LONG-TERM DAMAGE ON MASONRY TOWERS CASE STUDIES AND INTERVENTION STRATEGIES

M.R. Valluzzi, F. Casarin, E. Garbin, F. da Porto and C. Modena
Department of Structural and Transportation Engineering, University of Padova, Italy

ABSTRACT

Long-term damage typically occurs in historic masonry towers, and probably was the main reason why a very small sample survived of the huge stock of towers that characterised the skyline of the medieval towns. Interventions are documented during the last few centuries to prevent incipient collapses, and the most drastic remedy was the preventive demolition of upper parts of unsafe towers; nevertheless, sudden collapses were still recorded in recent years, not only in the most famous case of the Pavia Cathedral Bell Tower. The lack of reliable tools to forecast how visible damages will develop into collapses makes the threat to survival of monuments and public safety very insidious, forcing the adoption of any possible preventive measure, comprising monitoring and strengthening. The problem is illustrated through two case studies that well represent the general aspect of the problem.

1 INTRODUCTION

Historic massive structures suffer during their life a typical damage caused by overstress conditions due to high dead loads (Binda et al. [1]). The phenomenon (masonry creep) (Lecnzner [3]) reveals itself by the presence of very diffused thin cracks which can lead to sudden and unexpected collapses, even for compressive stresses of 50 to 70 % of the experimentally measured strength (Binda et al. [2]). Several experimental studies performed in the last decade by the Polytechnic of Milan (Binda et al. [2], [4]) contributed to clarify the phenomenon in order to adopt preventive measures, ranging from monitoring to repair and strengthening. Many structures, mainly masonry towers and large pillars of churches, are therefore under observation in order to preserve them from collapse, and several experimental works allowed to set up and calibrate specific solutions (bed joint reinforcement technique) to counteract the phenomenon and its effects (Binda et al. [5], [6]).

In hazardous conditions damage can involve the structure at different levels, therefore different intervention techniques can be adopted: (i) injection to reduce the stress concentration, (ii) insertion of tensile resistance material into the bed mortar joints (bed joint reinforcement) to improve the material toughness, (iii) partial rebuilding ("scuci-cuci") to replace the most damaged resistant parts. There are evident proof that the last "traditional" technique("scuci-cuci") has been extensively used in the past as an efficient alternative to the demolition of the upper part of the construction to reduce overstress, which is also cited in documents. Those techniques act locally on the improving the mechanical behaviour of the material for the rehabilitation of the proper load bearing capacity of the structure. In the following, two representative case studies of towers of masonry churches in Italy are described.

2 CASES STUDY

2.1. St. Giustina bell tower in Padova

The bell tower of St. Giustina Basilica in Padua is a three-leaf masonry structure 70 m tall, built during the XIII century up to 40 m and raised up to the current height in the XVII century. This event was responsible for the overloading conditions of the lowest, and poorer, part of the structure, characterized by a serious crack pattern, mainly concentrated at the corners (Figure 1a). Moreover, external walls with a thickness of one brick, hiding the column stripes that decorated the external faces of the bell-tower walls, were lately added to the building without a good connection to the older masonry. This caused the opening of deep vertical "natural" joints (Figure 2). Some spalling in the internal bricks of the bell-tower bricks was also noticed, possibly due to a worst quality of the structural elements used on the inside.

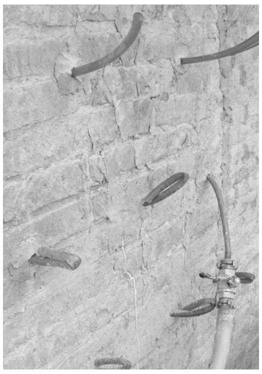
 a)  b)  c)

Figure 1: St. Giustina bell-tower. a) presence of diffuse cracking on the South-East corner; application of injections (a) and phases of insertion of reinforcement (b) and of mortar refilling (c).

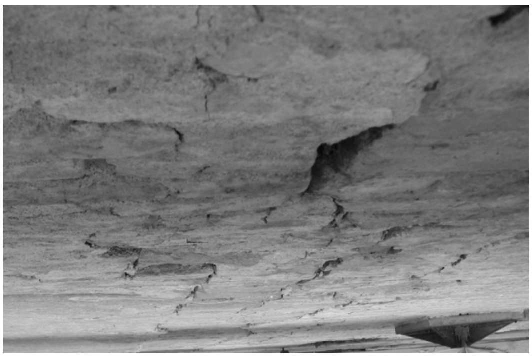
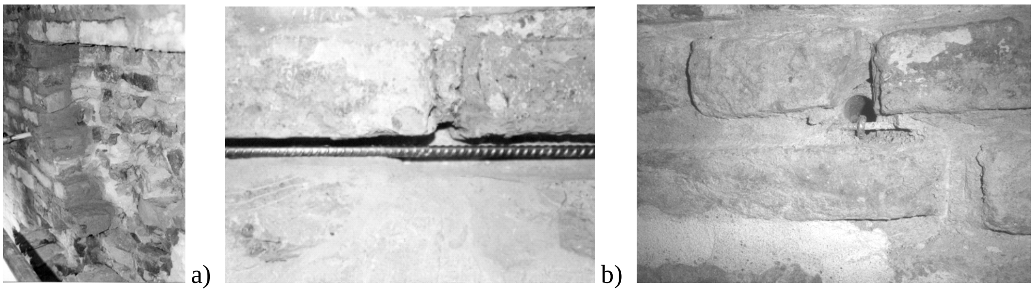
 a)  b)

Figure 2: St. Giustina bell-tower. a) "natural" joint declaring the presence of the late brick wall adjoined; b) cracking and spalling of brick elements.

There are signs of rebuilding of at least one whole corner performed in the past (also other similar interventions are visible in other towers still standing) which evidence the effectiveness of that solution in preserving the structure from collapse. The case under consideration is the demonstration of why this solution works, notwithstanding the fact that during the operation the local overstress is substantially increase. The damage in fact involves basically in its first phase the external leaf, where masonry is stiffer, and due to availability of a large resisting area on the usual thick sections (which allowed to execute the intervention on safety conditions), the structure is able to "accept" during time a stress re-distribution both for damage and rebuilding operations.
In the most deteriorated portions (corner and basement) diffused intervention of injections (Figure 1), partial rebuilding and bed reinforcement technique (Binda et al. [5]) have been executed

(Figure 3).



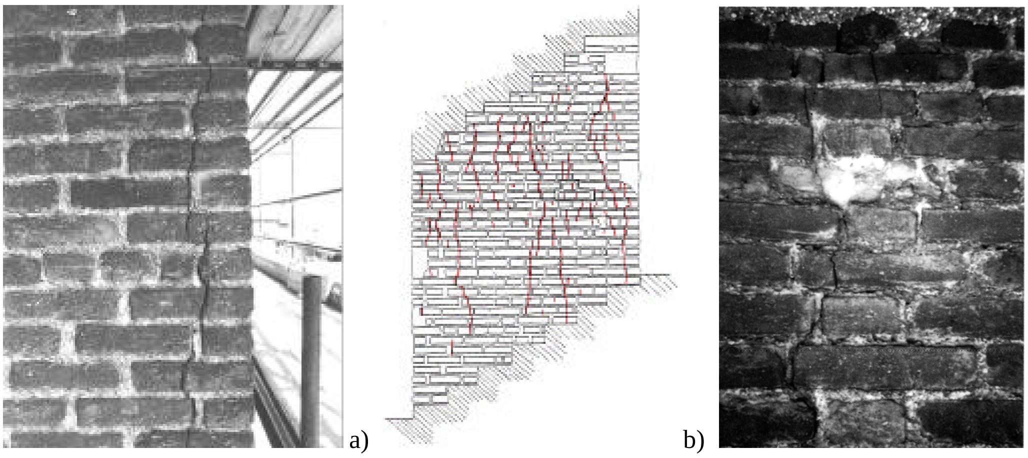
a) b) c)

Figure 3: St. Giustina bell-tower. a) partial rebuilding ("scuci-cuci") of the most deteriorated portions; b) c) phases of the bed joint reinforcement technique: insertion of bar and mortar refilling (before injecting the pin hole).

Local rebuilding ("scuci-cuci") was, for such reasons, extensively used during the works that are being done to improve the safety conditions of the tower, especially in the lower, less visible parts of the construction, combined with injections, that contribute by reducing stress concentrations. In the more visible parts steel injections are combined with the introduction of small diameter bars into the bed joints.

2.2. St. Giovanni Battista bell tower in Monza (Milan)

It is the bell tower of the Cathedral of Monza, a XVI century building made of solid brick masonry walls, which show passing-through large vertical potentially dangerous cracks on some particularly weak portions of the West and East sides (Modena et al. [7]). They are slowly but continuously opening as given by a monitoring roughly active since 1927. Wide cracks are also present in the corners of the tower up top 30 m (Figure 4a). Furthermore, a damaged zone at a height of 11 to 25 m with a multitude of very thin and diffused vertical cracks is present (Figure 4b,c).



a) b) c)

Figure 3: St. Giovanni Battista bell-tower. a) detachment of the corner; b) c) thin cracks on the wall (Binda et al. [6], [7]).

Design of intervention was mainly aimed in providing an overall confining action of masonry walls, limiting the dilation of the material. In the specific case, due to the large diffusion of the crack pattern (11x9.5 m) and to its extension in the wall depth (45 cm over 140 cm), to reconstruct a wall or the use of floor tie roads in order to reduce the lateral deformation of the structure was inapplicable. Therefore, repair and retrofitting of masonry was extensively performed by grout injection, to re-establish homogeneity, uniformity of strength and continuity of masonry walls, and by bed joint reinforcement technique by insertion into a groove (6 to 8 cm deep) of one or two small diameter reinforcing bars connected to the inner leaf by transversal short pins. Both excavated joints and drilled holes for pins insertion are successively sealed by mortar and grout, respectively.

3 CONCLUSIONS

The control of time-dependant behavior of masonry towers is a urgent problem to face in order to preserve the last examples which still resists in our heritage and, at the same time, to improve the safety of historic centres, where those structures stands, often in hazardous conditions.

The two cases study here presented are representative of the most typical situations of damage detectable: cracking concentrated on the external layers (often at the corners) or diffused in large portions of walls.

Rebuilding in the damaged portions demonstrated its validity also in the past, as it is able to improve the material properties; nevertheless, the intervention is often required for large zones to be effective, therefore it is characterized by a high degree of obtrusiveness. The bed joints reinforcement technique is now in interest for their specificity in counteracting the creep damage. First applications have concerned the use of stainless steel small diameter bars and further experimental works are focused on the advantages connected to FRP bars and thin strips. Researches are in progress in collaboration between the university of Padova and the Polytechnic of Milan.

REFERENCES

[1] Binda, L., Anzani, A., Gioda, G.: "An analysis of the time-dependent behaviour of masonry walls". 9th International Brick/Block Masonry Conference, Berlin, vol. 2, pp. 1058-1067, 1991.

[2] Binda, L., Gatti, G., Mangano, G., Poggi, C., Sacchi Landriani, G.: The collapse of the Civic Tower of Pavia: a survey of the materials and structure. Masonry International, vol. 6, n.1, pp. 11-20, 1992.

[3] Lenczner, D.: "Design of creep mechanism for brickwork". Proceedings of the British Masonry Society, n. 4, pp. 1-8, 1965.

[4] Binda, L., Anzani, A. & Mirabella Roberti, G.: "The failure of ancient Towers: problems for their safety assessment", Int. Conf. on "Composite Construction - Conventional and Innovative", Zurich, 699-704, 1997.

[5] Binda L., Modena C., Valluzzi M.R., Zago R.: "Mechanical effects of bed joint steel reinforcement in historic brick masonry structures", Structural Faults + Repair – 99, 8th International Conference and Exhibition, London, England, 11 pp. (on CD-ROM), 1999.

[6] Binda L., Modena C., Saisi A., Tongini Folli R., Valluzzi M.R. "Bed joints structural repointing of historic masonry structures", 9th Canadian Masonry Symposium 'Spanning the centuries', Fredericton, New Brunswick, Canada, 12 pp. (on CD-ROM), 2001.

[7] Modena C., Valluzzi M.R., T. Folli R., Binda L.: "Design choices and intervention techniques for repairing and strengthening of the Monza cathedral bell-tower", Construction and Building Materials, Special Issue, 16(7), Elsevier Science Ltd., pp. 385-395, 2002.