be filled back again without disturbing the existing stress state and causing redistribution of stresses. If the replaced material is not compatible with the original material of the wall, additional problems may also arise, such as chemical reactions, salt exposure, and so on. The use of flat-jack testing on historical structures should be carefully decided, especially if the accuracy of stress and E measurements is highly questionable.

Closure to "Structural Monitoring and Integrity Assessment of Medieval Towers" by Alberto Carpinteri and Giuseppe Lacidogna

November 2006, Vol. 132, No. 11, pp. 1681–1690.
DOI: 10.1061/(ASCE)0733-9445(2006)132:11(1681)

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The main objection raised by the discusser concerns the fact that the role of analytical modeling in structural monitoring should have been completely disregarded in the paper under discussion. Actually, the issue was not disregarded, but only referred to in the paper (Carpinteri et al. 2005), which focused on reporting results from nondestructive testing and assessment.

In addition, the discusser proposes some considerations that are based on a numerical model. The conclusions that he achieves are not completely correct, since he bases his calculation on an oversimplified geometry. To give more precise results and to reply to the objections, some results of our numerical simulation are recalled in the following. For the sake of brevity, it is not possible to add the nonlinear simulation results (including cracking, evolving load scenarios and soil-structure interaction), which will be submitted to the journal in a separate paper.

The first point concerns the scatter in the vertical stress that cannot be described correctly by the simple model proposed by the discusser. The model presented in this closure is able to catch most of the variations in such parameters, which can be ascribed to the nonuniform geometry of the tower (presence of apertures, voids and so on). Only in one of the measurement points do we have a sensible discrepancy with respect to the calculated value (limited to about half of the measured value). We agree with the discusser that this can occur for many reasons (first, heterogeneity of the historical masonry and details of the geometry that were not taken into account, eventually also poor refinement of the mesh). Regarding the vertical stress in the walls of the towers, it is worth noting that the original paper presented only in situ flat-jack test results. The choice of the location for measurements was dictated not only by engineering considerations but also by practical characteristics of the site.

The second main objection concerns the scatter in the measured Young's modulus. In our opinion, this scatter occurred because of the masonry heterogeneities in the *a sacco* walls. A unique value of the Young's modulus obtained, e.g., from nondestructive vibration tests, could be interpreted only as a mean value. Instead, performing several localized flat-jack tests gave us not only a meaningful value of the mean stiffness but also a valuable estimate of the scatter. The choice of the flat-jack technique is obviously far from the only possible one in each case. However, it was considered the most convenient in the proposed case study, since a proper procedure of application is provided. The closure is finally improved with nonlinear FEM results obtained by considering the most likely damage evolution scenario for the two towers.

Some Results on Numerical Modeling of Masonry Towers

Complete three-dimensional FEM models of the towers have been built by using 20-node isoparametric solid brick elements, to perform the analysis with the commercial code DIANA. At least five nodes are present in the thickness of the towers' wall. The models take into account the presence of openings and the variation of the wall thickness at different levels. However, the pres-

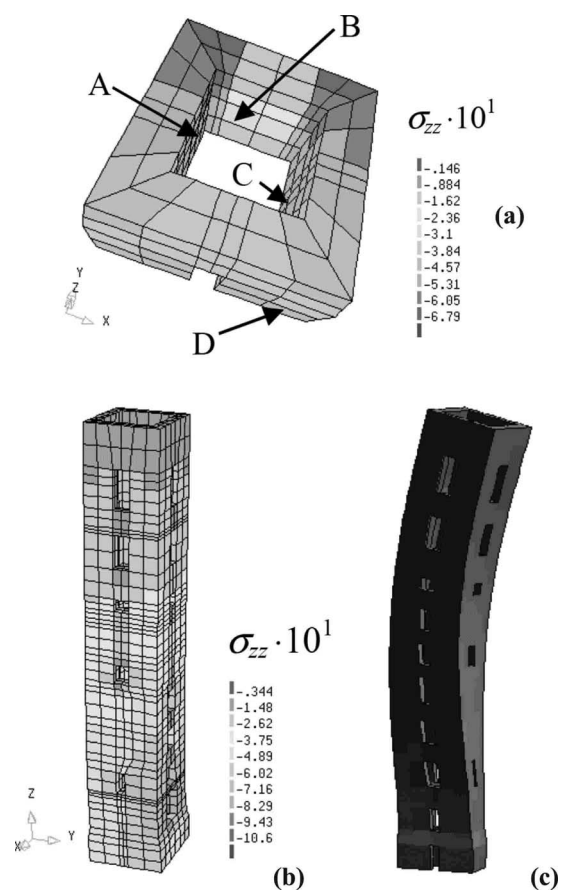

Fig. 1. (a) Mesh of the Torre Sineo model and contour plot of the vertical stress field [N/mm^2]; (b) details of the ground floor wall where the vertical stress field [N/mm^2] has been calculated and measured in situ; and (c) first torsional modal shape related to the fourth natural frequency

ence of wood floors has been disregarded. Each structure is mainly subjected to its dead load. As far as Torre Sineo is concerned, the effect of an increasing tilt of the foundation has also been considered, combined with the load provided by the wind action exerted on the upper region of the tower. The main mechanical parameters of the models have been directly determined by single and double flat-jack tests, and are summarized as follows: Young's modulus E equal to 5000 N/mm^2; Poisson ratio υ equal to 0.2; density of the masonry equal to 1600 kg/m^3; density of the stone at the ground level equal to 2400 kg/m^3. Further details of the experimental procedure can be found in (Carpinteri et al. 2006). The vertical stress in the whole Torre Sineo structure is depicted in Fig. 1(b). In Fig. 1(a), however, only the foundation wall is shown. The predicted vertical stresses are in good agreement with experimental flat-jack results. Point B, which is located beneath a large opening in the upper floor, is lightly loaded, with a stress of about 0.3 N/mm^2 (versus measured 0.297 N/mm^2). On the other side, point C is much more loaded, with a stress greater than 0.7 N/mm^2 (versus measured 1.059 N/mm^2). Point D, placed on the external wall opposite the tilt of the tower, presents a vertical stress of about 0.5 N/mm^2 (versus a measured one of 0.502 N/mm^2).

The very high stress measured at point A, equal to 2.4 N/mm^2, is not predicted by the numerical analysis, but it is likely to be ascribed to a local heterogeneity of the masonry wall and to the corresponding stress concentration. Discrepancies between calculated and measured local quantity in historic structures should warn scientists about the degree of unavoidable uncertainties when they are dealing with structural assessment. A good overall agreement between the calculated and measured stresses is also obtained for Torre Astesiano. The analysis reveals that the structures are in elastic conditions, since the level of stresses is everywhere smaller than the intrinsic strength. Such a consideration is still valid when the effect of the wind load is considered. The linear investigation was extended to a modal analysis, to give a first estimate of the dynamic response of the structure. In most cases, the first two or three modal deformations are basically connected with bending in the two orthogonal directions. An example of the first torsional shape of Torre Sineo (linked to the fourth natural frequency) is shown in Fig. 1(c).

Acknowledgments

The financial support provided by the European Union to the Leonardo da Vinci ILTOF Project (Innovative Learning and Training on Fracture) is gratefully acknowledged.

Notation

The following symbols are used in this closure:

A, B, C, D = measurement points;
ν = Poisson ratio; and
E = Young's modulus.

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