Université Gustave Eiffel

ASFA AUTOROUTES & OUVRAGES CONCÉDÉS

Numerical tool for structural management based on re-assessment oriented by observable disorders for concrete structures affected by internal swelling reaction.

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INTRODUCTION

Nowadays, a significant number of concrete infrastructures pertaining to motorway networks are affected by Internal Swelling Reactions (**ISR**), such as cast-in-place elements and precast elements. Chemical and physical processes associated with **ISR** initially manifest themselves through swelling and micro-cracking of the cement, and then, evolves into a more severe deterioration both locally (material-level) and globally (structure-level), undermining the structural performance of the affected infrastructure.

On the basis of this ascertainment, the **Université Gustave Eiffel** and the "**Association Professionnelle des Sociétés Françaises Concessionnaires ou Exploitant d'Autoroutes ou d'Ouvrages Routiers**", also known as **ASFA**, established a partnership the main objective of which is to develop a robust and easy-to-use numerical tool capable to assist in the evaluation of structures degraded by internal swelling reactions.

Deterioration-phenomenon caused by **ISR**, specifically Alkali-Silica Reaction (**ASR**) and internal sulphate attack (otherwise known as Delayed Ettringite Formation - **DEF**), has been an issue that researchers, engineers and infrastructure managers have been facing since 1940.

ASR is a chemical reaction between hydroxyl ions (OH-) and the alkalies (Na and K) from hydraulic cement (or other sources), and certain siliceous rocks and minerals, present in some aggregates. This reaction and the development of the alkali-silica gel reaction product can, under certain circumstances, lead to abnormal expansion and cracking of the concrete [Fig.1-a, b, c].

Fig. 1-a [1]

Fig. 1-c [1]

Figure 1:a) Map cracking due to ASR in a massive element, dam in Salanfe, Switzerland; 1:b) Dam in Songloulou, Cameroon, presenting severe cracking induced by ASR.

In the second case, **DEF**, cracking and decreasing in mechanical properties are due to an expansive process, linked to the delayed formation of the mineral ettringite, typically produced at early age hydratation (e.g. during precasting processes, massive cast-in-place structures) [Fig.2-a, b, 3-a, b] .

Several numerical models have been developed and are now available in literature, however, the amount of data required to correctly fits these models is considerable and demands complex and expansive investigations, at times insufficiently.

Fig. 2-a [1]

Fig. 2-b,3-a [1,2]

Fig. 3-b [2]

Figure 2:a) Global view of a road bridge affected by DEF; 2:b) Fracture mapping on the base of a pier of the bridge.
Figure 3:a) Overall view of Bellevue bridge; 3:b) Pier of the Bellevue Bridge with map cracking in the tidal zone.

In addition, managerial and operational aspects must to be considered, in fact, the motorway manager must ensure the correct serviceability and structural safety, using experimental and numerical test data, which require further interpretations and do not comply with the management-operational policies.

[1] (photos Seignol, J.F.) [2] (photos Divet, L.)

SCIENTIFIC CHALLENGES

This PhD work deals with several scientific challenges, such as:

- Relationship between degradation under free swelling and underswelling of stressed concrete;
- Connection between visible cracks on the facing and internal cracks (explicitly or through damage rules);
- Connection between cracking and mechanical performances decrease;
- Role of reinforcement on the cracking, and role of the cracking on the adherence of rebars;
- Parameter identification for ISR numerical models based on indirect observations (based on inverse problem techniques);
- Interaction between ISR and concrete creep, especially in the case of prestressed concrete.

PROJECT OBJECTIVES:

In light of all of the above, there is a gap between demand-product to be bridged, thus, from scientific standpoint:

- Numerical models that simulate **ISR** affected structures require a large amount of data (**INPUT PARAMETERS**);
- The resulting numerical models do not directly lead to management policy of affected structures (**OUTPUT PARAMETERS**);

whereas from an industrial point of view:

- The data provided by infrastructure managers, in the majority of cases, do not allow a correct and exhaustive modelling (**INPUT PARAMETERS**);
- Infrastructure managers require as much complete information as possible in order to perform, monitor and safeguard these structures (**OUTPUT PARAMETERS**).

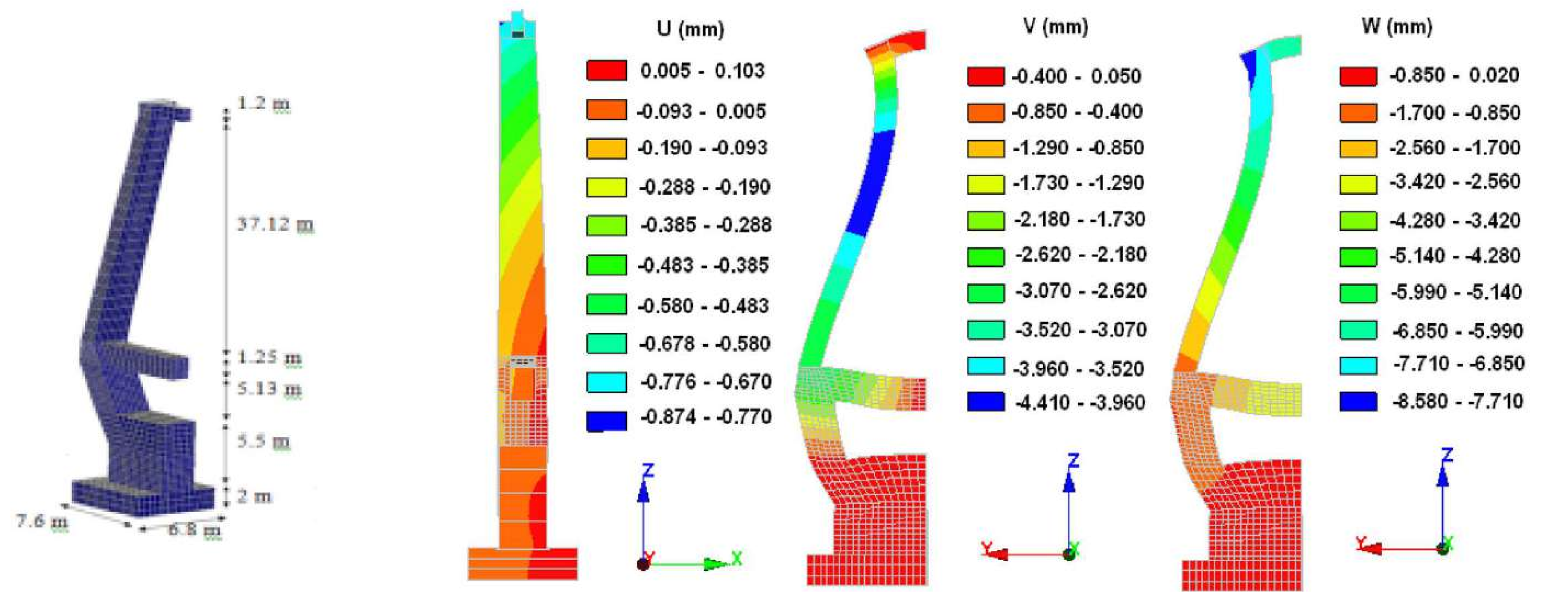

Figure 3: Pylon of a cable-stayed bridge affected by DEF.Numerical model mesh and results (displacement isovalues and deformed configuration).

This doctoral thesis aims to bridge the gap existing between academia and pressing industrial needs.

PH. D PROGRAM (APRIL 2019 → 2023)

- Modelling basic elements with simple geometry through the use of numerical models [Fig. 3] available in the literature, and then, in investigating their behaviour and interaction with internal and external cracks, progressively adding the typical behaviour complexities of reinforced concrete material.
- Modeling characteristic elements of standard infrastructure elements (e.g. deck composed of precast prestressed beams, massive abutments), then these models will be linked with the data provided by the diagnostics and observable data (façade crack detection, structural monitoring, mechanical tests, ...).

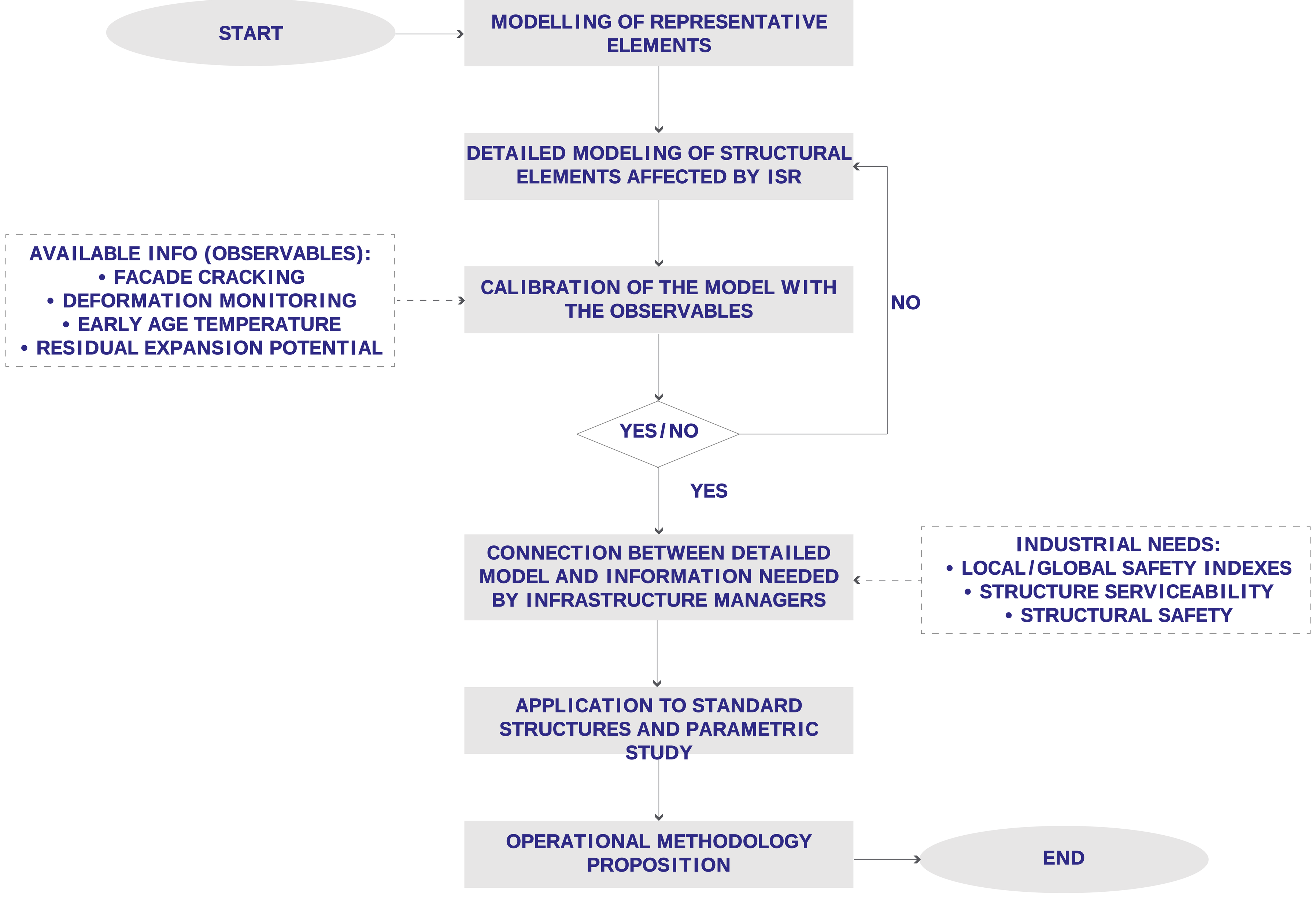

Figure 4: Flowchart Ph.D. Thesis.

- Methodology formulation and operational criteria proposition to reassess the ISR affected structures. Finally, development of a tool where the numerical processing phase will be hidden from the user giving more emphasis to providing valuable information such as present and future state of the structure, as well as expected efficiency of treatment methods (additional reinforcement, protection from moisture...) [Fig.4].