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Numerical simulations of behaviour of medieval stone false vaults

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1 Introduction

Stone masonry is one of the oldest materials used worldwide. Many building constructions were built of dry stone masonry without the use of mortar, for instance medieval temples in Angkor, Cambodia. There are false vaults, especially as the roofs of corridors and galleries or the entrance gates of temples. False vaults are created by overlapping horizontal layers of sandstone blocks. These vaults were used in areas where the static behaviour of the arch was not known.

Research and modeling of masonry with mortar has already been sufficiently researched. For this reason, research teams have recently begun to model dry masonry. Structures built of dry masonry or where the mortar has weathered now behave the same, in Lorenço et al. (2005).

The motivation for modeling historical structures is the conservation of cultural heritage for the future generations.

2 Numerical models

The mathematical description of the behaviour of materials is based on the relationship between the stress and strain tensor at a material point. These constitutive models only simplify real structures. Micromodel was chosen for the construction of false vaults. All sandstone blocks are modeled separately and there are interfaces between them for dry masonry micromodels. The models are based on the dimensions and properties of materials obtained in situ.

Simplified, the used rock was specified as an isotropic, linear elastic material expressed in the following equation

$$\sigma_{ij} = E_{ijkl}\varepsilon_{kl}, \tag{1}$$

where $\sigma_{ij}, E_{ijkl}, \varepsilon_{kl}$ is the Cauchy stress tensor, the fourth-order stiffness tensor, the infinitesimal strain tensor, respectively. The values of the quantities were taken from Chandran et al. (2006). The friction (μ = 0,5) is considered by Mohr-Coulomb with the exclusion of tension in horizontal joints.

Young´s Modulus (GPa)	Poisson´s Ratio	Density (kg/m^3)
20	0,2	2300

Table 1: Average Material Properties of Sandstone in Angkor

Two false symmetrical vaults were modeled. The first (narrower) vault contains a top block ending in front of the pivot point and the second (wider) vault is with the top block ending behind the pivot point.

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A preliminary stability assessment was carried out using a moment condition

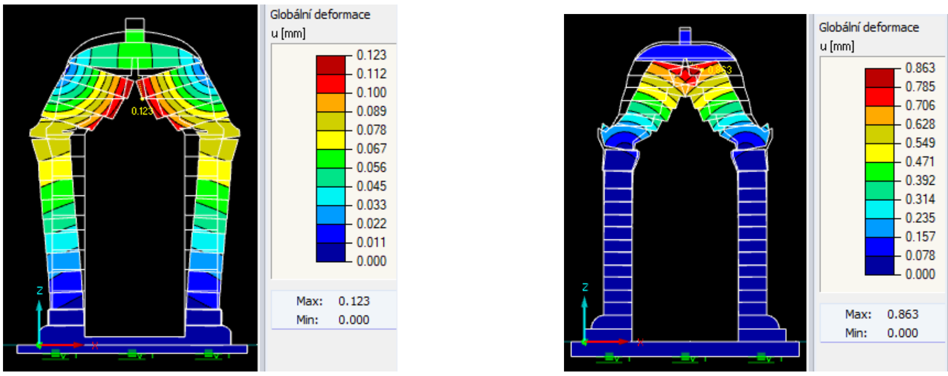
$$\sum F_i x_i \leq 0, \tag{2}$$

where F_i is the i-th force of the stone acting at the center of gravity and x_i is the distance of this force to the pivot point. A detailed assessment was carried out in the program RFEM Dlubal, which uses the finite element method.

3 Results and conclusion

When the inequality 2 is met, then, each of the halves of the symmetrical vault are stable. The result of the inequality 2 for the first vault is -3 634. The vault is stable due to the arrangement of the blocks. The blocks have small overlaps and each half of the vault itself does not cause a fall. Whereas the result of the second vault is +19 460. This vault is stable due to the existence of the top block and friction in the joints.

The behaviour of these vaults is shown in Fig. 1.



(a) The narrower vault

(b) The wider vault

Figure 1: Deformation of the vaults

However, the stability of vaults is affected by many other factors, which can be unstable subsoil, settlement of the structure, frequent temperature changes, wind load, surrounding vegetation, groundwater level, rotation in the foundation joint and structural defects.

The simplified approach is suitable for the preliminary assessment of the stability of undeformed constructions. A detailed analysis, including numerical simulations, is required for a comprehensive assessment.

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References

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