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SOME EXAMPLES OF REAL MASONRY STRUCTURES MODELING BY 3D-NSCD DISCRETE ELEMENT METHOD

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ABSTRACT

The aim of this paper is to provide answers to some questions of the archaeologists and leaders of cultural heritage agencies in charge of structures affected by structural problems and instabilities : Arles roman aqueduct, and Nîmes roman amphitheatre, both in the South of France.

The modeling is performed with NSCD discrete element method [1] [2]. The 3D geometric decomposition of the two structures is realistic and is obtained by a conversion from (dxf) CAO format to LMGC90 discrete element code which is dealing with the NSCD method [3].

A comparison with continuous modeling shows the unique possibilities of discrete modeling to account for observed failure phenomena on the real structures.

INTRODUCTION

A granular material is a collection of bodies, having their own specific physical properties and mechanical behaviors and interacting with each other according to various contact and friction laws. This paper presents an application of 3D NSCD (Non Smooth Contact Dynamics) method [1][2] due to the pioneering work of J.J. Moreau and M. Jean to the modeling of masonry structures.

NOMENCLATURE

3D masonry modeling, granular materials, contact, friction.

3D ARENES DE NIMES MODELING :

The “Arenes de Nîmes” is a roman amphitheater (cf. figures 1, and 2) in the South of France. Recently, this structure has been subjected to rehabilitation works. The real structure shows local degradation of some stones, in particular the plates of the annular exterior gallery, at the first floor (cf. figures 2 and 3). Based on the archaeological work of M. Fincker [4], a 3D

geometrical model of the complete amphitheatre was performed, reaching a precision level of +/-10 cm, on the general dimensions of the whole structure, and +/- 3 cm on individual blocks of the structure. To get an order of magnitude of the stresses involved in the structure, its finite element modeling was performed, considering only isotropic linear behavior of the material. This study revealed the presence of traction zones in the plates (figure 4, and 5).

Convinced that the modeling of this essentially discontinuous structure, made of large stone blocks, up to 6 meters long, and 60cm x 60 cm wide, with no mortar, was not realistic using a continuous model, we performed a complete discretization of the upper part of the structure, to analyse it using a discrete model, on the LMGC90 code. We based our analysis of the friction law on the results we obtained in the laboratory , considering a Mohr-Coulomb behaviour with no cohesion, and a friction coefficient of 0.8, between the blocks, and 0.9 between the rock foundation and the first row of building blocks.



Fig. 1 : Nîmes amphitheatre

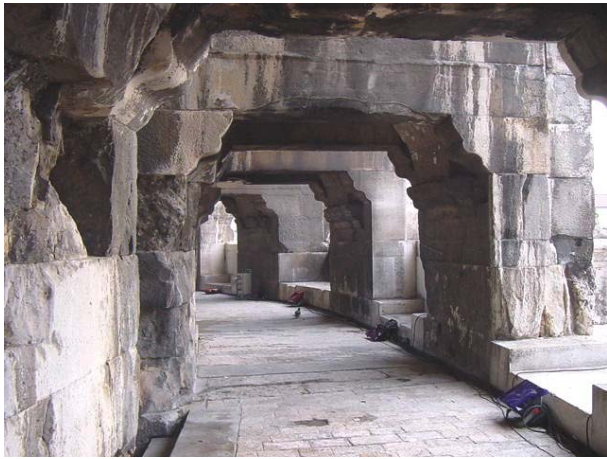


Fig. 2 : Detail of the exterior first floor gallery



Fig. 3 : 3D geometrical model

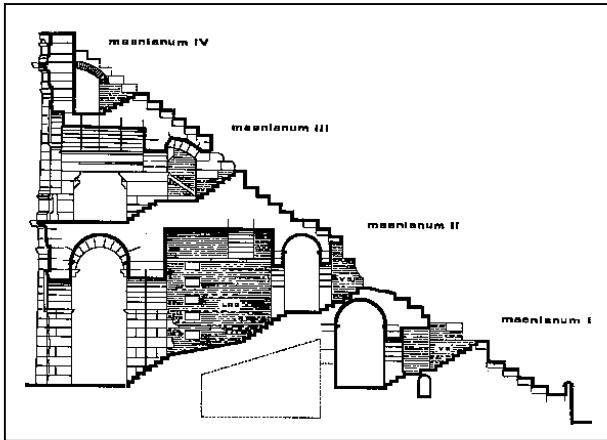


Fig. 4 : Archaeological data used to check the geometrical model (from [4])

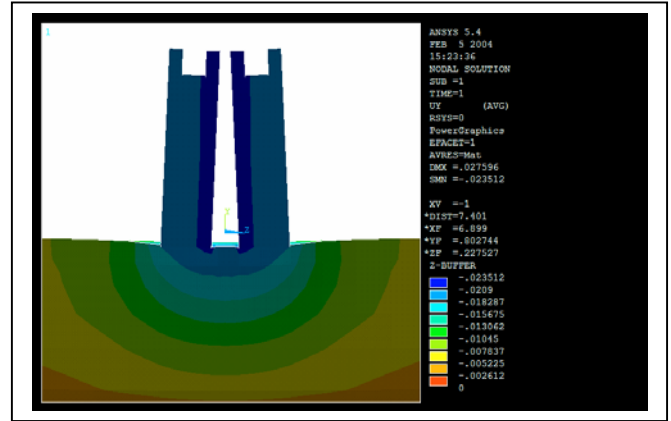


Fig 5 : Vertical displacement, with buttress

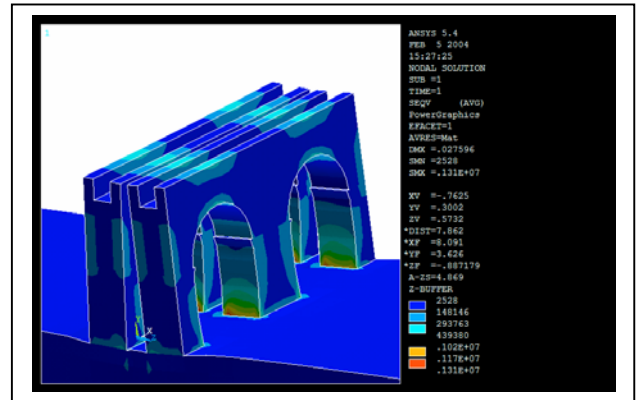


Fig 6 : Von Mises equivalent stress, without buttress

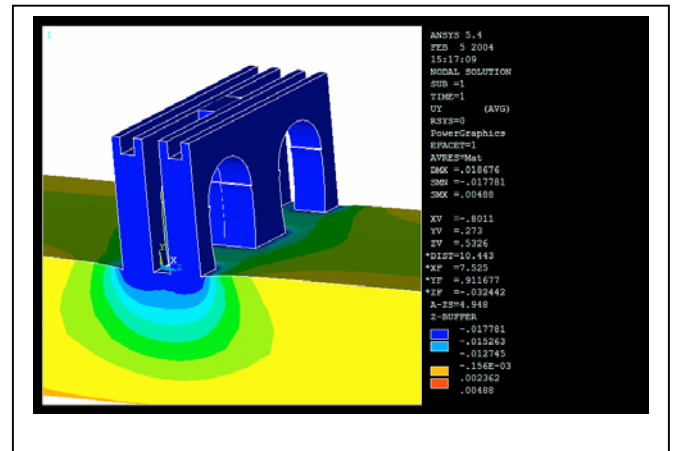


Fig 7 : Vertical displacement, with buttress

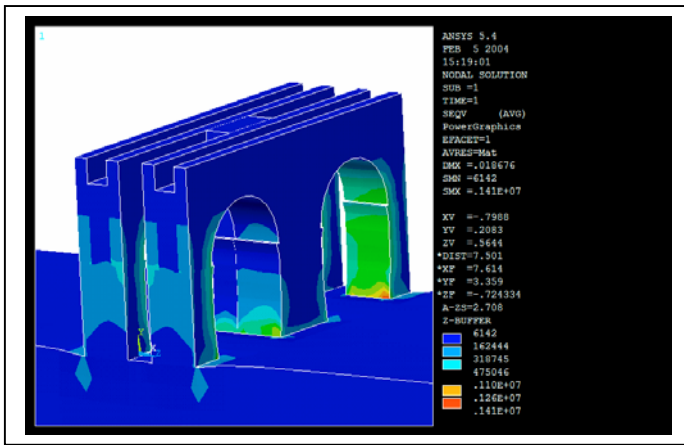


Fig 8 : Von Mises equivalent stress, with butress.

The aqueducts in the Vallon des Arcs on the territory of Fontvieille (10 miles East of the city of Arles) have been subject to several investigations over the last 20 years Ph. LEVEAU et al [5]. Among the different hypothesis formulated by the archaeologist, one was to consider the effect of the construction of the second aqueduct (carrying the water to the Barbegal mills) on the first aqueduct leading the water to Arles. A second hypothesis was the destruction of the aqueducts by an earthquake, indicated by the direction of failure of big sections of the structure toward the South East. It is admitted that the first Arles aqueduct was built using big blocks of stone, without lime mortar between the blocks, then the Barbegal aqueduct was built using smaller blocks and lime and brick mortar. The Arles aqueduct had thento be replaced on the same pilars by a construction made of small blocks of stones, using mortar, and using buttresses between the two aqueducts. A synthesis on these aspects is found in Thernot [6].

We decided to model the complete aqueducts using a finite element model., and studied the influence of the buttresses, and of the sequence of the construction. A modal analysis was performed on the whole structure i.e. the two complete aqueducts, and this analysis proved to be consistent with the localisation of the failures observed in situ, with the first calculated vibration modes. Then we isolated a section of the aqueducts, and made a comparison between the behaviour of a continuous model, and a discrete model, with the two geometries : with and without buttresses.

The mechanical properties of the stones are : density : 1820 kg/m³, Young modulus 16 Gpa, Poisson ratio : 0.24, for the elastic calculations under gravity. The soil characteristics are : Young modulus 50 MPa, Poisson ratio 0.25, density : 1650 kg/m³ . Other calculations were carried out using a Drucker-Prager criterion for the masonry, and an elasto-plastic behaviour of the soil. The results are being processed.

For the discrete model, a friction coefficient of 0.8 was assumed between the stones, and 0.9 between the foundation and the first layer of stones. The base of the foundation was submitted to horizontal periodic speed. The results obtained with the discrete model show a significant difference of behaviour between the two geometries (with and with-out buttresses).

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