[1] Logzit Nacer *
[2] Bentoumi Mohamed

# Estimation of the Mechanical Behavior and Durability of Old Concrete by Numerical Calculation

***Abstract: -*** Estimating the mechanical behavior of aged concrete correlated with potential durability is an important topic in the field of rehabilitation of civil engineering structures. The aim of this research is to propose numerical correlation models to estimate the mechanical behavior and durability of aged concrete compared to the results of new concrete. The study begins with the design of several types of new concrete and of concretes with accelerated artificial degradation, the class of the concretes varying from 25 to 35 MPa, in two aggregate variants, continuous and discontinuous granularity. On the basis of several samples characterized in the laboratory and in-situ by non-destructive tests, a numerical correlation is proposed for the direct estimation of the mechanical behavior of old concretes linked to durability class. The results obtained show the reliability of the proposed models, and provide a more realistic approach to knowledge of the overall condition of old concrete.

***Keywords:*** durability, mechanical behavior, numerical model, Old concrete.

## I. Introduction

Assessing the mechanical and durability properties of old concrete is important for the preservation and rehabilitation of aging structures. Over time, concrete undergoes physical and chemical changes that affect its strength, ductility and durability. Traditional experimental methods can be costly and require material samples, making numerical calculations of mechanical properties increasingly relevant. Thanks to advances in technology, numerical models can be used to simulate the behavior of old concrete under various loads and conditions. These simulations incorporate the effects of disintegration, cracking and carbonation, providing a detailed understanding of potential failures. Concrete porosity and permeability are key factors in understanding the behavior of these materials [1], [2], and [3]. Further studies by Tsivilis S et al [4] and Zhang X et al [5] show that mean and median pore sizes, respectively, have a significant impact on concrete permeability and absorption. Zhang, J et al [6] pointed out that with increasing median and critical pore sizes, the intrinsic gas permeability of concrete also increases. As a result, the capillary water absorption capacity of concrete has become one of the most critical indicators when assessing its overall durability [7].

The use of numerical models enables engineers to predict the behavior of old concrete structures, facilitating informed decisions on necessary interventions. Numerical calculation is thus an effective approach for ensuring the safety and functionality of historic infrastructures.

This article explores numerical calculation methods for assessing the mechanical behavior of old concrete, presenting the importance of experimental data for validating numerical models. Results include simulations using numerical models, compared with laboratory tests and non-destructive means on old concrete samples. Particular attention is paid to the influence of aging factors on mechanical properties.

To achieve this objective, models of artificial degradations are designed in the laboratory, once the response using non-destructive tests is identified and parameterized, tests on real cases will be carried out. The comparison between theoretical and practical models will serve as a basis for knowledge of the most realistic numerical approaches for characterizing degraded concrete.

## II. Méthodology

### *2.1 Aged concrete design*

Samples of old concrete were designed under an artificial protocol, and ordinary formulated concretes were placed in an accelerated aggressive environment to obtain degraded concrete. To broaden the scope of our study,

[1] LMSE Laboratory, University of Mohamed El Bachi El Ibrahimi of Bordj Bou Arreridj. Algeria.
Faculty of Science and Technology, University of Mohamed El Bachi El Ibrahimi of Bordj Bou Arreridj. Algeria
[2] Faculty of Science and Technology, University of Mohamed El Bachi El Ibrahimi of Bordj Bou Arreridj. Algeria.
mohamedbentoumi709@gmail.com
* Corresponding Author Email: n_logzit@yahoo.fr

two types of aggregate were used, continuous and discontinuous. Tables 1 and 2 show the formulation results for 25 MPa and 35 MPa class concretes for the two types of aggregate.

**Table 1:** Formulation of discontinuous-grain concrete.

| Materials Class | Cement ($kg/m^3$) | Water (l/m3) | Gravel (kg/m3) | | Sand (kg/m3) |
|---|---|---|---|---|---|
| | | | G (8/15) | G (15/25) | S (0/5) |
| Concrete class 25 MPa | 306 | 206 | 487 | 731 | 578 |
| Concrete class 35 MPa | 392 | 206 | 479 | 718 | 512 |

**Table 2:** Formulation of continuous-grain concrete.

| Material Class | Cement (kg/m3) | Water (l/m3) | Gravel (kg/m3) | | | Sand (kg/m3) |
|---|---|---|---|---|---|---|
| | | | G (3/8) | G (8/15) | G (15/25) | S (0/5) |
| Concrete class 25 MPa | 306 | 206 | 365 | 280 | 572 | 558 |
| Concrete class 35 MPa | 392 | 206 | 359 | 275 | 562 | 512 |

Mixing of the components, characterization in the fresh state and preservation of the specimens were carried out in accordance with current standards (Figures 1 and 2).

Two types of aggressive solution were chosen: a sulfuric acid solution with concentrations of 0.05 and 0.25 mol/liter, and an ammonium sulfate $(NH4)_2SO_4$ solution with concentrations of 0.05 and 0.25 mol/liter.

**Figure 1.** Specimen preparation.

**Figure 2.** Storage of test specimens in an aggressive environment.

After the specimens had been stored for some time, non-destructive ultrasonic tests [8] and [9] were carried out (see figures 3 and 4).

**Figure 3.** Non-destructive measurements, Marking of measurements.

**Figure 4.** Non-destructive measurements, Ultrasonic testing.

In the laboratory, tests were then carried out to determine the various strength and durability parameters. For concrete porosity, we adopted the correlation model of A. Benouisa and A. Grinib [10].

**Figure 5.** Phenophthalein carbonation test result.

The phenophthalein carbonation test [11] (figure: 5) showed a degradation of the concrete tested of 10 mm, which proves that the concrete is at least ten years old.

*2.2 Numerical modeling*

Before moving on to numerical modeling, a statistical study of the results obtained is deemed necessary [12] in order to decide on the various model values. The statistical calculation is based on the reliability of the results through the coefficient of variation of each group of values; to pronounce a reliability of the results, we admit a tolerance of the coefficient of variation lower than 12%.

Linear regression curves are used to represent the numerical correlation model. In the applied sciences, we frequently observe phenomena where there is reason to suspect the existence of a link between two variables. This link is called correlation. Two observed variables are said to be correlated when they occur in the same direction (positive correlation), or in opposite directions (negative correlation).

The index that measures the intensity of the linear link between two variables can be calculated according to the correlation coefficient R, which is a dimensionless number. The more closely the points are aligned along a straight line, the higher the value of the correlation coefficient, approaching +1 or -1 as the case may be.

## III. Results And Discussion

### *3.1 Mechanical behavior of degraded concrete*

The results of mechanical tests correlated with numerical models (see figures 6, 7, 8 and 9) show a significant reduction in mechanical performance as concrete ages.

The compressive strength of new concrete varies from 20 to 35 MPa, that of old concrete from 10 to 30 MPa, representing a 27% loss of strength. Numerical correlation adjusted by in-situ and laboratory tests shows a good approximation of the results, with the R coefficient close to 1. The numerical models proposed can characterize the mechanical behavior of old concrete.

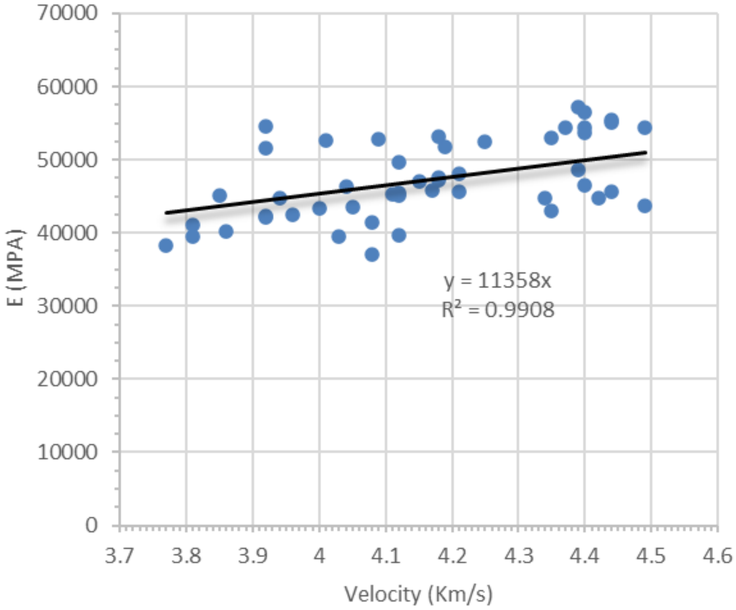


**Figure 6.** Modulus of elasticity of old concrete as a function of ultrasound velocity.

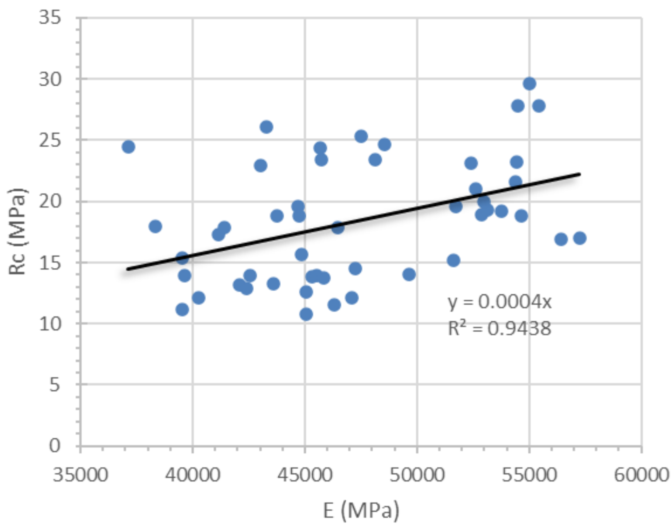


**Figure 7.** Strength of old concrete as a function of modulus of elasticity.

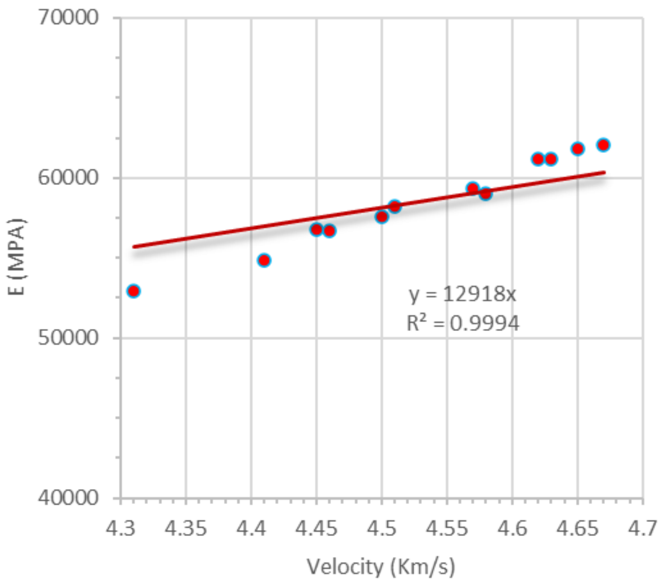


**Figure 8.** Modulus of elasticity of new concrete as a function of ultrasound velocity.

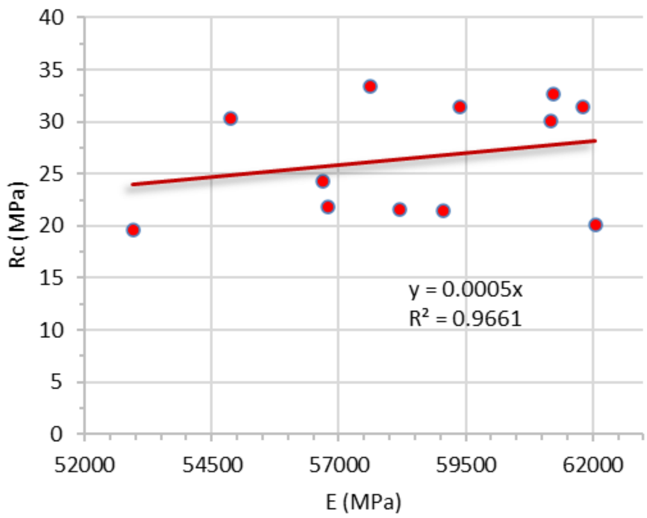


**Figure 9.** Strength of new concrete as a function of modulus of elasticity.

The modulus of elasticity of old concrete was 18% lower than that of new concrete. Numerical correlation adjusted by in-situ and laboratory tests shows good approximation of the results, with the R coefficient close to 1. The proposed numerical models can characterize the mechanical behavior of old concrete.

*3.2 Indicator of durability of old concrete*

To give an idea of the durability performance of older concretes, we prefer to choose the first-order index of durability: the porosity of a concrete is mainly the basic index of a concrete's durability.

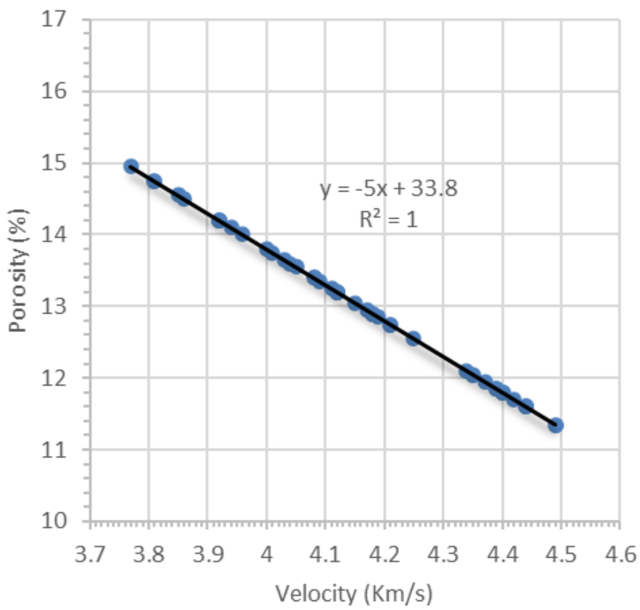


**Figure 10.** Porosity of old concrete as a function of ultrasound velocity.

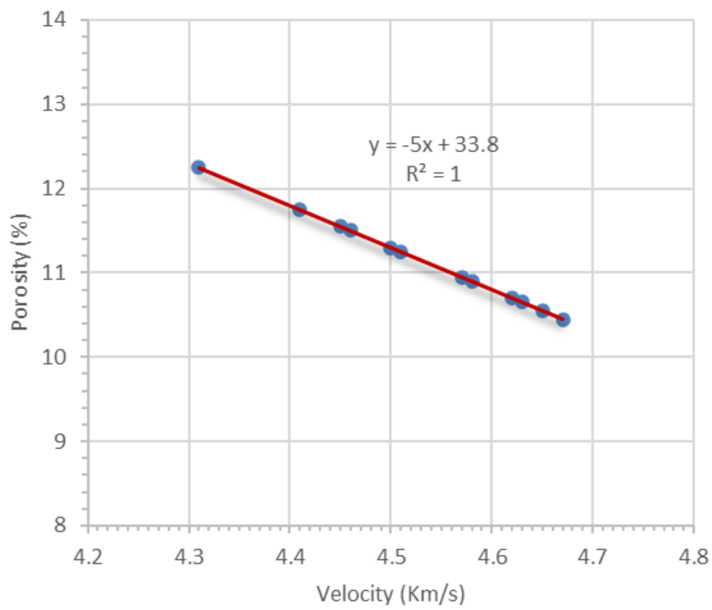


**Figure 11.** Porosity of new concrete as a function of ultrasound velocity.

Old concrete may have heterogeneities and microstructural defects, which hinder the propagation of ultrasonic waves and therefore reduce their speed. Ultrasonic velocity is directly related to concrete porosity. The average porosity of new concrete varies from 10 to 12% (figure 11), indicating a concrete of average durability. The results for old concrete (figure 10) give porosity values ranging from 11 to 15%, indicating concrete of low durability.

The numerical models proposed for estimating the durability class of old concrete, compared with the results for new concrete, give a satisfactory correlation.

## IV. Conclusion

The results of this correlation study between numerical models compared with in-situ tests and laboratory test results provide a satisfactory approach to understanding the mechanical behavior and durability of old concrete.

These results underline the importance of coupling experimental data and numerical calculations for the assessment of old concrete. The numerical models obtained can be a valuable tool for the management and rehabilitation of structures. By estimating the mechanical behavior of old concrete and predicting its potential durability, a technical judgment on the quality of in-situ concrete can be made quickly and easily.

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