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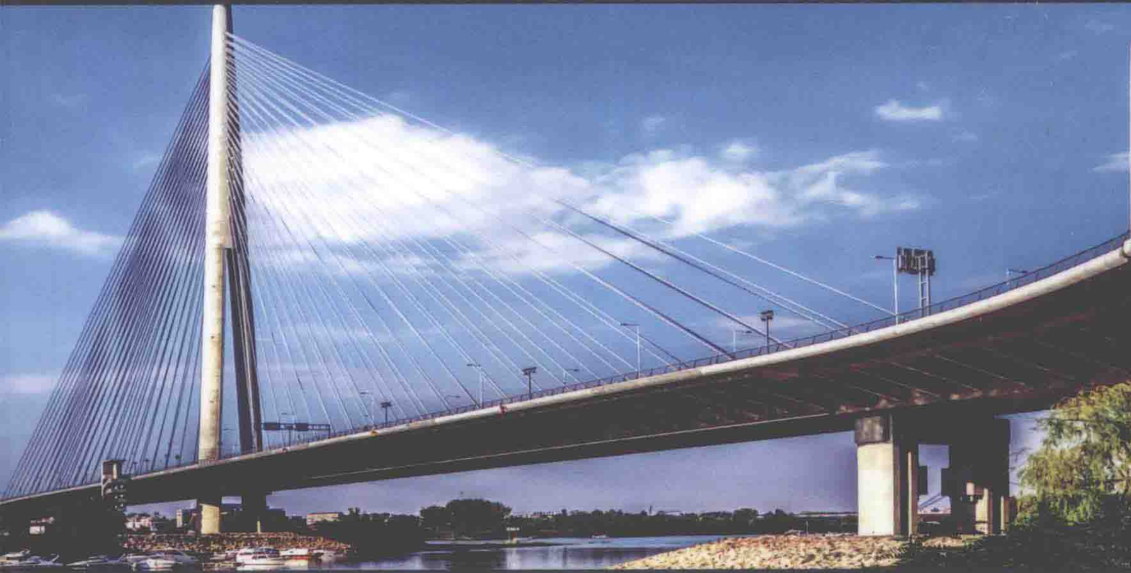

Structure Design and Degradation Mechanisms in Coastal Environments

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General Introduction

Any type of construction must ensure, from its inception, certain safety conditions for its users. This primarily occurs due to the mechanical performance of the structure which must be designed to account for cost optimization. Therefore, man has, over time, built structural codes based on the advancement of knowledge in the mechanical behavior of component materials of structures. These codes were designed to ensure safe behavior of the structure under mechanical stresses of its environment: supporting its own weight, excessive misuse and extreme climates (mainly snow and wind), while optimizing the cost of the structure. These codes have evolved to incorporate, in a modulated way, the hazards of accidental mechanical stresses such as seismic activity. Thus, we have seen established in these codes criteria dealing with the geophysical knowledge determining the geographical zoning of seismic activity.

The evolution of the landscape sector in construction over the past few decades can be schematically described in the following way:

– The advancement of knowledge in the mechanical behavior of materials coupled with the design of increasingly reliable building materials has allowed us to initiate more important construction projects with more gigantic structures, requiring increasingly important production costs.

– The continual aging of building heritage generates increasingly important maintenance and repair requirements.

Introduction written by Abdelkarim AÏT-MOKHTAR.

– The extension of entropic areas leads inexorably to saturation and to the occupation of other areas which are climatically less secure: flooding and/or submersible zones, for example. Added to this is climate change which currently tends to emphasize the hazards and make extreme conditions more frequent (rainfall, storms, hurricanes, cyclones, etc.).

– The increase in the globalized competition in economic and financial management continually tends to improve the optimization of project costs.

All these elements lead to a main requirement in the construction sector: the resistance over time, i.e. the durability of structures, including environmental stresses. This requirement is gradually being integrated into the specifications of international design codes.

Coastline buildings are among the most exposed to these environmental burdens and hazards. They simultaneously bring together two types of continuous attacks: (1) physical and chemical attacks such as chlorides and sulfates present in the seawater and (2) mechanical attacks of waves in coastal zones, particularly on protection structures such as dikes. Recent events (2010) that took place on the French Atlantic coast (Cyclone Xynthia) have testified to their violence, which, though temporary, generated substantial damage and casualties.

Thus, issues of material and structure durability and that of environmental hazards were echoed from the research community worldwide, with academic research prevalent in different national, European and international programs. The literature is becoming more abundant on the various aspects involved in these phenomena: from fundamental approaches in fluid mechanics and transport in porous media at microscopic scales up to applications in structural calculations on degraded structures, with monitoring concepts of residual performances and performance thresholds according to repair actions.

Far from being exhaustive, this book aims to provide a summary through the presentation of examples of scientific approaches on research topics related to the physical, chemical and mechanical processes involved in the mechanisms of degradation or destruction of structures located in coastal zones. This book is organized into six chapters:

Chapter 1 is devoted to the description of microstructure materials widely used in built structures and the techniques of its investigation at the laboratory scale. For this purpose, a presentation of the different tools used is addressed. Then, different methodologies of the literature are given. They allow us to numerically build the microstructure of a porous medium and determine its associated transfer properties.

Chapter 2 focuses on heat and moisture transport since water is the vehicle of the transfer of aggressive agents from the atmosphere to porous materials by diffusion and advection. In unsaturated cases, wetting/drying cycles of the material also induce heat transfers. All these aspects are presented with some applications on concrete materials.

Chapter 3 deals with chloride transfer, mainly in saturated media. Given the well-known heterogeneity of porous building materials, the homogenization techniques used in the literature on porous media are discussed first. Then, the periodic homogenization technique has been chosen for its application to the case of chloride ion transfers in saturated materials. The electro-capillary phenomena involved in this kind of ionic transfer are integrated and parametric studies are supplied.

Chapter 4 studies chloride transfer through unsaturated materials by integrating advection phenomena in addition to electro-capillary phenomena mentioned above. In this chapter, the volume averaging technique is used to establish the macroscopic equations governing ionic transport coupled to liquid water transport leading to the obtainment of water and chloride profiles through the material submitted to a marine environment.

Chapter 5 focuses on the action of the second aggressive agent, i.e. sulfates present in seawater. The degradation mechanism is different from that of chlorides since sulfates act by modification of the hydrates formed in concrete. They induce some crystallized phases that are expansive. Also, they induce strengths that give rise to cracks in the materials. These cracks weaken the material and make it more permeable to any other agents, such as chlorides themselves. This leads to the facilitation of corrosion processes in reinforced concrete.

Chapter 6 deals with monitoring of structures. It expands the scale of the study to encompass the structure or the building and focus on the monitoring of the structure's performances according to its degradation state. According to safety conditions, it also aims to define a critical state of degradation depending on loading conditions and stresses coupled with a probabilistic approach, including the uncertainties on these parameters.

In order to be complete regarding structures in marine environment, Chapter 7 deals with a different kind of structures. This concerns protection systems against marine floods such as dikes or earth-fills. This chapter describes mechanism and mode degradation of these kinds of structures.

Contents

1

Porous Construction Materials: Characterizations and Modeling

This chapter presents experimental methods and some modeling of microstructural properties of porous media, mainly applied to construction materials. The methods shown are generally recommended by some specialized users or by standards. Some models shown are based on the microstructural properties of the medium, while others describe simulated microstructures built numerically based on experimental data, such as porosity, tortuosity and connectivity, and on the hydration process in the particular case of cementitious materials.

In the final section of the chapter, the microstructural properties of a porous medium are linked to a transfer property, namely intrinsic permeability. For this purpose, several approaches are presented: calculation of the permeability from data on the pore structure (e.g. distribution of pore radii) and calculation from 3D constructed microstructures.

1.1. Definition of porous media

A porous medium is composed of a rigid solid matrix, or with low deformation, and of a void network. The porosity, denoted as ε_p in the

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following, is expressed by the ratio of the void phase volume and the total volume of the medium (equation [1.1]):

$$\varepsilon_p = \frac{V_{Voids}}{V_{total}} \quad [1.1]$$

The pores (Figure 1.1) can be connected and cross the medium from side to side. In this case, the pore structure is known as “percolating”. Trapped gaps or blind pores can also be found within the medium.

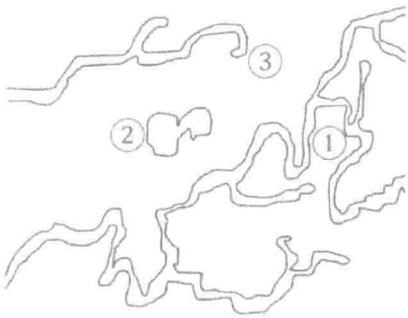

Figure 1.1. *Porosity: ① Percolation/connected porosity, ② Trapped gap, ③ Blind pore*

A lot of construction materials are porous. The pore structure, i.e. porosity and pore size and shape, depends, of course, on the type of the material. The porosity of construction materials is the place where transfer phenomena occur. These phenomena are affected by microstructural parameters, such as pore size distribution or connectivity. Generally speaking, it is necessary to consider all these parameters in order to study the transfer properties. For instance, the most porous material is not necessarily the most permeable material: pore size also affects the transfer by permeation.

From this point of view, two relevant microstructural parameters are usually used to characterize the pore structure: tortuosity and constrictivity. The tortuosity (τ) quantifies the elongation of the transfer path due to pore geometry, as shown in Figure 1.2(a).

Usually, tortuosity (equation [1.2]) is calculated as the ratio of the average pore length and the sample thickness. The tortuosity models the average transfer path through the material:

$$\tau = \frac{l}{l_0} \qquad [1.2]$$

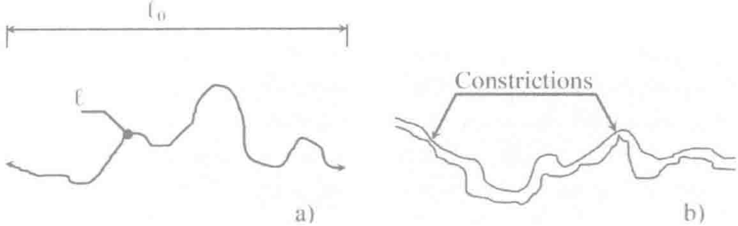

Figure 1.2. *Microstructural parameters: a) tortuosity and b) constrictivity*

The constrictivity (δ) (Figure 1.2(b)) consists of a reduction of the pore size along the pore. It reflects the fact that the pore section is not uniform but undergoes several constrictions that affect the transfer phenomena.

1.2. Different experimental tools for the characterization of porous materials

The transfer of chemical species in a porous medium is closely related to the porous microstructure [OLL 92]. Thus, its characterization is required to study the structure's durability. The knowledge of parameters such as porosity or pore-specific areas is necessary for the investigation of the physicochemical phenomena involved during mass exchanges between the wall of the pore and the pore solution interface inside the medium, which governs boundary conditions in the study of mass transfer.

1.2.1. *Measurements of porosity*

The main direct methods of porosity measurements in construction materials are water porosimetry and mercury intrusion porosimetry (MIP). These two methods are described hereafter. In the case of cementitious materials, recommended protocols exist, particularly in France [AFP 97, ARL 07].

1.2.1.1. *Water porosimetry*

Generally, the water porosimetry test is carried out according to the procedure recommended by the French association AFREM (*Association Française de Recherche et d'Essais sur les Matériaux et les Constructions*, French Association for the Research and Testing of Materials and Structures) [AFP 97] and the standard NF P18-459 [AFN 10]. The samples are first water-saturated with distilled water under vacuum at a saturation vapor pressure of 18 mmHg in order to obtain the saturated mass m_{sat}. The sample volumes V_{tot} are then determined from buoyancy weighing. Finally, samples are dried at a temperature between 60 and 105°C until mass stabilization to obtain the dried mass m_{dry}. The mass stabilization is obtained when the relative mass loss in 24 h is less than 0.05%. The porosity ε_p is calculated using equation [1.3]:

$$\varepsilon_p = \frac{m_{sat} - m_{dry}}{\rho_w . V_{total}} \times 100 \ (\%) \qquad [1.3]$$

where ρ_w is the density of water.

1.2.1.2. *Mercury intrusion porosimetry*

The MIP test is carried out by injecting mercury through a porous medium sample of 1–2 cm^3 placed under vacuum in a penetrometer. This injection is performed by varying the injection pressure P, which can reach more than 400 MPa, so that the mercury penetrates pores whose diameters D are between 0.003 and 360 µm. Each pressure increment permits the calculation of the diameter of the pores filled with a volume of mercury V_{Hg} according to the Laplace's law (equation [1.4]). The principle of measurement is schematized in Figure 1.3:

$$D = \frac{4\gamma\cos\theta}{P} \qquad [1.4]$$

where γ is the surface tension between the pore surface and the mercury (N/m). This parameter varies with the purity of mercury. The value usually used is 0.485 N/m. θ is the contact angle in degree between the mercury meniscus and the pore wall. The usual value for this parameter is 130°.

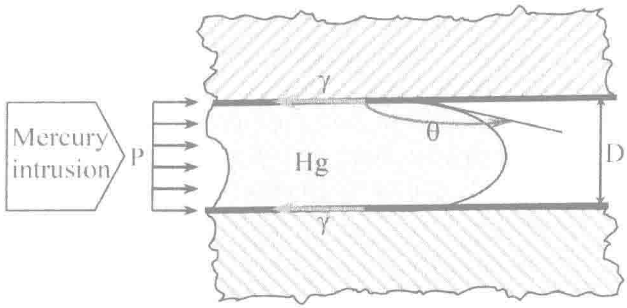

Figure 1.3. *Schematic view of the MIP principle. For a color version of the figure, see www.iste.co.uk/ait-mokhtar/coastal.zip*

At the end of the test, a pore size distribution of the porous network is obtained. The latter is given by a plot of the differential log of the mercury volume intrusion versus the pore diameter. Figure 1.4 gives an example of a result obtained by this method. The specific area of the material can also be calculated from the collected data.

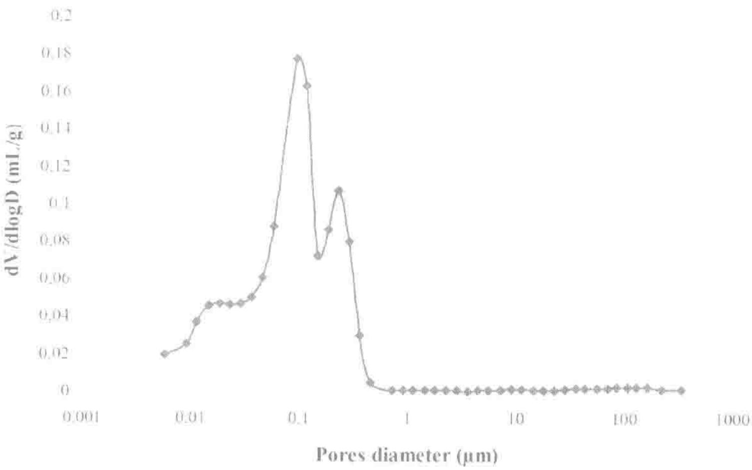

Figure 1.4. *Example of pore size distribution obtained by MIP on a mortar with W/C = 0.6 [HAM 09]*

The MIP is a measurement technique widely used to characterize a porous material. It gives a simplified representation of the microstructure of