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Seismic and Wind Actions on the Asinelli Tower in Bologna

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Summary

The Asinelli Tower, built in 1081 in Bologna, considered an outstanding monument for its slenderness and height, shows a significant out of plumb in western direction. Its great historical importance and bold masonry structure are a source of worry for its stability in presence of most frequent ambient disturbances like wind or seismic events. The seismic actions and the longitudinal and transversal (the vortex shedding phenomenon) effects of the wind have been analysed using a finite three-dimensional elements model.

1. Historical notes and structural peculiarities

To understand the structural behaviour of Asinelli Tower, it's important to revue its history that is full of events like earthquakes, fires, lightning and wind gusts; this events caused a number of serious but not irreparable damages. The Tower was built in 1081 (date fixed through the thermoluminescent method) up to 60m of height; its was built mainly for defence and prestige just in the time of the contrasts between Papacy and the Sacred Roman Empire. In 1200 the Municipality increased the height of other 40m up to 97.2m of height. In 1398, after an earthquake and a following fire, consolidation and restoration works were realised. Some horizontal solid diaphragms and structural reinforcements, consisting in a masonry vault at the middle floor, in a rib-groined vault at the top floor and in a more solid basement, were added afterwards. The base portico with ornamental function and a restraining of the Tower's lower part through two horizontal circumferencial chains, were built about in 1480. The number of horizontal chains was increased by other nine, placed at several heights, in 1913. The structure presents a hollow square section that has a side dimension included between 8.7 and 6m. The vertical walls are made of sack masonry that has an external-facing wall in «selenite» masonry up to 3 m of height and in brick masonry up to 60m; the upper parts are made by full brick masonry. One of its peculiarities consists in a significant out of plumb (2.25 m in western direction) due to constructional defects. Surveys of the damage has shown a considerable fragility of the corners and some cracks in the East and the West sides up to 35m of height.

2. The mathematical models and the results of the studies

The structural behaviour has been analysed using a finite three-dimensional elements model (fig. 1 and 2a,b), taking into account wind and seismic actions according to the Italian Code and the EC1. First of all, the dead load analysis (fig. 2c), which shows as the out of plumb effect produces an unbalancing of compression tensions (until 1.7 N/mm^2), has been carried out.

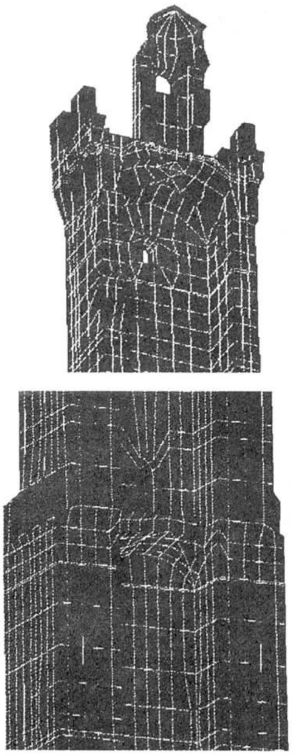
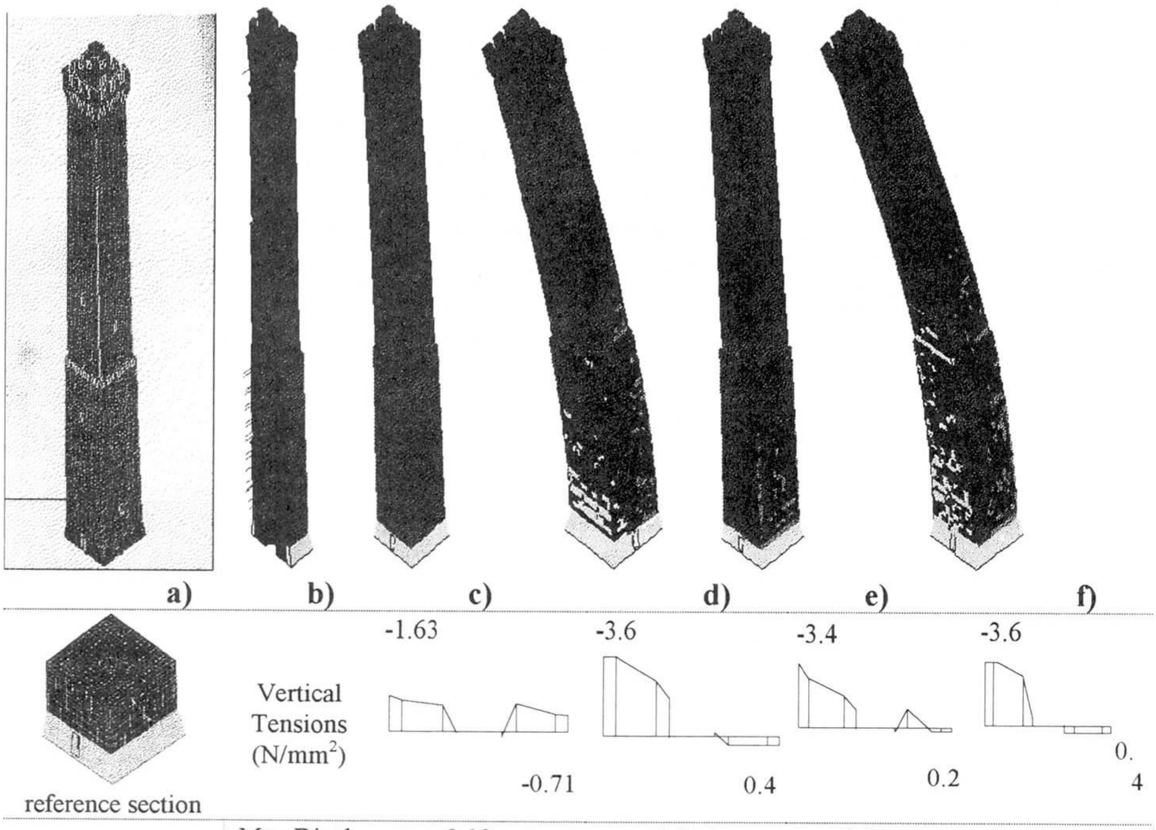


Figure 1

The dynamic behaviour of the structure has been defined through a modal analysis (T_1=3.68s), and then two kind of dynamic analyses have been carried out: a response spectrum analysis as regard the earthquake and time-history analyses concerning the longitudinal turbulent wind. Seismic actions have also been considered in the diagonal (S-W) and normal (W) direction, through linear and non-linear static equivalent analyses based on a 3D masonry failure domain (fig.2d). The results show that earthquakes only a little stronger than those expected by the Codes may seriously damage the tower and cause the collapse when the horizontal ground acceleration reaches 0.07g. Similarly it has been analysed the longitudinal and transversal effects of the wind, the last due to the vortex-shedding phenomenon. As regard the longitudinal turbulent wind (fig. 2e), the effects are much less dangerous than earthquakes and the structure remains substantially in the elastic field, preserving sufficient safety margins. On the contrary the vortex shedding phenomenon (fig. 2f), evaluated according to the EC1, seems to produce serious effects comparable with those of the expected earthquakes. Nevertheless the Code seems too much severe and not well defined in case of square section masonry towers; thus the vortex-shedding phenomenon probably doesn't generate an actual risk of collapse.



Max Displ.	0.10m	1.5m	0.25m	1.7m
	c) Dead load analysis	d) Earthquake long. dir.	e) Wind long. dir.	f) Vortex-shed. transv. dir.

Figure 2