Automatic modelling of discrete cracking phenomena

In masonry structures

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POLYTECH.MONS

Since the civil authorities have understood the necessity to preserve the old building heritage to be transmitted to the next generations, important budgets are allocated to finance heavy restoration campaigns. Many historical buildings have been forgotten for decades and it is important to understand the behaviour of damaged buildings before that efficient solutions may be proposed for the future.

The engineers, by coupling powerful calculation methods with classical on-site investigations, can precise the structural behaviour of the building. We present here an application of such a method, the Finite Element Method, to study the rather complex configuration of the Magdalene church made of interactions between the superstructure and the undergrounds parts (soft soils …).

The church and its pathologies

The erection of Magdalene church in Tournai began during the 13th century. It is characterized by an architecture associated with the transition between romanic and gothic style. The church is recognized as “Historical Heritage” by the Belgian authorities.

Although some damages are not recent, the church seems to suffer new pathologies affecting some important structural parts (namely the main diaphragm arch) since its abandon in 1965. The structural problems led the civil authorities to install temporary strengthening devices.

From a local point of view, the observation of disorders shows that pathologies affect the main diaphragm arch (see Fig 2) as well as a set of 2 spans located in the middle part of eastern nave.

From a global point of view, sensitive settlements may be noticed. They affect essentially the external walls of the transept and the western bell tower. The altitude variations of a stone ribbon all around the church’s walls were taken using an optical level. That ribbon was supposed to have been built horizontally.

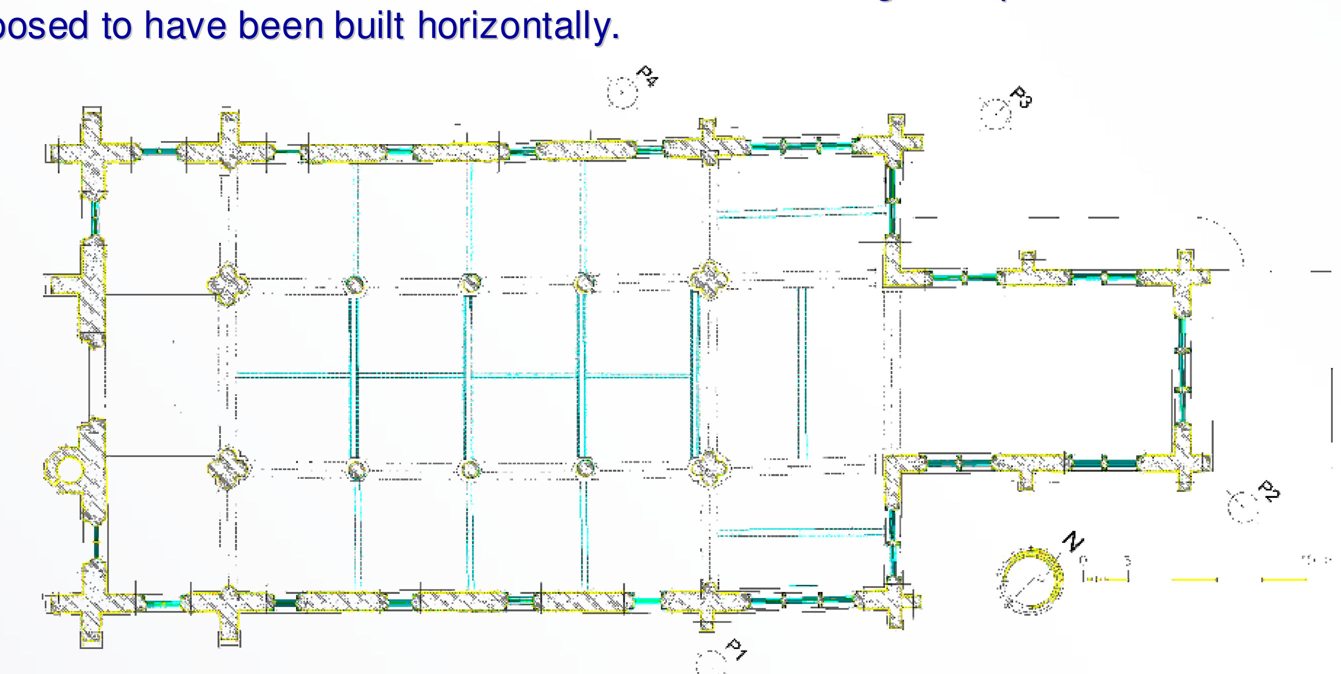

Fig 1 : The Magdalene church, plane view

A preliminary geotechnical campaign has been performed. Under the level of the masonry foundations, the quality of soils may be considered as very poor. This could be explained by the fact the church is located along the Escaut River. Nevertheless, the conclusions of the preliminary campaign are based on a limited number of tests that have been performed outside the church as illustrated in Figure 1 (P1, P2, P3 and P4).

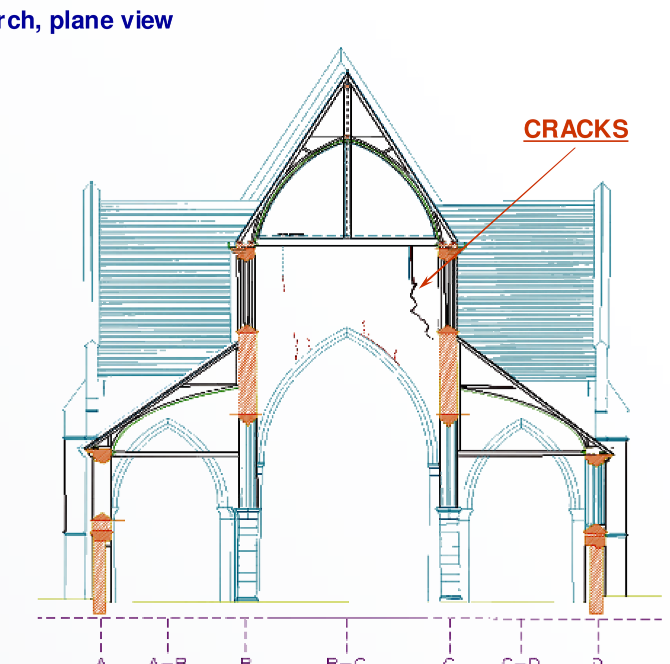

Fig 2 : The church’s main pathologies

Finite elements modelling of the mansonry building

The soil is modelled with springs that are connected between the estimated level of the bedrock (obtained from the preliminary geotechnical analysis) and the basis of the masonry structure. An iterative process for simulating the soil’s behaviour is performed until a correct trend equation between the settlements observed in the model and in the reality is achieved.

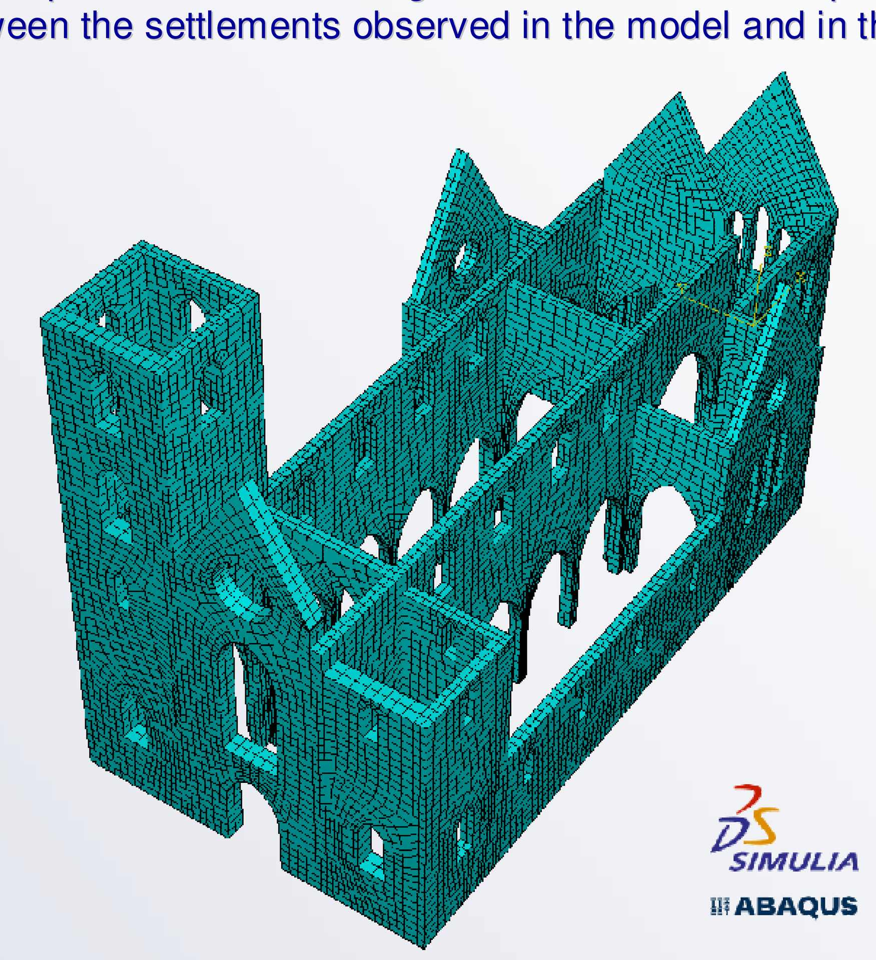

Fig 3 : Global model of the superstructure

In the model, it’s important to notice that, although geometrical simplifications were necessary, inertia and cross-section area properties were carefully respected.

The final model used for the computation (see Fig 3) is composed of three main parts :

1. Soft soil : the part under the bottom face of the foundation is modelled by springs made with 8 nodes bricks (compressive strength of the soil – no pressure bulb). The geometrical extension of springs is located directly under the width of external walls and internal pillars. The stiffness of the springs has been set on the basis of the collected settlement information.

2. Bedrock : the bedrock itself is not included but its particular effect has been taken into account through the length of the springs. The vertical translation of each node at the bottom face of the soft soil has been constrained.

3. Superstructure : a complete 3D model of the superstructure made with 8 nodes bricks has been used. The action of timber frameworks and roof structures has been taken into account through the introduction of equivalent local and distributed loads. The morphology was obtained from a precise topographical survey.

A tool for modelling discrete cracking phenoma

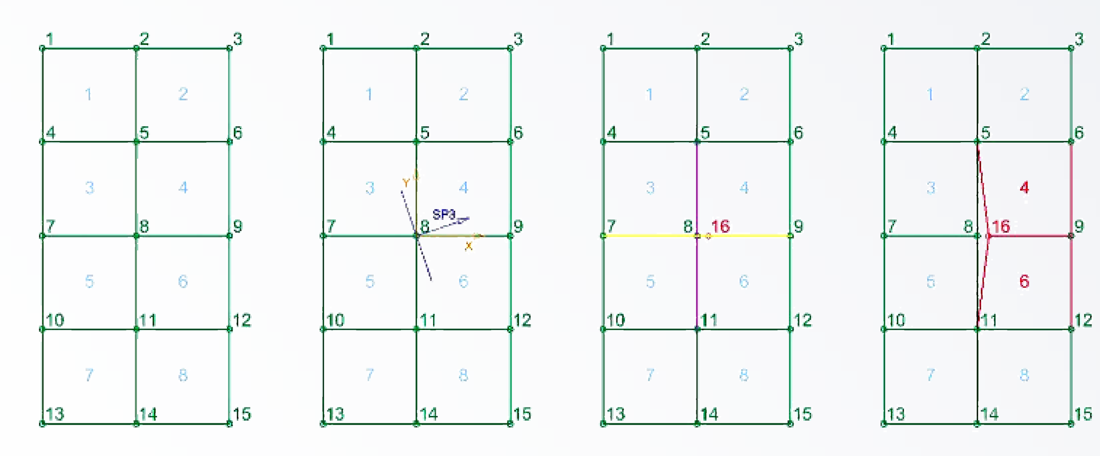

Fig 4 : Initiation of a crack through node duplication

Due to a lack of knowledge about the characteristics of the walls of the church (no test results were available), we decided to consider each material as homogenous and linear elastic. Of course this kind of behaviour is not very appropriate when applied to masonry structures and soils. Nevertheless, this kind of assumptions has already been used by recognized specialists.

Moreover, a crack propagation process has been implemented for the masonry model. This is an automatic, discrete and iterative process based on the value of the maximum principal stress : it is assumed that a crack appears in the most stressed zone if the tensile stress is greater than a given limit value (Rankine Criterion). Initiation of a crack is simulated locally by duplication of one node into two nodes in the model (see Fig 4). On the basis of this new geometry, a new calculation is performed and propagation of crack is simulated. This process continues until stabilization of the stress state is reached everywhere in the model.

The practical implementation is achieved through a coupling between Matlab and ABAQUS Software.

This software detects the node with the highest principal stress and calculates the orientation of the associated vector. This vector reflects the orientation of the real crack plane. As we only depend on the size and orientation of the mesh for the morphology of the crack, we have to determine the modelled crack plane closest to the real one. Then the program duplicates the node in order to create the discrete crack itself. Once those steps are done, a new source file is written (Matlab) and automatically submitted to the computing engine of the finite element software. This last, calculates the stress and displacement fields. The results obtained will be used for the next iteration.

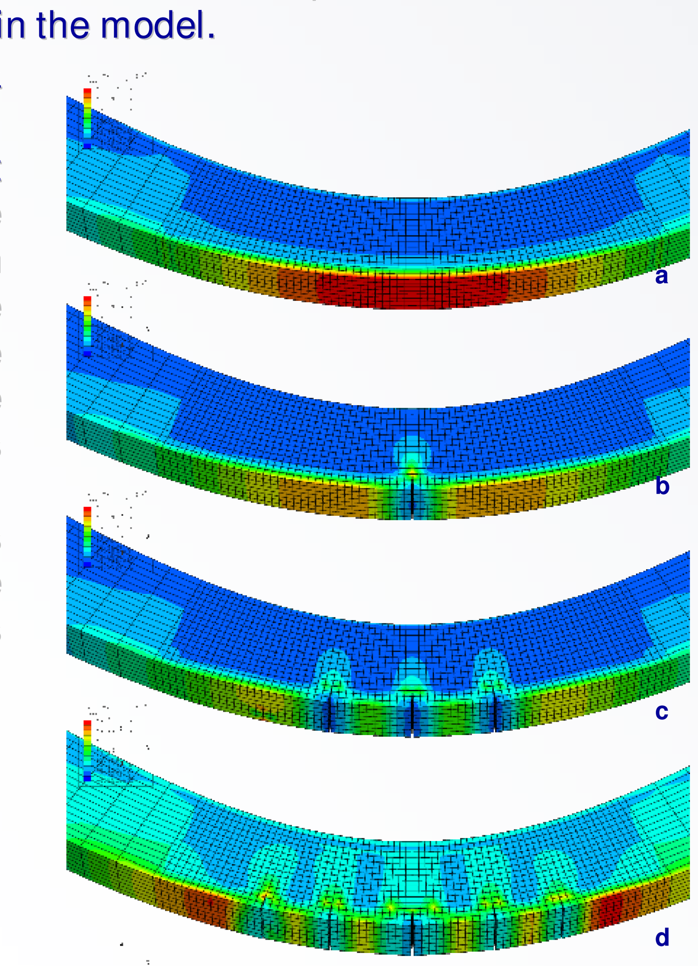

Fig 5 : Major steps in the crack propagation process in a test beam (a, b, c), final step (d), max principal stress

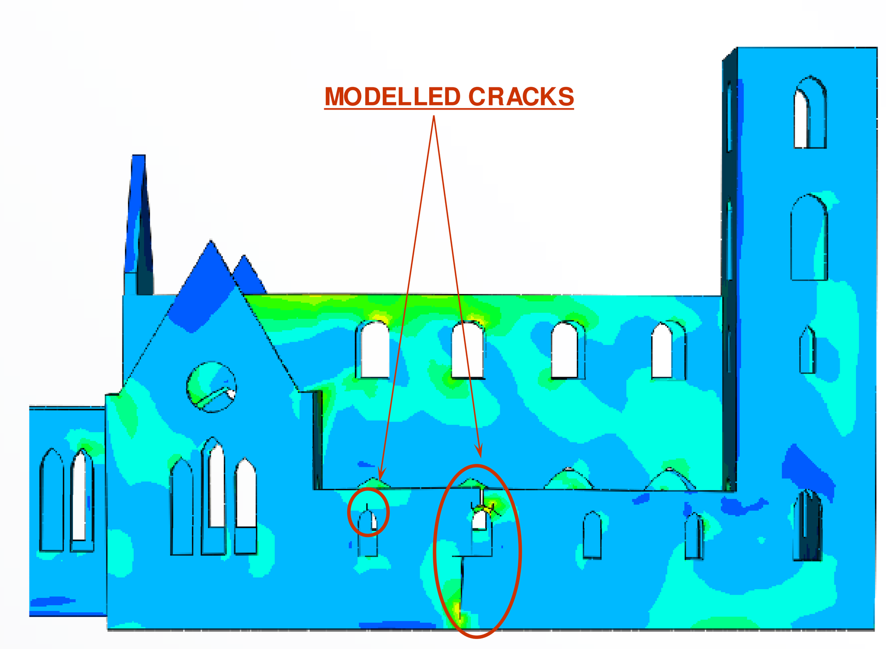

Fig 6 : Cracked model of the church, max principal stress

In order to validate the results provided by this coupling, we studied the propagation of cracks in a model of a beam composed with a material presenting high compressive strength and rather low tensile strength (see Fig 5). We could, then, compare the numeric results with the analytic calculus.

Conclusion

Although it is important to observe the stress state of a structure, it is even more interesting to get an overview of the behaviour of a construction suffering from cracks. The cracking tool presented here allows to take into account the stress redistributions in redundant systems.

Noël J. & Descamps T., *An automatic tool fot modelling discrete cracking phenomena in masonry structures : Case study on a belgian cultual building*, Journée de Mécanique des Structures JMS08, Hassan 1er University, Marocco, 2008

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