

Seismic Assessment of Artefacts: The Case of Juno's Fountain of The National Museum of Bargello

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Abstract. Earthquakes represent huge risks for cultural heritage. Although there is a large literature about prevention on historical buildings, the seismic assessment on collections and exhibition designs is usually underestimated. “RESIMUS” long running project involves different knowledge and fields; its goal is to prevent seismic damages to museum collections and artefacts, combining both museographical solutions and anti-seismic methods. This contribution focuses on the “Fontana di Giunone”, designed in 1555 by Bartolomeo Ammannati and currently kept at the Museo Nazionale del Bargello. The museographical and historical researches have been combined with the seismic performance of the reconstructed Fountain. In this paper the first results provided by the seismic analysis of this artefact are shown. A 3D structural model has been set, based on the three dimensional digital model provided by an detailed laser scanner survey. An elastic dynamic analysis has been performed, by representing the seismic input through an ensemble of seven ground motions expressing the seismic hazard of the area. The analysis has provided the seismic response of the sculptures, evidencing its sensitivity to the dynamic properties of the considered ground motions.

1. Introduction

RESIMUS is a multidisciplinary research group, whose purpose is to define a new methodology of analysis applied to museums so to measure the capacity, the so-called efficiency, of a site in case of dangerous events. The research focuses on an outstanding case-study: the National Museum of Bagello. Specifically, the goal is combining knowledge on museography and anti-seismic methods –in order to prevent risk to the museum collections and artifacts in case of earthquakes. In this phase, the research focuses on the seismic performance of the Fountain of Juno. First, the paper illustrates the artistic value of the masterpiece, its particular history, recent studies, and its set up. It is well known that cross-disciplinary studies facilitate the correct interpretation and exhibition of art works in the museum settings; in seismic areas, museum practices have to include anti-seismic methods to prevent risks. A brief literature review [1-8] illustrates the growing interest that the scientific community is addressing to the seismic assessment of artefacts in recent years. The research program is aimed at assessing the reliability of a case-study subjected to seismic actions. The case-study under examination is the statue of Venus, the most vulnerable (i.e. slender) sculpture of Ammananti's Juno Fountain, currently located in the courtyard of the Bargello Museum in Florence. In this paper, some preliminary results of the research, still in progress, are shown. A dynamic elastic analysis has been performed through a Finite Element (FEM) code , by assuming the ensemble “statue-pedestal” as a continuum

body standing on the courtyard floor, therefore neglecting the interface [9,10] between both soil and pedestal and pedestal and statue. A finite element model has been set, on the basis of a detailed laser scanner survey. The seismic input assumed in the analysis has been defined according to the Italian Technical Code, by selecting an ensemble of seven ground motion spectrum-compatible to the seismic hazard of the area for the Collapse Prevention (CP) limit state. The analysis has been provided the elastic response of the case-study under the assumed seismic input, and pointed out the sensitivity of such response to the dynamic properties of the assumed ground motions, as a consequence of the relationship between the main frequency of the system and the ones of the ground motions.

The paper shows that multidisciplinary approaches are needed for a comprehensive interpretation and exhibition of artifacts. The paper inaugurates a series of studies, whose final aim is to include anti-seismic methods and relative technological and museographic solutions inside the museum environments.

2. The case study: the Fontana di Sala Grande

2.1 The Fountain history

Juno's Fountain (Figure 1), also known as "Fontana di Sala Grande", is one of the sculptural masterpieces by Bartolomeo Ammannati [11]. Currently exhibited at the National Museum of Bargello [12,13], the fountain attracts the interest of scholars and curators for its interesting layout, original destination, and uncertain history.

In the middle of the XVI Century, Cosimo I de' Medici moved his residence to Palazzo Pitti and transformed Palazzo Vecchio in a sort of headquarter of the Ducato, with new spaces and offices (Uffizi). He converted a Medieval fortress in a modern palace, so to host and impress foreign visitors. The first works in the throne room were designed by Baccio Bandinelli and Giuliano di Baccio d'Agnolo and coordinated by del Tasso [15]. The works concentrated on the North wall of the hall. When Vasari succeeded to Tasso in the job direction, the Sala Grande's yard was suspended for ten years, until Francesco I's wedding (1555). Vasari sponsored his friend Ammannati to the Duke, and he became the designer of the South wall of the Sala Grande.

In continuity to Bandinelli's work, Ammannati's design foresaw a rich architectural articulation, an internal fountain, and many statues in marble and bronze. The architectural arrangement of the sculptures is one of the main features of the unique composition. The so-called *Concerto di Statue* (Concert of Statues) fascinates for its original conception: a magnificent fountain to be placed inside the Sala Grande (now Salone dei Cinquecento) of Palazzo Vecchio.

The fountain is a tribute to the Medici's magnificence. The feminine statue at the top of a rainbow alludes to both the goodness and the duchess Eleonora di Toledo; the two peacocks are her emblems. A rainbow originates from two sources of water: Arno, a powerful man sitting on a lion, and Spring of Parnasus, a gentle feminine figure laying on a wing-horse. Inside the water, Cerere (Venus), pressing her breasts, embodies life and richness. Two of the sculptures, Fiorenza and Prudenza, are placed laterally to the group. According to the original project [14], these two pieces should have been positioned in the niches of the South wall of Sala Grande. When Vasari presented Ammannati's project of the Sala and of the Fountain to Michelangelo, the latter suggested raising the height of the room so to harmonize the global proportions. Vasari, as head of the *Fabbriche Medicee* (Medici's Yard) applied Michelangelo's recommendations: the Sala Grande became the Salone dei Cinquecento (see Figure 2), and the fountain works (1560) stopped; meanwhile, Ammannati started working on the Neptune Fountain in *Piazza della Signoria*, the so-called *Biancone*.

There are no drawings describing Ammannati's design; the only information we have about the project is the sculptures themselves and some writings reporting the project as a "concerto di statue" (concert of sculptures). After the project interruption, archive documents testify the presence of the marbles in the Medici's properties through time [16], others [14] indicate the presence of some statues inside Ammannati's *bottega* (atelier). Borghini [17], for example, recognizes the statues of Arno and Parnasus at Pratolino Villa. Probably, Ammannati finished the back of the statues when they were set up in the Pratolino's garden. In 1588, the sculptures moved to Palazzo Pitti; there, Ammannati himself

curated the arrangement in the courtyard. Juno's Fountain changed location once again in 1635, when the pieces of the fountain were scattered between the Casino di San Marco and the Boboli gardens.



Figure 1. Current reconstruction at the National Museum of Bargello

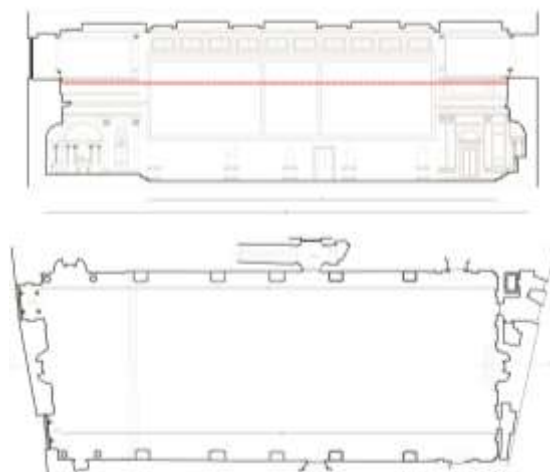


Figure 2. Salone de' Cinquecento (The red line indicates the old height of Sala Grande)

2.2 The set up. Behind the scene: documentation and survey campaigns

The final set up is the result of a long process, which involved the curators of the museum and the University of Florence. Today, Juno Fountain is considered a unique sculptural group, testimony of the greatness of the Medici's family, which can finally be admired in one of the most important museum of the world.

The first intuition about the Fountain's original layout is by [Detlef Heikamp \[18\]](#). The scholar conducted a rigorous study on Ammannati as sculptor, and he finalized a reconstructive proposal for the group of sculptures ([Figure 3](#)). Years later, the traditional study combined to the new technologies helped finding a liable solution, which, at the end, is not far from Heikamp's suggestion. The current reconstruction suffers the limit of the missing historical documents about the original project (how was the South wall configuration project? Where were displayed the sculptures? Which was the relation among water, light, and volumes?) and of the subsequent wandering phase [\[19\]](#). During the XX century, the statues were reunited at the National Museum of the Bargello.

The current set up has been realized in occasion of the 500 years from the birth of Ammannati, celebrated in 2011 [\[13\]](#). It has been possible thanks to the combination of different methodologies and expertise. The curators' knowledge has been fundamental for the interpretation of the sculpture iconology and, therefore, the coherency between positions and meanings [\[16\]](#), the restorers analyzed the statues, the 3D modeling (subsequent to the three 3D scanner laser survey campaigns) allowed the correct documentation and the preview of the set up [\[20\]](#), the museographers designed the reconstruction [\[12\]](#) and, with the structure team, calculated the new structure (in particular the new arch holding the cast of Juno and of the peacocks). The sculptures of Cerere and Fiorenza are now placed beside the group. The two sculptures were part of the challenging sculptural program. Their position is a quotation of Guerra's sketch ([Figure 4](#)). The original marbles of Juno and the peacocks are placed near the recomposed fountain.

The preparation works involved the uses of new technologies and specific professionals. The survey campaigns and the treatment of the data set, allows the realization of detailed virtual models. Such models served to multiple purposes: global virtual reconstruction, 3D print, caster and restoration, exhibition proposals, documentation and preservation. Such cross-disciplinary work is now the invaluable support for the continuation of the study on the Fountain. The research is currently focusing on the safety and conservation of the Fountain, in particular, on the seismic risk.



Figure 3. Heikamp's reconstruction.



Figure 4. Guerra's sketch in Prato.

3. The seismic analysis

The vast documentation about the current arrangement of fountain and its fame bring the RESIMUS research group to use Ammannati's masterpiece for this seismic analysis. In a preliminary analysis [21] the five sculptures constituting the Fountain have been checked in terms of slenderness on the basis of their geometry; since Venus came out to be the slenderest statue of the complex, the dynamic analysis has been performed on the model representing Venus only. The following Sections shows the model adopted for analysis, the selected ground motions represented the seismic input and the obtained results.

3.1 The model

The structural analysis has been performed on a 3D Finite Element (FE) model consisting of four-nodes tetrahedral isoparametric elements. Such model has been set on the basis of a 3D laser scanner survey. The survey was made using a Cam/2 Faro Photon unit, based on phase shift measurement technology; to complete some parts of the back of the statue, a Nextengine unit was used, since it better fits with the narrow space between the statue and the wall. All the scans were later aligned on morphological similarities, creating a pointcloud with all the information about shape and detailed characteristics of the statue. The FE model used for the analysis has been set from geometrical survey by making a series of changes. As a first step, the virtual model, rendered after the survey campaign, has been reduced in size and definition through the software MeshLab [22] in order to be used for the analysis. Furthermore, the surface model provided by the laser-scanner survey has been transformed in a volume one (second step), by introducing a set of nodes in the volume inscribed by the statue surface, and completed by additional nodes representing the pedestal (third step). In Table 1 the number of polygons referred to each model is listed.

Table 1. Number of polygons of the geometrical models.

Model	Initial surface model	Simplified surface model	Simplified volume model	Simplified volume model including the pedestal
Number of polygons or tetrahedrons	900,000	10,000	34,592	43,929

3.2 The seismic input

The seismic input has been represented through an ensemble of seven ground motions, spectrum-compatible to the elastic spectrum provided by the Italian Code, NTC 2008 [23] for the site. The Museum area, such as the rest of the Florence basin, consists of plio-pleistocene palustrine and alluvial deposits, followed by two sedimentary cycles related to the paleo-Arno river and the holocene geomorphic evolution [24]. As a consequence, as the investigation on the foundation soil is still in progress, a soil-type B, according to the NTC 2008 classification, has been assumed. The considered seismic intensity refers to a Return Period of 949 years, i.e. the *Collapse Prevention* limit state, with a class of use (c_u) equal to 2 (strategic buildings). The ground motions have been selected by the database Itaca [25] through the software Rexel [26]. In Figure 5 the elastic spectra of the ground motions are shown and compared to the corresponding spectrum provided by NTC 2008. As can be noted, the seven ground motions differ very much from each other both in the maximum acceleration and in the frequency content.

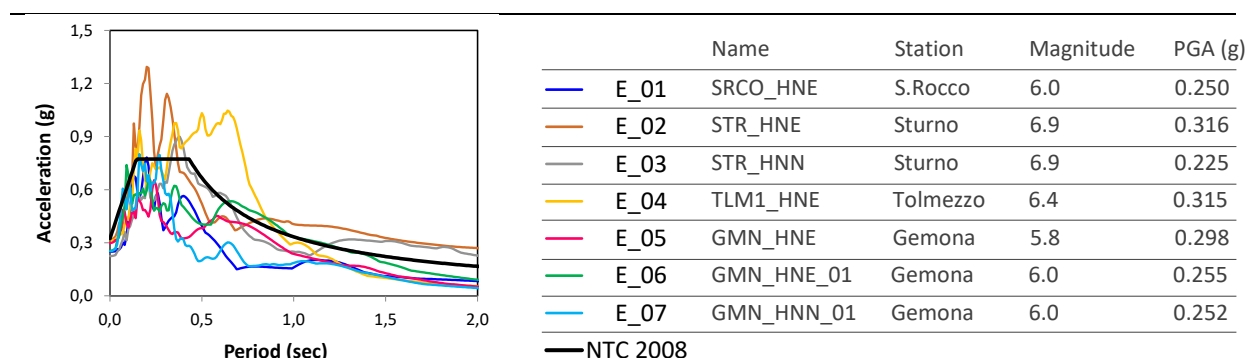


Figure 5. Elastic spectra of the assumed ground motions.

3.3 The analysis

The analysis has been performed through the software Strauss 7 [27]. An elastic time-history analysis has been performed on the FE model described in § 3.1. In the analysis, the marble of the statue has been described through a Young's modulus equal to 50 GPa, a Poisson's coefficient equal to 0.2 and a density equal to 2700 kg/m³. The pedestal, made in masonry, has been represented through a Young's modulus equal to 5 GPa, a Poisson's coefficient equal to 0.2 and a density equal to 1700 kg/m³. No link components have been introduced between the statue and the pedestal or between the pedestal and the floor. Therefore, the system "statue+pedestal" has been assumed as a single body, simply standing on the floor. A viscous damping equal to 4% has been assumed for the system.

A preliminary modal analysis, whose results are shown in Figure 6, has been made on the FE model to check its dynamic behavior. As can be seen from the Participation Factor (PF) shown in Figure 6, the first and the third eigenmodes refer to the x -axis (front to back of Venus), with a PF of about 57 % and 23%, respectively; the second mode occurs along the y -direction (lateral bending), while the fourth mode is a torsional one. Since the system is very rigid, its fundamental frequency is high (over 17.62 Hz, corresponding to a period of 0.058 sec).

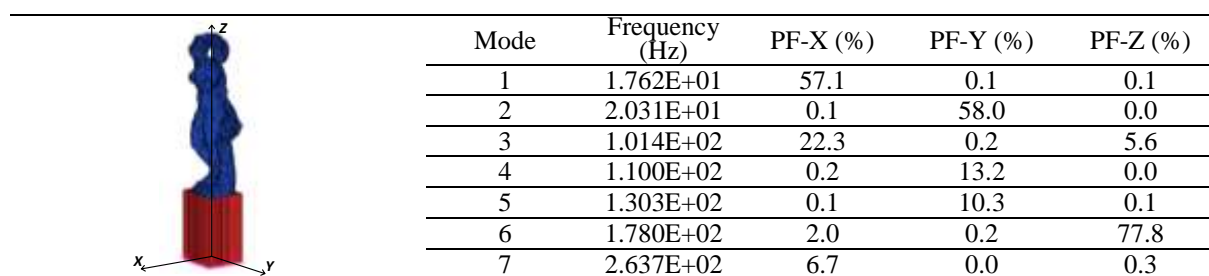


Figure 6. Results of the modal analysis.

By comparing the period of the first mode to the elastic spectra of the ground motions representing the seismic input (Figure 5), it can be seen that their peaks in acceleration occur for higher periods compared to the fundamental one of Venus. It can be expected, therefore, that no resonance phenomena will occur in the dynamic response of the system. As a consequence of the obtained eigenmodes, the time-history analysis has been performed along the x-direction only, that is the most sensitive to the statue dynamic response. The response parameter assumed in the analysis is the top displacement of the system, i.e. the displacement of the top of the sculpture.

4. Results

Figure 7 shows the stress distribution found for the case-study subjected to its own weight only. Even when no horizontal actions are applied, the statue experiences a slight horizontal displacement (0.05 mm), due to its asymmetry. As regards the stress level, in the pedestal it is almost uniform, as well as in the top part of the sculpture. In the bottom part of the statue, instead, due to the reduction in cross section (see Figure 7), there is a peak of stress, which achieves 0.18 MPa in tension and 0.82 MPa in compression. Therefore, the maximum stress arising in the material under gravitational loads are well below its elastic capacity.

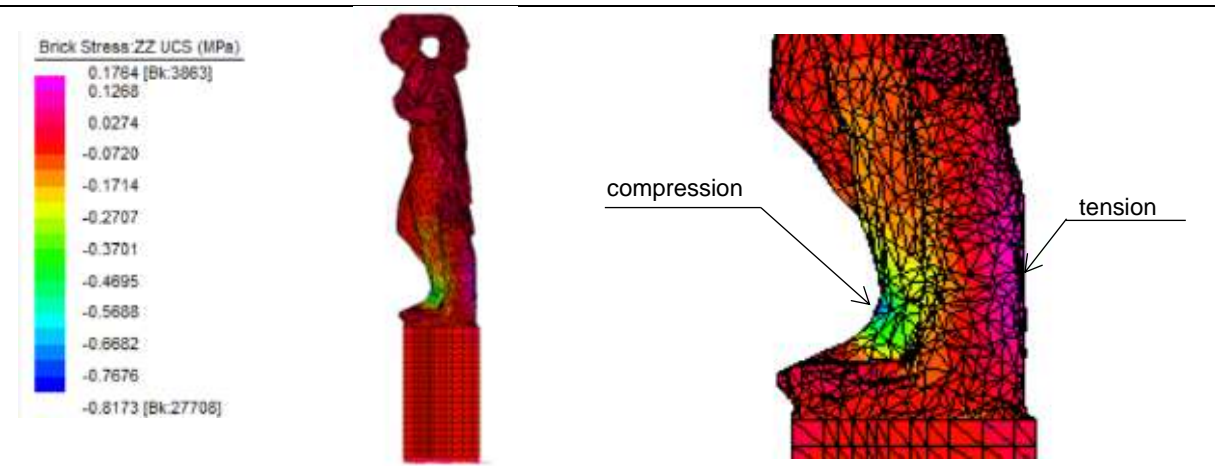


Figure 7. Stress distribution under gravitational loads.

In Figure 8, the time-histories of the top displacement provided by the seven ground motions are shown, together with their maximum value and the first (higher) peak in frequency of each record. The dynamic response of the case-study could be related both to the content in frequency of the considered ground motions and to their accelerations at the fundamental Period of the system. The maximum stress arising in the statue in the dynamic analysis is equal to 1.10 MPa and 3.14 MPa for tensile and compressive stress, respectively. The tensile stress in the material under seismic excitation, therefore, results to be more than 6 time larger than the one due to gravitational loads. It should be reminded, however, that the analysis has been performed by assuming a linear elastic behavior for the system, and neglecting any possible interaction between the statue and the pedestal and the pedestal and the soil.

5. Conclusive remarks

This paper presents the preliminary results of a multidisciplinary research concerning the seismic vulnerability of Ammananti's Juno Fountain, currently located in the courtyard of the Bargello Museum in Florence. More precisely, the analysis focuses on Venus, the main and slender statue of the sculptures complex. A 3D Finite Element (FE) model, consisting of four-nodes tetrahedral isoparametric elements, has been set on the basis of a detailed laser scanner survey.

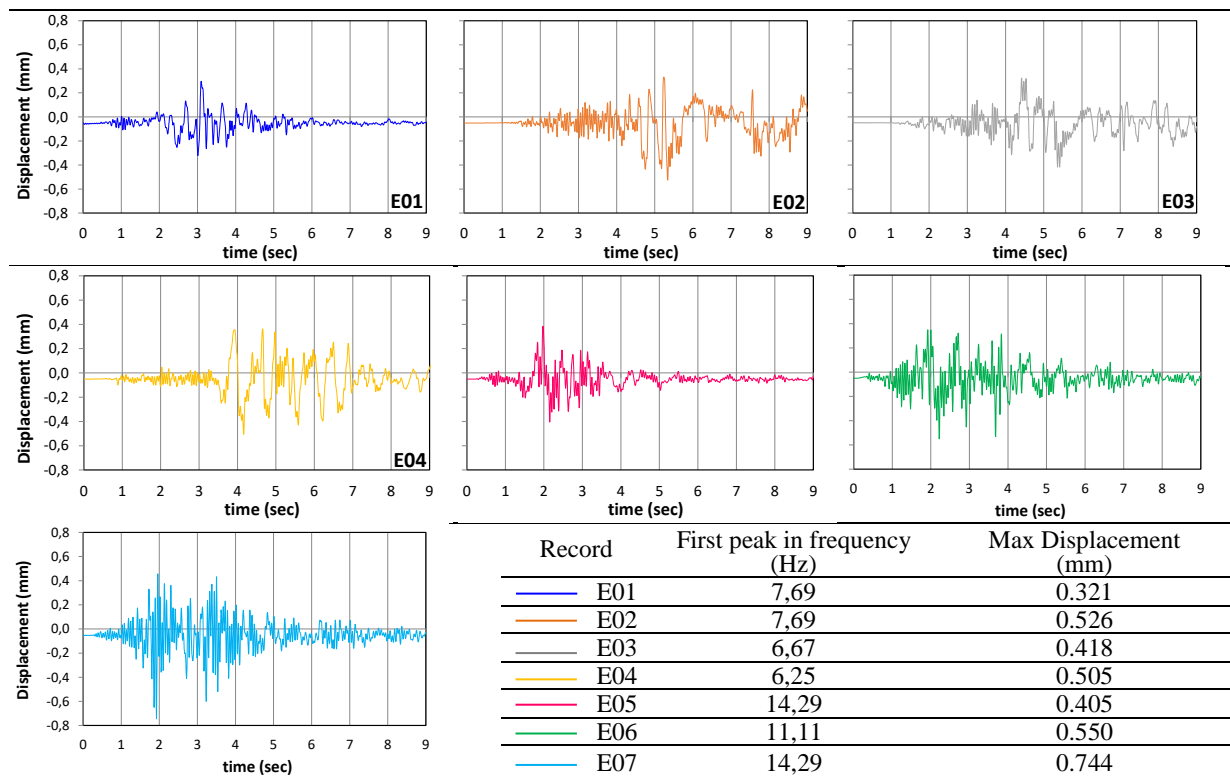


Figure 8. Top displacement provided by the time-history analysis

An elastic time-history analysis has been performed, by representing the seismic input through an ensemble of seven ground motions spectrum compatible to the elastic spectra as provided by the Italian Code for the Collapse Prevention limit state of the sculpture site. The top displacement time-histories of the case-study have been compared to the frequency content of the seismic input, compared to the sculpture's one. The maximum stress, both tensile and compressing, arising in the statue due to gravitational loads and to seismic excitation does not seem to exceed the capacity assumed for the material. The performed analysis neglects *i*) the possible nonlinearity of the seismic response of the case-study, and *ii*) the possible sliding between the statue and its pedestal. Therefore, further analyses should be performed, by representing the statue through more refined models.

6. References

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