Andrea Scotti
Mechanics and design of concrete structures**.**

Degradation, corrosion and analysis of the durability of concrete structures.

Introduction

The problem of corrosion is one of the most important issues that have to be consider in the design phase of a structure. A wrong assessment of the behavior of reinforced concrete subjected to corrosion could, in fact, effect drastically the assessment of the durability of a structure.
In structures designed and built in order to resist corrosion, the effects of deterioration are not important and usually are localized in some zones easily fixable. The problem, instead, is for old structure where, either during the design phase or during the construction phase, the problem of corrosion has not been considered enough. In these designs, usually, during the life of the structure, the measure of the security of the structure itself has to keep into account the effects of deterioration due to aggressive agents.
For concrete structures, in fact, for deterioration it is meant the local or global losses of continuity and a consequent reduction of the resistant sectional area.
The goal of this paper is, first of all, to have a general idea of all the processes involved in the corrosion and the deterioration of reinforced concrete. Once the principal processes will be understood it will be exposed a numerical model to assess the durability of structures already corroded.

Concrete deterioration

The principal degradation processes involved during the service life of reinforced concrete structures can be divided into 5 major categories:

1: Phisical processes

1.1: Icing -deicing cycles.
When the temperature reaches low values the water contained in h concrete's pores can ice with a consequent increase of its volume (almost 9%). When the phenomenon is repeated several times the tension stresses can lead to the cracking of the concrete paste.
Usually these phenomena involve in a first moment the external part of concrete given the low coefficient of thermal transmission of concrete, but when the damage is present in the external part of the structure it can reach the core of the section.
One of the theories proposed to study this degradation process is the theory of the hydraulic pressure (Powers) and it explains the damage due to the ice de-ice cycle assuming that the formation of ice pushes the remaining water in the inner concrete causing an increasing in the water pressure in the pores.

1.2: Fire.
When the temperature rises over 100, 150 degrees Celsius, after an initial expansion, the

concrete paste reduces its dimensions due to thermal decomposition of the hydrates components of the paste itself. The problem with this volume reduction is the formation of stresses on the interface with the aggregates. With their silicon nature, in fact, the aggregates tend to increase their volume instead of reducing it.
So, the firsts cracking begin on the interface between concrete and aggregates but if the temperature keeps on growing the structures can be subject to additional problems.
When the temperature reaches 500 °C, in fact, due to the high thermal conductivity of the rebars compared to the one of concrete the rebars tend to deform more than the surrounding concrete causing other stresses between rebars and concrete.

2: Chemical processes

2.1: Sulphatic degradation.
This kind of degradation occurs when concrete is in contacts with waters or grounds containing sulphates elements or when the aggregates contain sulphate. The reactions of the sulphates with the hydrate components present in the concrete paste cause the formation of products with higher molecular volume. When the production of these products is enough, it is possible to observe the formation of micro cracking due to the presence of bigger molecules.

2.2: Degradation due to seawaters.
The deterioration due to seawaters depends on the position of the structure respect to the sea level and it is concentrated almost entirely in the zone between the high and the low tide.
This degradation can be:
MECHANIC, due to the dynamic action of high and low tides that can produce superficial erosion.
CHEMICAL, due to the crystallization of the salts present in the water into the concrete pores.

3: Mechanical processes

The mechanical processes involved in the degradation of concrete are several but, the most important can be summarize into three different groups:

1:ABRASION, superficial damage due to the friction with a stronger material
2: EROSION, CAVITATION, IMPACT especially for structures build into a water stream

4:Structural processes

Those deterioration processes are the most common and usually their assessment is taken into account during the stages of the design In this category, in fact we can find overloads, settlements and Fatigue.

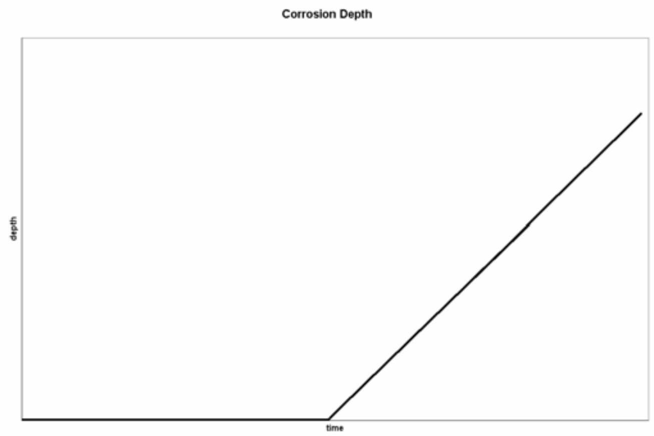
5: Rebars corrosion.

If the concrete structure is well designed and built, the rebars are in a perfect environment to resist corrosion. Concrete, in fact is an alkaline environment with pH more than 13. This alkaline environment produces a tiny film (just few molecular layers) on the rebars that can prevent the propagation of oxidation.

During the life of the structure the rebars have two completely different behaviors. In the first stage the film produced by the basic environment let the rebars to be completely non corroded. Only when the film is broken the propagation of corrosion can begin. Usually the local failure of the film is due to three different reasons:

1) The concrete's alkalinity is neutralized by the presence of carbon dioxide present in the environment that let the alkalinity drop from 13 to 9. (Carbonation)
2) The presence of chlorides in the environment. When the chlorides are more than 0.4-1% of the total concrete weight the film on the rebars is usually damaged
3) The presence of electric fields in the structure

Once the oxide film covering the rebars is broken the behavior of the corrosion is linear with time. That means that if we plot the depth of corrosion versus time we will have a graph like [Pedeferri 1987]



Corrosion Velocity

Once the corrosion of the rebars has began the most important factor to assess the gravity of the corrosion is its velocity. The corrosion velocity is usually expressed as the penetration velocity and it is expressed in μm/year.

Until the penetration velocity is less than 1.5-2 μm/year the consequences of corrosion are irrelevant compared to the normal design life of the structure. The corrosion begins to be a problem when the penetration velocity reaches values higher than 2 μm/year. At this rate, in fact, the corrosion products accumulate on the interface between rebars and the surrounding concrete, causing a decreasing in the friction between the two and the formation of cracks in the concrete.

Indicatively the ranges of penetration velocity can be summarized as:

- <2 μm/year: *Irrelevant*
- Between 2-5 μm/year: *Low*
- Between 5-10 μm/year: *Moderate*
- Between 10-50 μm/year: *Intermediate*
- Between 50-100 μm/year: *High*
- >100 μm/year: *Very high*