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Abstract

Finite element modeling of existing masonry towers:
The "Asinelli Tower"

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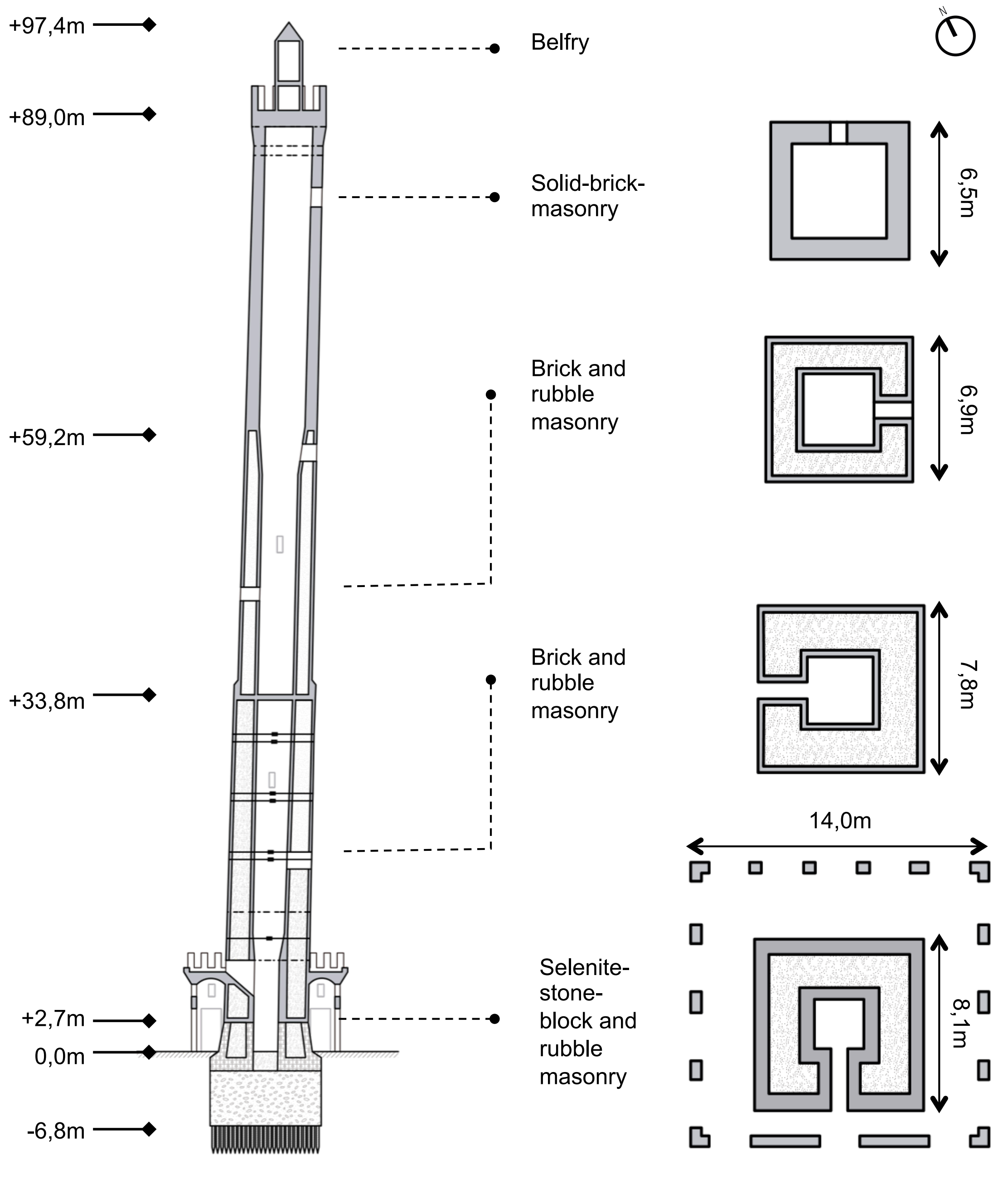
Recent technological developments in mechanical investigation techniques and non-destructive monitoring of masonry buildings provide today an amount of information, unthinkable up until yesterday. Likewise the techniques of automated laser survey allow a rapid and precise definition of the geometry of a building, with a level of detail never previously reached.

On the other hand, the applications to the modeling of complex masonry historical structures are not as widespread, and constitute an interesting subject of research. Despite the fact that numerical modeling techniques based on the finite element method have progressed considerably, and the computing power available is constantly growing. The difficulties that are encountered are manifold, and reside especially on the absence of well-consolidated procedures for the definition of the model and for the management of uncertainties.

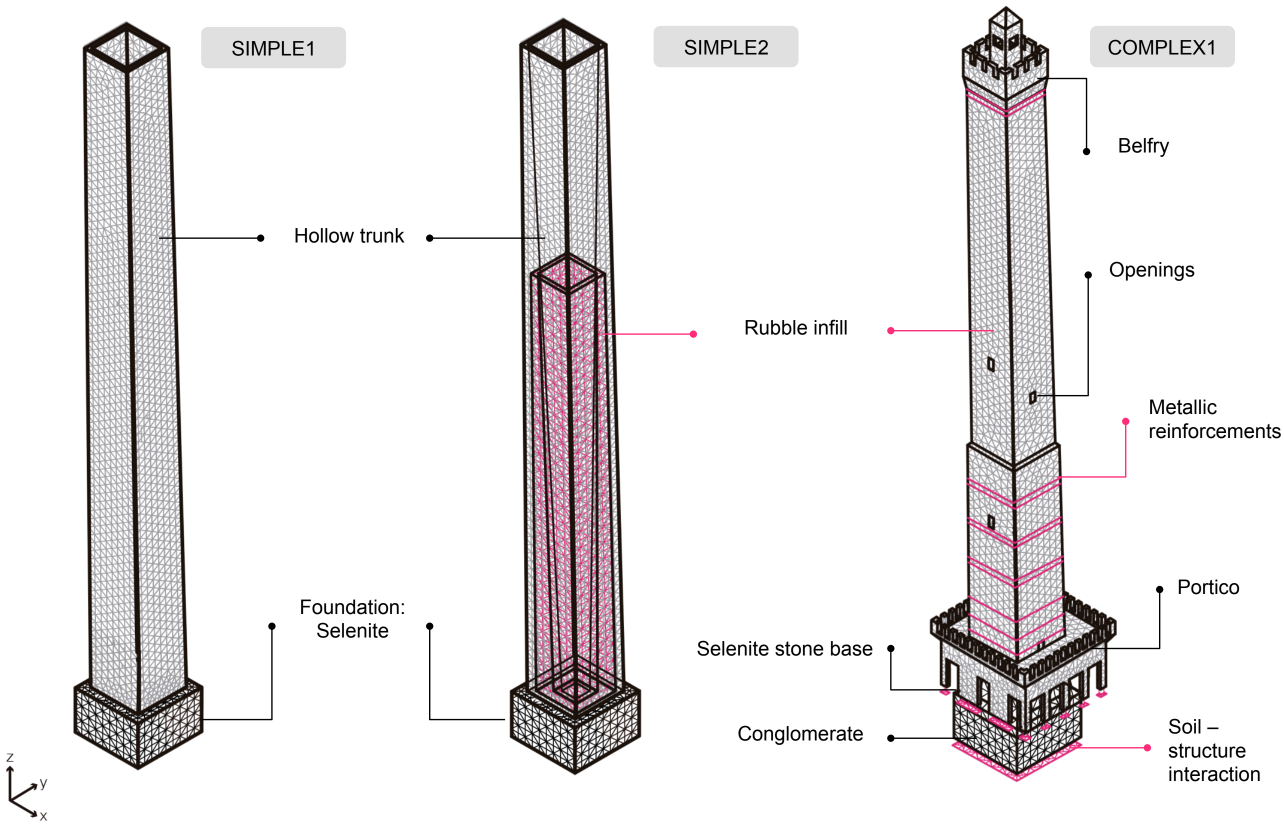
The Asinelli Tower in Bologna is taken as a case study to define a general methodology for the analysis of historical masonry towers.

The case study is found in the Bologna's city center. The Asinelli tower is the highest tower and oldest masonry structure in the city (from the year 1109). Besides, it is the highest leaning tower in Italy.
This construction represents a viewpoint from which it is possible to peer into every part of Bologna. Together with its adjoining tower (the Garisenda), it stands as the symbol of the city.

The Asinelli tower is a 98-meter high structure, with a foundation made of a conglomerate foundation base with wooden piles and a selenite block and rubble base, surrounded by a masonry portico. The is structure made of a brick and rubble masonry cross-section made of two brick-faced walls and a rubble core filled with mortar, bricks and stones; and a solid-brick-masonry wall cross-section. The tower has been reinforced over the last centuries, trough a series of steel cables developed in 1706 and 1913.



Using the finite element code DIANA (TNO Diana, Netherlands) the difficulties that are typically encountered in building models of increasing complexity are addressed, proposing a general procedure (Figure 3). These three models were chosen to assess the difference between the modeling procedure, the computational efficiency and the accuracy of the results.



Subsequently, the three models are subjected to a series of analyses.

The three models with isotropic materials are used for a linear static analysis and a modal analysis to obtain the linear static response and comparing the results with theoretical models previously developed and experimental measurements recently done.
The study of the tower, although not directed to the formulation of an explicit judgment on the structural stability, has led to the formulation of an anisotropic cracked masonry model, capable of representing the dynamic behavior of the tower with greater efficiency compared to what is available in the scientific literature. The anisotropic model of the brick and rubble masonry material is proposed for the Complex1 model to consider the damage present in the masonry due to vertical cracks.
Furthermore, sometimes the linear analysis cannot be representative of the structure's real behavior, and therefore it is necessary to perform a nonlinear analysis to obtain the ultimate limit state response. The european codes consider the implementation of nonlinear analysis for structures in which the residual strengt and stifness are influenced by the present damage, in this case, the historical constructions. Thereby, a modal pushover, which is a nonlinear static analysis that applies an acceleration, proportional to the first modal shape, is performed to obtain the capacity curve and cracking pattern for each model.

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