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CONTINUOUS SEISMOMETRIC MONITORING OF THE NATIONAL ARCHAEOLOGICAL MUSEUM "GAIO CILNIO MECENATE" IN AREZZO, ITALY

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Abstract

The multiple sources of vibration in urban areas contribute to the deterioration process of historical buildings and the objects contained within them modifying their dynamic properties. This is the case of the museums and artworks. In contexts of high historical value the Structural Health Monitoring (SHM) systems represent an effective and non-invasive technique for diagnosing building health status. Although the near-zero impact of continuous monitoring, practical applications are still quite limited and the effect of environmental loads on buildings and their content is far from being completely investigated. In this context the National Institute of Geology and Volcanology (INGV) and the Department of Architecture of the University of Florence (DIDA) in 2019 undertook a long-term seismometric monitoring campaign of the National Archaeological Museum "Gaio Cilnio Mecenate" in Arezzo. The museum, a former medieval monastery built on the ruins of a Roman amphitheater, is an emblematic case-study since it is an artifact of historical importance containing a wide variety of archaeological heritage. Seismometric devices were installed first in the attic and in the hypogeal ambulatory level, then at each intermediate level for a limited period of time. Continuous data acquisition allowed to record streams of ambient noise to monitor potential evolving conditions of mechanical properties that may affect the safety of the structure. It also allowed to study the effects of the abrupt reduction of urban noise during the stop of human activities due to the SarsCov2 pandemic.

Keywords: Seismic protection; Historical manufacts; Art contents; SHM.

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1 INTRODUCTION

The multiple sources of vibration that can be recorded in urban areas contribute to the deterioration process of historical buildings and the objects contained within them by significantly modifying their dynamic properties. Many historical monumental buildings are used as museums and in most cases they host artworks of inestimable economic and cultural value. Recent seismic events in Italy have highlighted the high vulnerability of artworks which, due to their fragility, are highly susceptible to damage from shaking, overturning and collisions.

Several studies have proposed solutions to mitigate the vulnerability of these objects to seismic and human actions. Pieraccini et al. [1] investigated the effect of urban loading and the passage of tourists on Michelangelo's David exposed at the Accademia Gallery. Sonda et al. [2] proposed an innovative isolation system for Michelangelo's Pietà Rondanini.

In this regard in 2019 the National Institute of Geophysics and Volcanology (INGV) and the Department of Architecture of the University of Florence (DIDA) undertook a long-term seismometric monitoring campaign, still ongoing, of the National Archaeological Museum "Gaio Cilnio Mecenate" in Arezzo. The museum represents an emblematic case-study since it is an artifact of historical and architectural importance containing a wide variety of artistic and archaeological heritage.

In a context of such historical value the Structural Health Monitoring (SHM) system represents a completely non-invasive diagnostic technique that does not interfere with the use of the building. To record the free vibrations of the structure seismometric devices were installed on each floor. Continuous data acquisition has allowed to record environmental noise streams to identify and monitor potential evolving conditions of mechanical properties that could affect the safety of the structure. The oscillation levels were then compared with the standards provided by national codes.

The present study represents a first step toward understanding how much of the cultural heritage exhibited in the museum is at risk.

2 THE NATIONAL ARCHAEOLOGICAL MUSEUM OF AREZZO

The National Archaeological Museum "Gaio Cilnio Mecenate" is hosted in the former olivetan monastery of St. Bernardo in the historic center of Arezzo, Tuscany. The building stands on the ruins of an ancient Roman amphitheater dated between the end of the first century AD and the beginning of the second century AD. In 1333 the property was donated to Abbot Bernardo of Mino Tolomei of Siena, who built the monastery later dedicated to him. The monks used the pre-existing walls as foundation elements and were thus obliged to follow the layout of the amphitheater, realizing a non-straight central corridor with a broken course parallel to the South facade. In the eighteenth century the building underwent further transformations, including the realization of a wider and more rectilinear ambient that cancels the perspective effect given by the broken corridor. In 1823 the convent complex opened as the Archaeological Museum, becoming a state museum 150 years later. Between 1929 and 1934 the building was further enlarged and regularized in its interiors and underwent radical transformations as a result of major rehabilitation works. A few years later the complex suffered very serious damage as a result of the 1943 bombing that destroyed the church, the bell tower and the northern cloister. In the 1985-1995 decade the building was finally affected by interventions that involved the slabs of the various levels.

3 GEOLOGICAL AND GEOTECHNICAL SETTING OF THE AREA

The museum is located in an area corresponding to the paleo creek bed of the Castro stream that runs through the built-up area of Arezzo. The lithology of the area is characterized by holocene fluvial-lacustrine deposits consisting of gravels and sandy clays with intercalations of peat levels. These lithologies are not particularly risky for the stability of the building: both the substrate and the soil do not have a conformation such as to lead to high degrees of local amplification, nor is the soil at risk of liquefaction.

4 DATA ACQUISITION INSTRUMENTS

The instrumentation used for the dynamic monitoring of the museum consists of four SARA triaxial seismometric stations composed of a 24-bit SL06 digitizer matched to an SS20 seismometer having an own frequency of 2 Hz. A seismic station was installed for each floor and each station was connected to a GPS antenna for synchronization. The horizontal components of the sensors were oriented along to the North-South and East-West axes, corresponding respectively to the transverse axis and longitudinal axis of the building. From 17/12/2019 the stations were activated in continuous acquisition at a sampling rate of 200 sps.

5 SOURCES OF VIBRATION

5.1 Effects of anthropogenic factors

The continuous recording of environmental seismic noise allowed the identification of daily and weekly periodicities. The daily trend is characterized by increasing signal amplitude during the morning hours until reaching a maximum that remains constant throughout the morning. During the afternoon hours there is a gradual decrease in signal amplitude until reaching a minimum during the night-time. The same characteristics are found when observing the weekly trend of the signal: differences emerge in terms of seismic noise amplitude between weekdays and holidays, when the signal appears less intense. This overall trend in amplitudes highlights the dependence of the structure behavior on anthropogenic activities taking place in its vicinity.

The records include the period of activity closure caused by the epidemic emergency due to the CoVid-19 virus and allowed to assess how much the arrest affected the environmental seismic noise level. Since March 2020 there has been a decrease in the level of high-frequency environmental seismic noise and therefore related to human activities. However the day-night trend continues to be well recognizable in temporal trends and this suggests that much of the noise sources due to anthropogenic activities continued to be present.

Waveforms also show that during the night-time period in particular stations recorded numerous transients of very high amplitudes. The presence of the railway line less than 200 m from the museum suggests that most of the transients are due to train passages during the night. The structure due to the more energetic transients undergoes slight temporary changes that are reabsorbed when the transient effect ends. The magnitude of the change is on the order of 3% of the modal frequency in the absence of disturbance, but the amplitudes of the oscillation are extremely small and should not be a problem from a damage point of view.

5.2 Effects of seismic actions

The municipality of Arezzo is located in an area classified as seismic zone 2 (zone with medium seismic hazard where strong earthquakes can occur). Continuous monitoring allowed to record seismic events that occurred during the period of operation of the seismic stations. With reference to the event that occurred in Pieve Santo Stefano (AR) on 12/07/2020 of magnitude 3.0, the strongest among the earthquakes occurred at a shorter epicentral distance, the maximum displacement value was recorded by the station in the attic in the N-S component. The displacement was on the order of about 4 μm, five times greater than that recorded by the station in hypogeal rooms. The shaking produced by the event did not produce a significant variation in the main frequency.

6 VIBRATIONS AND EFFECTS ON BUILDINGS

Vibrations within a building can be produced by sources external to the base of the buildings or by forces that originate within the buildings themselves. Specific codes set maximum permissible amplitude and frequency values beyond which effects of damage or disturbance to buildings or persons may occur. The most recent national code is the UNI 9916 [3]. This code identifies velocity as the physical quantity used to measure vibration from the perspective of damage on buildings. It defines two parameters that provide a quantitative measure of vibration and sets the permissible limits depending on the type of source producing the vibrations and their frequency content:

- point peak velocity (ppv), defined as the maximum in a fixed time interval of the modulus of the velocity vector in a three-dimensional space

$$ppv = \max(\sqrt{X^2 + Y^2 + Z^2}) \tag{1}$$

- point peak velocity of a component (pcpv), the maximum value in a fixed time interval of the modulus of one of the orthogonal components of motion measured simultaneously

$$pcpv = \max(|Z|) \; pcpv = \max(|X|) \; pcpv = \max(|Y|) \tag{2}$$

In the case of short-term vibrations, such that fatigue phenomena can be excluded, the code provides that pcpv (2) should be considered. For vibrations due to mine blasts, engines, traffic, the parameter to be used is ppv (1). The limit values given by [3] are expressed as a function of the type of sources, building classification and involved frequency band. The maximum threshold value of the pcpv for buildings of cultural interest is 8 mm/s recorded at the upper floor of the building.

7 ANALYSIS OF RECORDED DATA

In the case of the National Archaeological Museum of Arezzo data recorded by the velocimeter installed in the attic of the building were used. The hourly ppv, over a frequency band between 8 and 20 Hz, and the hourly pcpv were calculated on several week-long recording intervals selected over the entire monitoring period. The following ranges were chosen:

05/02/2020	11/02/2020
29/02/2020	06/03/2020
10/03/2020	16/03/2020
17/03/2020	23/03/2020
07/05/2020	13/05/2020
08/06/2020	14/06/2020
18/11/2020	24/11/2020
01/03/2021	07/03/2021
22/07/2021	28/07/2021
10/01/2022	16/01/2022

Table 1: Selected recording intervals.

Figure 1 shows the pcpv trends on the three components of motion for three different monitoring periods. Each color corresponds to a component of the motion, the dashed blue line corresponds to threshold limit provided by code. The reference period (year, julian day) is reported in each graph.

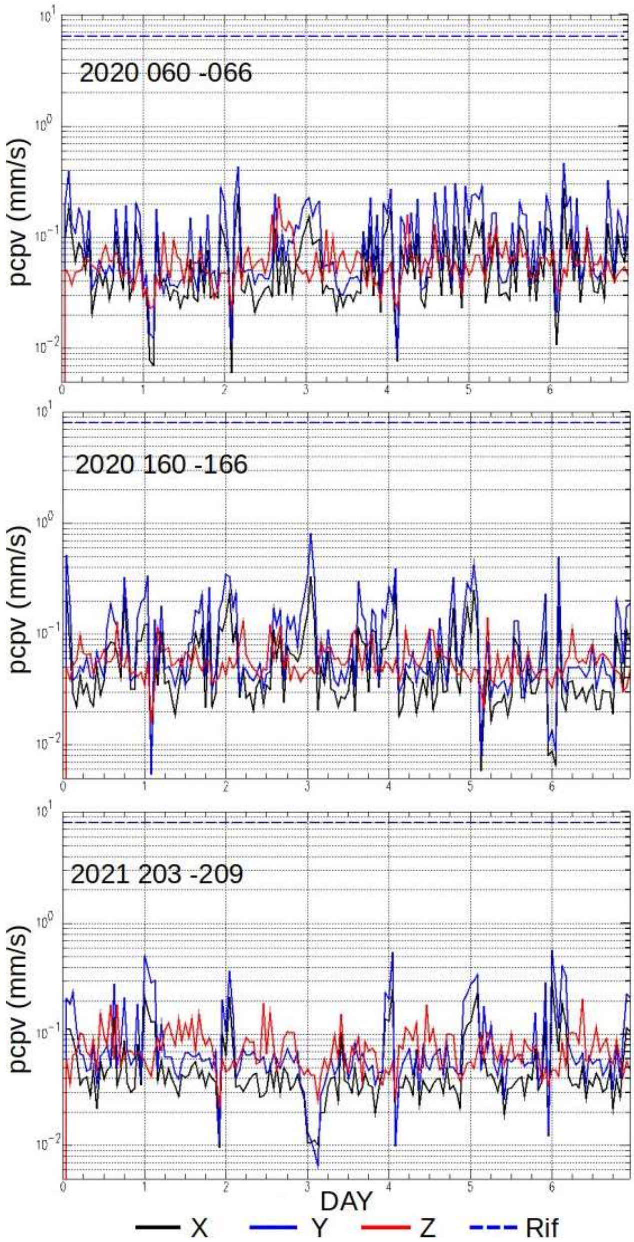

Figure 1: Hourly pcpv calculated for different intervals during monitoring time.

Figure 2 shows the hourly ppv trends for the same intervals as Figure 1. Each color corresponds to a different recording period, the dashed blue line corresponds to the threshold limit provided by code. Both pcpv and ppv show trends of hourly vibration maxima that are well below the threshold provided by code for buildings of historical interest. Vertical components have slightly lower pcpv values than horizontal ones. Among these the transverse component (Y) to the main axis of the building presents slightly higher values than the longitudinal one (X). A periodicity of about one day is recognizable in both trends, particularly evident in the high-frequency band over which ppv was calculated (Figure 2). This highlights the dependence of vibrations on the rhythm of human activities, with the lowest level of the oscillations corresponding to the night-time hours and the highest level corresponding to the central hours of the day.

From 9/03/2020 to 18/05/2020 there was the period of non-essential activity closure due to the SARS-COV2 epidemic. Numerous scientific papers ([4], [5], [6]) have shown that during this period the average seismic noise level was significantly reduced within urban areas. Figures 3 and 4 show the trends of pcpv for each motion component and ppv calculated for seven-day intervals before (29/02/2020 – 06/03/2020), during (13/03/2020 – 19/03/2020) and after (08/06/2020 – 14/06/2020) the lockdown. The colors indicate the recording periods according to the legend. In the distribution of maxima (Figures 3 and 4) a slight reduction in amplitudes during the lockdown with respect to the other periods is quite evident. The effect is particularly clear when looking at the trend of the root mean square (RMS). Figure 5 shows the comparison of the RMS calculated on each component of motion for the same monitoring periods used for the evaluation of pcpv and ppv in Figures 3 and 4. The different colors indicate the recording periods according to the legend.

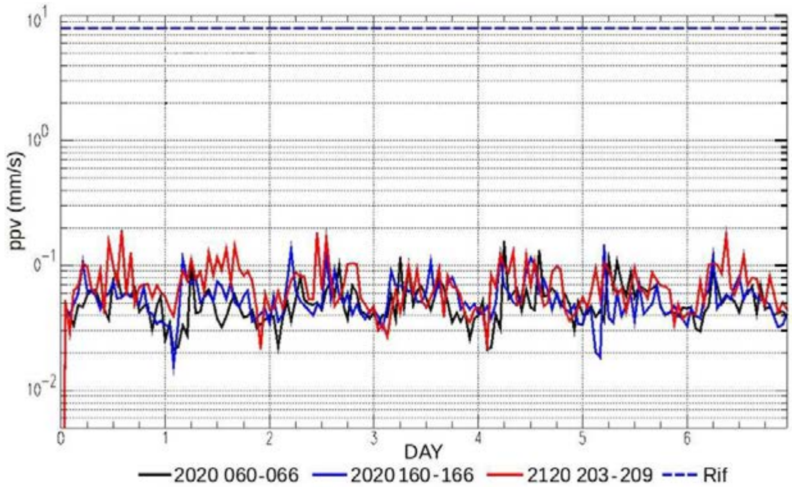

Figure 2: Hourly ppv calculated for different intervals during monitoring time.

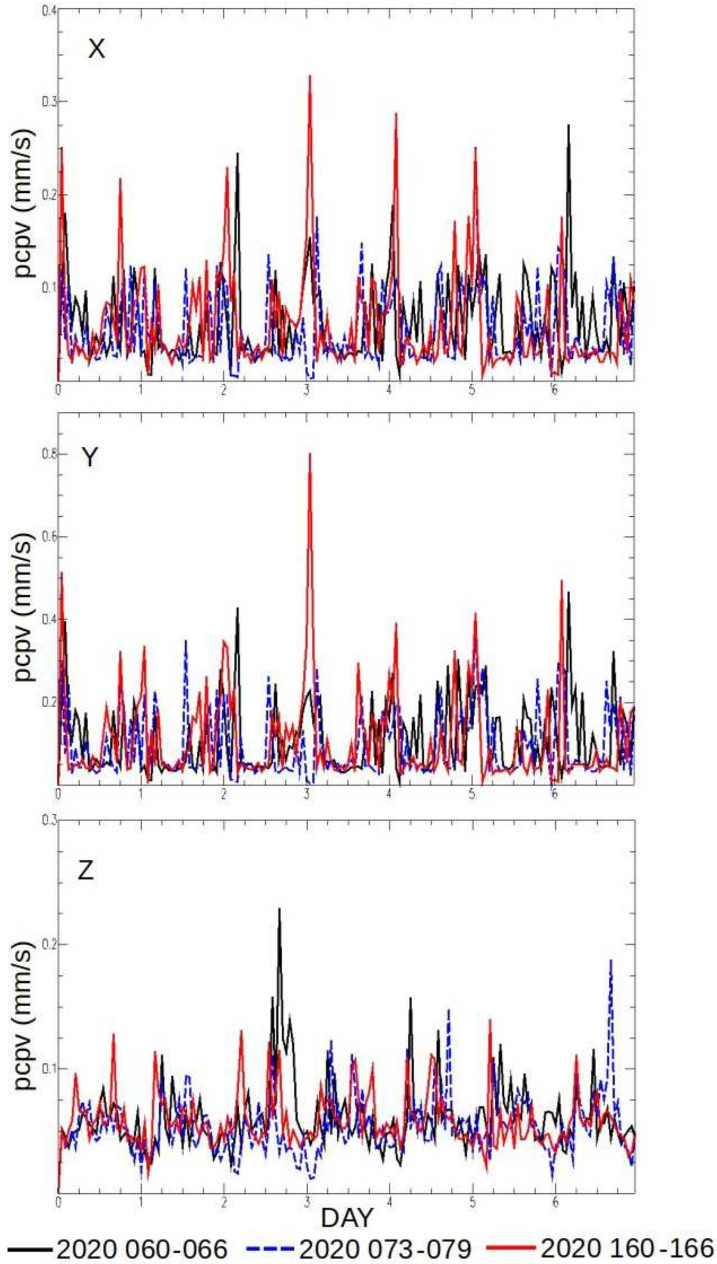

Figure 3: Trends of pcpv before, during and after the total activity closure period for Sars-COV2 epidemic.

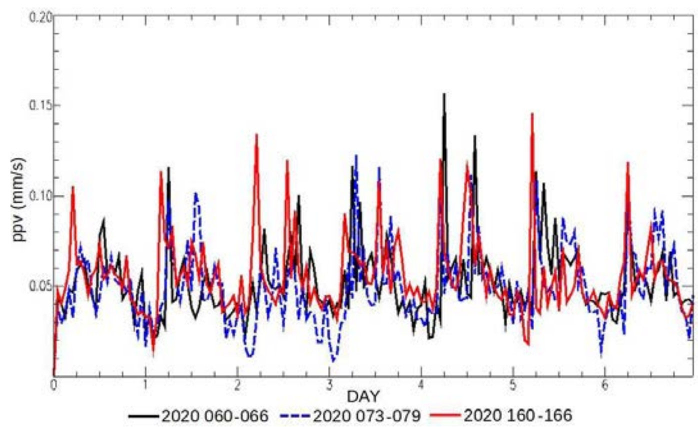

Figure 4: Trends of ppv in the 8-2 Hz spectral band before, during and after lockdown for Sars-COV2 epidemic.

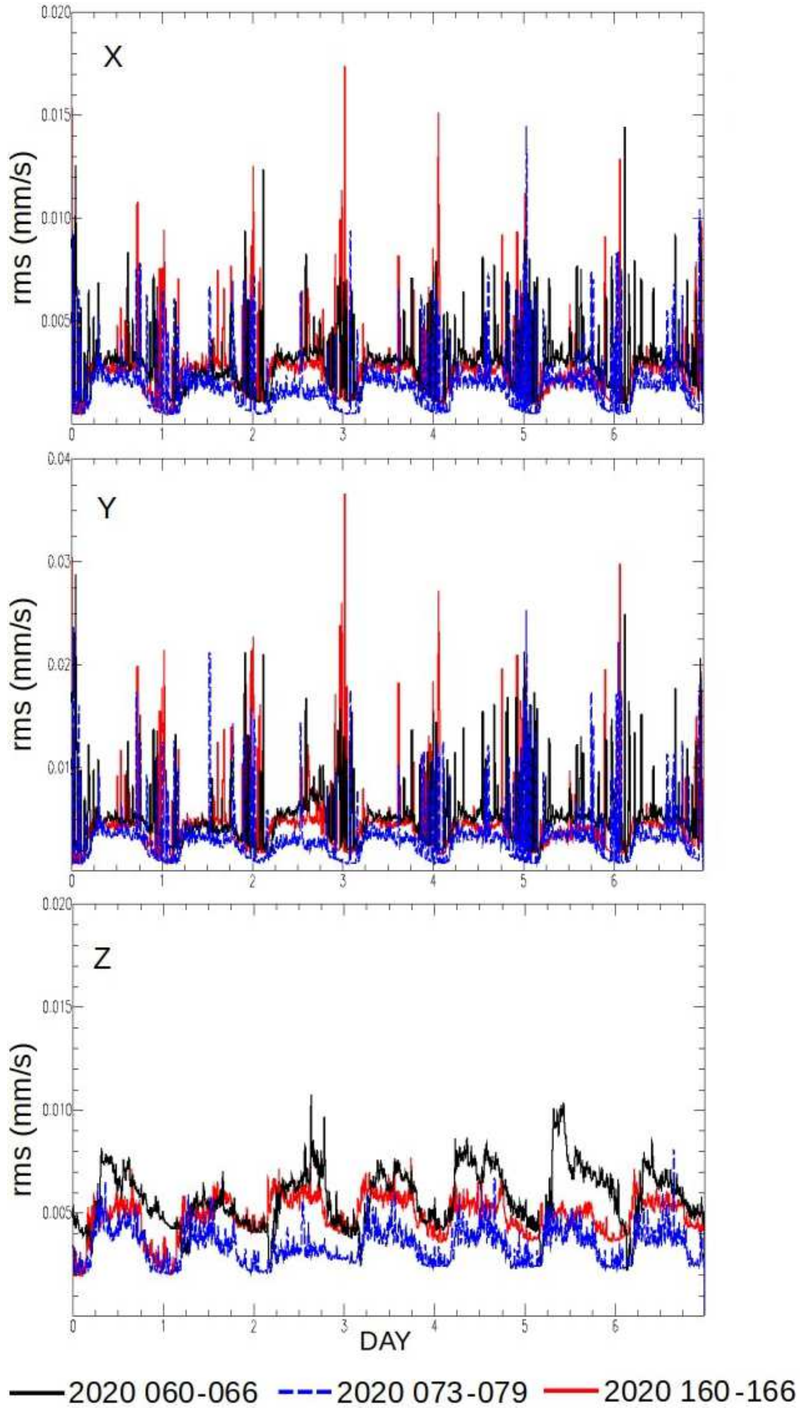

Figure 5: Trends of RMS before, during and after the total activity closure period for Sars-COV2 epidemic.

8 CONCLUSIONS

The National Archaeological Museum "Gaio Cilnio Mecenate" of Arezzo was the subject of a continuous seismometric monitoring campaign having the aim of identifying the dynamic characteristics of the building and assessing how much environmental seismic noise affects its dynamic response. The analysis of the data recorded through the monitoring network placed inside the museum allowed to identify anomalies in the structure behavior during seismic actions, anthropogenic activities and night-time transients. The recorded data were then compared with the threshold values provided by code beyond which damage on buildings and disturbance to users could occur. The results show that ambient noise levels from human activities, traffic, transients and seismic events always remain below the limits provided by code. The results also highlight the crucial role of environmental seismic noise which, from being an element of seismic disturbance, has become a source of information significant for monitoring and structural assessment of buildings and objects contained within them.

Despite recent research efforts for seismic evaluation and efficient protection of freestanding components and art objects, the dynamic properties and seismic vulnerability of the most common museum system configurations are still not thoroughly investigated. The acquired experience may provide a useful base for further developments of the topic at the artwork level and it may indicate the ranking of vulnerability of the entire collection in order to proceed with more detailed analyses and possible solutions for protection and isolation of artworks. The relevance of this issue from a cultural and a political-economic point of view, the high seismic vulnerability of our buildings and the uniqueness of the artworks recall the urgency of addressing the problem.

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