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RESTAURO MONUMENTALE E ARCHITETTONICO
CONSOLIDAMENTO STRUTTURALE

## FOLIGNO (Pg)

# ST. FELICIANO CATHEDRAL

REINFORCEMENT RESTORATION
AND CONSERVATION

## HISTORY

St. Feliciano cathedral is the most important monument in Foligno. It was built to commemorate the Saint Bishop, who died as a martyr in the 3rd century. At the beginning it was the mortuary chapel where the Saint wanted to be buried. The basilica was built in successive stages on this tomb and in 1100 was already a larger church with a nave and two aisles, a raised presbytery and the crypt underneath. The minor façade dates back to the first half of the 12th century, while the one on Piazza Grande was built as Bishop Anselmo desired between the end of the century and the beginning of the next one. Between the end of the 15th century and the beginning of the 16th century the interior of the church, with the form of a Latin cross, was shaped according to Renaissance tastes by different architects who designed also the dome. Between the end of the 18th century and the beginning of the 19th century architect Giuseppe Piermarini from Foligno made the third big rebuilding of the interior. Based on Vanvitelli's designs the cathedral assumed the magnificent and austere neoclassic look that restoration has perfectly revived.

## STRUCTURAL DAMAGES AND DESIGN DIRECTIVES

Most of the damages at the time of the intervention concerned the structural elements of the cathedral; deep cracks on the extrados of the vaults, while the facade had undergone a detachment which had led to the horizontal 8 cm displacement at the height of the roof vaults. The earthquake caused also a dangerous torsion of the bell tower that made the spire fall onto the roof of the Cathedral, resulting in heavy damages to the two bell cells. The Dome also needed reinforcement against tensile strength highlighted by an analysis of the finite elements which had put in evidence its structural limits.

The settecentist cornices, built with an inclination of the bricks to limitate the effect of mutual contrast of an arch, bent during the earthquake and shifted relatively.

The need to solve these problems, respecting basic criteria such as efficacy, durability, reversibility and above all compatibility with existing materials, made it necessary to use both traditional intervention procedures and innovative materials and technologies (**Carboniar**® and SMADs).

## CONSERVATION WORKS

Work started in April 1999 with the initial consolidation of antique plasters by injecting of natural hydraulic lime and acrylic resins and the use of phleboclysis bags predisposed on the surface to allow the slow letting and the complete diffusion of the binding products into the plaster.
Cornices and stucco decorations were consolidated using brass bars or wooden poles, integrated with salt free synthetic pastes. Stone elements were consolidated through micro-gluying and the application of steel bars.

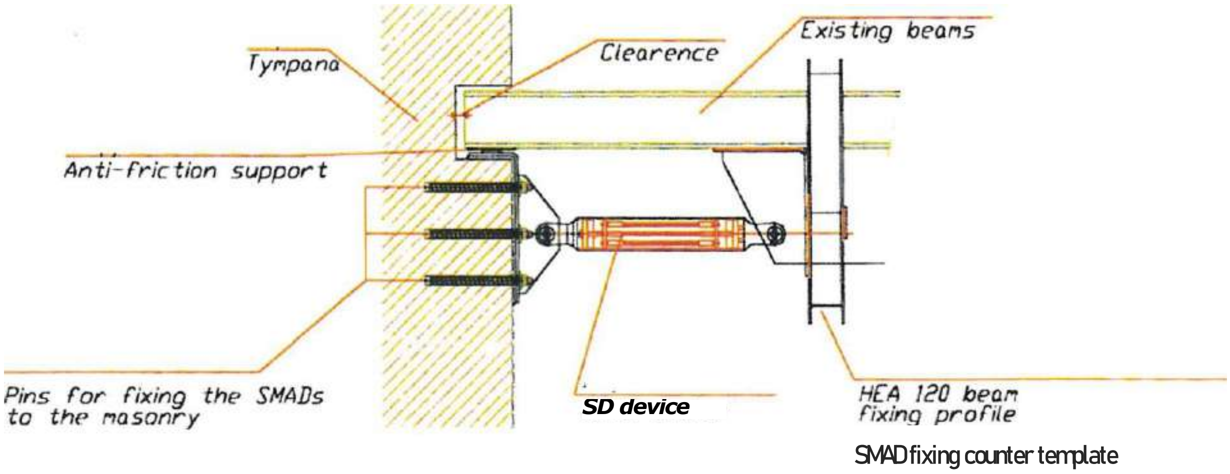
The painted areas in the vestry were restored with micro-injection of an emulsion of acrylic resin added with suitable inert charges, into cracks or small existing holes at different depth and with different concentration. The restoration of the mosaic on the facade was fulfilled sealing the damages on the surface with natural, hydraulic lime mortar previously injected in depth with the addition of acrylic resin, and the final integration of missing mosaic tile.

*(Steps of the conservation work)*

## STRUCTURAL CONSOLIDATION

The damages of brick walls, due to structural deficiency, were treated in order to reconstruct their original solidity, by injection of a mixture of natural hydraulic lime (lar Calx Romana), whose main characteristic are to avoid the stiffening of the structure, to ease perspiration and to avoid the formation of expanding salts, such as Ettringite and Thaumasite.

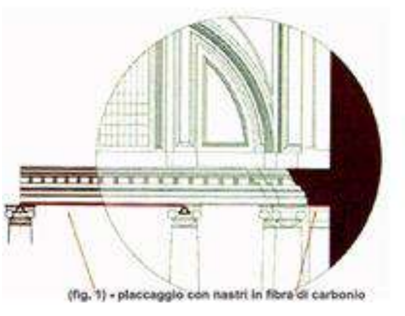
The facade was connected to the lateral walls up to the first counterfort with metallic fixing positioned placed higher than the internal entablature.
Shape Memory Alloy Devices SMADs were placed inside the Tympanum to tie it to the cover structure and avoid future dislocation. These devices grant a substantial reduction of the effects of seismic origins loads. Comparative laboratory tests on masonry elements placed on a bumping table have evaluated effect of loads on the structure constrained with steel tie rods or with SMADs. In the first case the acceleration caused the collapse. SMADs, on the contrary, reduced acceleration and the structure, referring to the part above the anchoring, wasn't even damaged.




*(How SMADs work)*

## THE USE OF CARBON SHEET TAPES

The consolidation of vaults was carried out in the most complete respect of the ancient design criteria. The technique used to build these vaults follows the late Gothic criteria that, compared to the early Gothic, had finally understood the importance of the building vaults, not merely placing them on the ribs, but reinforcing the extrados with stiffening ribs that reduced free span. Therefore, at the time of the consolidation, the aim was to grant the correct working of the ribs in case of earthquakes, not the stiffening of vaults. By application of **Carboniar®** system (carbon fiber sheet tapes and epoxy resin) the complete recovery of their original efficiency was achieved. Carbon fibers sheet tapes were also used to reinforce cornices, after being positioned into their original configuration by means of hydraulic jacks, they were also wrapped with carbon sheet at the extrados, in such way to transform them a real beam.

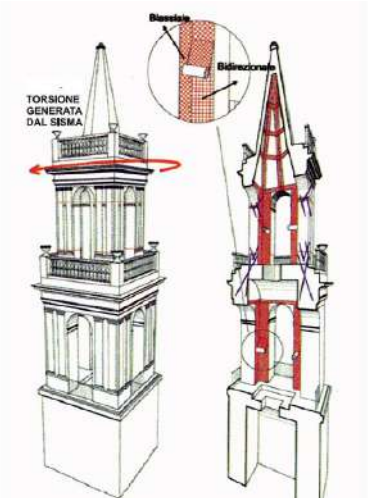



(fig.1)

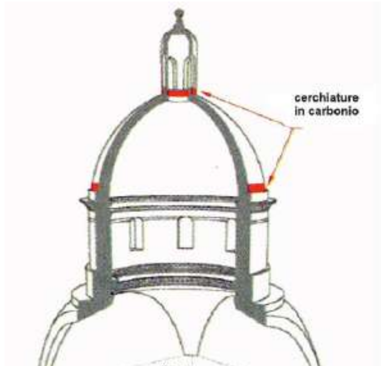
The spire on the bell tower was rebuilt with the addition of a carbon fiber bandage within the pyramid to improve strength and ductility of this structure, very sensible to earthquakes. As it is not possible to determine the structure's behavior in relation to seismic waves, two different fiber sheet were applied one onto the other: the first one $0^0$-$90^0$ direction, the other one crossing at ca. 45°. This system let the structure work along all load directions. In the area where bell cells connect to the structure there were evident detaching problems solved with the use of stainless steel bars. (fig.2)

**Carboniar®** system was also applied to consolidate the dome and the lantern. In both cases a carbon fiber sheet ring reinforcement was applied at the base of the spherical vault. (fig.3)

The sizing was carried out in such a way that the carbon fibers sheet absorb the tensile loads identified by a finite element analysis of the structure.



(fig. 2)



(fig. 3)

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