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Statistical modelling of cracking in large concrete structures under Thermo-Hydro-Mechanical loads: Application to Nuclear Containment Buildings. Part 2: Sensitivity analysis

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ABSTRACT

As demonstrated in Part I of this contribution, the precise and full prediction of the cracking patterns and concrete's global behaviour in ageing structures is a complex task. Though the suggested modelling strategy allows the prediction of the main cracking patterns, its drawbacks are mainly related to (a) the use of the so-called Statistical Size Effect Law requiring various random field realizations (more than 30) and (b) the identification of a consequent number of Thermo-Hydro-Mechanical parameters (more than 50) which variations may also affect the computed cracking patterns and ageing behaviour. In part II of this contribution, the aim is to evaluate the effect of such uncertainty-related variations on concrete's early age and long term behaviours (in comparison with the effect of the intrinsic spatial variation of mechanical properties in part I). With that regard, a 1st order sensitivity analysis to the various input's variation is performed using the OFAT method. Throughout the study, the robustness (model's convergence) and predictiveness (physical representativeness of numerical results) of the suggested model in Part I are evaluated within the identified inputs' variation domains. The obtained results, in terms of the 1st order global sensitivity indexes, provide a subjectively quantitative and objectively qualitative ordering of the most influential parameters within the model's associated physical hypotheses. In particular, the obtained results show (a) the relevance of the Gaussian function to describe the spatial correlation of the Young's modulus property (b) the dependence of early age behaviour on, both, the spatial scattering of the mechanical properties and the maturity process; but mostly, on the structural size effect assessment (c) the main dependence of long term behaviour on the drying history and applied prestressing loads and (d) the importance of uncertainties propagation through the Thermo-Hydro-Mechanical calculations and through the operational lifespan of ageing concrete structures.

1. Introduction

The uncertainties related to a given quantity are the consequence of either the intrinsic variations of its measurement system composed by, both, the material and studied phenomena or of an induced error of the measuring method (Ditlevsen and Madsen, 1996). In the case of concrete cracking, the sources of uncertainties are numerous and can be classified into two groups (Baroth et al., 2011):

– The first group encloses the internal sources of uncertainties related to the internal state of the structure. It has to do with the concrete's properties (more than 50 parameters are needed for a full THM calculation covering both early age and delayed behaviour (Bouhjiti et al., 2018) – Fig. 1), the structural design (geometry and rebars disposals for example – Fig. 2) and the internal interactions between different structural parts (restraining effects for instance).
– The second group is related to external sources of uncertainties; mainly, the variation of the THM boundary conditions. Some of those uncertainties are inevitable and cannot be reduced or deleted. Yet, they are quantifiable (such as the CoV of the mechanical

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Nomenclature

CoV	coefficient of variation
DOE	design of experiments
FE	finite elements
GSA	global sensitivity analysis
NCB	Nuclear Containment Buildings
OFAT	one-factor-at-a-time
OP	operational phase
POP	pre-operational phase
RF	random fields
RH	relative humidity
RSV	representative structural volume
SSEL	statistical size effect law
THM	Thermo-Hydro-Mechanical
VeRCoRs	French acronym for ‘’ VErification Réaliste du COnfinement des RéacteurS ‘’ meaning ‘’ Realistic assessment of the nuclear reactors’ tightness “

properties). Other epistemic uncertainties can be reduced thanks to a better understating of the phenomena and an improvement of the measurement precision and quality (for instance the parameters related to the use of RF and to the modelling of THM properties' spatial randomness). And, finally, other ontological uncertainties which are rather related to the human nature of continuous learning process and skills' improvement; for example, the construction quality on the field.

In front of such diverse sources of uncertainties, and considering the consequent number of inputs and hefty computational time (from 4 h to 2 days for a full THM analysis at the RSV scale – Figs. 1 and 2), the decision making process with regards to cracking control, maintenance and repair operations remains quite complex. Therefore, and for the previously presented modelling strategy (Bouhjiti et al., 2018), the model's sensitivity to such uncertainty-induced variations is a key question with regards to its robustness (model's convergence) and predictiveness (model's physical representativeness) in terms of qualitative and quantitative description of cracking. Moreover, for the sake of applicability and practicality of use, the identification of the model's most influential parameters is required. On the one hand, this would gear experimental work towards the identification of critical parameters and the understanding of key phenomena. On the other hand, it would introduce – in the case of non-influential parameters – additional hypotheses aiming at facilitating the model's usage and eventually reducing its required inputs' number for the considered structural volumes and loads. Indeed, such simplifications remain strongly dependent on the considered structure and its environment; they can only be performed if the model's ability to accurately describe the foreseen THM behaviour is not altered.

Existing contributions with that regard remain partial focusing on one of the THM calculation steps without evaluating the uncertainties propagation through the THM steps and throughout the operational lifespan of structures. Moreover, they are limited to either the early age behaviour until the thermo-hydration phase ends (Briffaut et al., 2012; Xian et al., 2014) or the long term behaviour where early age effects are overlooked (Defraeye et al., 2013; Trabelsi et al., 2012; de Larrard et al., 2010):

- Early age sensitivity analysis: In (Briffaut et al., 2012; Xian et al., 2014), a 1st order sensitivity analysis is performed to study the effects of concrete's thermal behaviour during hydration on its cracking risk based on a global stress analysis. By using the ratio of the developed stress (within a viscoelastic framework) to the tensile strength as an index, it is shown in Briffaut et al. (2012) that the self-induced cracking risk of a 1.2 m thick wall is up to 30% higher when the effects of hydration and temperature on the concrete's thermal capacity are not considered. This, however, should be viewed as a relative increase of the developed tensile stresses in the concrete volume and not as a given probability of cracking. Indeed, the

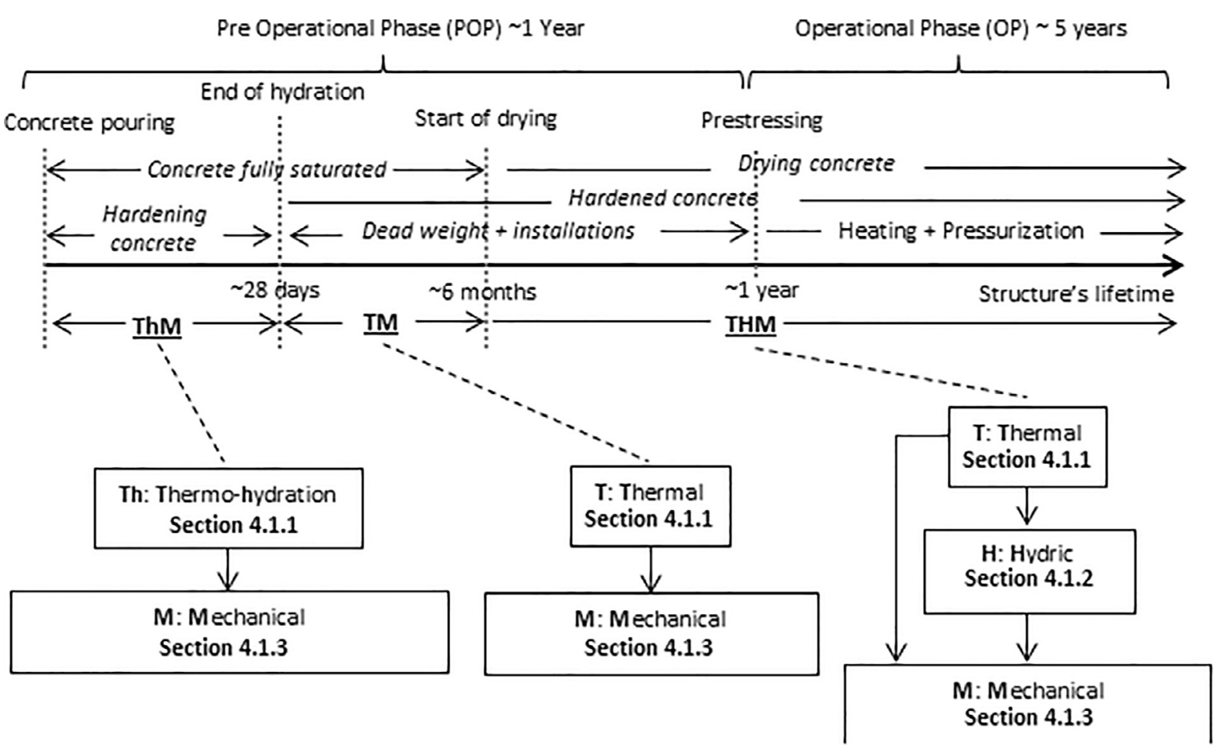

Fig. 1. Overall view of the THM modelling steps applied to the 1:3 scale VeRCoRs mock-up in Fig. 2 (Bouhjiti et al., 2018).