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Stress Analysis in Masonry Arch Structures

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Summary:

Masonry arch structures are often encountered in old historical buildings as carrying elements for the vertical loading. Damage to these structures occurs due to the abutment settlement and their load carrying ability is very difficult to define in that stage. An acceptable computational model has to include cracking of the masonry units in direct tension, splitting of the units due to mortar dilatancy at high values of normal stress and sliding in contacts at low values of normal stress between masonry units. In this work we have tried to analyze range of the applicability of common numerical methods for analysis of these complex structures. The observed parameters were: model definition, mechanical constants of constitutive materials, changes in loading and changes in boundary conditions. Conclusions about various analysis methods, required assumptions, modifications, model sensitivity and suggestions for further study are outlined.

Keywords: masonry arch, analytical models, linear and nonlinear, load, displacements, stresses.

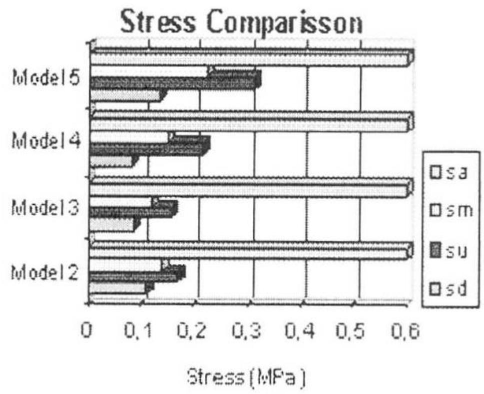
Analyzed models

There are several structural shapes common in the masonry arch systems: half circle, elliptical, oval and segment arch. The oval arch was selected for the studies presented in this work on the ground of the preliminary analysis and its frequent use.

Fig.1 Calculated stress distribution

In the work we have tried to check various analysis methods and their applicability for everyday use.
When the loading conditions are normal, such as increase in live load and limited vertical settlements, generally available mathematical and elastic numerical models give results of the same value. The results were not so sensitive to variations in the input parameters within one model.
Among the elastic FEM models the ones with plane shell FEM (shell elements) simulated the stress change within the cross section and were therefore closer to the real stress distribution.

Fig. 2 Comparison of calculated stresses at arch crown



The calculated stresses for Model 1 to 4 were of the same order and occurred at the same section. Between linear elastic and nonlinear models stresses occurred at the same place but their intensity varied for about 30%. Observed general trend was that as the model became more refined, stresses were growing bigger for the same loading. Sensitivity of the response results, within one model type,due to changes in input data in the range of customary values (number and size of FEM, variations in material characteristics) can be neglected.
Nonlinear model has shown far greater sensitivity. The model's sensitivity was in direct correlation with its complexity (which can partly explain the increase in the stresses in the same section and for the same loading for Model 5).

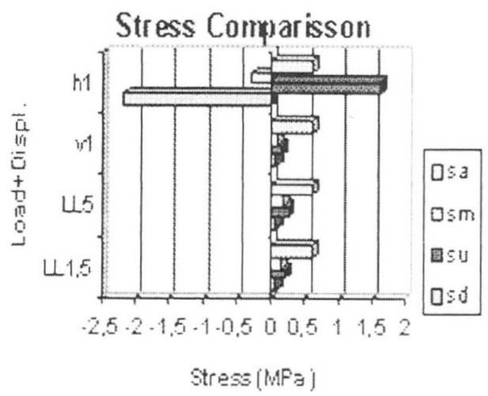


Fig 3. Comparison of the stress values caused by changes in live load (1,5 and 5 kN/m2) and abutment displacements (1cm)

Changes in live load do not endanger the system stability and present at the maximum 20% of the total load. Inherent carrying reserves are significant and for most live loads that occur in the buildings total stresses remain well under the allowable. The increase in live load for 300% has caused the increase in total stress for about 20%. They remained well under the allowed values. Massive arch structure is much more sensitive to the changes of boundary conditions.

Vertical abutment settlement of 1/300 can be still considered as tolerable and inside the elastic range, while the stresses did not change their sign and were under the allowed values. Stresses caused by horizontal displacement of 1cm are 26 times greater than the stresses caused by vertical settlement of the same abutment and for the same amount. By comparing the horizontal and vertical abutment settlements, horizontal settlements are very undesirable and should be prevented.

Nonlinear analysis which can include cracking of the masonry units in direct tension, splitting of the units due to mortar dilatancy at high values of normal stress and sliding in contacts at low values of normal stress between masonry units (such as Model 5) must be used. Reasonable insight in the true structural behavior by changes in the boundary conditions can be presented only through the nonlinear analysis. Linear analysis can give us only a hint of the structural behavior at that stage.

While the linear elastic models are relatively easy to use and give reliable results for standard material values, the present stage of the nonlinear modeling techniques requires a broad inside view in the material data, numerical methods and are not applicable for everyday use.