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Repair and Strengthening of a Medieval Brickwork Bell Tower

Réparation et renforcement d'un clocher médiéval en maçonnerie

Reparatur und Bewehrung eines mittelalterlichen Glockenturmes aus Mauerwerk

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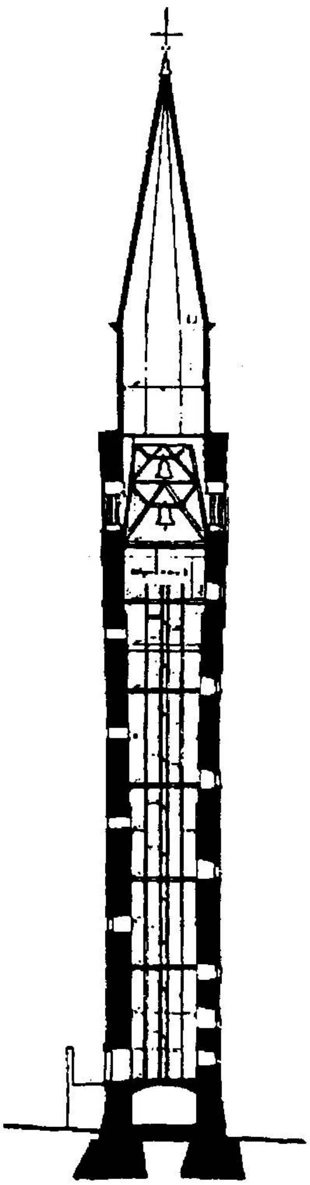


Figure 1

The described case study is the evaluation, repair and strengthening of the bell tower of the Cathedral of Pordenone, in Friuli, the Italy's region stricken by a strong earthquake in 1976. The structure, built during the last years of the 13th century, is 72 m high (Figure 1) and dominates with its imposing mass the historical center of the town.

The masonry walls are sufficiently strong and generally well constructed and preserved, and demonstrated to be tough enough to survive the earthquake.

Some major concerns about its actual safety level were however justified by the not negligible inclination (about 1%) and by evident traces of past heavy damages, often caused by lightnings, which were repaired between the end of the last century and the beginning of the present one.

The tower history and the repairs performed during the centuries have been found to be well documented.

In particular, pictures exist of the damages at the northern corner of the tower, which was near to collapse at the beginning of this century, and the inner part of such corner still presented damages and cracks in 1990.

The previous interventions appeared to be in general very efficient. Such are in particular the strong iron ties applied at five different levels and the reconstruction of the masonry in the outer part of the northern corner.

The preliminary investigations made in order to decide if new strengthening interventions were necessary were first of all based on the study of the existing documentation and on the accurate survey for detecting all the damages and cracks of the masonry walls.

Soil characteristics were investigated by spt tests and water table was monitored with piezometers.

The mechanical characteristics of the existing materials, masonry and iron ties, were then assessed by means of adequate in situ tests (flat-jacks for masonry).

Measures were also made of the dynamic response properties of the overall structure. Based on the obtained data FEM numerical models were constructed and used for analysing the structural behaviour of the whole structure and the relevant local states of stress in the masonry walls: in static conditions, during the bells motions and during the earthquake. The results showed the need of a strength improvement. Interventions were finally decided and executed aimed to improve the actual conditions of the structure without however substantial changes.

This was obtained first by reconstructing damaged masonry portions using traditional materials and techniques. In particular hand made solid clay units and mortars and injections made with hydrated lime mixed with "cocciopesto", which gives hydraulic properties to the admixtures, have been used.

Then, the inactive ties have been substituted and some new ties have been added. Finally, the confinement of the inner parts of the masonry walls have been substantially improved where an external confinement is already provided by the existing iron ties by means of five steel diaphragms in the positions indicated in Figure1. They are included in the system of the internal stairs as shown in Figure 2 a. Their principal characteristics are shown in Figure 2 b.

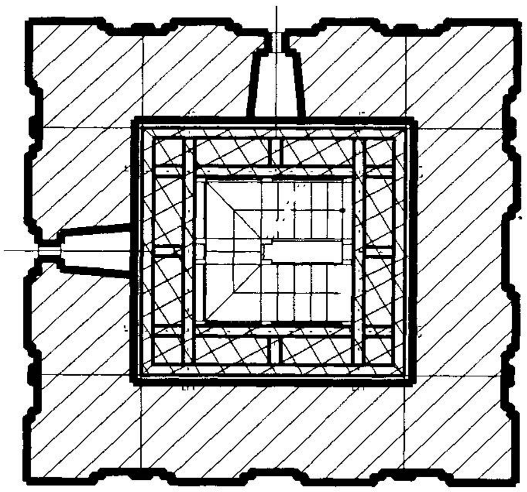


Figure 2 a: section of the tower at the level of one of the diaphragms.

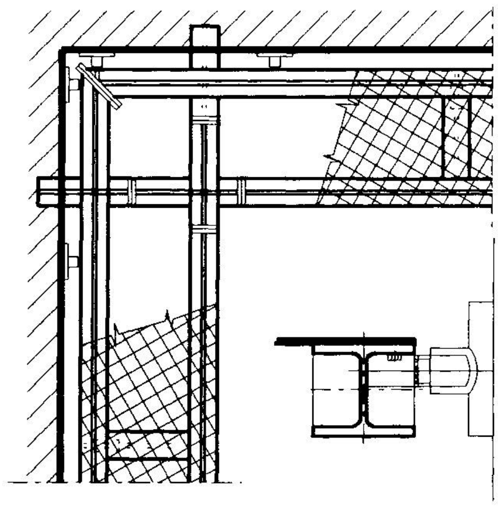
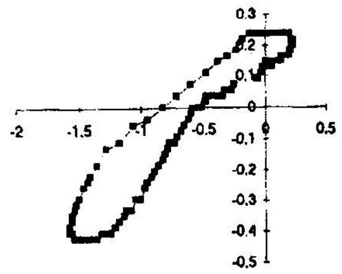


Figure 2 b: details of the steel diaphragms and of the devices used to put them in contact with the masonry walls.

The installation of the diaphragms inside the tower has been made possible by the use of several bolted joints. This construction technique allows the maintenance and, in case, the removal or substitution to be easily executed.



A monitoring system was finally installed to realise an automatic control of: tower inclination, cracks movements, temperature in the walls thickness, water table level and dynamic excitations.

In Figure 3 the daily variation of the tower inclination is shown, which is typically measured through the displacements of the pendulum, in sunny days.