | | 0 |

| **Código testigo** | **PL5SE** | |
|---|---|---|
| Diámetro (m) | 0,1 | |
| Altura (m) | 0,0533 | |
| Área (m2) | 0,008 | 1,003848 |
| Wo (kg) | 0,979 | |
| Wn (kg) | 1,003847657 | |
| tn (s) | 9604,000 | |
| m (s/m^2) | 3380630,718 | resistencia a la penetración de agua |
| k (kg/m^2 s^0,5) | 0,032 | coeficiente de absorción capilar |
| εe (s/m2) | 5,948 | porosidad efectiva |

coef ASTM mm/ s^0,5

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 12-10-2010 | 0 | 0 | 0 | 0 | 978,940 | 0,97894 |
| 12-10-2010 | 300 | 5 | 0,08 | 17,3 | 980,9 | 0,9809 |
| 12-10-2010 | 600 | 10 | 0,17 | 24,5 | 983,77 | 0,98377 |
| 12-10-2010 | 900 | 15 | 0,25 | 30 | 987,46 | 0,98746 |
| 12-10-2010 | 1800 | 30 | 0,5 | 42,4 | 990,75 | 0,99075 |
| 12-10-2010 | 3600 | 60 | 1 | 60 | 993,58 | 0,99358 |
| 12-10-2010 | 7200 | 120 | 2 | 84,9 | 996,01 | 0,99601 |
| 12-10-2010 | 10800 | 180 | 3 | 103,9 | 997,41 | 0,99741 |
| 12-10-2010 | 14400 | 240 | 4 | 120 | 998,8 | 0,9988 |
| 12-10-2010 | 18000 | 300 | 5 | 134,2 | 1000,5 | 1,0005 |
| 12-10-2010 | 21600 | 360 | 6 | 147 | 1000,4 | 1,0004 |
| 13-10-2010 | 86400 | 1440 | 24 | 293,9 | 1005,4 | 1,0054 |
| 14-10-2010 | 172800 | 2880 | 48 | 415,7 | 1007,1 | 1,0071 |
| 15-10-2010 | 259200 | 4320 | 72 | 509,1 | 1007,8 | 1,0078 |
| 16-10-2010 | 345600 | 5760 | 96 | 587,9 | | 0 |

| **Código testigo** | **PL5SI** |
|---|---|

| | | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,0515 | | |
| Área (m2) | 0,008 | | 0,957561 |
| Wo (kg) | 0,941 | | |
| Wn (kg) | 0,957561415 | | |
| tn (s) | 12100,000 | | |
| m (s/m^2) | 4562164,200 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,019 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 4,045 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 12-10-2010 | 0 | 0 | 0 | 0 | 941,200 | 0,9412 |
| 12-10-2010 | 300 | 5 | 0,08 | 17,3 | 942,7 | 0,9427 |
| 12-10-2010 | 600 | 10 | 0,17 | 24,5 | 944,49 | 0,94449 |
| 12-10-2010 | 900 | 15 | 0,25 | 30 | 946,13 | 0,94613 |
| 12-10-2010 | 1800 | 30 | 0,5 | 42,4 | 948,28 | 0,94828 |
| 12-10-2010 | 3600 | 60 | 1 | 60 | 950,37 | 0,95037 |
| 12-10-2010 | 7200 | 120 | 2 | 84,9 | 952,17 | 0,95217 |
| 12-10-2010 | 10800 | 180 | 3 | 103,9 | 952,46 | 0,95246 |
| 12-10-2010 | 14400 | 240 | 4 | 120 | 953,4 | 0,9534 |
| 12-10-2010 | 18000 | 300 | 5 | 134,2 | 954,7 | 0,9547 |
| 12-10-2010 | 21600 | 360 | 6 | 147 | 955,1 | 0,9551 |
| 13-10-2010 | 86400 | 1440 | 24 | 293,9 | 958,3 | 0,9583 |
| 14-10-2010 | 172800 | 2880 | 48 | 415,7 | 959,1 | 0,9591 |
| 15-10-2010 | 259200 | 4320 | 72 | 509,1 | 959,5 | 0,9595 |
| 16-10-2010 | 345600 | 5760 | 96 | 587,9 | | 0 |

**VELÓDROMO**

| Código testigo | ChD5PE | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,0547 | | |
| Área (m2) | 0,008 | | 1,057985 |
| Wo (kg) | 1,030 | | |
| Wn (kg) | 1,0579851 | | |
| tn (s) | 22500,000 | | |
| m (s/m^2) | 7519827,278 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,024 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 6,514 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 12-10-2010 | 0 | 0 | 0 | 0 | 1030,740 | 1,03074 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 12-10-2010 | 300 | 5 | 0,08 | 17,3 | 1032,8 | 1,0328 |
| 12-10-2010 | 600 | 10 | 0,17 | 24,5 | 1035,7 | 1,0357 |
| 12-10-2010 | 900 | 15 | 0,25 | 30 | 1037,15 | 1,03715 |
| 12-10-2010 | 1800 | 30 | 0,5 | 42,4 | 1039,58 | 1,03958 |
| 12-10-2010 | 3600 | 60 | 1 | 60 | 1042,08 | 1,04208 |
| 12-10-2010 | 7200 | 120 | 2 | 84,9 | 1044,94 | 1,04494 |
| 12-10-2010 | 10800 | 180 | 3 | 103,9 | 1046,1 | 1,0461 |
| 12-10-2010 | 14400 | 240 | 4 | 120 | 1048,6 | 1,0486 |
| 12-10-2010 | 18000 | 300 | 5 | 134,2 | 1050,8 | 1,0508 |
| 12-10-2010 | 21600 | 360 | 6 | 147 | 1051,5 | 1,0515 |
| 13-10-2010 | 86400 | 1440 | 24 | 293,9 | 1058,6 | 1,0586 |
| 14-10-2010 | 172800 | 2880 | 48 | 415,7 | 1059,3 | 1,0593 |
| 15-10-2010 | 259200 | 4320 | 72 | 509,1 | 1059,9 | 1,0599 |
| 16-10-2010 | 345600 | 5760 | 96 | 587,9 | | 0 |

| **Código testigo** | **ChD5PI** | |
|---|---|---|
| Diámetro (m) | 0,1 | |
| Altura (m) | 0,0502 | |
| Área (m2) | 0,008 | 0,927107 |
| Wo (kg) | 0,910 | |
| Wn (kg) | 0,927107174 | |
| tn (s) | 22500,000 | |
| m (s/m^2) | 8928429,707 | resistencia a la penetración de agua |
| k (kg/m^2 s^0,5) | 0,015 | coeficiente de absorción capilar — coef ASTM mm/ s^0,5 |
| εe (s/m2) | 4,339 | porosidad efectiva |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 12-10-2010 | 0 | 0 | 0 | 0 | 910,150 | 0,91015 |
| 12-10-2010 | 300 | 5 | 0,08 | 17,3 | 911,3 | 0,9113 |
| 12-10-2010 | 600 | 10 | 0,17 | 24,5 | 912,97 | 0,91297 |
| 12-10-2010 | 900 | 15 | 0,25 | 30 | 914,75 | 0,91475 |
| 12-10-2010 | 1800 | 30 | 0,5 | 42,4 | 916,35 | 0,91635 |
| 12-10-2010 | 3600 | 60 | 1 | 60 | 918,07 | 0,91807 |
| 12-10-2010 | 7200 | 120 | 2 | 84,9 | 920,46 | 0,92046 |
| 12-10-2010 | 10800 | 180 | 3 | 103,9 | 921,31 | 0,92131 |
| 12-10-2010 | 14400 | 240 | 4 | 120 | 922,8 | 0,9228 |
| 12-10-2010 | 18000 | 300 | 5 | 134,2 | 924,3 | 0,9243 |
| 12-10-2010 | 21600 | 360 | 6 | 147 | 925,6 | 0,9256 |
| 13-10-2010 | 86400 | 1440 | 24 | 293,9 | 930,3 | 0,9303 |
| 14-10-2010 | 172800 | 2880 | 48 | 415,7 | 933,5 | 0,9335 |
| 15-10-2010 | 259200 | 4320 | 72 | 509,1 | 935,4 | 0,9354 |
| 16-10-2010 | 345600 | 5760 | 96 | 587,9 | | 0 |

| **Código testigo** | **ChD5SE** |
|---|---|

| | | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,05425 | | |
| Área (m2) | 0,008 | | 0,995353 |
| Wo (kg) | 0,956 | | |
| Wn (kg) | 0,99535262 | | |
| tn (s) | 40000,000 | | |
| m (s/m^2) | 13591284,59 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,025 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 9,236 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 12-10-2010 | 0 | 0 | 0 | 0 | 957,880 | 0,95788 |
| 12-10-2010 | 300 | 5 | 0,08 | 17,3 | 959,2 | 0,9592 |
| 12-10-2010 | 600 | 10 | 0,17 | 24,5 | 961,09 | 0,96109 |
| 12-10-2010 | 900 | 15 | 0,25 | 30 | 962,4 | 0,9624 |
| 12-10-2010 | 1800 | 30 | 0,5 | 42,4 | 965,57 | 0,96557 |
| 12-10-2010 | 3600 | 60 | 1 | 60 | 969,63 | 0,96963 |
| 12-10-2010 | 7200 | 120 | 2 | 84,9 | 974,98 | 0,97498 |
| 12-10-2010 | 10800 | 180 | 3 | 103,9 | 977,73 | 0,97773 |
| 12-10-2010 | 14400 | 240 | 4 | 120 | 980,5 | 0,9805 |
| 12-10-2010 | 18000 | 300 | 5 | 134,2 | 983,4 | 0,9834 |
| 12-10-2010 | 21600 | 360 | 6 | 147 | 985,7 | 0,9857 |
| 13-10-2010 | 86400 | 1440 | 24 | 293,9 | 995,6 | 0,9956 |
| 14-10-2010 | 172800 | 2880 | 48 | 415,7 | 995,8 | 0,9958 |
| 15-10-2010 | 259200 | 4320 | 72 | 509,1 | 996 | 0,996 |
| 16-10-2010 | 345600 | 5760 | 96 | 587,9 | | 0 |

| Código testigo | ChD5SI | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,0507 | | |
| Área (m2) | 0,008 | | 0,953783 |
| Wo (kg) | 0,922 | | |
| Wn (kg) | 0,953782802 | | |
| tn (s) | 32400,000 | | |
| m (s/m^2) | 12604600,68 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,022 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 7,982 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 12-10-2010 | 0 | 0 | 0 | 0 | 922,270 | 0,92227 |
| 12-10-2010 | 300 | 5 | 0,08 | 17,3 | 924,5 | 0,9245 |
| 12-10-2010 | 600 | 10 | 0,17 | 24,5 | 927,04 | 0,92704 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 12-10-2010 | 900 | 15 | 0,25 | 30 | 929,22 | 0,92922 |
| 12-10-2010 | 1800 | 30 | 0,5 | 42,4 | 931,99 | 0,93199 |
| 12-10-2010 | 3600 | 60 | 1 | 60 | 935,38 | 0,93538 |
| 12-10-2010 | 7200 | 120 | 2 | 84,9 | 939,25 | 0,93925 |
| 12-10-2010 | 10800 | 180 | 3 | 103,9 | 941,02 | 0,94102 |
| 12-10-2010 | 14400 | 240 | 4 | 120 | 943,2 | 0,9432 |
| 12-10-2010 | 18000 | 300 | 5 | 134,2 | 945,2 | 0,9452 |
| 12-10-2010 | 21600 | 360 | 6 | 147 | 946,1 | 0,9461 |
| 13-10-2010 | 86400 | 1440 | 24 | 293,9 | 953,9 | 0,9539 |
| 14-10-2010 | 172800 | 2880 | 48 | 415,7 | 954,1 | 0,9541 |
| 15-10-2010 | 259200 | 4320 | 72 | 509,1 | 954,2 | 0,9542 |
| 16-10-2010 | 345600 | 5760 | 96 | 587,9 | | 0 |

**Cs BIOLOGICAS**

| **Código testigo** | **EN5PE** | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,0525 | | |
| Área (m2) | 0,008 | | 1,003814 |
| Wo (kg) | 0,969 | | |
| Wn (kg) | 1,003814466 | | |
| tn (s) | 32400,000 | | |
| m (s/m^2) | 11755102,041 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,025 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 8,443 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 12-10-2010 | 0 | 0 | 0 | 0 | 969,480 | 0,96948 |
| 12-10-2010 | 300 | 5 | 0,08 | 17,3 | 971,2 | 0,9712 |
| 12-10-2010 | 600 | 10 | 0,17 | 24,5 | 973,01 | 0,97301 |
| 12-10-2010 | 900 | 15 | 0,25 | 30 | 975,37 | 0,97537 |
| 12-10-2010 | 1800 | 30 | 0,5 | 42,4 | 978,68 | 0,97868 |
| 12-10-2010 | 3600 | 60 | 1 | 60 | 983,43 | 0,98343 |
| 12-10-2010 | 7200 | 120 | 2 | 84,9 | 988,77 | 0,98877 |
| 12-10-2010 | 10800 | 180 | 3 | 103,9 | 991,22 | 0,99122 |
| 12-10-2010 | 14400 | 240 | 4 | 120 | 993,3 | 0,9933 |
| 12-10-2010 | 18000 | 300 | 5 | 134,2 | 995,1 | 0,9951 |
| 12-10-2010 | 21600 | 360 | 6 | 147 | 996,1 | 0,9961 |
| 13-10-2010 | 86400 | 1440 | 24 | 293,9 | 1004,1 | 1,0041 |
| 14-10-2010 | 172800 | 2880 | 48 | 415,7 | 1004,3 | 1,0043 |
| 15-10-2010 | 259200 | 4320 | 72 | 509,1 | 1004,6 | 1,0046 |
| 16-10-2010 | 345600 | 5760 | 96 | 587,9 | | 0 |

| **Código testigo** | **EN5PI** |
|---|---|

| | | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,052 | | |
| Área (m2) | 0,008 | | 1,002989 |
| Wo (kg) | 0,973 | | |
| Wn (kg) | 1,002989447 | | |
| tn (s) | 25600,000 | | |
| m (s/m^2) | 9467455,621 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,024 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 7,392 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 12-10-2010 | 0 | 0 | 0 | 0 | 972,780 | 0,97278 |
| 12-10-2010 | 300 | 5 | 0,08 | 17,3 | 974,6 | 0,9746 |
| 12-10-2010 | 600 | 10 | 0,17 | 24,5 | 976,96 | 0,97696 |
| 12-10-2010 | 900 | 15 | 0,25 | 30 | 979,02 | 0,97902 |
| 12-10-2010 | 1800 | 30 | 0,5 | 42,4 | 981,95 | 0,98195 |
| 12-10-2010 | 3600 | 60 | 1 | 60 | 985,69 | 0,98569 |
| 12-10-2010 | 7200 | 120 | 2 | 84,9 | 990,2 | 0,9902 |
| 12-10-2010 | 10800 | 180 | 3 | 103,9 | 992,9 | 0,9929 |
| 12-10-2010 | 14400 | 240 | 4 | 120 | 995,9 | 0,9959 |
| 12-10-2010 | 18000 | 300 | 5 | 134,2 | 998,6 | 0,9986 |
| 12-10-2010 | 21600 | 360 | 6 | 147 | 1000 | 1 |
| 13-10-2010 | 86400 | 1440 | 24 | 293,9 | 1003,3 | 1,0033 |
| 14-10-2010 | 172800 | 2880 | 48 | 415,7 | 1003,6 | 1,0036 |
| 15-10-2010 | 259200 | 4320 | 72 | 509,1 | 1003,8 | 1,0038 |
| 16-10-2010 | 345600 | 5760 | 96 | 587,9 | | 0 |

| **Código testigo** | **EN5SE** | | |
|---|---|---|---|
| Diámetro (m) | 0,1 | | |
| Altura (m) | 0,053 | | |
| Área (m2) | 0,008 | | 1,015384 |
| Wo (kg) | 0,974 | | |
| Wn (kg) | 1,015383879 | | |
| tn (s) | 22500,000 | | |
| m (s/m^2) | 8009967,960 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,035 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 10,038 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 12-10-2010 | 0 | 0 | 0 | 0 | 973,660 | 0,97366 |
| 12-10-2010 | 300 | 5 | 0,08 | 17,3 | 975,45 | 0,97545 |
| 12-10-2010 | 600 | 10 | 0,17 | 24,5 | 977,36 | 0,97736 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 12-10-2010 | 900 | 15 | 0,25 | 30 | 978,67 | 0,97867 |
| 12-10-2010 | 1800 | 30 | 0,5 | 42,4 | 982,49 | 0,98249 |
| 12-10-2010 | 3600 | 60 | 1 | 60 | 989,14 | 0,98914 |
| 12-10-2010 | 7200 | 120 | 2 | 84,9 | 997,53 | 0,99753 |
| 12-10-2010 | 10800 | 180 | 3 | 103,9 | 1002,7 | 1,0027 |
| 12-10-2010 | 14400 | 240 | 4 | 120 | 1006,9 | 1,0069 |
| 12-10-2010 | 18000 | 300 | 5 | 134,2 | 1010,4 | 1,0104 |
| 12-10-2010 | 21600 | 360 | 6 | 147 | 1012,7 | 1,0127 |
| 13-10-2010 | 86400 | 1440 | 24 | 293,9 | 1015,7 | 1,0157 |
| 14-10-2010 | 172800 | 2880 | 48 | 415,7 | 1015,88 | 1,01588 |
| 15-10-2010 | 259200 | 4320 | 72 | 509,1 | 1016,1 | 1,0161 |
| 16-10-2010 | 345600 | 5760 | 96 | 587,9 | | 0 |

| Código testigo | EN5SI | |
|---|---|---|
| Diámetro (m) | 0,1 | |
| Altura (m) | 0,05 | |
| Área (m2) | 0,008 | 0,948478 |
| Wo (kg) | 0,927 | |
| Wn (kg) | 0,954 | |
| tn (s) | 44100,000 | |
| m (s/m^2) | 17640000,000 | resistencia a la penetración de agua |
| k (kg/m^2 s^0,5) | 0,017 | coeficiente de absorción capilar — coef ASTM mm/ s^0,5 |
| εe (s/m2) | 6,952 | porosidad efectiva |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 12-10-2010 | 0 | 0 | 0 | 0 | 926,750 | 0,92675 |
| 12-10-2010 | 300 | 5 | 0,08 | 17,3 | 927,78 | 0,92778 |
| 12-10-2010 | 600 | 10 | 0,17 | 24,5 | 928,81 | 0,92881 |
| 12-10-2010 | 900 | 15 | 0,25 | 30 | 929,82 | 0,92982 |
| 12-10-2010 | 1800 | 30 | 0,5 | 42,4 | 931,9 | 0,9319 |
| 12-10-2010 | 3600 | 60 | 1 | 60 | 934,54 | 0,93454 |
| 12-10-2010 | 7200 | 120 | 2 | 84,9 | 937,65 | 0,93765 |
| 12-10-2010 | 10800 | 180 | 3 | 103,9 | 940,8 | 0,9408 |
| 12-10-2010 | 14400 | 240 | 4 | 120 | 943,3 | 0,9433 |
| 12-10-2010 | 18000 | 300 | 5 | 134,2 | 946,8 | 0,9468 |
| 12-10-2010 | 21600 | 360 | 6 | 147 | 950,9 | 0,9509 |
| 13-10-2010 | 86400 | 1440 | 24 | 293,9 | 961,5 | 0,9615 |
| 14-10-2010 | 172800 | 2880 | 48 | 415,7 | 961,6 | 0,9616 |
| 15-10-2010 | 259200 | 4320 | 72 | 509,1 | 961,8 | 0,9618 |
| 16-10-2010 | 345600 | 5760 | 96 | 587,9 | | 0 |

**AUDITORIUM ARQ**

| Código testigo | AMPE |
|---|---|

| | | | |
|---|---|---|---|
| Diámetro (m) | 0,1013 | | |
| Altura (m) | 0,0499 | | |
| Área (m2) | 0,008 | | 0,953075 |
| Wo (kg) | 0,901 | 0,898 | |
| Wn (kg) | 0,95307496 | | |
| tn (s) | 78681,531 | | |
| m (s/m^2) | 31598881,461 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,023 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 12,909 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 26-03.2011 | 0 | 0 | 0 | 0 | 901,160 | 0,90116 |
| | 300 | 5 | 0,08 | 17,3 | 905,61 | 0,90561 |
| | 600 | 10 | 0,17 | 24,5 | 906,84 | 0,90684 |
| | 900 | 15 | 0,25 | 30 | 907,9 | 0,9079 |
| | 1800 | 30 | 0,5 | 42,4 | 909,87 | 0,90987 |
| | 3600 | 60 | 1 | 60 | 912,6 | 0,9126 |
| | 7200 | 120 | 2 | 84,9 | 917,33 | 0,91733 |
| | 10800 | 180 | 3 | 103,9 | 920,7 | 0,9207 |
| | 14400 | 240 | 4 | 120 | 923,49 | 0,92349 |
| | 18000 | 300 | 5 | 134,2 | 926,55 | 0,92655 |
| | 21600 | 360 | 6 | 147 | 929,14 | 0,92914 |
| 27-03-2011 | 86400 | 1440 | 24 | 293,9 | 953 | 0,953 |
| 28-03-2011 | 172800 | 2880 | 48 | 415,7 | 953,79 | 0,95379 |
| 29-03-2011 | 259200 | 4320 | 72 | 509,1 | 954,29 | 0,95429 |
| 30-03-2011 | 345600 | 5760 | 96 | 587,9 | 954,55 | 0,95455 |
| | 432000 | 7200 | 120 | 695,5 | | 0 |
| | 518400 | 8640 | 144 | 793,04 | | 0 |

| Código testigo | AMPI | | |
|---|---|---|---|
| Diámetro (m) | 0,1014 | | |
| Altura (m) | 0,0515 | | |
| Área (m2) | 0,008 | | 0,957781 |
| Wo (kg) | 0,943 | 0,939 | |
| Wn (kg) | 0,957780768 | | |
| tn (s) | 28657,653 | | |
| m (s/m^2) | 10805034,616 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,011 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 3,607 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| | 0 | 0 | 0 | 0 | 942,780 | 0,94278 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 300 | 5 | 0,08 | 17,3 | 946,26 | 0,94626 |
| | 600 | 10 | 0,17 | 24,5 | 946,82 | 0,94682 |
| | 900 | 15 | 0,25 | 30 | 947,55 | 0,94755 |
| | 1800 | 30 | 0,5 | 42,4 | 948,21 | 0,94821 |
| | 3600 | 60 | 1 | 60 | 949,52 | 0,94952 |
| | 7200 | 120 | 2 | 84,9 | 951,1 | 0,9511 |
| | 10800 | 180 | 3 | 103,9 | 952,72 | 0,95272 |
| | 14400 | 240 | 4 | 120 | 953,78 | 0,95378 |
| | 18000 | 300 | 5 | 134,2 | 954,82 | 0,95482 |
| | 21600 | 360 | 6 | 147 | 955,79 | 0,95579 |
| | 86400 | 1440 | 24 | 293,9 | 960 | 0,96 |
| | 172800 | 2880 | 48 | 415,7 | 962,43 | 0,96243 |
| | 259200 | 4320 | 72 | 509,1 | 964,14 | 0,96414 |
| | 345600 | 5760 | 96 | 587,9 | 965,34 | 0,96534 |
| | 432000 | 7200 | 120 | 695,5 | | 0 |
| | 518400 | 8640 | 144 | 793,04 | | 0 |

| **Código testigo** | **AMSE** | | |
|---|---|---|---|
| Diámetro (m) | 0,1015 | | |
| Altura (m) | 0,0505 | | |
| Área (m2) | 0,008 | | 0,941008 |
| Wo (kg) | 0,925 | 0,922 | |
| Wn (kg) | 0,941008172 | | |
| tn (s) | 15126,679 | | |
| m (s/m^2) | 5931449,597 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,016 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 3,859 | porosidad efectiva | |

| **Fecha** | **Tiempo Ac (s)** | **Tiempo Ac (min)** | **Tiempo Ac (hr)** | **t^0,5 (s^0,5)** | **Peso (g)** | **Peso (kg)** |
|---|---|---|---|---|---|---|
| | 0 | 0 | 0 | 0 | 925,240 | 0,92524 |
| | 300 | 5 | 0,08 | 17,3 | 929,64 | 0,92964 |
| | 600 | 10 | 0,17 | 24,5 | 930,79 | 0,93079 |
| | 900 | 15 | 0,25 | 30 | 931,14 | 0,93114 |
| | 1800 | 30 | 0,5 | 42,4 | 932,52 | 0,93252 |
| | 3600 | 60 | 1 | 60 | 934,65 | 0,93465 |
| | 7200 | 120 | 2 | 84,9 | 937,08 | 0,93708 |
| | 10800 | 180 | 3 | 103,9 | 938,83 | 0,93883 |
| | 14400 | 240 | 4 | 120 | 939,72 | 0,93972 |
| | 18000 | 300 | 5 | 134,2 | 940,39 | 0,94039 |
| | 21600 | 360 | 6 | 147 | 940,89 | 0,94089 |
| | 86400 | 1440 | 24 | 293,9 | 946,1 | 0,9461 |
| | 172800 | 2880 | 48 | 415,7 | 948,94 | 0,94894 |
| | 259200 | 4320 | 72 | 509,1 | 952,22 | 0,95222 |
| | 345600 | 5760 | 96 | 587,9 | 954,31 | 0,95431 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 432000 | 7200 | 120 | 695,5 | | 0 |
| | 518400 | 8640 | 144 | 793,04 | | 0 |

| Código testigo | AMSI | |
|---|---|---|
| Diámetro (m) | 0,1015 | |
| Altura (m) | 0,0517 | |
| Área (m2) | 0,008 | 0,951266 |
| Wo (kg) | 0,934 | 0,931 |
| Wn (kg) | 0,951266275 | |
| tn (s) | 31581,784 | |
| m (s/m^2) | 11815594,253 | resistencia a la penetración de agua |
| k (kg/m^2 s^0,5) | 0,012 | coeficiente de absorción capilar — coef ASTM mm/ s^0,5 |
| εe (s/m2) | 4,034 | porosidad efectiva |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| | 0 | 0 | 0 | 0 | 934,390 | 0,93439 |
| | 300 | 5 | 0,08 | 17,3 | 938,35 | 0,93835 |
| | 600 | 10 | 0,17 | 24,5 | 939,07 | 0,93907 |
| | 900 | 15 | 0,25 | 30 | 939,49 | 0,93949 |
| | 1800 | 30 | 0,5 | 42,4 | 940,66 | 0,94066 |
| | 3600 | 60 | 1 | 60 | 941,99 | 0,94199 |
| | 7200 | 120 | 2 | 84,9 | 943,74 | 0,94374 |
| | 10800 | 180 | 3 | 103,9 | 945,05 | 0,94505 |
| | 14400 | 240 | 4 | 120 | 946,2 | 0,9462 |
| | 18000 | 300 | 5 | 134,2 | 947,35 | 0,94735 |
| | 21600 | 360 | 6 | 147 | 948,36 | 0,94836 |
| | 86400 | 1440 | 24 | 293,9 | 953 | 0,953 |
| | 172800 | 2880 | 48 | 415,7 | 954,66 | 0,95466 |
| | 259200 | 4320 | 72 | 509,1 | 956,38 | 0,95638 |
| | 345600 | 5760 | 96 | 587,9 | 957,25 | 0,95725 |
| | 432000 | 7200 | 120 | 695,5 | | 0 |
| | 518400 | 8640 | 144 | 793,04 | | 0 |

**MURO CONTENCIÓN**

| Código testigo | MCI_E | |
|---|---|---|
| Diámetro (m) | 0,1014 | |
| Altura (m) | 0,0511 | |
| Área (m2) | 0,008 | 0,980809 |
| Wo (kg) | 0,970 | 0,966 |
| Wn (kg) | 0,980808657 | |
| tn (s) | 32062,062 | |
| m (s/m^2) | 12278622,663 | resistencia a la penetración de agua |
| k (kg/m^2 s^0,5) | 0,008 | coeficiente de absorción capilar — coef ASTM mm/ s^0,5 |

| εe (s/m2) | 2,726 | porosidad efectiva |
|---|---|---|

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| 26-03.2011 | 0 | 0 | 0 | 0 | 969,560 | 0,96956 |
| | 300 | 5 | 0,08 | 17,3 | 971,81 | 0,97181 |
| | 600 | 10 | 0,17 | 24,5 | 972,26 | 0,97226 |
| | 900 | 15 | 0,25 | 30 | 972,53 | 0,97253 |
| | 1800 | 30 | 0,5 | 42,4 | 973,5 | 0,9735 |
| | 3600 | 60 | 1 | 60 | 974,54 | 0,97454 |
| | 7200 | 120 | 2 | 84,9 | 975,8 | 0,9758 |
| | 10800 | 180 | 3 | 103,9 | 976,6 | 0,9766 |
| | 14400 | 240 | 4 | 120 | 977,52 | 0,97752 |
| | 18000 | 300 | 5 | 134,2 | 978,01 | 0,97801 |
| | 21600 | 360 | 6 | 147 | 978,57 | 0,97857 |
| | 86400 | 1440 | 24 | 293,9 | 982,8 | 0,9828 |
| | 172800 | 2880 | 48 | 415,7 | 984,7 | 0,9847 |
| | 259200 | 4320 | 72 | 509,1 | 986,46 | 0,98646 |
| | 345600 | 5760 | 96 | 587,9 | 987,65 | 0,98765 |
| | 432000 | 7200 | 120 | 695,5 | | 0 |
| | 518400 | 8640 | 144 | 793,04 | | 0 |

| **Código testigo** | **MCI_I** | | |
|---|---|---|---|
| Diámetro (m) | 0,10155 | | |
| Altura (m) | 0,0518 | | |
| Área (m2) | 0,008 | | 0,988453 |
| Wo (kg) | 0,982 | 0,979 | |
| Wn (kg) | 0,988453228 | | |
| tn (s) | 25616,413 | | |
| m (s/m^2) | 9546821,338 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,005 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 1,531 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| | 0 | 0 | 0 | 0 | 982,030 | 0,98203 |
| | 300 | 5 | 0,08 | 17,3 | 983,53 | 0,98353 |
| | 600 | 10 | 0,17 | 24,5 | 983,88 | 0,98388 |
| | 900 | 15 | 0,25 | 30 | 984,06 | 0,98406 |
| | 1800 | 30 | 0,5 | 42,4 | 984,5 | 0,9845 |
| | 3600 | 60 | 1 | 60 | 985,13 | 0,98513 |
| | 7200 | 120 | 2 | 84,9 | 985,91 | 0,98591 |
| | 10800 | 180 | 3 | 103,9 | 986,51 | 0,98651 |
| | 14400 | 240 | 4 | 120 | 986,98 | 0,98698 |
| | 18000 | 300 | 5 | 134,2 | 987,41 | 0,98741 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 21600 | 360 | 6 | 147 | 987,81 | 0,98781 |
| | 86400 | 1440 | 24 | 293,9 | 989,2 | 0,9892 |
| | 172800 | 2880 | 48 | 415,7 | 989,74 | 0,98974 |
| | 259200 | 4320 | 72 | 509,1 | 990,35 | 0,99035 |
| | 345600 | 5760 | 96 | 587,9 | 990,64 | 0,99064 |
| | 432000 | 7200 | 120 | 695,5 | | 0 |
| | 518400 | 8640 | 144 | 793,04 | | 0 |

| **Código testigo** | **MCD_E** | | |
|---|---|---|---|
| Diámetro (m) | 0,1018 | | |
| Altura (m) | 0,0515 | | |
| Área (m2) | 0,008 | | 0,981681 |
| Wo (kg) | 0,972 | 0,969 | |
| Wn (kg) | 0,981681411 | | |
| tn (s) | 22823,376 | | |
| m (s/m^2) | 8605288,286 | resistencia a la penetración de agua | |
| k (kg/m^2 s^0,5) | 0,008 | coeficiente de absorción capilar | coef ASTM mm/ s^0,5 |
| εe (s/m2) | 2,367 | porosidad efectiva | |

| Fecha | Tiempo Ac (s) | Tiempo Ac (min) | Tiempo Ac (hr) | t^0,5 (s^0,5) | Peso (g) | Peso (kg) |
|---|---|---|---|---|---|---|
| | 0 | 0 | 0 | 0 | 971,760 | 0,97176 |
| | 300 | 5 | 0,08 | 17,3 | 974,52 | 0,97452 |
| | 600 | 10 | 0,17 | 24,5 | 974,88 | 0,97488 |
| | 900 | 15 | 0,25 | 30 | 975,19 | 0,97519 |
| | 1800 | 30 | 0,5 | 42,4 | 975,82 | 0,97582 |
| | 3600 | 60 | 1 | 60 | 976,77 | 0,97677 |
| | 7200 | 120 | 2 | 84,9 | 978,12 | 0,97812 |
| | 10800 | 180 | 3 | 103,9 | 979,12 | 0,97912 |
| | 14400 | 240 | 4 | 120 | 979,84 | 0,97984 |
| | 18000 | 300 | 5 | 134,2 | 980,42 | 0,98042 |
| | 21600 | 360 | 6 | 147 | 981,18 | 0,98118 |
| | 86400 | 1440 | 24 | 293,9 | 983,8 | 0,9838 |
| | 172800 | 2880 | 48 | 415,7 | 985,13 | 0,98513 |
| | 259200 | 4320 | 72 | 509,1 | 986,59 | 0,98659 |
| | 345600 | 5760 | 96 | 587,9 | 987,9 | 0,9879 |
| | 432000 | 7200 | 120 | 695,5 | | 0 |
| | 518400 | 8640 | 144 | 793,04 | | 0 |

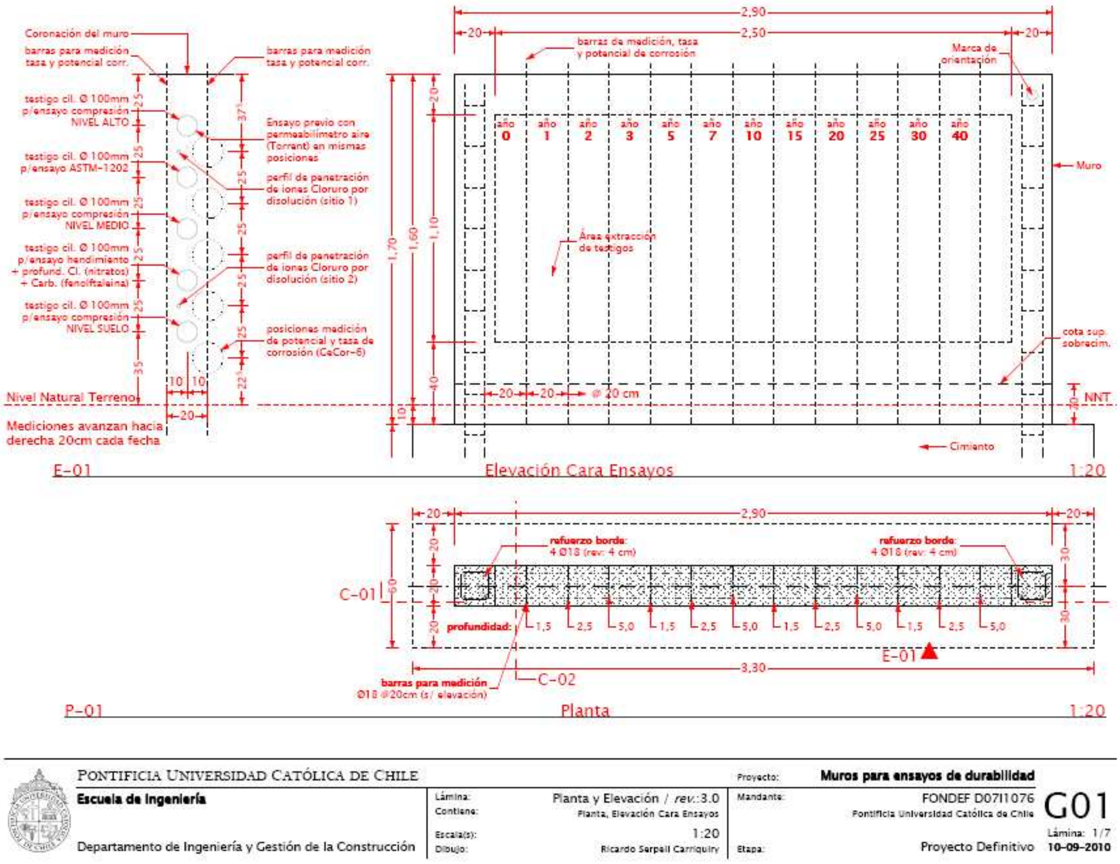
Hydration Rate

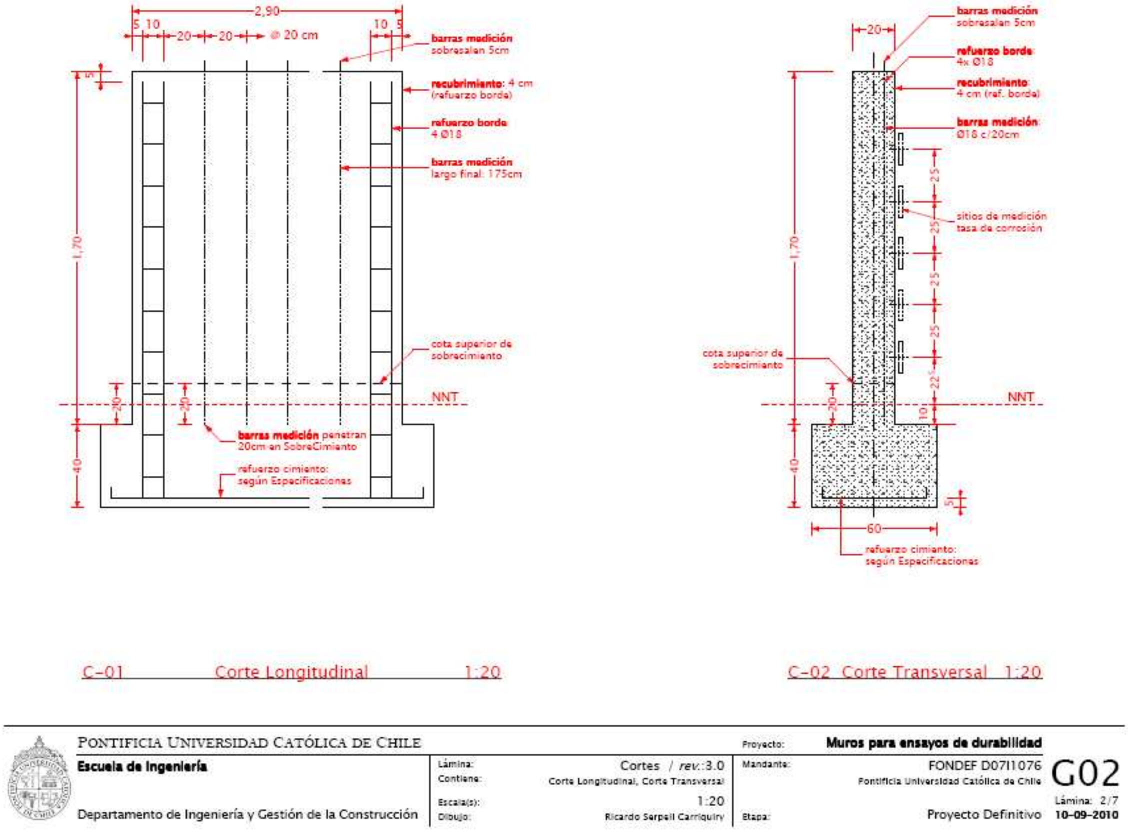
| | Wd1 | Wh1 original | Wi1 | Wd2 | Wh2 rehidratada | Wi2 | Wn1 | Wn2 | av |
|---|---|---|---|---|---|---|---|---|---|
| HS | 100,73 | 96,92 | 94,65 | 100,28 | 91,49 | 89,21 | 4,70 | 9,70 | 0,49 |
| HP | 100,13 | 96,84 | 94,42 | 100,49 | 88,82 | 86,38 | 4,27 | 12,61 | 0,34 |

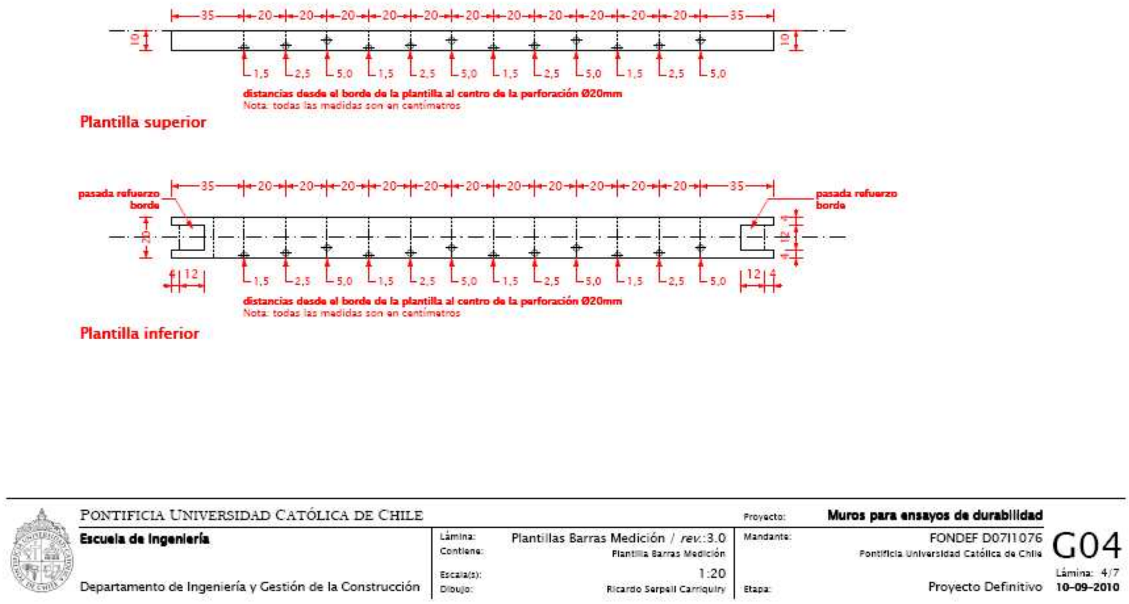
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| EDS | 100,09 | 97,01 | 94,77 | 100,12 | 96,96 | 94,55 | 3,99 | 4,14 | 0,96 |
| EDP | 100,96 | 97,45 | 94,58 | 100,43 | 96,36 | 93,27 | 4,64 | 5,31 | 0,87 |
| ELS | 100,50 | 97,04 | 94,01 | 100,22 | 95,14 | 92,26 | 4,68 | 6,24 | 0,75 |
| ELP | 100,66 | 95,44 | 92,77 | 100,34 | 94,23 | 91,47 | 6,27 | 7,21 | 0,87 |
| MS | 100,87 | 98,17 | 94,36 | 100,08 | 97,23 | 93,23 | 4,22 | 4,48 | 0,94 |
| MP | 100,08 | 97,20 | 93,04 | 97,21 | 93,37 | 89,39 | 4,58 | 5,63 | 0,81 |
| | **Wd1** | **Wh1** | **Wi1** | **Wd2** | **Wh2** | **Wi2** | **Wn1** | **Wn2** | **av** |
| | | **original** | | | **rehidratada** | | | | |
| ChDP | 100,32 | 96,19 | 94,43 | 100,17 | 95,44 | 93,67 | 4,83 | 5,44 | 0,89 |
| ChDS | 100,14 | 96,08 | 93,73 | 100,01 | 95,89 | 93,48 | 5,01 | 5,11 | 0,98 |
| MCI | 100,79 | 97,10 | 96,05 | 100,39 | 96,52 | 95,44 | 4,09 | 4,30 | 0,95 |
| MCD | 100,21 | 98,40 | 97,05 | 102,58 | 95,84 | 94,44 | 2,36 | 7,13 | 0,33 |
| AMP | 100,67 | 96,85 | 95,95 | 100,46 | 72,45 | 71,67 | 4,16 | 28,20 | 0,15 |
| AMS | 100,83 | 95,99 | 94,82 | 100,54 | 79,34 | 40,26 | 5,27 | 36,99 | 0,14 |
| PLP | 100,76 | 96,83 | 95,82 | 100,25 | 92,00 | 90,90 | 4,31 | 8,68 | 0,50 |
| PLS | 100,17 | 95,15 | 93,81 | 100,86 | 84,39 | 83,22 | 5,56 | 16,80 | 0,33 |

# APPENDIX B: MONITORING STATIONS

Drawings






Technical Specification

PROPUESTA DE ESPECIFICACIONES TÉCNICAS (v.6)
CONSTRUCCION DE ESTACIONES DE MONITOREO
FONDEF D07I1076

1. **Generalidades:**

   Las presentes especificaciones definen las condiciones y el método de ejecución de los trabajos necesarios para la construcción de 4 muros de Hormigón Armado, incluidas sus fundaciones. Dos de ellos se ubicarán en dependencias del Campus San Joaquín de la PUC, Santiago, y dos en dependencias de la Facultad de Arquitectura de la Universidad de Valparaíso en Playa Ancha, Valparaíso.

   Se deberá entregar una cotización para los 2 muros de Santiago y para los 2 muros de Valparaíso de manera separada. La adjudicación de este contrato podrá ser por los 4 muros, por los 2 muros de Santiago o por los 2 muros de Valparaíso.

   En caso que la construcción de los 4 muros sea hecha por 2 Contratistas, tanto el cemento como los áridos deberán ser comprados en el lugar especificado por el Mandante.

   Los planos de referencia y detalles se caratulan G01, G02, G03, G04, G05, G06 y G07 (revisión 3.0) de fecha 10.09.2010 y se complementan con estas especificaciones.

   El emplazamiento exacto de estos elementos será definido por el Mandante previo al inicio de las obras. Se deberá considerar que la cara de ensayos deberá estar orientada al Poniente y a más de 30 metros de distancia de cualquier edificación, estando alineados entre sí y separados entre cantos a 1,10 metros, como se indica en el plano G03.

   Los muros (A y B) contemplan diferentes clases de Hormigón entre sí definidos más adelante, y sus dimensiones son de 0,20 m de espesor, 2,90 m de largo y 1,70 m de alto, sobresaliendo 1,60 m del nivel del terreno circundante.

   En la vista de elevación Poniente se dispondrá de una marca de Orientación en el extremo superior derecho en bajo relieve de Ø 5 cm y 1 cm de profundidad.

   A modo de serie de preguntas y respuestas se realizará una reunión el día 15 de Septiembre a las 16:30 hora en la Sala de Reuniones del Departamento de Ingeniería y Gestión de la Construcción, ubicado Avda. Vicuña Mackena 4860, Edificio San Agustín, 3er piso.

2. **Aportes:**

   El Mandante proveerá el equipo de pesaje del hormigón y el equipo de mezclado. También proveerá la dosificación del hormigón y supervisará y aprobará cada una de las fases de la construcción.

   El Contratista proveerá la mano de obra, los moldajes, cemento, áridos, aditivos y las enfierraduras, así como todo tipo de herramientas y equipos necesarios para la ejecución de las obras.

3. **Nivelación:**

   Previo al inicio de los trabajos el contratista deberá despejar y nivelar el terreno.

4. **Excavaciones:**

   Tendrán 0,60 m de ancho por 3,30 m de largo con paredes verticales y fondo horizontal en un solo plano. La profundidad será de 0,55 m.

5. **Emplantillado:**

   Sobre el sello de excavación se ejecutará un emplantillado de hormigón pobre de 3 sacos de cemento por m3 de hormigón y de 5 cm de espesor.

6. **Cimiento y Sobrecimiento:**

Serán de hormigón de la misma calidad que los respectivos muros. El cimiento será de 0,6m de ancho por 3,3m de largo y 0,4m de profundidad. El sobrecimiento será de 0,2m de ancho, 0,2m de alto y del largo del muro. Ambos elementos se ejecutarán en una sola operación y servirá como base para el posterior moldaje del muro. Extremo cuidado se le dará a cumplir las dimensiones del sobrecimiento debido a que se utilizará como guía del moldaje del muro.

7. **Enfierraduras:**

La calidad del acero a usar es A63-42H, de primer uso, libre de todo tipo de contaminación por aceites u otros, y exento de óxido suelto o signos evidentes de corrosión.

Se distinguen armaduras de refuerzo consistentes en:

a. Enfierradura del cimiento: armadura inferior Ø10 @ 15 cm en el sentido transversal y 4Ø12, espaciados a 10cm, en sentido longitudinal.
b. Enfierradura de los pilares ubicados en los extremos del muro: 4Ø18 longitudinales y estribos de Ø6 @20 cm según planos G01 y G02.
c. Amarras: convencionales de alambre negro #18 sólo en el cimiento y en el refuerzo perimetral del muro.
d. Recubrimiento: El recubrimiento será de mínimo 4cm salvo los indicados en el punto f para la enfierradura de los muros.
e. Enfierradura muros: 12Ø18 @20 cm colocados verticalmente. Los recubrimientos especificados serán los indicados en la planta del plano G01 y orientación según el plano G03.
f. Deberán tomarse todas las medidas necesarias para asegurar la ubicación precisa de los fierros verticales de muros, proponiéndose el uso de plantillas afianzadas al moldaje para el hormigonado del sobrecimiento y en el coronamiento, y algún tipo de separador en los muros, lo que se ilustra los planos G04, G05, G06 y G07. En ningún caso se admite la colocación de trabas metálicas ni amarras de alambre para estos elementos. En caso de idear alguna solución constructiva distinta a la propuesta, esta deberá ser presentada en la reunión con el Mandante mencionada en el Punto 1.

8. **Moldajes:**

Se deberá usar un moldaje de placa de terciado de 15 mm de espesor con refuerzos de madera de pino de 2”x 3” a 60 cm, debidamente reforzados en la base, a media altura y en el coronamiento, con travesaños horizontales, puntales y diagonales afianzadas rígidamente al terreno. No se permite el uso de amarras de alambre, ni pernos que atraviesen el hormigón; sólo pueden usarse medios de apuntalamiento y sujección exteriores.

Se usará el desmoldante que definirá el Mandante y deberá ser aplicado siguiendo estrictamente la recomendación del fabricante, cuidando de no exceder la dosis especificada. Deberá disponerse de matacantos en encuentros verticales de 1x1 cm.

9. **Hormigón:**

La dosificación por metro cúbicodel hormigón de los muros será la indicada en la Tabla siguiente:

| Material | Tipo | Muro 1 | Muro2 |
|---|---|---|---|
| | | Kg | Kg |
| Cemento | “Ciego” | 270 | 400 |
| Agua | Potable | 162 | 160 |
| Gravilla | Chancada | 825 | 780 |
| Arena | Chancada | 1105 | 1045 |

Notas:

- Se deberá hacer llegar una muestra de los áridos a utilizar por el Contratista al Mandante por lo menos una semana antes de la fecha estipulada para el inicio de los trabajos, con el fin de ajustar la dosificación.
- Las correcciones de la dosificación por humedad y granulometría de los áridos y por densidad del hormigón fresco serán realizadas por el Mandante.
- El pesaje de los materiales y tareas de mezclado serán supervisados por el equipo de investigadores.
- Se incluirá un aditivo plastificante con el fin de obtener una trabajabilidad medida con cono de Abrams de 10 +/- 2 cm.

**10. Proceso de hormigonado:**

Las faenas de hormigonado se efectuarán en un mismo día para ambos cimientos, para posteriormente realizar el de los muros cuando los moldajes estén en condiciones de recibir el hormigón.

Cuando exista junta de construcción, se debe remover cualquier lechada, realizar una limpieza profunda y humedecer las juntas de construcción antes de la colocación del hormigón fresco. Cuando se requiera o se permita adherencia, se debe usar uno de los siguientes métodos:

- Usar un adhesivo aceptado, aplicado de acuerdo con las recomendaciones del fabricante;
- Desbastar la superficie de modo que se exponga uniformemente el agregado y no quede lechada, rebabas, partículas sueltas de agregado o daños superficiales en el hormigón; o
- Usar lechada de cemento con la misma dosificación del mortero empleado en el hormigón.

La compactación del hormigón deberá ser realizada con vibrador de inmersión adecuado al espesor y a la enfierradura (sugerida P35). El diámetro de la cabeza deberá ser entre 30 a 65 mm, con una frecuencia mayor o igual a 8000vpm.

Los moldajes deberán quedar en contacto con el hormigón 7 días para asegurar un conveniente curado, el que se efectuará mojando 2 veces al día los moldajes (una vez en la mañana y otra en la tarde. Se considerará el uso de una aspillera en la parte superior de muros y cimiento durante el tiempo que dure el curado. Deberá cuidarse el descimbre del moldaje para evitar fisuras, agrietamiento, desconchamiento o pérdida de hormigón en cantos y bordes.

**11. Aseo:**

Terminados los trabajos, la obra se entregará libre de excedentes y normalizada el área utilizada de forma de no perturbar su uso habitual.

Equipo de Investigadores
10/09/2010

Construction process pictures

# APPENDIX C: MATERIALS AND DOSE SELECTION

Concrete 1

| | 4 | 7 | 28 | 90 | 150 |
|---|---|---|---|---|---|
| Comp1 (Mpa) | 26,21 | 33,20 | 34,07 | 39,90 | 46,14 |
| Comp2 (Mpa) | 24,96 | 30,89 | 34,27 | 39,04 | 43,93 |
| Promedio | 25,59 | 32,05 | 34,17 | 39,47 | 45,04 |
| Dv | 0,88 | 1,63 | 0,14 | 0,61 | 1,56 |
| Hendimiento (Mpa) | | | 3,82 | 3,32 | 3,8 |
| dias | | | 55 | 97 | 157 |
| Ion Cl 1 (Q) | | | 4572,54 | 4309,38 | |
| Ion Cl 2 (Q) | | | 4057,29 | 4565,07 | |
| Promedio | | | 4314,92 | 4437,23 | |
| Dv | | | 364,34 | 180,80 | |
| Sorp 1 (coef) | | | 0,00949 | 0,00336 | 0,00480 |
| Sorp 2 (coef) | | | 0,00877 | 0,00295 | 0,00560 |
| Promedio | | | 0,00913 | 0,00316 | 0,00520 |
| Dv | | | 0,0005 | 0,0003 | 0,0006 |
| Perm Aire1 (kT)_1 | | | 0,35 | 0,28 | 0,31 |
| Perm Aire2 (kT)_1 | | | 1,1 | 1 | |
| Perm Aire3 (kT)_1 | | | 0,0017 | 0,0023 | 0,0037 |
| Perm Aire4 (kT)_1 | | | 0,57 | 0,001 | 0,037 |
| Perm Aire1 (kT)_2 | | | 0,12 | 0,1 | 0,078 |
| Perm Aire2 (kT)_2 | | | 0,27 | 0,11 | 0,22 |
| Perm Aire3 (kT)_2 | | | 0,001 | 0,0019 | 0,0026 |
| Perm Aire4 (kT)_2 | | | | 1,7 | |
| PROMEDIO | | | 0,3447 | 0,3994 | 0,1086 |
| DV | | | 0,3901 | 0,6227 | 0,1275 |

Concrete 2

| | 4 | 7 | 28 | 90 | 150 |
|---|---|---|---|---|---|
| Comp1 (Mpa) | 18,35 | 19,95 | 26,31 | 30,59 | 33,2 |
| Comp2 (Mpa) | 16,64 | 21,54 | 26,19 | 31,70 | 36,82 |
| Promedio | 17,50 | 20,74 | 26,25 | 31,15 | 35,01 |
| Dv | 1,20 | 1,12 | 0,09 | 0,78 | 2,56 |
| Hendimiento (Mpa) | | | 3,03 | 2,94 | 3,24 |
| dias | | | 55 | 97 | 157 |
| Ion Cl 1 (Q) | | | 1747,584 | 1966,401 | |
| Ion Cl 1 (Q) | | | 1297,179 | 1442,628 | |
| Promedio | | | 1522,38 | 1704,51 | |
| Dv | | | 318,48 | 370,36 | |
| Sorp 1(coef) | | | 0,01138 | 0,00851 | 0,01090 |
| Sorp 2(coef) | | | 0,01299 | 0,00475 | 0,01030 |
| Promedio | | | 0,01218 | 0,00663 | 0,01060 |

| | | | |
|---|---|---|---|
| Dv | 0,0011 | 0,0027 | 0,0004 |
| Perm Aire1 (kT)_1 | 0,025 | 0,027 | 0,025 |
| Perm Aire2 (kT)_1 | 0,2 | 0,093 | 0,11 |
| Perm Aire3 (kT)_1 | 0,18 | 0,001 | 0,0011 |
| PROMEDIO | 0,135 | 0,040 | 0,045 |
| DV | 0,096 | 0,047 | 0,057 |

Concrete 3

| | 4 | 7 | 28 | 90 | 150 |
|---|---|---|---|---|---|
| Comp1 (Mpa) | 12,12 | 14,73 | 20,97 | 25,98 | 27,66 |
| Comp2 (Mpa) | 12,36 | | 22,34 | 24,72 | 26,8 |
| Promedio | 12,24 | 14,73 | 21,66 | 25,35 | 27,23 |
| Dv | 0,17 | #¡DIV/0! | 0,97 | 0,89 | 0,61 |
| Hendimiento (Mpa) | | | 1,35 | 2,38 | 3,88 |
| dias | | | 35 | 97 | 157 |
| Ion Cl 1 (Q) | | | 3171,6 | 1435,968 | 927,207 |
| Ion Cl 2 (Q) | | | 2808,63 | 1428,813 | 890,307 |
| Promedio | | | 2990,12 | 1432,39 | 908,76 |
| Dv | | | 256,66 | 5,06 | 26,09 |
| Sorp 1 (coef) | | | 0,0194 | 0,0118 | 0,0124 |
| Sorp 2 (coef) | | | 0,0124 | 0,0092 | 0,0139 |
| Promedio | | | 0,01590 | 0,01048 | 0,01315 |
| Dv | | | 0,00491 | 0,00185 | 0,00106 |
| Perm Aire1 (kT)_1 | | | 1,3 | 1,8 | 0,56 |
| Perm Aire2 (kT)_1 | | | 0,04 | 0,11 | 0,023 |
| Perm Aire3 (kT)_1 | | | 0,77 | 1,1 | 0,32 |
| Perm Aire4 (kT)_1 | | | 0,069 | 3,2 | |
| Perm Aire1 (kT)_2 | | | 0,55 | 0,02 | 0,07 |
| Perm Aire2 (kT)_2 | | | 4,4 | 2,9 | 2,6 |
| Perm Aire3 (kT)_2 | | | 0,7 | 0,59 | 0,4 |
| Perm Aire4 (kT)_2 | | | 0,031 | 0,066 | 0,022 |
| PROMEDIO | | | 0,9825 | 1,22325 | 0,570714 |
| DV | | | 1,45014 | 1,28142 | 0,91851 |

Concrete 4

| dias | 4 | 7 | 28 | 90 | 150 |
|---|---|---|---|---|---|
| Comp1 (Mpa) | 19,83 | 22,59 | 30,47 | 37,33 | 45,53 |
| Comp2 (Mpa) | 19,21 | 22,76 | 29,25 | 38,06 | 45,53 |
| Promedio | 19,52 | 22,68 | 29,86 | 37,69 | 45,53 |
| Dv | 0,43 | 0,12 | 0,87 | 0,52 | 0,00 |
| Hendimiento (Mpa) | | | 2,45 | 3,61 | 4,54 |
| dias | | | 35 | 97 | 157 |
| Ion Cl 1 (Q) | | | 2603,259 | 781,551 | 917,523 |

| | | | |
|---|---|---|---|
| Ion Cl 1 (Q) | 2050,236 | 780,453 | 878,616 |
| Promedio | 2326,75 | 781,00 | 898,07 |
| Dv | 391,05 | 0,78 | 27,51 |
| Sorp 1 (coef) | 0,00968 | 0,00544 | 0,009 |
| Sorp 2 (coef) | 0,01001 | 0,00539 | 0,0105 |
| Promedio | 0,00985 | 0,00542 | 0,00975 |
| Dv | 0,00023 | 0,00003 | 0,00106 |
| Perm Aire1 (kT)_1 | 0,21 | 0,0024 | 0,0024 |
| Perm Aire2 (kT)_1 | 0,05 | 0,038 | 0,027 |
| Perm Aire3 (kT)_1 | 0,099 | 0,11 | 0,09 |
| Perm Aire4 (kT)_1 | 0,1 | 0,053 | 0,0088 |
| Perm Aire1 (kT)_2 | 0,084 | 0,033 | 0,027 |
| Perm Aire2 (kT)_2 | 0,051 | 0,0065 | 0,0088 |
| Perm Aire3 (kT)_2 | 0,073 | 0,09 | 0,044 |
| Perm Aire4 (kT)_2 | 0,027 | 0,001 | 0,033 |
| PROMEDIO | 0,08675 | 0,0417375 | 0,030125 |
| DV | 0,05595 | 0,04080 | 0,02799 |

Aggregate surface estimation

**_C2 CERCA_**

| 02-08-2011 | 11 | 12 | 21 | 22 | Total | |
|---|---|---|---|---|---|---|
| M (mm/mm) | 54 | 54 | 54 | 54 | | |
| ΣI | 104 | 89 | 105 | 121 | 419 | |
| ΣΠ | 16 | 16 | 16 | 16 | 64 | |
| l/p (mm) | 1,102 | 1,102 | 1,102 | 1,102 | | |
| Sv (mm^-1) | 11,798 | 10,097 | 11,912 | 13,727 | 11,883 | 1,483 |
| | | 1,4831293 | | | | |
| min medido (mm) | 1,5 | 1 | 1 | 1 | | |
| conversion | 0,028 | 0,019 | 0,019 | 0,019 | | |

**_C2 LEJOS_**

| 02-08-2011 | 11 | 12 | 21 | 22 | Total | |
|---|---|---|---|---|---|---|
| M (mm/mm) | 18 | 18 | 18 | 18 | | |
| ΣI | 143 | 123 | 117 | 106 | 489 | |
| ΣΠ | 16 | 16 | 16 | 16 | 64 | |
| l/p (mm) | 3,306 | 3,306 | 3,306 | 3,306 | | |
| Sv (mm^-1) | 5,408 | 4,651 | 4,424 | 4,008 | 4,623 | 0,587 |
| | | 0,58694712 | | | | |
| min medido (mm) | 2 | 2 | 2 | 2 | | |
| conversion | 0,111 | 0,111 | 0,111 | 0,111 | | |

**_C3 CERCA_**

| 02-08-2011 | 11 | 12 | 13 | 14 | Total | |
|---|---|---|---|---|---|---|
| M (mm/mm) | 54 | 54 | 54 | 54 | | |
| ΣI | 112 | 123 | 133 | 109 | 477 | |
| ΣΠ | 16 | 16 | 16 | 16 | 64 | |
| l/p (mm) | 1,102 | 1,102 | 1,102 | 1,102 | | |
| Sv (mm^-1) | 12,706 | 13,954 | 15,088 | 12,366 | 13,528 | 1,244 |
| | | 1,24402569 | | | | |
| min medido (mm) | 1,5 | 1 | 1 | 1 | | |
| conversion | 0,028 | 0,019 | 0,019 | 0,019 | | |

## *C3 LEJOS*

| 02-08-2011 | 11 | 12 | 13 | 14 | Total | |
|---|---|---|---|---|---|---|
| M (mm/mm) | 18 | 18 | 18 | 18 | | |
| ΣI | 91 | 93 | 82 | 86 | 352 | |
| ΣΠ | 16 | 16 | 16 | 16 | 64 | |
| l/p (mm) | 3,306 | 3,306 | 3,306 | 3,306 | | |
| Sv (mm^-1) | 3,441 | 3,517 | 3,101 | 3,252 | 3,328 | 0,188 |
| | | 0,1878109 | | | | |
| min medido (mm) | 2 | 2 | 2 | 2 | | |
| conversion | 0,111 | 0,111 | 0,111 | 0,111 | | |

## *C4 CERCA*

| 02-08-2011 | 11 | 12 | 21 | 22 | Total | |
|---|---|---|---|---|---|---|
| M (mm/mm) | 54 | 54 | 54 | 54 | | |
| ΣI | 92 | 112 | 91 | 87 | 382 | |
| ΣΠ | 16 | 16 | 16 | 16 | 64 | |
| l/p (mm) | 1,102 | 1,102 | 1,102 | 1,102 | | |
| Sv (mm^-1) | 10,437 | 12,706 | 10,324 | 9,870 | 10,834 | 1,272 |
| | | 1,27173568 | | | | |
| min medido (mm) | 1,5 | 1 | 1 | 1 | | |
| conversion | 0,028 | 0,019 | 0,019 | 0,019 | | |

## *C4 LEJOS*

| 02-08-2011 | 11 | 12 | 21 | 22 | Total | |
|---|---|---|---|---|---|---|
| M (mm/mm) | 18 | 18 | 18 | 18 | | |
| ΣI | 103 | 91 | 90 | 128 | 412 | |
| ΣΠ | 16 | 16 | 16 | 16 | 64 | |
| l/p (mm) | 3,306 | 3,306 | 3,306 | 3,306 | | |
| Sv (mm^-1) | 3,895 | 3,441 | 3,403 | 4,840 | 3,895 | 0,669 |
| | | 0,66866154 | | | | |
| min medido (mm) | 2 | 2 | 2 | 2 | | |
| conversion | 0,111 | 0,111 | 0,111 | 0,111 | | |

# APPENDIX D: JORNADAS CHILENAS DEL HORMIGÓN PAPER

## PONTIFICIA UNIVERSIDAD CATÓLICA DE CHILE

## "CARACTERIZACIÓN DE ESTRUCTURAS DE HORMIGÓN ARMADO FABRICADAS CON CEMENTO CON ALTO CONTENIDO DE PUZOLANAS NATURALES"

**Fernando Bustos[1] y Mauricio López[2]**

RESUMEN

La durabilidad del hormigón atrae cada vez mayor interés, debido a que un diseño enfocado en durabilidad asegura la vida útil de una estructura incurriendo en mínimos gastos. Aún así, es poco lo que se hace para asegurar durabilidad dado que la principal preocupación hoy está en cumplir los requisitos de resistencia.
Uno de los principales problemas de durabilidad en estructuras de hormigón armado es la corrosión de su armadura. La corrosión puede ser iniciada por la existencia de carbonatación y/o presencia de cloruros, fenómenos que dependen de la permeabilidad del recubrimiento. Esta investigación buscó determinar propiedades mecánicas, indicadores de durabilidad y deterioro de distintos hormigones. Lo anterior se realizó en estructuras ubicadas en un ambiente urbano y en uno marino, considerando en cada uno un rango de antigüedad entre 5 y 50 años.
El estudio determinó que es necesario asegurar una mayor durabilidad del hormigón a nivel de suelo, dado los mayores niveles de corrosión existentes. Para lo anterior, se aceptan como indicadores de durabilidad los ensayos de permeabilidad de iones cloruro y absorción capilar. Dado que la permeabilidad al oxígeno no muestra diferencias significativas con el paso del tiempo, se acepta como indicador a edades tempranas. Además se determinó que la carbonatación no afecta, de manera significativa, la permeabilidad del recubrimiento.

***Palabras claves:*** *durabilidad, puzolanas naturales, permeabilidad, corrosión*

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INTRODUCCIÓN

El tema emergente más importante de la construcción en el nuevo milenio es la sustentabilidad. ¿Pueden nuestras estructuras ser construidas en una manera que no se tenga un impacto negativo en el balance de los recursos finitos de nuestro planeta?

¿Cómo se puede determinar una adecuada especificación para el hormigón, proyecto a proyecto, de manera que se alcance un adecuado desempeño durante la vida requerida de la estructura sin malgastar recursos? Una sobre especificación es un derroche de recursos e injusto para el cliente, mientras que una especificación deficiente conlleva a una reparación prematura y costosa (1), no siendo ninguna de estas alternativas sustentable.

Lo anterior adquiere real importancia al tomar conciencia de la gran cantidad de contaminantes que se emiten y recursos y energía que se consume en la fabricación de hormigón, sobre todo en la producción de cemento. Es por esto que el desafío para los profesionales del hormigón en el siglo XXI es la especificación y logro de hormigones durables, un aspecto fundamental de sustentabilidad (1), el cual cobra gran relevancia en Chile si se analizan algunas de sus estadísticas: el déficit de infraestructura alcanza los USD 22.700 millones, mientras que la inversión en infraestructura es de USD 24.100 millones y el costo mínimo de conservación y reposición es de USD 723 millones; según el Informe Comisión Infraestructura, Chile 2010, marzo 2003.

En lo que a la durabilidad respecta, la corrosión del refuerzo en el hormigón armado es hoy en día la mayor causa de fallas en el mundo (1). La carbonatación (reacción del dióxido de carbono, $CO_2$, del ambiente con los hidróxidos de calcio, $Ca(OH)_2$, de la pasta de cemento) y el ingreso de cloruros favorecen la ocurrencia de la corrosión, al romper la capa de alto pH que rodea y le da protección a la enfierradura.

Resultados de ingreso de cloruros, así como corrosión de barras de acero en el hormigón después de una exposición en el largo plazo, son raramente encontrados en la literatura técnica (Uddin et al., 2004); más aún en hormigones hechos con cementos ricos en puzolanas, lo que es la principal característica de los cementos chilenos. Es por esto que si bien se han hecho, estudios a largo plazo son aún necesarios y serán muy útiles para el entendimiento de escenarios de deterioro y ejecución de pasos para hacer estructuras durables de hormigón (Uddin et al., 2004).

La adición de materiales cementicios suplementarios (SCM), como las puzolanas naturales, es una manera de mejorar la permeabilidad del hormigón (2). Si bien la ceniza volante y la microsílice son los SCM más usados en el mundo, se ha probado que las puzolanas naturales también tienen un gran impacto en el desempeño del hormigón (3), mejorando la trabajabilidad, disminuyendo el calor de hidratación, aumentando la resistencia al ataque de sulfatos, reduciendo las expansiones alkali-sílice y aumentando la resistencia última (4; 5; 6); pudiendo ser aún más atractivas debido a su origen natural.

Por otro lado, dada la compleja naturaleza de los efectos ambientales, se cree que no es posible mejorar el desempeño de estructuras de hormigón solo mejorando las características de los materiales. Sin embargo, se necesita un mínimo de conocimiento acerca de los procesos de deterioro más importantes y los parámetros que los gobiernan (3) para así, analizando cómo se interrelacionan los factores que afectan la durabilidad, establecer la calidad que debe tener un hormigón para tener un adecuado desempeño en el largo plazo.

## 1. METODOLOGÍA EXPERIMENTAL

En el contexto del desarrollo del proyecto Fondef D07i1076 “Definición e Implementación de un Sistema de Especificación por Durabilidad para Estructuras de

Hormigón Armado", se evaluaron propiedades mecánicas, medidas de permeabilidad y de deterioro en diversas estructuras.
Dichas estructuras se encuentran ubicadas en un ambiente urbano (Santiago) y en un ambiente marino (Valparaíso, a menos de 600m del mar), en un rango entre los 5 y 50 años de antigüedad en cada uno. Se consideró como estructuras "nuevas" aquellas comprendidas entre los 5 y 15 años y como estructuras antiguas aquellas que tienen entre 20 y 50 años.
Las ubicaciones fueron seleccionadas porque corresponden a zonas con alta concentración de dióxido de carbono ($CO_2$) y cloruros, respectivamente.
Además, en cada frente de trabajo se midieron tres zonas: entre 0.2 y 0.4m (zona 1), entre 1 y 1.4m (zona 2) y entre 1.8 y 2.2m (zona 3).

### 1.1 Métodos de Evaluación

En cada estructura, diecisiete testigos fueron extraídos para realizar ensayos destructivos y de laboratorio, de acuerdo a la Norma Chilena NCh 1171/1 "Hormigón – Testigos de Hormigón Endurecido – Parte 1: Extracción y ensayo".
Los diferentes métodos de evaluación fueron separados en tres partes para categorizar el hormigón en términos de sus propiedades físicas y mecánicas, durabilidad y daño que pueda presentar.
Los diferentes métodos de evaluación y la categoría en la cual se clasificaron se resumen en la Tabla 1 mostrada a continuación.

Tabla 1: Métodos de evaluación utilizados

| ***Evaluación de propiedades físicas y mecánicas*** | ***Evaluación del potencial de durabilidad*** | ***Evaluación de deterioro*** |
|---|---|---|
| • **Resistencia a compresión** | • **Permeabilidad al aire** | • **Profundidad de carbonatación** |
| • **Resistencia al hendimiento** | • **Permeabilidad a los iones cloruros** | • **Penetración de cloruros** |
| • **Índice esclerométrico** | • **Absorción Capilar** | • **Perfil de cloruros** |
| • **Velocidad del pulso ultrasónico** | • **Porosidad** | • **Potencial de corrosión** |
| • **Humedad Relativa Interna** | • **Absorción Superficial Inicial (ISAT)** | • **Tasa de corrosión** |
| • **Grado de Hidratación** | | • **Resistividad** |

En el presente trabajo se muestran los resultados correspondientes a la carbonatación, penetración de cloruros y potencial y tasa de corrosión como indicadores de deterioro; y

permeabilidad al aire, permeabilidad a los iones cloruro y absorción capilar como indicadores de durabilidad.
La profundidad de carbonatación de midió aplicándole fenolftaleína a los testigos extraídos, mientras que la penetración de cloruros se calculó aplicando nitrato de plata en una concentración 0.1 N (7) a una de las mitades obtenidas después de realizar el ensayo de hendimiento.

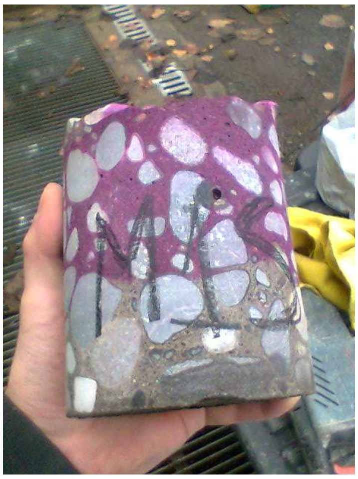


Figura 1: Reacción de la fenolftaleína con capa carbonatada

El potencial de corrosión fue medidos usando el equipo GeCor-8, el cual usa el electrodo de $Cu/CuSO_4$ recomendado por la ASTM C876. Para esto, se hizo un mapa de la enfierradura (tanto de barras principales como de estribos) y se midió en muchos puntos el potencial de corrosión; luego, en aquellas zonas de mayor riesgo, se procedió a medir la tasa de corrosión.

Figura 2: Equipo GeCor

Para la medición de absorción capilar y permeabilidad ión cloruro se usaron testigos de 100mm de diámetro y 50mm de espesor donde está la cara expuesta a la superficie de acuerdo a las normas ASTM C1585-04 y ASTM C1202-05, respectivamente. La permeabilidad al aire fue medida según la norma Suiza SN EN 206-1 usando el equipo Permea-Torr.


Figura 3: Equipo Permea-Torr

## 2. RESULTADOS Y ANÁLISIS

Hoy en día los cementos son más finos y tienen mayor cantidad de silicato tricálcico, por lo que se hidratan más rápido (8) y permiten usar menos cemento al alcanzar resistencias tempranas más rápidamente. De esta manera, se podría pensar que habrá diferencias en el desempeño de las estructuras dependiendo de la época en que fueron construidas.

### 2.1 Resistencia a compresión

De las propiedades mecánicas la resistencia a la compresión es la más usada a la hora de especificar un hormigón.
Dado que la resistencia a la compresión depende en gran medida de su razón agua/cemento (característica de la cual también dependen propiedades de durabilidad), se aceptaba que un buen valor de resistencia aseguraría también una buena durabilidad (2).

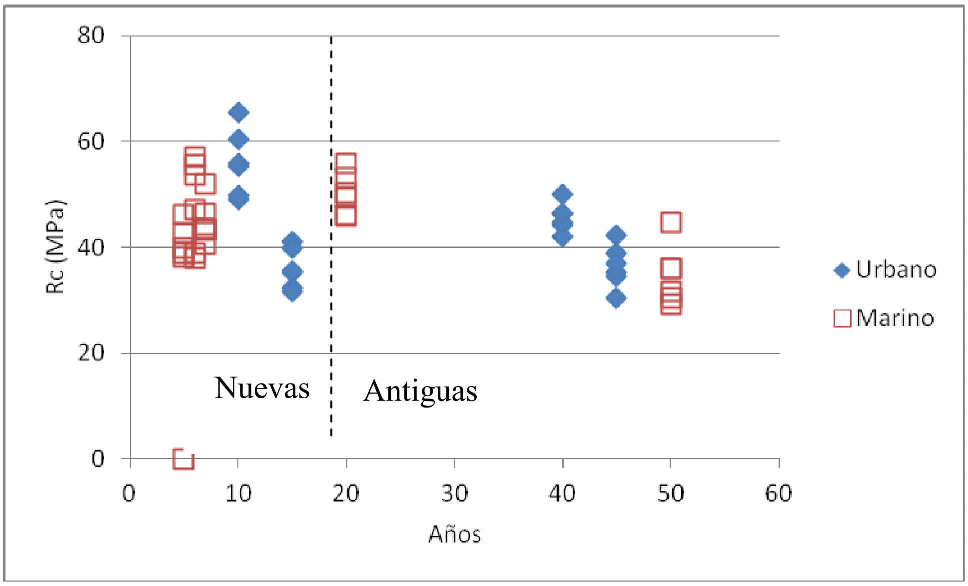



Figura 4: Resistencia a la compresión de las estructuras

De la Figura 4 se puede apreciar que las resistencias obtenidas corresponden a lo usualmente se encuentra y especifica en la industria de la construcción chilena, por lo que tomando el argumento anterior, se podría pensar que todas un buen desempeño en términos de durabilidad.

2.2 Indicadores de durabilidad

Si bien los resultados de propiedades mecánicas nos hablan de hormigones buenos, conformes a su diseño, dado el estado visual de algunos nace la necesidad de saber qué tan bien están realmente, motivo por el cual indicadores de durabilidad pueden ser de gran ayuda.

De los valores de la permeabilidad al aire se puede observar que no se ve un cambio sustancial a medida que pasa el tiempo, tanto para estructuras en ambiente urbano como para estructuras en ambiente marino. De esta manera, es posible considerar que sobre cierta edad e independientemente del factor época de construcción, cualquier elemento sometido a estas agresividades ambientales tendrá un comportamiento similar en términos de la permeabilidad al aire.

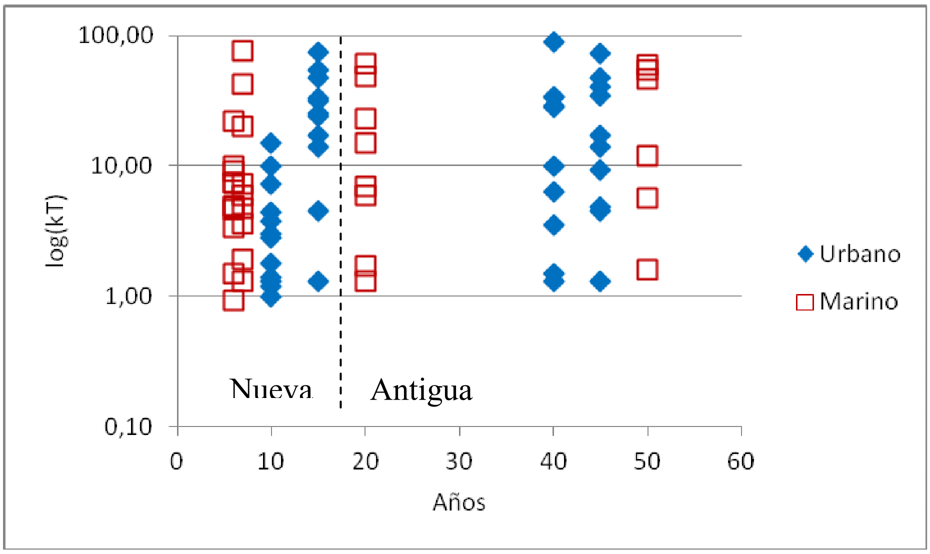


Figura 5: Permeabilidad al aire el función del tiempo

En cambio, al mirar los resultados de la permeabilidad de cloruros en la Figura 6, se puede ver que dicha permeabilidad decrece con el tiempo hasta un valor relativamente constante pasados los 20 años.
Si bien lo anterior se podría atribuir a un mayor grado de hidratación con el tiempo, no hay que olvidarse que corresponden a hormigones diferentes con cementos de distintas características (factor época). Según esto, se podría decir que usando mayor cantidad de cemento y/o cementos menos finos (aquellos usados hasta la década de los 80´s) se mejora el desempeño con respecto a la permeabilidad de cloruros.
En función de los distintos ambientes, poco o nada se puede concluir dado que no existen diferencias apreciables.

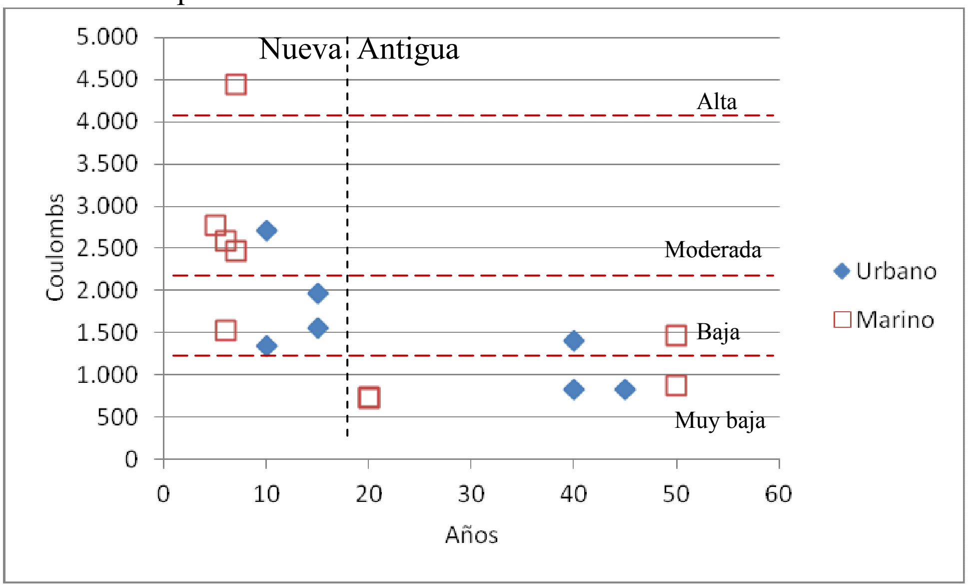


Figura 6: Permeabilidad a los cloruros en función del tiempo

Finalmente, la Figura 7 muestra los resultados para absorción capilar. De ella se puede ver que no hay un patrón o comportamiento de los datos.
Dado que este ensayo depende de los poros capilares presentes en la cara de ensayo, los valores estarán condicionados al desgaste que haya tenido la superficie bajo determinada agresividad ambiental.

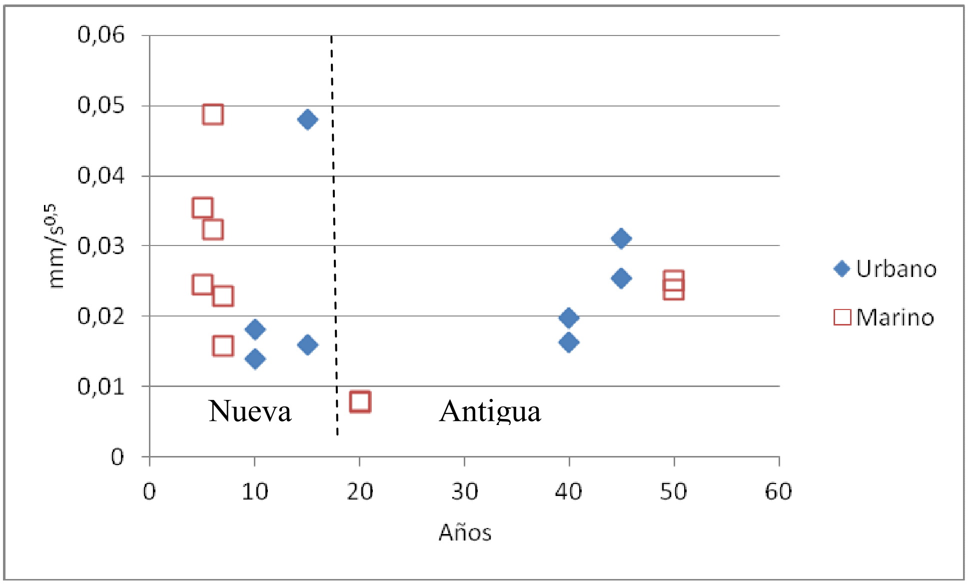



Figura 7: Absorción capilar en función del tiempo

## 2.3 Indicadores de deterioro

Dado que como indicadores se usó la penetración de cloruros, profundidad de carbonatación, potencial de corrosión y tasa de corrosión, se requiere de un análisis conjunto para poder conocer el verdadero estado de las estructuras.

Dado que la profundidad a la que se encuentren los cloruros o haya carbonatación también depende del tiempo que haya transcurrido, se acepta que ambos siguen un comportamiento que depende de la raíz cuadrada del tiempo. Dicho coeficiente se calcula como sigue:

$$K = X\,(t_0)^{-0,5}(\text{mm/año}^{0,5}) \qquad (1),$$

donde X corresponde a la penetración de cloruros o de carbonatación en milímetros y $t_0$ la edad en años. Las distintas categorías se pueden ver en el Anexo 1.

Con respecto a las medidas de corrosión, el potencial de corrosión sólo corresponde a una medida cualitativa acerca de la probabilidad de que la corrosión de la enfierradura se esté llevando a cabo. Valores de las distintas categorías se encuentran en el Anexo 2.

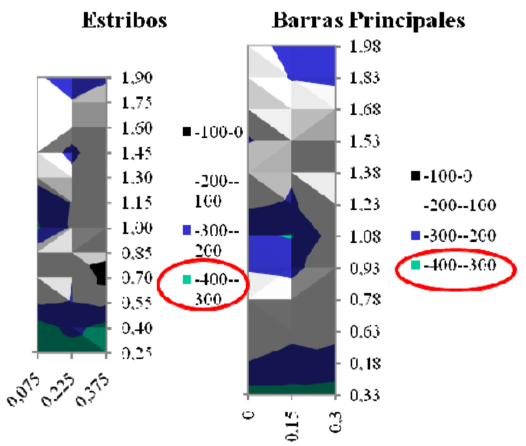
Los valores para las distintas estructuras se muestran de manera resumida en la siguiente Tabla.

Tabla 2: Resultados de deterioro

| | Coeficiente Penetración Cl ($mm/año^{0,5}$) | Coeficiente Carbonatación ($mm/año^{0,5}$) | Potencial Corrosión (mV) |
|---|---|---|---|
| Antiguas | 7,45 | 4,21 | -239,9 |
| | 1,80 | 4,42 | -373,5 |
| | 2,00 | 4,55 | -27,9 |
| | 1,01 | 3,94 | -486,7 |
| | 3,42 | 3,08 | -244,5 |
| | 4,39 | 3,22 | -594,11 |
| | 3,32 | 3,39 | -256,1 |

| | | | |
|---|---|---|---|
| | 5,57 | 3,48 | -448 |
| Nuevas | 7,41 | 5,31 | -575,5 |
| | 4,55 | 5,40 | -559,2 |
| | 3,99 | 3,48 | -28,3 |
| | 5,08 | 4,98 | -638,2 |
| | 8,84 | 7,45 | |
| | 6,67 | 6,87 | |
| | 9,01 | 6,50 | -658,55 |
| | 5,61 | 2,48 | 26,65 |

De los resultados podemos ver que existen potenciales de corrosión muy negativos, por debajo de los -350mV, lo que nos dice que hay una alta probabilidad que se esté produciendo corrosión.
Observando los valores de penetración de cloruros y carbonatación, podemos ver que en más de una estructura con potenciales de corrosión de riesgo (menor a -350mV) el dióxido de carbono o los cloruros ya han llegado a la enfierradura. De esta manera, en estas estructuras podríamos estar seguros de que la corrosión se está llevando a cabo.
Además, el hecho de que las estructuras nuevas usen menos cemento se puede ver reflejado en los altos coeficientes de difusión que presentan, tanto para cloruros como para el dióxido de carbono, reflejando una muy baja resistencia a la carbonatación. Si esto lo comparamos con la resistencia a compresión, se ve que las estructuras nuevas tienen resistencias más elevadas que las antiguas, pero su comportamiento en términos de durabilidad no es mejor.
Finalmente, observando los mapas de potencial de las estructuras se puede ver que a mediana o baja altura se registran los potenciales de mayor riesgo, motivo por el cual es necesario asegurar mayor durabilidad en esas zonas.



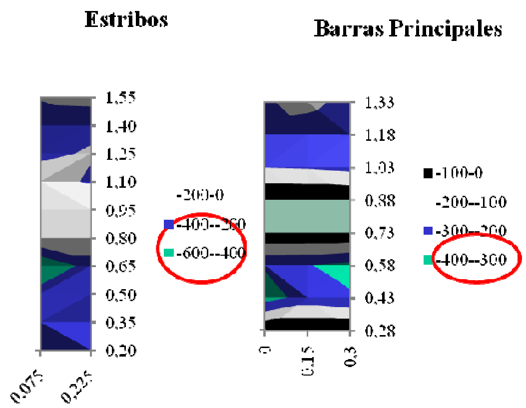



Figura 8: Mapas de Potencial

## 2.4 Efecto carbonatación en la permeabilidad del hormigón

Como se mencionó con anterioridad, la carbonatación afecta la durabilidad del hormigón armado al disminuir su pH, destruyendo la capa protectora (de alto pH) que rodea la enfierradura. Esto es una manera indirecta de deteriorar una estructura, pero no se sabe si afecta alguna propiedad del hormigón por si sola.

Los productos de la carbonatación ocupan mayor volumen que los elementos del hormigón no carbonatado, de esta manera, tanto la porosidad como la permeabilidad superficial del hormigón carbonatado se deberían reducir (9).

Además, dado que el dióxido de carbono reacciona con el hidróxido de calcio presente en el hormigón, mientras menos hidróxido de calcio haya, menos dióxido de carbono se necesitará para remover remover todo el hidróxido de calcio presente (9; 1), siendo más susceptibles a la carbonatación. Esto sucede con los cementos con adiciones, como los que usan puzolanas naturales, ya que al tener menor contenido de cemento, tienen menos hidróxido de calcio que remover.

Con el fin de entender el desempeño en esta materia de hormigones con cementos puzolánicos, se midió la permeabilidad a los iones cloruros y la absorción capilar en testigos tomados en las estructuras, la permeabilidad al aire en las estructuras in-situ y los resultados fueron cruzados con la profundidad de carbonatación medida. Los resultados se pueden en las Figuras 9 a la 11.

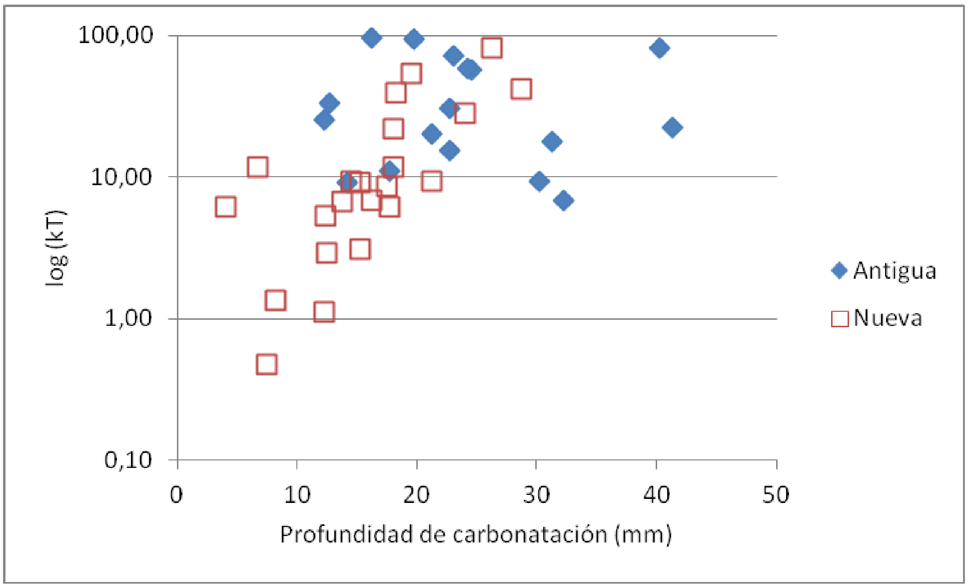



Figura 9: Permeabilidad al aire vs. carbonatación

La Figura 9 muestra que las estructuras "antiguas" tienen un desempeño similar en términos de su permeabilidad al aire; están en el mismo rango independientemente del grado de carbonatación presente.

Por otro lado, la permeabilidad al aire de las estructuras "nuevas" se incrementa gradualmente a medida que la profundidad de carbonatación aumenta. Sin embargo, dado que existe un traslape entre permeabilidades de estructuras "antiguas" con "nuevas", no es posible afirmar que la permeabilidad al aire crece con un incremento en la profundidad de carbonatación hasta un valor límite, desde donde el cual se vuelve

constante. Una explicación de esto se puede encontrar considerando que las características de los hormigones han cambiado con el tiempo.
De acuerdo con las diferencias existentes entre los tipos de cemento en distintos periodos de tiempo, al haber menos cemento, menos dióxido de carbono se necesita para remover el hidróxido de calcio presente, haciéndolos más susceptibles a carbonatarse; lo que explicaría que las estructuras "nuevas" lleguen al mismo nivel de permeabilidad que las estructuras viejas.
Así, dado que hay una dependencia entre permeabilidad al aire con la profundidad de carbonatación (o con la edad dado que a mayor edad habrá mayor presencia de carbonatación), se podría afirmar que la permeabilidad se deteriora gradualmente con la carbonatación.
De la Figura 10 y 11, se puede observar que el desempeño de las estructuras "nuevas" no es mejor que el de las "antiguas", en términos de la absorción capilar y permeabilidad a los cloruros, como uno podría pensar.

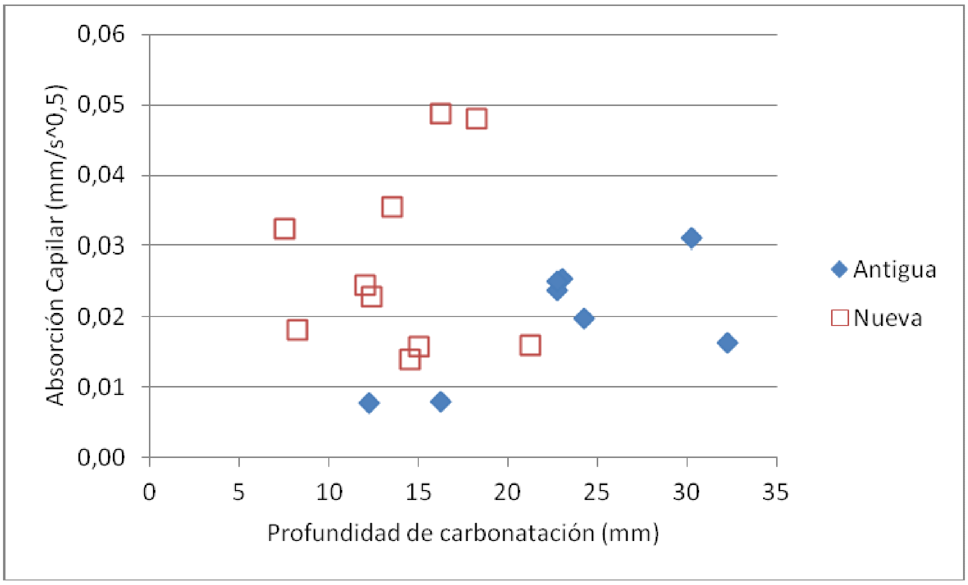


Figura 10: Absorción Capilar vs. carbonatación

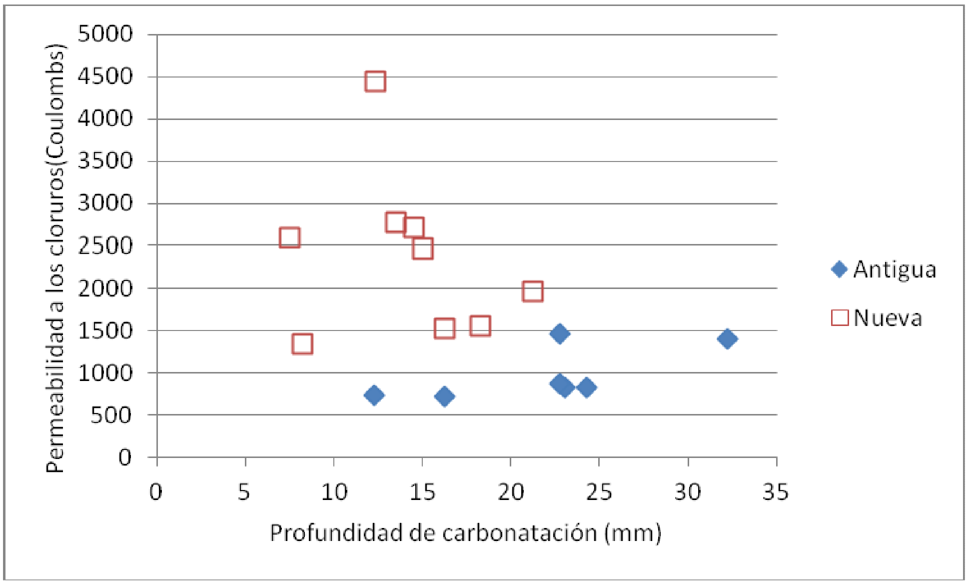


Figura 11: Permeabilidad a los cloruros vs. carbonatación

Lo anterior puede ser atribuido a dos razones: dado que los productos de la carbonatación ocupan mayor volumen, se obtienen una superficie más compacta en las estructuras “antiguas” que presentan un mayor índice de carbonatación; y/o, el menor contenido de cemento en las estructuras “nuevas” implica más agua por unidad de cemento, por lo que se formará mayor cantidad de poros capilares a edades tempranas, disminuyendo la permeabilidad.

Con la intención de establecer de mejor manera el efecto de la carbonatación en la permeabilidad del hormigón, en los testigos extraídos cuyo largo fue superior a 100mm se extrajeron 2 probetas de 50mm de espesor, una afecta por carbonatación y otra no. En cada una de las probetas se midió la permeabilidad a los cloruros y la absorción capilar, realizando finalmente un análisis estadístico con los datos.

Tabla 3: Valores de ensayos a probetas con y sin carbonatación

| | Permeabilidad ion Cl | | Abs. Capilar | |
|---|---|---|---|---|
| | Exterior | Interior | Exterior | Interior |
| Antiguas | 887.8 | 1716.1 | 0.031 | 0.028 |
| | 1409.9 | 1430.4 | 0.025 | 0.031 |
| | 824.9 | 632.6 | 0.016 | 0.033 |
| | 878.7 | | 0.02 | 0.027 |
| | 1469.8 | | 0.024 | 0.015 |
| | 724.7 | | 0.025 | 0.022 |
| | 746.5 | 351.2 | 0.008 | |
| Nuevas | 1555.9 | 1518.6 | 0.008 | 0.005 |
| | 1964.4 | 3824.7 | 0.048 | 0.04 |
| | 1352.9 | 1148.3 | 0.016 | 0.027 |
| | 2706.7 | 1927.3 | 0.018 | 0.01 |
| | 1535.9 | | 0.014 | 0.009 |
| | 2593.7 | | 0.049 | 0.036 |
| | 2772.0 | 1917.0 | 0.032 | 0.019 |
| | 4442.3 | 1132.5 | 0.025 | 0.024 |
| | 2471.3 | 1101.5 | 0.035 | 0.017 |
| | | | 0.023 | 0.011 |
| | | | 0.016 | 0.012 |

Los resultados muestran que las diferencias entre las dos probetas de un mismo hormigón no son significativas. En otras palabras, la carbonatación no afecta la absorción capilar ni la permeabilidad de cloruros con un 95% de confianza.

## 3. CONCLUSIONES

Lo primero que cabe mencionar es que los resultados no deben ser extrapolados a otras regiones, dado que corresponden al desempeño de determinadas estructuras sometidos a la agresividad ambiental propia de donde se encuentran ubicadas.

En relación a los indicadores de durabilidad, sólo se consideran como válidos los ensayos de permeabilidad a los cloruros y la absorción capilar. Dado que la permeabilidad al aire es muy sensible a microgrietas (presentes en casi todas las superficies de estructuras de hormigón evaluadas), independiente del origen que presenten, se descarta como indicador de potencial durabilidad.
Con respecto al deterioro de las estructuras, es necesario tener la mayor información posible al respecto. Si bien el potencial de corrosión es un método fácil y rápido de implementar, sólo nos da una probabilidad, por lo que necesita ser complementada. Potenciales más negativos se encuentran entre los 0 y 1.5m de altura, motivo por el cual dichas zonas merecen mayor atención en una estructura en términos de su durabilidad.
La carbonatación si bien es un iniciador de corrosión cuando ésta llega al nivel de la enfierradura, parece tener efectos por si sola en la permeabilidad.
Para la permeabilidad al aire se ve que hay un aumento a medida que también lo hace la profundidad de la capa carbonatada hasta estabilizarse en un rango. Esto se puede deber a que aún cuando los productos de carbonatación disminuyen los espacios libres, se produce un choque entre estos elementos de mayor volumen creando grietas que pueden aumentar la permeabilidad. Diferencias en este comportamiento puede ser explicadas por el efecto “época de construcción”, dado que tanto el hormigón como los cementos con que se fabrican han cambiado conforme al tiempo; hormigones con menos cemento son más propensos a carbonatarse.
En relación a la permeabilidad a los cloruros y absorción capilar, la carbonatación no muestra diferencias significativas entre probetas carbonatas y no carbonatadas.
Finalmente, dado que las estructuras pueden considerarse como buenas en términos de su resistencia, no lo son en términos de durabilidad. Dado que se comprueba que resistencia no garantiza durabilidad, se hace necesario especificar por durabilidad.

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# 6. ANEXOS

Anexo 1: Criterios de resistencia a la carbonatación

| **$K_{CO2}$ (mm /año$^{0,5}$)** | **Resistencia a la carbonatación** |
|---|---|
| $\leq 3$ | Alta |
| $6 > K_{CO2} > 3$ | Moderada |
| $\geq 6$ | Baja |

## Anexo 2: Categorías para el potencial y tasa de corrosión

La norma ASTM C876 establece el siguiente criterio de evaluación.

| Ecorr vs $Cu/CuSO_4$ (mV) | Riesgo | Estado de corrosión | Probabilidad de corrosión |
|---|---|---|---|
| (Más positivo) > - 200 | Bajo | Pasivo | < 10 % |
| -200 a -350 | Moderado | Transición activo – pasivo | Incierta |
| (más negativo) < -350 | Alto | Activo | > 90 % |

| Velocidad de corrosión Icorr ($\mu A/cm^2$) | Nivel de corrosión |
|---|---|
| < 0,1 | Despreciable |
| 0,1 a 0,5 | Moderado |
| 0,5 a 1 | Elevada |
| > 1 | Muy elevada |

## Anexo 3: Análisis estadístico

| *Fuente* | *Suma de Cuadrados* | *Gl* | *Cuadrado Medio* | *Razón-F* | *Valor-P* |
|---|---|---|---|---|---|
| Entre grupos | 0,002014 | 15 | 0,000134267 | 16,78 | 0,1870 |
| Intra grupos | 0,000008 | 1 | 0,000008 | | |
| Total (Corr.) | 0,002022 | 16 | | | |