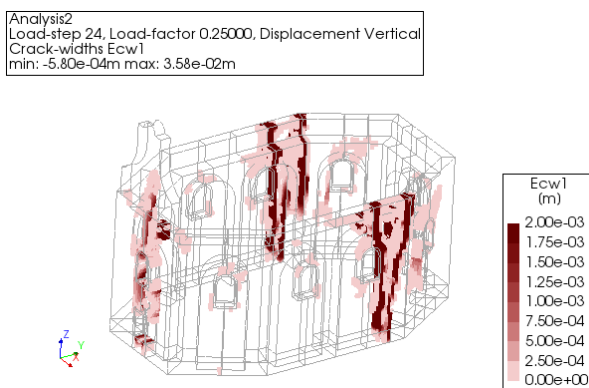


**Fig. 8.** Effect of soil deterioration of subsoil; in red zone was applied additional settlement 2.5 cm.



**Fig. 9.** Calculated cracks due to deterioration of foundations.

From the above figure the crack strain obtained in the structures can be found which occurred due to the increased differential settlements. Here it is interesting to notice that most of the crack strains that can be observed here were found to be in accordance of the damage observed on the site. This supports the considered hypothesis behind the occurrence of damages (due to differential settlements). More comments, scenarios of calculations and other details are in [6].

Non uniform settlement of the St. Barbara Church foundations was as the second example. For FEM modeling was chosen in this case software ATENA. For constitutive modeling was chosen similar nonlinear quasi-brittle constitutive model as in the previous case. Quite conservative parameters for numerical modelling are listed in Table 10.

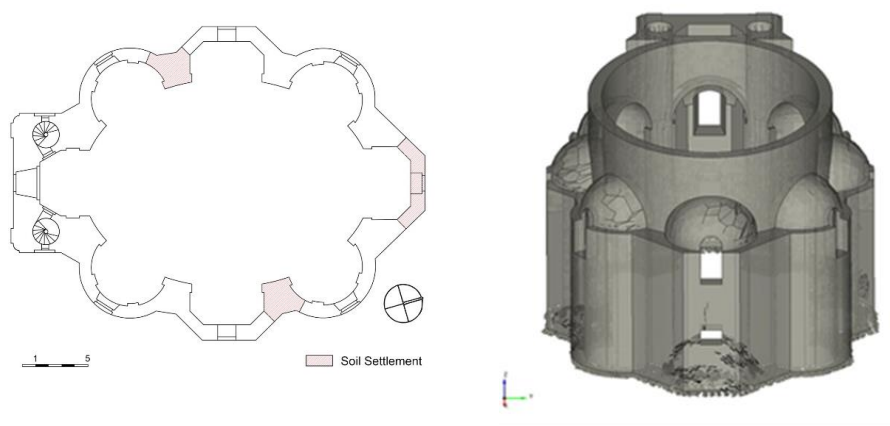
**Table 10.** Material properties for the numerical model (St. Barbara).

E (GPa)	$\nu$	$f_c$ (MPa)	$G_c$ (N/m)	$f_t$ (MPa)	$G_t$ (N/m)	P (kN/m <sup>3</sup> )
2.0	0.2	2.9	9100	0.2	70.0	20.0

Degree of damage can be classified as Negligible (width up 0.15 mm), Very slight (width around 1 mm), Slight (width up 5 mm) Moderate (width from 5 mm to 15 mm), Severe (width from 15 mm to 25 mm), Very severe (width more than 25 mm). To consider the effect of differential settlement in the numerical model, vertical displacements were added in areas showing signs of damage or detachment in the foundation stones that were



identified through visual inspection. The loads were then applied to the structure in two different intervals. In the first interval, the loads comprised of the self-weight and the dead load were applied to the structure, along with a spring stiffness of 26.36 MPa. This caused a uniform settlement of 18 mm. Additional settlement of 80 mm was applied in the highlighted region, see Fig. 10.



**Fig. 10.** Additional settlements and filtered crack width showing 15 mm (Severe) degree of damage.

Cracks of width larger than 15 mm corresponding to “Severe” degree of damage and expected to disrupt the functioning of the structure were filtered from the smaller cracks, Fig. 10. It was observed that at load step 80 which accords with 80 mm displacement showed a complete arch-like crack formation of thickness 15mm at the rear wall of the church. It is important to note here that, although this load can completely detach the section of the wall under the window, the failure is very local, therefore it is possible, that the superstructure would still prevent collapse. However, it is evident that the wall completely detaches itself from the superstructure and so, a differential settlement of 80 mm was taken as the failure criterion for the church. More interesting and complex information can be found in [8].

## 5 Concluding remarks

Large amount of analyses, smart numerical calculations and laboratory testings were done in the frame of SAHC Universities cooperation. So we have a lot of independent observations and opinions about the current state of the Broumov Group Churches. We are proud, that the SAHC program was awarded by the EU Prize for Cultural Heritage / Europa Nostra Awards 2017. The introduction of the work of SAHC group is seen in the short movie [20]. From the survey in site and consequent analysis it is seen, that significant role plays the date of realization, the locality, the bricklayer skills and the amount of money. The recommended values of the walls bearing capacities were validated and this can be compared in [21]. Generally, the bearing capacities of walls are considered as sufficient. But the poor drainage of rainwater caused the deterioration of foundations and consequently propagation of cracks due to non-uniform settlement. So in the future, it is necessary to pay attention to this phenomena.

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