Proposition for PhD students from the China Scholarship Council

# Survival models to failure events for concrete infrastructures

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The prediction of the service life of concrete infrastructures (bridge, dam, power plants, etc.) is a major issue at several steps. Firstly when dimensioning the structure to ensure a minimum predefined service life, and optimizing the design according to this imperative. More and more often, the question of lengthening the lifetime of infrastructures arises, accompanied by the setting up of a maintenance strategy to be elaborated, or even of interventions to be carried out on the structure for its repair. In all cases, this lifetime prediction requires the availability of modeling tools adapted to the needs of the engineering community, whether for the design of structures or for the management of an existing heritage.

Many deterministic degradation models have been developed in order to simulate the "physical" behavior of the structure as realistically as possible. Depending on their refinement level these models require to inform a large number of input parameters, more or less accessible in engineering practice, whether in terms of designing structures or managing a heritage.

Another scientific challenge has to be addressed in addition to the above mentioned pitfall: many hazards and uncertainties affect the behavior and degradation of concrete structures, which must be integrated into the modeling. These uncertainties may arise from the variability of the material, structural parameters such as the geometry, exposure conditions (climatic environment) and usage (loading). Civil engineering infrastructures are always complex systems exposed to coupled degradations and whose lifetime can be limited by several failure modes. Taking into account these uncertainties leads to no longer consider lifetime but determination of a lifetime probability, or even to describe the service life no longer by a deterministic value but by a law of statistical distribution that innovative modeling tools for engineers would determine.

This is the issue that the proposed research work intends to address. The scientific obstacles are relatively numerous:

- The "physical" models developed by the academic research community are numerically costly, which complicates their implementation through reliability methods.
- The behavior of infrastructures is strongly determined by the time variant conditions of exposure (relative humidity, temperature, atmospheric concentration of carbon dioxide, etc.) whose evolution in the decades to come according to scenarios of global warming must be accounted for.
- The lifetime of a structure is to be defined from several possible failure modes, which can occur successively or simultaneously, even though it is not systematically possible to define precise or constant thresholds to establish the failure. For example, the

corrosion of a steel rebar in a reinforced concrete structure can be initiated by the carbonation of the concrete cover or by the chloride ingress to the reinforcement, without a consensus having been reached yet on the concentrations of aggressive species defining this corrosion initiation.

- The assessment of the service life distribution law must be updatable, according to the inspection or diagnosis campaigns giving at one moment an experimental estimation of the degradation level in the structure, or as function of refinement of the climatic scenarios. If updating methods exist, they are very complex to implement on numerically costly degradation models and with a large number of random input variables.

The aim of the thesis is to invest the mathematical methods relating to survival models, whether parametric or semi-parametric, associated or not to degradation processes, such as Gamma processes. An additional challenge is to make them evolve to integrate time series as covariates, particularly relating to climate change (temperature, external humidity, etc.) in addition to the covariates relating to the material (concrete mixes, etc.) and the structure (geometry, coating, etc.) or even usage (loading). The challenge here is to initiate a close collaboration between the academic communities of mathematical and statistical methods on the one hand, and civil engineering on the other hand, with the aim of developing surrogate models, or degradation processes, to physical degradation models and to propose adapted tools for the needs of civil engineers (design and maintenance).

This thesis project will deal with the issue of failure of reinforced concrete infrastructures due to the corrosion of reinforcing steel. This issue has to be addressed taking into account many uncertainties, whether on the corrosion mechanisms and on the subsequent mechanical failure mode (reduction of the steel section, loss of steel/concrete adherence, cracking of the concrete cover under pressure of the corrosion products). In addition to this is the uncertainty, already mentioned, related to the evolution of the atmospheric conditions of the degradation through the scenarios of global warming: relative humidity, temperature, pressure of atmospheric $CO_2$, etc. are key parameters for the lifespan of concrete structures whose changes in the coming decades are uncertain.

The challenge will be to conform the statistical and/or survival models to the actual behavior of concrete structures, on the basis of physical considerations, which are absent from the mathematical models. The major innovation expected from this project will be to make available to the civil engineering community modeling tools for the estimation of lifetime distribution laws for concrete structures, as well as their updating over time, either based on data from inspection campaigns and related to the material evolutions due to its exposure, or in relation to a revision of the global warming scenarios.