Anti-Seismic Marble Basements for High Vulnerable Statues in Italy: Bronzes of Riace, Annunciazione by Francesco Mochi, San Michele Arcangelo by Matteo di Ugolino

New anti-seismic basements made of marble and granite have been developed by ENEA for earthquake protection of the *Bronzes of Riace* at the Archeological Museum of Reggio Calabria, the *Annunciazione* by Francesco Mochi and the *St. Michele Arcangelo* by Matteo di Ugolino at the Opera del Duomo Museum of Orvieto, Italy. These basements are also useful for the preventive conservation of other high vulnerable statues with analogous reduced support at the base, such as the *David by Micheangelo* in Florence

Gerardo De Canio, Simonetta Bonomi, Alessandra Cannistrà

Introduction

This paper describes the new anti-seismic basements made of marble for earthquake protection of high vulnerable statues of primary importance in Italy:

- two *Bronzes of Riace* at the Archeological Museum of Reggio Calabria,
- three statues at the Opera del Duomo Museum (MODO) of Orvieto, namely: the two marble statues of the *Annunciazione* made by Francesco Mochi, and the bronze statue of *S. Michele Arcangelo* made by Matteo di Ugolino da Bologna.

The new basements are also useful for other high vulnerable statues standing on their legs, e.g., the David by Michelangelo in Florence. The design approach of the basements was to confer the seismic isolation property to the geometry of the surfaces, according to the following design targets: maximum seismic isolation, low stiffness and low dissipation; reversibility; full compatibility of the materials; easy maintenance.

Gerardo De Canio
ENEA, Unità Tecnica Tecnologie dei Materiali
Simonetta Bonomi
Soprintendente per i Beni Archeologici della Calabria
Alessandra Cannistrà
Curatore Museo OPSM - Opera del Duomo di Orvieto

Anti-Seismic Basements for the Bronzes of Riace

The two statues, *"Bronze A the young"* and *"Bronze B the old"*, were previously located at the ground level of the museum and provided with laminated rubber anti seismic devices. Moving the statues from the ground

level to the new exposition room on the first floor of the museum required the upgrading of the basements according to the new seismic classification of the site and the change in the maximum hazard spectra. The previous devices inserted in the old basement provided a seismic isolation coefficient value of 2.5-3 and, to avoid overturning, the statues where anchored with strengthening forces of 1800N applied to each shoulder by means of steel cables inserted in the cave legs (ref. [1]). The need to reduce the strengthening anchoring forces, together with the new expected seismic demand due to the new seismic classification, induced to re-design the anti-seismic basements to increase the isolation coefficient, reducing the risk of exceeding the seismic capacity of the two statues.

The design results are, for each statue, a basement made of two blocks of marble type *Carrara*, showed in Fig. 1, and the surfaces of the blocks modelled as an ellipsoid of revolution, where 4 spheres made of the same material of the blocks are located. In short, the basement is made of the following elements: *BI= marble lower block, S= marble spheres, DO= Horizontal*

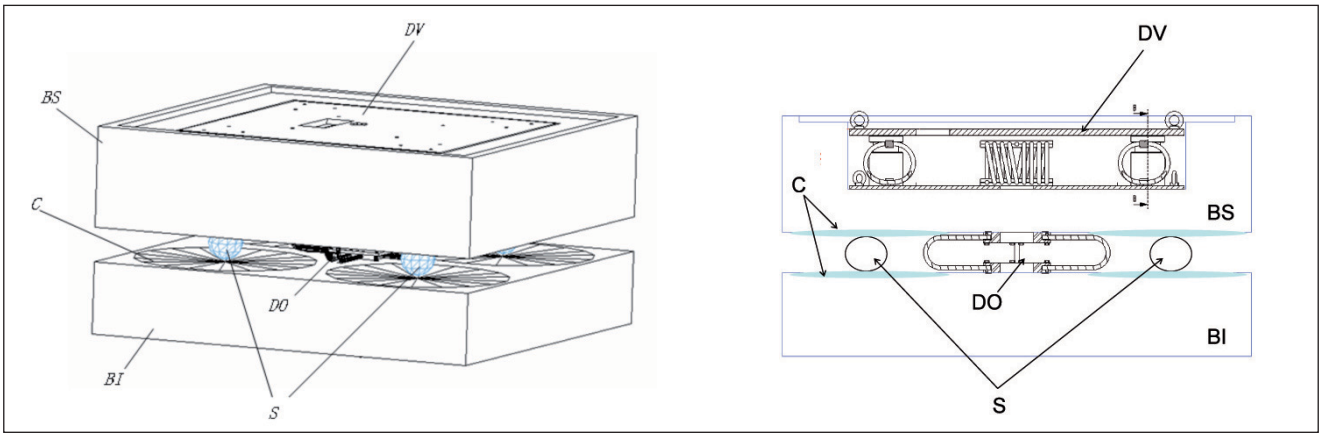

FIGURE 1 Marble anti-seismic basement for the Bronzes of Riace
Source: ENEA

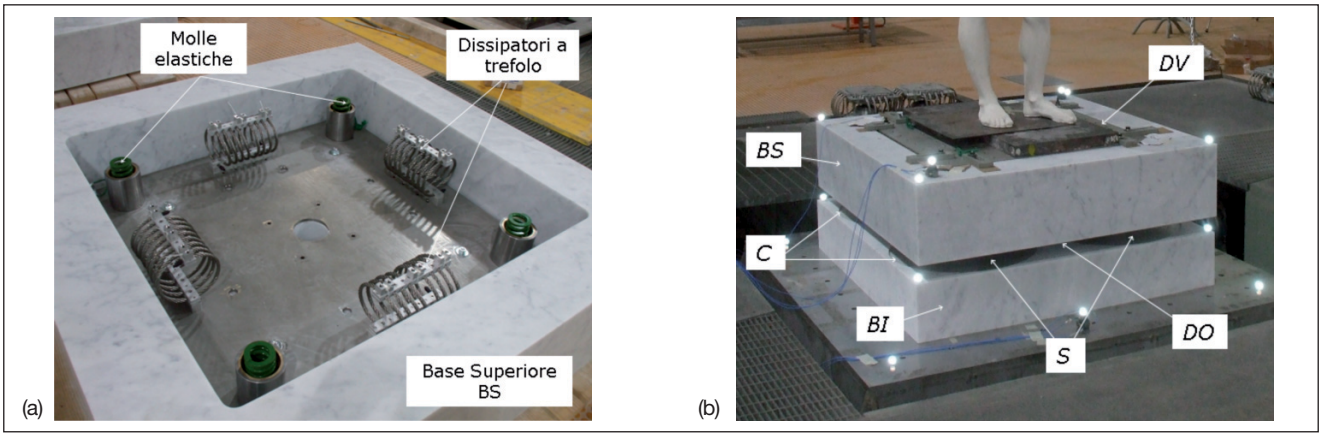

FIGURE 2 Marble basement for the Bronzes of Riace: a) Details of the vertical isolation device inserted into the upper block, b) Basement ready for the shaking table tests
Source: ENEA

displacement limitation and *re-centering device, BS= marble upper block, DV=vertical isolation device* inserted in the BS upper block.
However, stiffness and principal frequency of the basement are not constant, due to the elliptical geometry of the rolling surfaces, the principal frequencies are ranging from 0.015Hz to 0.025 Hz depending on the position along the surface, with zero value at the centre, where the re-centering function is demanded to the element *DO*. The vertical isolation is provided by two stainless steel plates connected by four shock absorbers made of dissipative cables plus four springs inserted in piston guides confining and de-coupling the vertical and the horizontal motions, therefore the horizontal isolation is demanded to the basement geometry and the vertical isolation is demanded to the shock absorbers inserted in the upper basement.

Shaking Table Tests

The shaking table tests on the basements have been performed at the Qualification of Materials

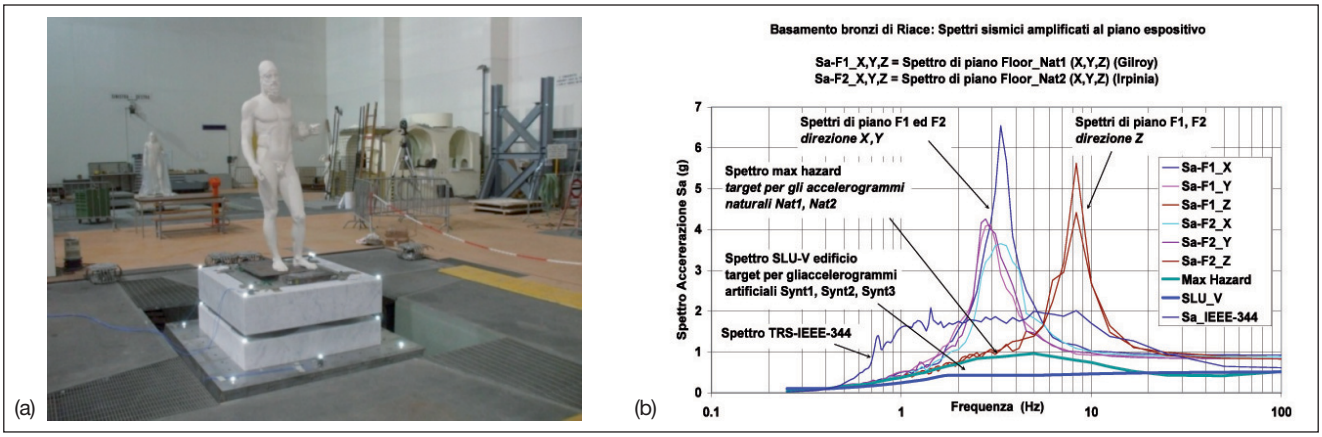

FIGURE 3 Shaking table tests of the marble anti-seismic basements for the Bronzes of Riace (ref. [2]): a) test set-up, b) test acceleration spectra at the base table
Source: ENEA

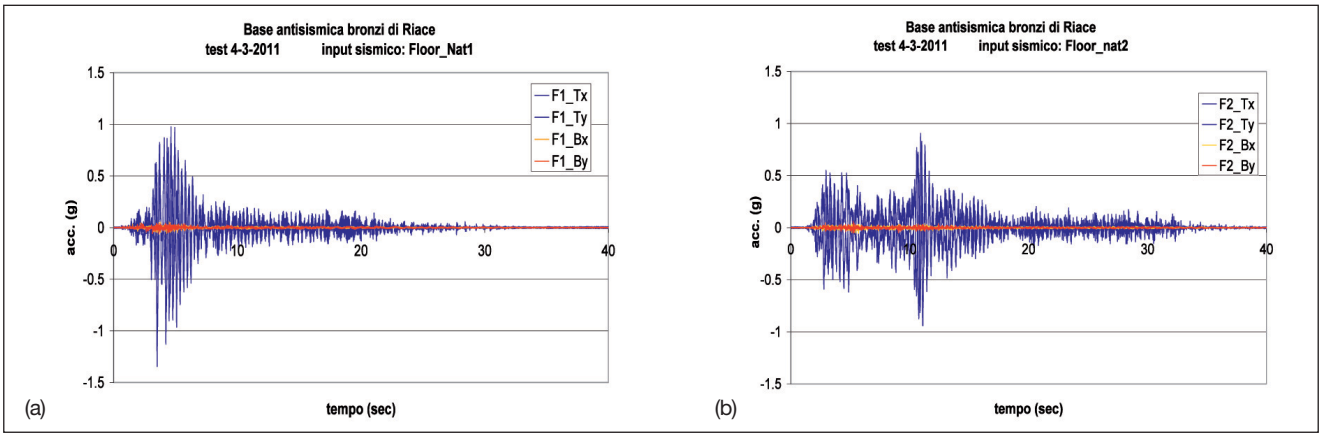

FIGURE 4 a) Floor-Nat1, F1_Tx,y= base table, F1_Bx,y= basement. Isolation Coeff.= 22; b) shaking table test Floor-Nat2, isolation Coeff.= 20
Source: ENEA

and Components Laboratory of the ENEA Casaccia Research Centre, Rome (Italy); test set-up and details of the basements are showed in Fig. 3.
The input time histories were natural accelerograms rescaled to the max hazard of Reggio Calabria, return period of 2475 years, amplified on the first floor of the museum. Also three artificial accelerograms were applied, compatible to the Ultimate Limit State of the museum amplified on the first floor at different damage conditions of the building. At the end of the test campaign were three X,Y,Z accelerograms also applied, compatible with the RRS (Required Response Spectrum) for NPP (Nuclear Power Plant) class 1-E equipment (essential for safety) in compliance with the IEEE-344 specifications. All tests reached the reduction coefficients of 15-20 for the horizontal accelerations and 2.5-3 for the vertical accelerations; the overall maximum acceleration measured on the basement in all the tests was 0.08g.
During the tests with natural earthquake, the max acceleration peak on the basement was 0.062g. In the vertical direction, with Peak Floor Acceleration PFA=2g, with isolation coefficient 2.4 and max basement vertical acceleration 0.86g.

The two forces of 1800N at each leg to prevent overturning are not yet necessary and have been reduced to 600N and 300N in the new basement, just to replace the weights of the shield on the left arm and the lance on the right arm.

Anti-Seismic Basements at the Opera del Duomo Museum, Orvieto, Italy

In this chapter the anti seismic basements for the two marble statues of the Annunciazione by Francesco Mochi, and the bronze statue of *S. Michele Arcangelo* at the Opera del Duomo Museum of Orvieto in Italy are described, as well as the design of the basements for the 12 statues of the St. Apostles, either if the 12 statues will be repositioned in the Cathedral or in the annexed Museum.

Annunciazione by Francesco Mochi

Devices of the same family as those for the Bronzes of Riace have been developed for the Annunciazione by Francesco Mochi at the Cathedral of Orvieto (Fig. 5)
The devices, made of black granite, will be positioned

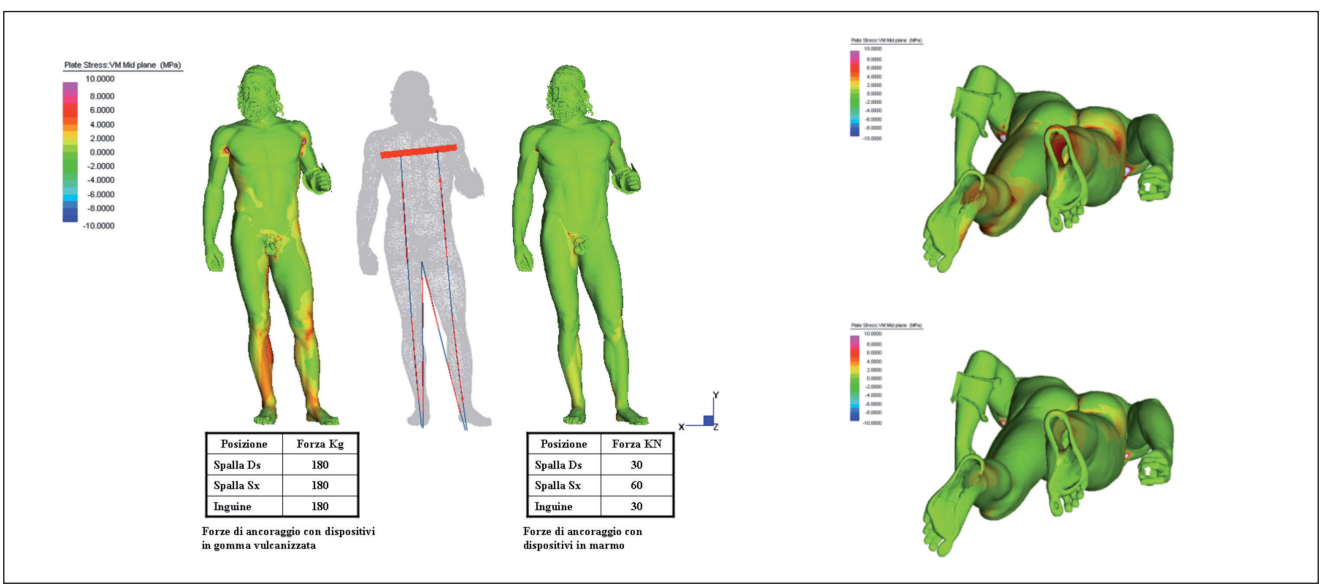

FIGURE 5 Bronze A: comparison of the stress fields by the old and new strengthening forces
Source: ENEA

FIGURE 6 The Cathedral of Orvieto (Italy) and the two statues of "The Annunciazione" by Francesco Mochi
Source: ENEA

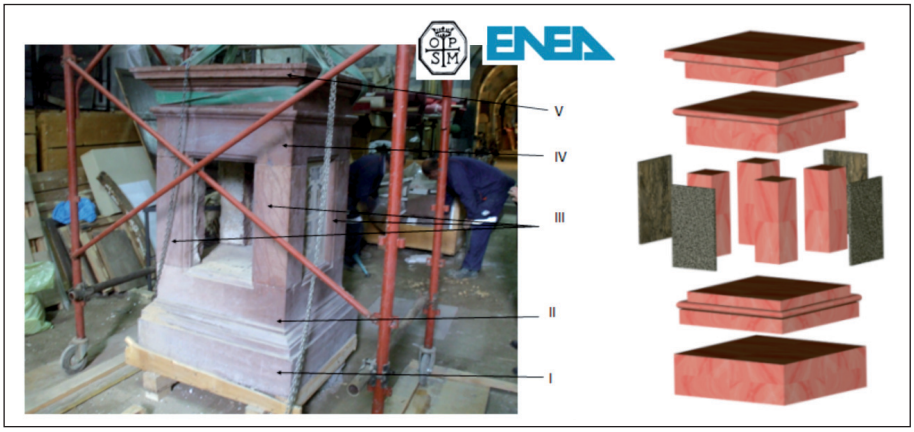

FIGURE 7 Original basement composed of several blocks
Source: ENEA

FIGURE 8 The anti-seismic basement for The Annunciazione by Francesco Mochi
Source: ENEA

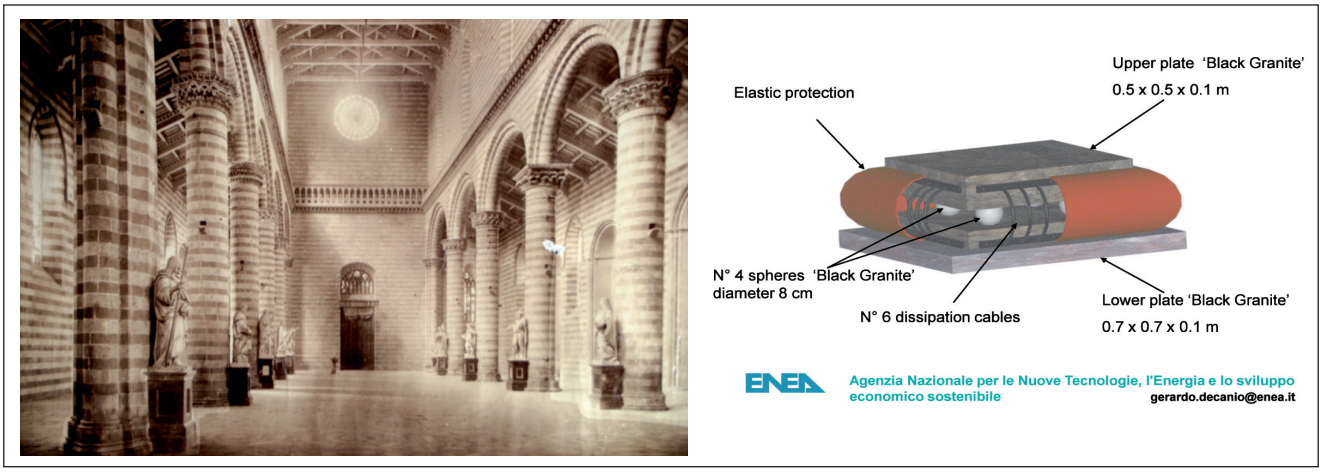

FIGURE 9 Image rendering of the repositioned statues of the 12 Apostles in the Orvieto Cathedral (ref. [3]) and the Black Granite anti-seismic device
Source: ENEA

on the original basement and covered with the same stone.

The two statues representing *The Annunciazione*, together with other 12 statues representing the St. Apostles were removed from the Cathedral of Orvieto in the XIX century. The rendering in Fig. 9 show the statues of the 12 Apostles as they will look if repositioned in the Cathedral. In the figure the design of the anti-seismic device for the 12 statues is also represented, either if they will be repositioned in the nave of the cathedral or in the Museum.

S. Michele Arcangelo by Matteo di Ugolino

Figure 10 represents the bronze statue of S. Michele Arcangelo on the façade of the Cathedral and the design of the new basement with the granite anti-seismic device.

This statue was heavily deteriorated by severe weather conditions and large oscillations due to inadequate strengthening forces, therefore the statue was removed from the façade and then moved into the museum, at the end of its restoration.

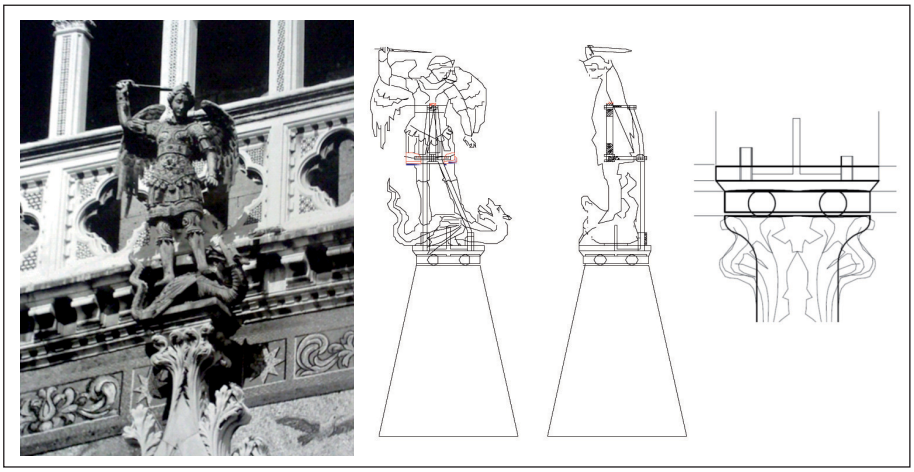

FIGURE 10 *S. Michele Arcangelo* on the façade of the Cathedral and design of the basement for the museum exposition
Source: ENEA

Marble Basement for High Vulnerable Statues: Proposal *for the David* by Michelangelo

The ***David by Michelangelo*** in Florence, Italy, one of the statues of the absolute importance ever acknowledged by humankind, is highly vulnerable to earthquakes because it is standing directly on its feet and because the legs are seriously cracked. Therefore, the same type of basement can be useful to protect this statue from earthquake-induced overturning and shear stress. In this case, due to the mass of the actual basement and statue, a marble basement of 2m x 2m with 25 spheres as shown in Fig. 2, are needed.

Conclusions

New anti-seismic basements made of marble have been developed for high vulnerable statues in Italy. For the ***Bronzes of Riace***, the very low acceleration at the base of the statues allows to reduce the strengthening forces to the values equivalent to the shield on the left arm and the lance on the right hand. Basements of the same family have been used for the two statues of the ***Annunciazione*** by Francesco Mochi, and the ***St. Michele Arcangelo*** by Matteo di Ugolino at the Opera del Duomo Museum of Orvieto, Italy. Analogous basements have been designed for the statues of the ***12 Apostles*** to be positioned either in the Orvieto Cathedral or in the annexed museum.
The results allow to propose the same type of basement for the ***David by Michelangelo*** in Florence, Italy.

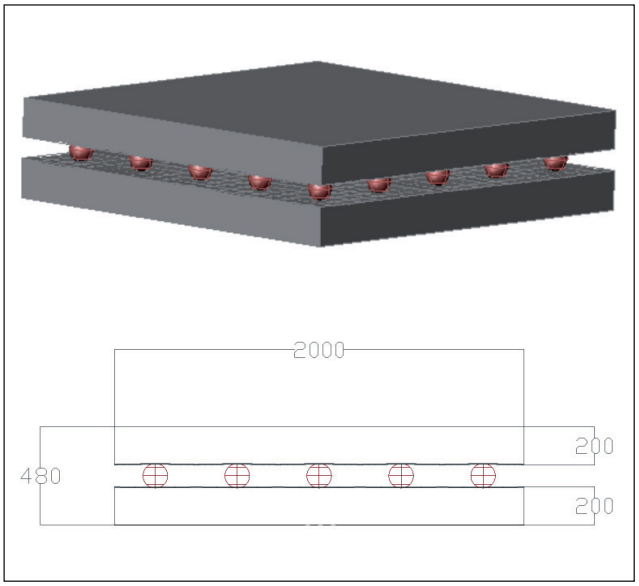

FIGURE 11 Proposal for the base isolation for the *David by Michelangelo*
Source: ENEA

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