CONCRETE CARBONATION MODELLING AND MONTE CARLO SIMULATION METHOD FOR UNCERTAINTY ANALYSIS OF STOCHASTIC FRONT DEPTH

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This summary paper represents the application of two methods for determination of the depth of carbonation in concrete. Application of the deterministic and stochastic modelling using Monte Carlo simulation were the two techniques which showed reliable results for the prediction of carbonation depth.

Key Words : *carbonation modelling, Monte Carlo simulation, stochastic analysis, deterministic model, durability prediction*

1-INTRODUCTION

One of the major parts of new structural concrete design methods is the durability design. Nowadays there is an increasing demand to predict the service life of concrete and its performance at various times in the future. Therefore, construction of an appropriate model, which consists of important and practical parameters, is the main interest of many researchers. Using the best prediction model is the most important part of the service life investigation of concrete structures.

This summary paper has been prepared to introduce two methods of investigation for concrete carbonation: Deterministic and Stochastic Modelling of concrete carbonation front depth.

The deterministic model is constructed based on the results of accelerated and in-situ tests. The in-situ tests are used to calibrate the accelerated ones. Due to this calibration a confident and reliable model can be obtained. This model is used in the Monte Carlo simulation method. Using this powerful tool, more results and information can be obtained by means of computerised simulation than running real physical tests. For this purpose an applied computer program was prepared.

Due to the increasing interest of researchers in the structural management systems, this program can help the designers in the stages of concrete cover design, decision making for repair methods, and prediction of the stochastic concrete carbonation front depth. Also it can be used in reliability theory to find out the failure probability at a specified time in the future.

2-OVERVIEW

One of the main causes of reinforced concrete corrosion is the carbonation of concrete. It is mainly due to the diffusion of CO_2, which exists in the atmosphere. This process is very slow and related to the ambient conditions. Also the mix proportion of concrete has a great influence on the depth of carbonation.

It is necessary to introduce models that are simple and powerful in the structural and durability prediction phase of concrete design procedures. Many models exist with some important and partly unnecessary parameters. Thus it was decided to find an appropriate model with the major parameters as follows:

a. Water to cementitious materials ratio, w/(c+csf)
b. Condensed silica fume to cementitious materials ratio, csf/(c+csf); and
c. Ambient relative humidity, RH%.

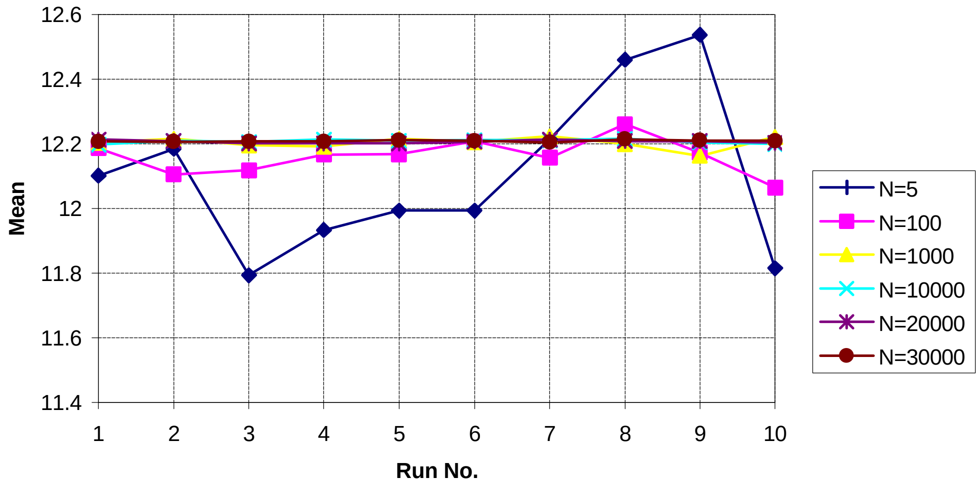

Fig.1 Effect of no. of random numbers on the mean of concrete carbonation front depth at a given year

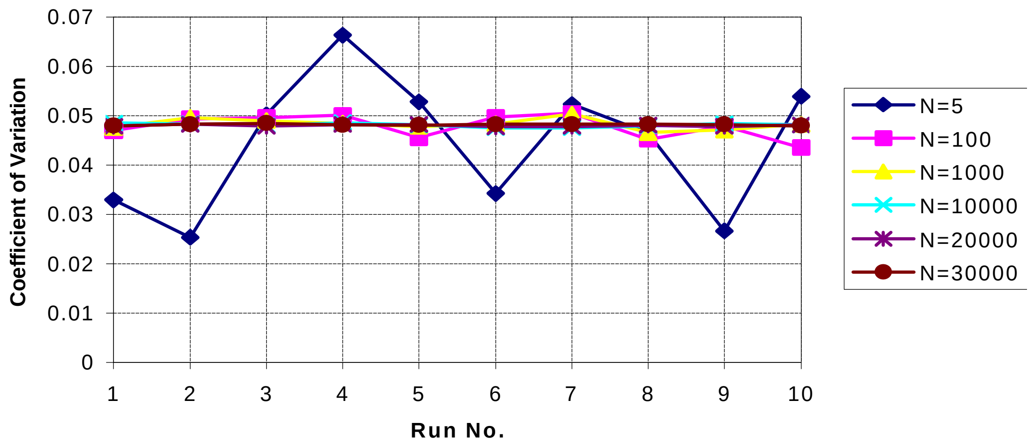

Fig.2 Effect of no. of random numbers on the coefficient of variation of concrete carbonation front depth at a given year.

After finding the best model, the deterministic model, it will be used in the remaining parts of stochastic model construction and Monte Carlo simulation for uncertainty analysis of concrete carbonation front depth. It makes this research program more applicable and usable in the routine works of structural concrete design.

In simulating a physical process like concrete carbonation by using computer, it is necessary to generate some random numbers. After generation of sufficient random numbers one must select the appropriate statistical distributions of the input data. In physical measurements the Normal distribution is used extensively. The obtained data from real tests of concrete carbonation also show that this distribution is valid apparently. In the simulation method of this research work, the deterministic model and Normal distributions are used for construction of the stochastic one. The results of simulation show the characteristics of stochastic model.

3-DETERMINISTIC MODEL

The deterministic model is constructed based on the above mentioned tests. The user must consider the following limitations of the model:

1. w/(c+csf) varies between 0.35 and 0.50.
2. csf/(c+csf) varies between 0.00 and 0.10.
3. RH varies between 40% and 90%.

As an example, the concrete carbonation front depth at 20 years is calculated.

The input data are:
w/(c+csf)=0.42,
csf/(c+csf)=0.07, and
RH=55%.

Using the deterministic model the depth of carbonation after 20 years will be 29.13 mm.

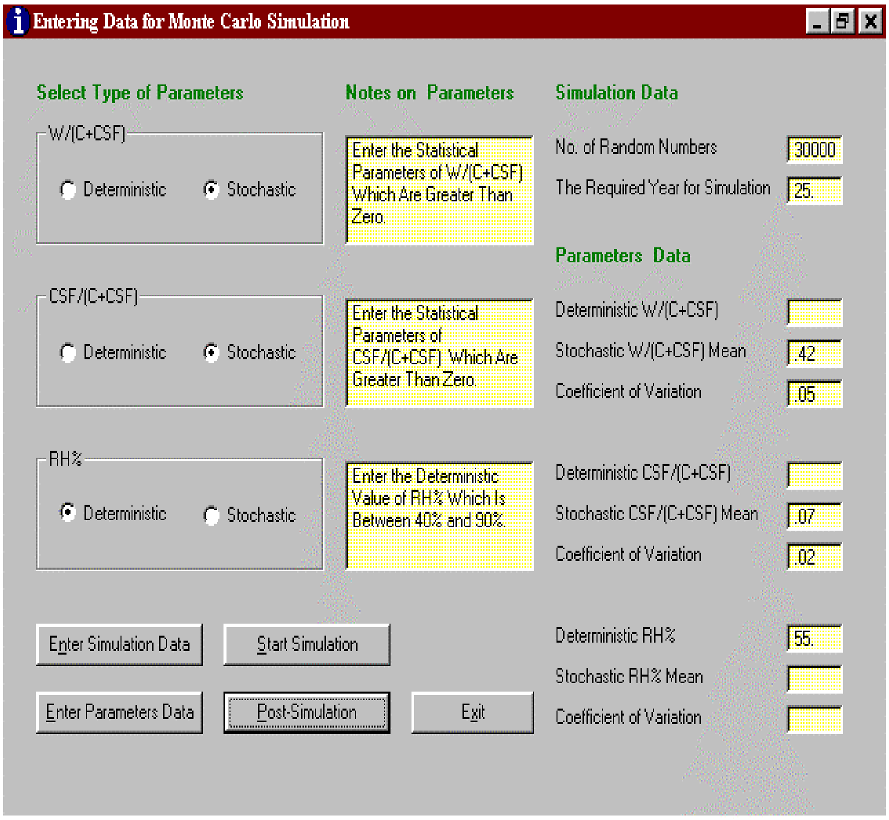

Fig.3 Input data screen of the computer program for a stochastic example

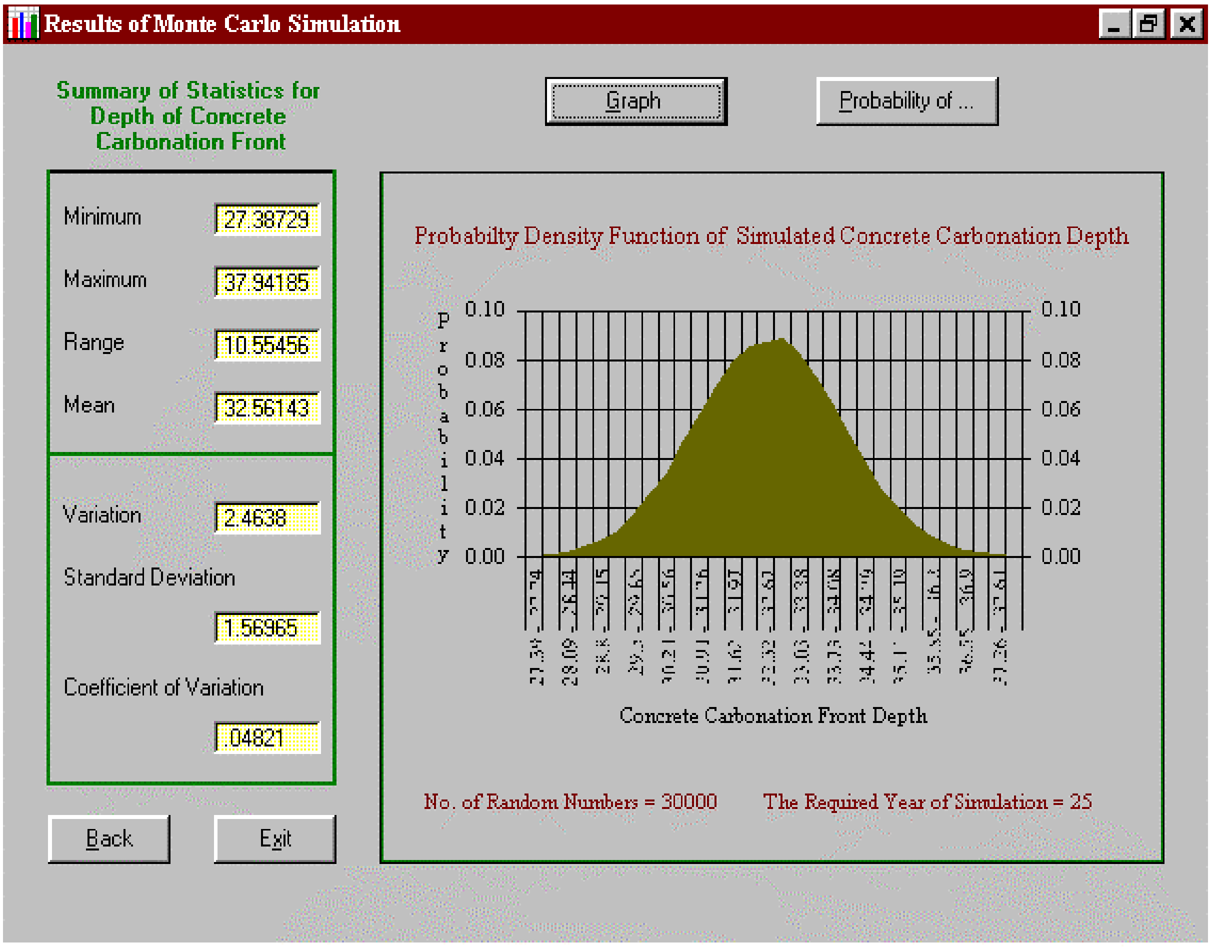

Fig.4 Output sub-screen of the computer program for a stochastic example

4- STOCHASTIC MODEL AND MONTE CARLO SIMULATION

The heart of the stochastic model is the deterministic model of the previous section. By generating enough random numbers the behaviour of the stochastic depth of concrete carbonation can be simulated. The computer program, which is prepared by the Visual Basic 6.0 Package, can be very powerful for this purpose. It resembles a real laboratory and the user can experiment as number of tests as he likes.

There is no limitation for this model. Only the input data which are the mean and coefficient of variation values of the parameters, must be greater than zero. The computer program distinguishes the situation and uses the correct generated numbers for the deterministic model.

The statistical summary and distribution of concrete carbonation front depth can be displayed by the computer program for convenience.

The more the no. of random numbers, the better statistical distribution of front depth is obtained. This is clearly shown in Figs. 1 and 2. Figs 3,4 and 5 also show the input and output windows of the program for a stochastic example.

The capability of Monte Carlo simulation method and computer program for concrete carbonation front depth can be discovered by means of the obtained results. As it is seen from the stochastic example, the introduced method is appropriate for non-linear equation of mean behavior like the one which was introduced for deterministic model in this research work. In the example the input coefficients of variations are 0.05 for w/(c+csf) and 0.02 for csf/(c+csf), but the corresponding value for front depth is 0.04821.

5-CONCLUSION

This summary paper proposes the idea of making deterministic and stochastic models through the use

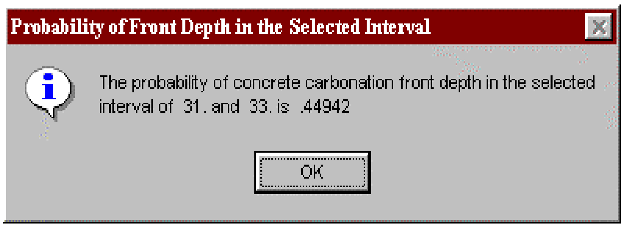

Fig.5 Output sub-screen of the computer program for a stochastic example

of a powerful tool like Monte Carlo simulation method. In the Monte Carlo simulation method it is possible to run more and more tests to find out the relationships between parameters and their effects on the concrete carbonation front depth. These models are useful for structural design, durability design, and evaluation of repair systems.

The simulation computer program facilitates the attempts of decision-making parts in the work, which in them have great influences on the economy of the projects.

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