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Mutual seismic assessment and isolation of different art objects

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ABSTRACT

New developments of a research programme dedicated to the seismic performance assessment and base isolation protection of art objects are presented in this paper. The investigation field has been extended from massive marble statues, considered at first step of this study, to slender free-standing columns, and bronze statues with highly vulnerable geometrical portions. A semicircular marble column and an equestrian bronze sculpture located in the main hall of the Restoration Laboratories of the Opificio delle Pietre Dure Institute in Florence are examined as representative case studies of the two classes, respectively. Rocking and sliding effects are simulated in the time-history assessment analyses of both artefacts, carried out by introducing all simultaneous components of seismic action as input. The results show an overturning-related near-collapse response of the column, and a plasticization-induced collapse of the statue, at the maximum considered earthquake level. In view of the different material and structural characteristics of the two artworks and several other art objects and equipments situated in the same hall, a mutual advanced seismic protection strategy is adopted, consisting in the base isolation of the floor by means of double curved surface sliders. This retrofit measure guarantees completely undamaged response conditions of the column and the statue, without requiring direct interventions on the two artworks. At the same time, the base-isolated floor constitutes a highly protective support for the hi-tech equipments housed in the Laboratories, as well as for any other artefact to be placed on it in the future.

1. Introduction

Art objects are among the most seismically vulnerable heritage assets, as demonstrated by extensive and often irreparable damage, and even complete collapse suffered in past and recent earthquakes worldwide. Low seismic performance capacities have been particularly surveyed in the following types of artworks: elements made of small tensile strength materials (marble, stone, terracotta, ceramics, etc), as a consequence of their cracking response; irregularly shaped metal (bronze, iron, steel) exhibits with local narrow cross sections, due to the severe plastic demand likely to arise in these critical portions; and members that are slender enough to undergo overturning, such as free-standing columns, steles, cabinets and showcases, made of various materials.

The dynamic response of these classes of artefacts is normally amplified by rocking and sliding effects, even under moderate seismic actions. The mount making strategies traditionally adopted to annul these effects consist in fixing the objects tightly to the base or the pedestal [1,2], which also allows mitigating the risk of falling off for overturning-prone elements. However, fastening strategies have several drawbacks, the most important of which are: (a) the need to drill holes to house connectors (bolts, screws, dowels, or chemical anchors), both in the bases or pedestals of the artworks and in the adjacent floors and/or walls, which is often incompatible with the artistic value of the exhibits and the interfacing surfaces; (b) the full transmission of the seismic accelerations from the supporting floor to the objects, without any mitigation of their dynamic response.

Based on these criticisms, more effective installation strategies have been studied and applied both in permanent and temporary exhibitions. The most performing solutions were obtained by adapting to art objects the base isolation techniques devised for the advanced seismic protection of buildings and bridges [3–11]. Several applications are currently noticed worldwide [12], a mutual characteristic of which is represented by the separate isolation of each single artefact, even when various objects are exhibited in the same place (e.g., in museum halls, art galleries, etc). This involves different design solutions for objects differing in dynamic, geometrical and material characteristics. As a consequence, each isolation system must be incorporated in, or hidden below, the base or the pedestal of the relevant artwork, which

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raises concerns in terms of philological restoration principles, onlooker's observation viewpoint and aesthetics. In addition, separate isolation interventions are currently very expensive.

In order to overcome these limitations, an alternative seismic isolation strategy was recently devised by the first two authors [13], within a research line dedicated to the seismic assessment and advanced protection of high-value finishes [14,15], as well as of contents, plants and non-structural components [16–19]. The proposed strategy consists in incorporating an isolation system at the base of the bearing floor where the artworks are located, when the seismic isolation of the entire building — which would allow to protect the contents too — is not possible or too costly, as is the case of several museums and historical structures. This allows avoiding any manipulation of bases and pedestals of the objects, as well as easily moving them in case of future relocations or setup modifications. Moreover, isolators in standard production for building structures and similar installation details can be adopted, which also significantly limits the cost of the interventions. A first hypothesis of application was demonstratively proposed in [13], where massive marble statues were examined as supported exhibits.

New advancements of this research programme are offered here, focusing attention on objects belonging to the two other highly vulnerable classes mentioned above, i.e. slender free-standing members, and metallic artworks including critical geometrical portions. Furthermore, temporary placements in depository or safekeeping areas are examined, in addition to the permanent exhibitions considered at the first step of the study, since most of the collections are not on display, but rather placed in restoration or storage zones where the threat of seismic damage can be even greater — due to density — than in galleries [1].

The representative examples selected for the two classes of artworks are a semicircular marble column and an equestrian bronze statue to be placed, for the development of restoration works, in the joined Laboratories of Stones and Bronzes of the world-famous Opificio delle Pietre Dure Institute in Florence. Hi-tech diagnostic and restoration equipments are also situated in these Laboratories, which suggests their mutual seismic protection with the artefacts housed in the same hall, easily reached by the considered base-isolated floor solution.

The response of the column and the statue is examined according to the seismic assessment procedure proposed in [13], articulated on a set of four performance levels expressly formulated to the purpose. The effects of rocking and sliding on the dynamic response of the objects, as well as the safeguard of their artistic value, are taken into account in the finite element analyses. The isolation system designed for the floor is described by including key technical details of installation. The improvement of seismic performance of the two artworks in protected conditions is finally evaluated by comparison with the response in fixed-floor configuration.

2. Case study objects

2.1. Location layout

The Opificio delle Pietre Dure was founded in Florence by Grand Duke Cosimo de'Medici during the first half of the 16th century, as a special section of the Uffizi Museum. In 1588, it was separated from the latter by Grand Duke Ferdinando I, to make an independent institution, and its headquarters were established in a new building situated between Piazza S. Marco and Piazza Santissima Annunziata, adjacent to the Accademia Gallery Museum. Several other buildings were added in the following centuries, until the end of 19th century. The Institute is one of the most important art restoration centres worldwide, divided in several special departments dedicated to any type of artworks, each one including diagnostic, intervention, research and teaching activities, and a Museum where selected restored masterpieces of various ages are currently housed.

A drawing of the ground floor plan of the Institute is displayed in Fig. 1, where the L-shaped wing of the Laboratories of Stones and Bronzes is highlighted by a hatched background and a continuous-line perimeter contour. This wing is the late 19th century addition of the block, and is constituted by a one-story building, whose façade is shown in Fig. 1 too. The dimensions of the building and the *X*, *Y* axes of the global reference coordinate system adopted in the finite element analyses are also indicated in the plan of Fig. 1.

The structure is made of good quality stone masonry, with a wooden roof constituted by a set of transversal trusses and secondary beams. The building contains the biggest plants, mobile equipments and artefacts, as well as the widest stocks of materials for the development of the restoration activities. As a consequence, the possible earthquake-induced overturning or structural collapse of the most vulnerable art objects can cause severe damage to several adjacent assets and equipments, as well as seriously affect the safety of the personnel and the visitors. Therefore, in consideration of the high seismic vulnerability of most of its contents, the building of the Laboratories was identified as a well-suited case study for a pilot application of the base-isolated floor strategy, as discussed in Section 4.

2.2. Characteristics and finite element model of the marble column

The case study column is a sculpted monobloc marble element shaped as a semicircular drum, with a multilayer toroidal ring at

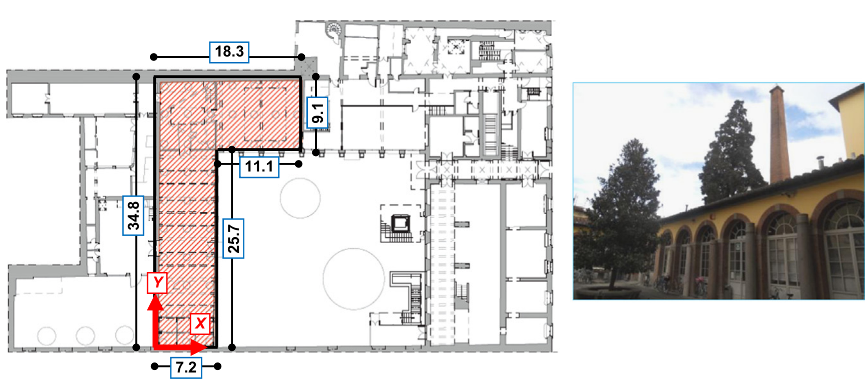

Fig. 1. Plan of the ground floor of Opificio delle Pietre Dure Institute, with the main hall of the Laboratories of Stones and Bronzes highlighted by a hatched background (dimensions in metres), and view of the building façade.