

# Analysis methods for the structural response of monuments and criteria for their selection

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## ABSTRACT

For the determination of action effects required for carrying out safety verifications before, and possibly after, the interventions to a monument, all analysis methods are in principle available for use, i.e. elastic (equivalent-) static or dynamic analysis with a global behaviour factor ( $q$ ), as well as inelastic static (pushover) or dynamic (response-history) analysis. However, it is not recommended (at the present stage of development) to use inelastic response-history analysis, due to the complexity of the structural systems of monuments and the limited experience available.

The following topics will be covered in this presentation:

General criteria for the selection of analysis method: For the *initial* selection, the aspects taken into account are the configuration and the dynamic characteristics of the monument's structural system, as well as its importance. A key criterion in selecting the *final* method of analysis is the ability of the method (and the associated model) to reproduce analytically the past response of the monument, in particular its damage pattern. As a rule, the most appropriate choice is the combination of methods and/or models, e.g. elastic analysis of the full model of the monument with inelastic analysis of selected parts of it (the most sensitive and/or important ones).

Principles of reliable modelling of the monument: The general requirements for setting up the analytical model will first be outlined, followed by a description, also with the aid of examples, the available modelling methods, i.e.:

- (Continuum) Finite elements (2D or, whenever deemed really necessary, 3D), possibly in combination with some bar elements.
- Equivalent frames, consisting of vertical elements (piers) and horizontal elements (lintels), interconnected through rigid zones.
- (Special) Macroelements, each intended for modelling a specific part of the monument
- Strut-and-tie systems
- Limit analysis, i.e. modelling of each critical part of the monument as a kinematic mechanism that is analysed using kinematic methods

Comparative evaluation – calibration of analysis methods for monuments: A number of case-studies will be presented, involving analysis of monumental structures with an unreinforced load-bearing masonry structural system, and with a timber-framed masonry system. Modelling will involve finite elements as well as equivalent frames, and pertinent comparisons both with test results and among the alternative models will be presented. Special emphasis will be given to the modelling of spandrels, whose strength and deformability is commonly underestimated in most studies.