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Second World War Damages of the Architectural Heritage: St. Maria Del Popolo Agli Incurabili Church in Naples

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Abstract The research concerns the case-study of the church of Santa Maria del Popolo into the historical Incurabili Hospital in Naples, seriously damaged during a bombing raid in 1943. The construction of a reinforced concrete trussed roof and floor above the main nave has caused serious structural problems and the church shows evident signs of deterioration today. The present situation offers the occasion to deep, in an interdisciplinary way, the delicate issue of the recent past strengthening operations realized with reinforced concrete that, associated with highly territorial seismicity, alarm about the condition of many historical buildings. In order to have a clear knowledge of the structural behavior of the church, assessing the actual *in situ* condition, a numerical FE analysis has been performed with the scope of evaluating the state of stress in the structural elements of the walls and of the roof, pointing out the structural deficiencies. The numerical damage assessment has been validated by means of comparisons with crack patterns. Providing a reliable model, it has been possible to fully simulate the behavior of historical structures when subjected to different and severe types of load, e.g. seismic loads.

Keywords: Monument, World War II restoration concept, seismic vulnerability

Introduction

Since the beginning of the 20th century new materials and innovative techniques have inspired many solutions in restoring the architectural heritage. The exhortation, expressed within international assemblies as the Athens Conference in 1931, to «the judicious use of all the resources at the disposal of modern technique and more especially of reinforced concrete» was legitimated by satisfactory effects with regard to strengthening. However, there was not equal confidence in the expressive potential of new materials: «this work of consolidation should whenever possible be concealed in order that the aspect and the character of the restored monument may be preserved» (art. V). As a consequence, the widespread beliefs in respecting the architectural and formal configuration of the pre-existing building have suggested after the World War II the concealing of new concrete structures inside the antique ones or rather giving the concrete the allusive shape of the traditional technique. This restoration approach poses, today, serious theoretical and practical issues as those regarding the "life service" cycle of modern materials or their seismic response into masonry structures; issues, these last, which are evident in the following case-study and that technicians and researchers have to face up at the present.

The Church of St. Maria Del Popolo Agli Incurabili: Problems of Restoration of Previous Restoration Works

War damages and restoration works On March 5th, 1943 the bombs directly hit the Hospital of the Incurabili in the ancient centre of Naples while it was intensely in its functions of lifesaving injured people from the war offenses (Villari, Russo, Vassallo 2005): the church of St. Maria del Popolo, enclosed into the historic hospital walls, was seriously damaged in its vertical structures and, particularly, in the roof as a rare photograph taken by Roberto Pane before 1949 testifies (Pane 1949).

(a) (b) (c)

Figure 1: Naples, church of St. Maria del Popolo: (a) The interior before the 1943 (from Borrelli 2002); (b) The nave in the present conditions; (c) Transversal section of the nave covered by the reinforced concrete roof (ASBAN, without date)

The building, founded in the first half of 16th century (Borrelli 2002), is characterized by a single nave constructed in Neapolitan yellow tuff and concluded by a rectangular apse covered by a dome. The church nave is free from constructions on the South side and confines with chapels and the ancient hospital rooms on the North; it is scanned by six arches on each side, closed at the bottom by masonry panels corresponding to the upper slender windows. A choir, used by the nuns for assisting to religious services, weights on the internal façade (Fig. 1b) and it is separated from the nave by three arches, at the present closed by lapillous concrete blocks. Finally, the whole space is enriched by stuccoes that cover all the surfaces with decorative themes which are frequent in the Neapolitan baroque art.

The effects of bombing raids were evident, as mentioned above, especially on the building wooden roof that supported a wooden coffered ceiling (Fig. 1a): damages were relevant, above all, near the church main façade on the West because of the loss of the roof beams and of the exposure of the internal space to meteoric agents. The need to operate firstly onto the hospital ruins induced the Allied military forces to postpone any intervention in the church until 1954 – almost a decade after the bombardments – when a strengthening yard is documented by archival sources (ASBAN, 4/482) (Fig. 1c). According to a procedure recurring in many coeval yards, the church of St. Maria del Popolo was interested by an unpublished work of war damages remission effectuated by the Genio Civile (Ministry of Public Works): the operation was focused, particularly, on the damaged nave covering structure that was wholly replaced. A new structure, made by reinforced concrete trusses connected by a slab (Fig. 2b), was realized in order to conclude the nave internal space with the scope of calling back the substituted parts with simplified forms and with the reduction of the lacunars in relation to the pre-existent ones (Fig. 1a). The 20th century coffered ceiling simulates the previous one at the intrados although it does not reproduce the outline and, so, its ancient design (Fig. 1b): as it can be noticed today, the trusses' tie-beams define, constructively and alternatively, the transversal ribs of the coffered ceiling slab and they are connected by hollow beams in the longitudinal direction.

At a lower look, the stuccoes covering and the roses in the middle of the lacunars give a traditional facies to the modern work: the coffered ceiling is distinguishable in its technical and constructive characteristics only at the extrados and, so, in a part which is not visible from the church nave (Fig. 1c). A sequence of nine reinforced concrete trusses (Fig. 2b), alternated by rafters connecting the top beam to the outer walls, constitutes the postwar roof of the church, whose "mixed" structure requires, at the present, meditated and necessary interventions for the conservation of materials and the strengthening of masonry parts.

(a)

(b)

Figure 2: Naples, church of St. Maria del Popolo: (a) The structural conditions of the south side; (b) A reinforced concrete truss of the roof

The Building State During Last Decades

During the years following the strengthening works in 1954, the hospital administration asked for further restoration works in order to reintroduce the practice of worship in the church. These interventions, concerning mainly the restorations of the fresco, were never performed and presumably the church was not re-opened to the public. On November 23th, 1980 the earthquake, cause of considerable damages to the city monumental heritage, has put to a "structural test" the building as it has been modified after Second World War. The vertical trend of the cracking pattern in fact, outlined in the pilasters (Fig. 2a), revealed a lack of resistance to seismic actions of the South wall of the nave, considering also that it is not constrained to any other adjacent building. In 1993 a survey campaign was undertaken to look for the causes of the alarming cracking pattern of the external walls. The survey results let exclude, after a foundations check, any foundational subsidence of the church (ASBAN, 57/985). The compression test on the tuff panels and on the binder left out the hypothesis of materials not enough resistant to compressive stresses, while a disjointedness between pilasters and wall panels was detected on the southern side of the nave as well as wall gaps due to previous interventions and, at least, detachment of whole masonry blocks.

The above analyses, concerning a structural interpretation that has highlighted the "historical" operational deficiency in the way the wall panels were built, did not refer to the reinforced concrete covering built in the Second postwar period, while they suggested, as a solution, the construction of an external masonry cover of the pilasters, connected to the wall panels by stainless steel bars (ASBN, 57/985).

This project was never executed, while tubular-steel were put to sustain three arcades on the southern side of the nave. Today the church is still closed to the public and the presence of the temporary props recalls the necessity of a conclusive solution to the heavy instability of the wall panels. As well, water infiltrations coming from the roof provoked the fall of the concrete cover from the trusses frame and the detachment of the finishing elements. This condition seems to underline the formal dissimulation, carried out in the postwar period, of a "modern" constructive technique that, across the years, revealed itself to be structurally not compatible with the preexistence.

Numerical Simulations of the Behavior of the Nave Masonry Structures

A complete three-dimensional FE model of the church structural complex has been built using commercial computer code SAP 2000 (CSI-Computer and Structures Inc. 1999). The FE modeling strategy is based on the concepts of homogenized material. In particular the walls have been modeled by means of thick shell elements, while frame elements have been used to model the trusses of the roof. The 3D model (Fig. 3) consists of 14005 joints, 13057 shell elements and 245 one-dimensional truss elements. For the masonry tuff elements the hypothesis of linear elastic behavior has been

adopted, with Young modulus equal to 1000 MPa and own weight equal to 19 kN/m^3 to account also for the plasters, coatings and stuccoes.

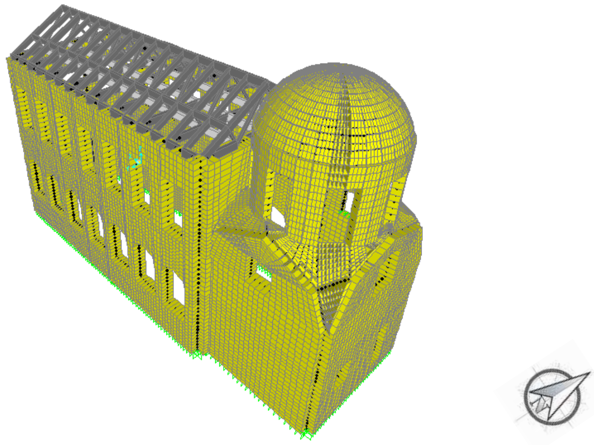

Figure 3: Naples, church of St. Maria del Popolo. Perspective view of the 3D FE model of the church

In order to assess the safety of the church and clearly justify the damage described in the previous sections, both static and seismic analyses have been performed to understand the origin of the cracking patterns and to obtain, from a numerical point of view, the actual state of conservation of the church.

The Static Analysis Linear static analyses have been performed to give an internal force distribution among the single elementary parts and also to identify the weak points of potential failure in the building. Two different models have been investigated in order to reproduce the changes occurring during the history: the first model takes into account the roof made of RC members (present state); while the second one considers the presence of timber roofs (earlier state, before World War II). Two different assumptions have been adopted for addressing the effect of horizontal connection among the vertical structural elements due to the different roof solutions: model (1) with RC roof considers the insertion of rigid diaphragms, through a kinematic constraint; model (2) with timber roof instead is modeled with simple frame elements. In this step the structural model was subjected to its dead load only.

The static linear analyses provide the stress distribution inside structural elements in the two vertical and horizontal directions. As a matter of cracking pattern the maximum value of the compression is reached in the columns along the South wall of the nave where the compression is about 1 MPa, a high value, but anyway feasible for the stone materials. As expected the compressive vertical stresses derived in the case of RC roof are 20-30% higher than those values obtained when timber roof was considered. In any case, even if the stresses are higher, they can be considered still feasible for such tuff materials.

The Dynamic Behavior The linear investigation was extended to a modal analysis in order to give an estimation of the dynamic response of the church. Substantially this result will confirm that churches, designed to withstand vertical (compressive) static load, are not always adequate to withstand horizontal actions deriving from seismic events, which are probably the main cause of the degradations.

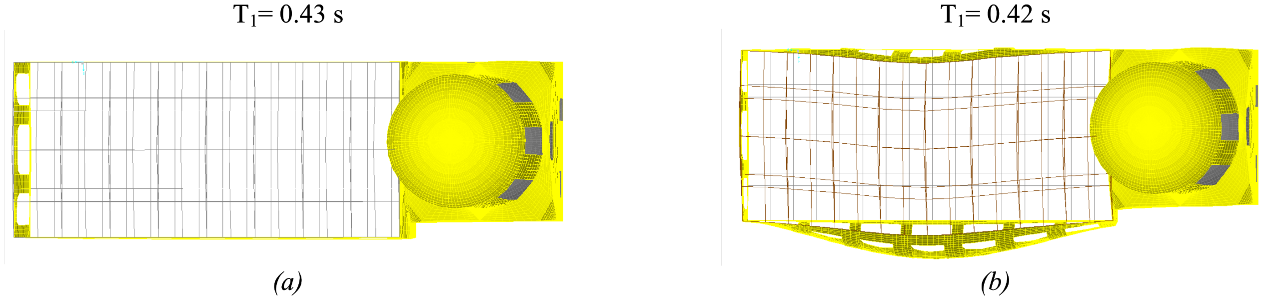

Figure 4: Naples, church of St. Maria del Popolo. Modal shapes: (a) concrete roof; (b) wooden roof

The period and the modal shapes of the two 3D FE models are provided in Fig. 4a and Fig. 4b respectively for the case with rigid diaphragm (RC roof) and without horizontal connection (timber roof). As can be argued from the Fig. 4a the first mode of the “as is” building (model with rigid diaphragms) involves translation in the longitudinal direction, thus confirming that the building shows a greater stiffness in this direction. Instead the model with timber roof (Fig. 4b) presents the first mode shape that involves in translation in the weakest transversal direction. The periods and modal participating modal mass ratios, derived by the two FE models, show that the introduction of the rigid diaphragm influences the fundamental modal shapes and participating masses, while seems to be not influential on periods.

The Seismic Analysis In order to give a structural interpretation of the damage growth due to recent seismic events, dynamic simulations of the church (with RC roof only) is presented considering both the response spectrum registered by National Accelerometric Network (http://itaca.mi.ingv.it/ 2010) at Torre del Greco, that is the closer station to the church area, during the Irpinia earthquake of the 1980 and the inelastic design spectrum provided by Italian Code (NTC ’08 Ministero delle Infrastrutture 2008) for the site of interest with PGA equal to 0.167g. The inelastic spectrum is obtained from the elastic one trough a reduction factor equal to 2, which accounts for the limited ductility and deformation capacity of masonry structures. The seismic actions provided by the NTC’08 have been applied along the two main directions of the church in two different analyses. The Italian code inelastic spectrum matches quite closely the real waveform and in any case results conservative as suggested into a design phases. The comparison between the numerical stress distributions inside the structural elements and the in situ inspection of the cracking patterns show a good agreement between the FE simulations and the actual state of conservation. Fig. 5 shows this comparison and it is clearly shown that, according to numerical outcomes the peak stresses in compression (Fig. 5b) can be found in the central columns in the South wall of the nave; the same areas are nowadays mostly damaged (masonry crushing, Fig 5a). Fig. 6 summarized the results of the numerical simulations providing both compressive and tensile stress values achieved in the critical structural elements of the South wall of the nave and the right South wall of the apse respectively. It is clearly highlighted the crucial influence of the seismic actions. In any case the RC truss presents reduced stresses while the only damages are related to rain water leakage.

Conclusions

In this paper the St. Maria del Popolo church in Naples has been analyzed for assessing structural behavior and seismic vulnerability in consequence of an invasive restoration conducted after World War II. For this purpose, 3D linear analyses of the structural complex have been carried out through FE in the static and dynamic ranges to investigate the origin of the surveyed crack pattern. By this procedure it has been possible to obtain a proof of the configuration of the cracks, which was found to depend primarily on the Irpinia earthquake of the 1980. The substitution of the timber roof with a heavier RC roof yielded to higher stresses in the masonry, but in any case lower than those occurred during the last major earthquake. A crucial task in masonry building modeling is the evaluation of the mechanical properties: in this research conservative values already available from similar experiences are assumed. The reliability of the model was assessed by comparing the monitored main damages with the numerically predicted ones. According to the FE model developed stress concentrations were detected, with peak values close to the strength of masonry. These peaks are located in the neighborhood of the damaged portions. By a comparison between the stresses due to the seismic shocks acting in the horizontal directions it was observed that the church is especially vulnerable in the along-nave longitudinal direction, due to low stiffness and the presence of localized thinned portions of the walls. The comparison demand (design seismic loads) vs. capacity (material and topology strength) confirms the susceptibility of this type of building to extensive damages.

As a consequence, the results of the research open, at the present, delicate issues concerning the possible ways of strengthening the "mixed" building respecting all its historical values, among which those referred to the Second postwar works have to be taken into account in the project, too.

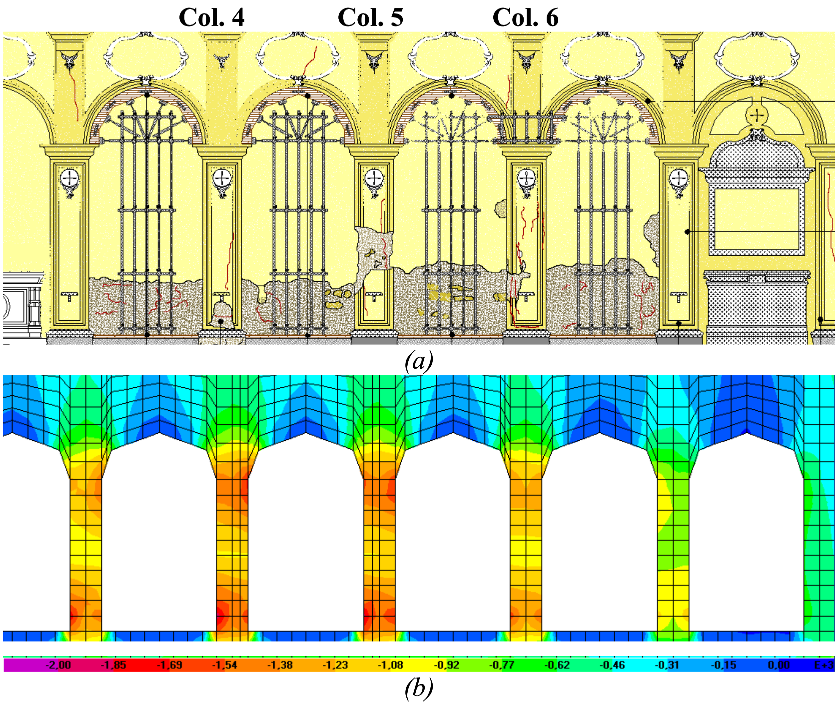

Figure 5: Naples, church of St. Maria del Popolo. Comparison between numerical analyses and state of conservation of nave: (a) cracking patterns; (b) compressive stress (MPa)

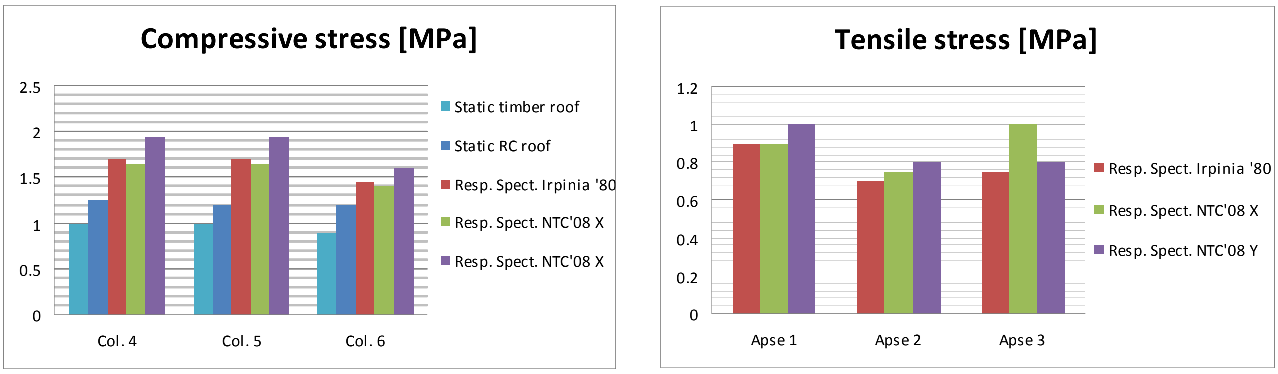

Figure 6: Summary of simulation results

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Abbreviation:
ASBAN: Archive of the *Soprintendenza per i beni architettonici e paesaggistici per Napoli e provincia* (Naples).

Although the present paper is the outcome of a collective research among the four authors, the second par. is due to Valentina Russo, the third par. to Emanuela Vassallo and the fourth, fifth, sixth and seventh par. are due to Gian Piero Lignola and Alberto Zinno. The Introduction the Conclusions come from a collective work of synthesis made by all the authors.