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The new base-isolated Research Center of the Camerino University: design and testing

A. Dall'Asta[1], G. Leoni[1], F. Micozzi[1], L. Gioiella[1], N. Ceccolini[1], and L. Ragni[2]

[1] University of Camerino, Ascoli Piceno, Italy
[2] Università Politecnica delle Marche, Ancona, Italy

Abstract

This paper deals with the new Research Centre designed for the University of Camerino built following the seismic events in Central Italy in 2016. The first part of the paper illustrates the design choices made for the isolated structure to achieve a high level of resilience and robustness of the building, i.e. to limit damage to structural and non-structural components and equipment under moderate and design seismic actions and to avoid disproportionate consequences in the event of extreme actions, larger than the design ones. The second part of the paper is focused on static and dynamic tests performed during the construction phase of the building. At the end of the structural system construction (including sub-structures, the isolation system composed by elastomeric bearings and flat sliders and the steel super-structure), the building has been tested by means of static and dynamic (snap-back) in-field tests up to a displacement of the isolation system of 280 mm and 220 mm, respectively. Displacements have been imposed by means of a properly designed testing mechanism and different measure instruments have been placed in the building to register the structural response.

Keywords: Hybrid base-isolation system, elastomeric bearings, seismic reliability, seismic robustness, in-field tests, in-field snap-back tests.

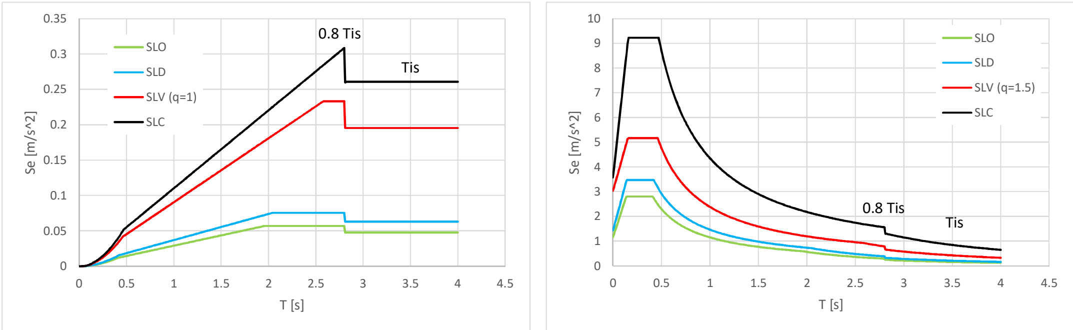
1 Introduction

The research centre of the Camerino University is one of the buildings that have been built after the seismic events in Central Italy in 2016 and financed by the national

Civil Protection Department (DPC). The building is conceived to guarantee speed of execution as well as a high level of safety, due to the potentially high-risk activities carried on in the chemistry and physics laboratories. The building is also intended for public use and may even become a coordination centre of civil protection where managing post-earthquake activities. The structural design solution chosen is an isolated system with a steel braced super-structure with pinned joints and a r.c. sub-structure able to adapt to the complex morphology of the area. The hybrid isolation system comprises High Damping Rubber Bearings (HDRBs) and low-friction sliders (LFSs) and has been designed by adopting procedures and strategies able to guarantee a high level of reliability, resilience (i.e. absence of damage even after strong events) and robustness (i.e. safety against very severe actions larger than the design ones). The first two objectives have been reached by adopting a large isolation period able to drastically reduce seismic actions in the super-structure. In particular, an isolation period within the range of constant displacements has been assumed, so that the system is also not very sensitive to the variation properties of the HDRBs. The strategy adopted to obtain an adequate robustness consists in assuming a displacement capacity of both devices and seismic gaps significantly greater than the maximum design displacement and a steel superstructure equipped with over-strength elasto-plastic braces. This permits to limit disproportionate consequences in case of extreme actions causing an increase in the stiffness of the HDR bearings (due to hardening behaviour) or the closure of the gaps. Moreover, the robustness under exceptional scenario (such as fire events or explosions) leading to the loss of vertical bearing capacity of isolators is ensured by adopting safety supports around the devices. Finally, with the aim of further increasing the reliability of the building, an in-field experimental campaign has been planned during the design phase of the building and carried out at the end of the structural system construction. In this paper a brief description of the building is presented first, together with the design procedure of the base-isolation system. Successively, the experimental campaign has been described and preliminary results are illustrated. More detailed information about the design process and tests may be found in [1] and [2].

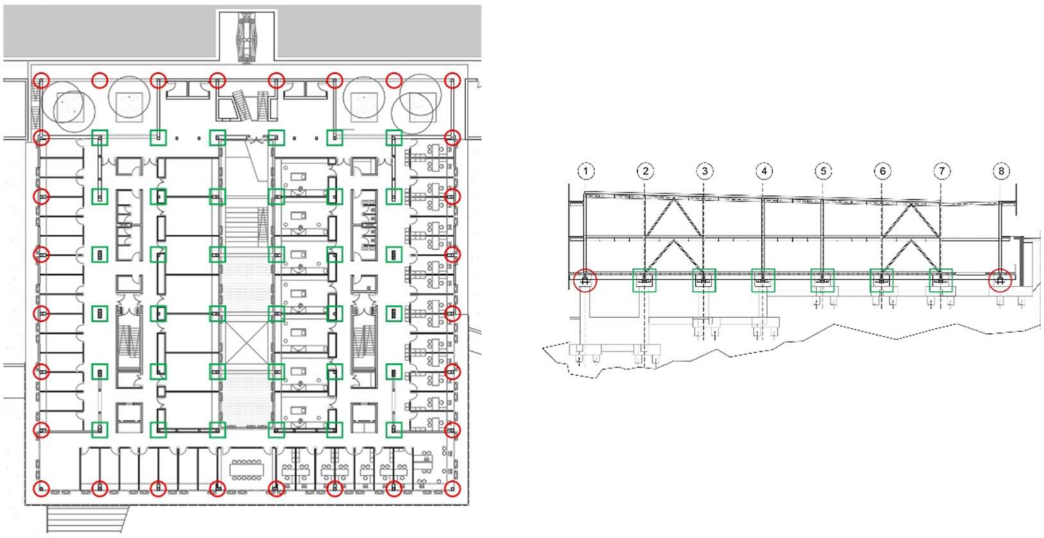
2 Methods

The hybrid isolation system has been preliminary designed by assuming nominal properties for HDRBs at a shear deformation of 100%, i.e. a shear stiffness equal to 0.4 MPa and a damping coefficient equal to 10%, while the friction of the sliders has been neglected since a friction coefficient less than 1% was required. According to the Italian seismic code [3], the design was carried out by considering elastic spectra reduced by the equivalent damping of the HDR bearings for all the periods $T \geq 0.8T_{is}$ (Figure 1). By assuming a design isolation period equal to T_{is}=3.5 s and an average design shear strain equal to γ=1.5 the following isolation devices have been obtained: elastomeric isolators with diameter D_{is}=600 mm, total rubber height h_{is}=184 mm, equivalent stiffness K_{heq}=0.62 kN/mm and displacement capacity d_{max}=350 mm and sliding supports with displacement capacity d_{max}=400 mm. The isolation system configuration is reported in Figure 2, together with a section of the base-isolated building. The effective isolation properties are reported in Table 1. After the design, a modal analysis and a response spectrum analysis of the building have been carried out by modelling all the structural components as linear elastic elements and by assuming for the bearings nominal properties consistent with the level of displacement reached at each considered limit state.



(a) (b)

Figure 1: Displacement (a) and pseudo-acceleration (b) spectra at different limit state



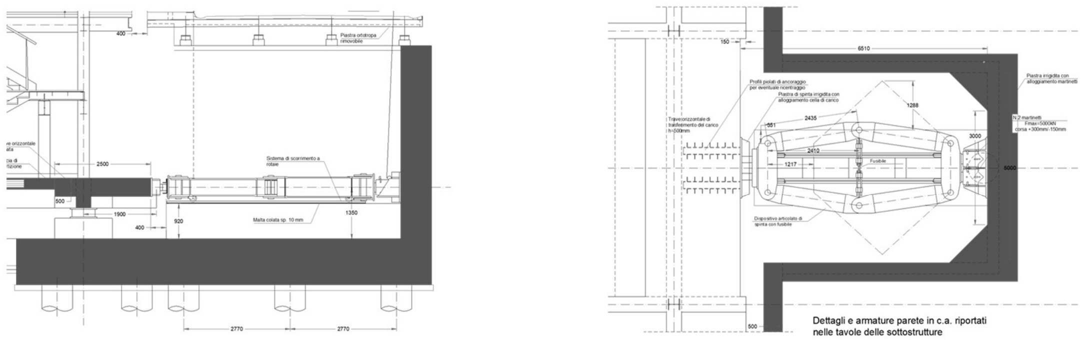
(a) (b)

Figure 2: Plan view (a) and longitudinal section (b) of the building, where red circles represent HDRB bearings and green squares represent flat sliders

Successively, Upper Bound (UB) and Lower Bound (LB) analyses have been carried out in order to account for the variation of the properties of the bearings along the service life of the building. Indications given in the code EN 15129 "Antiseismic devices" [4] have been followed, related to aging, temperature, production variability as well as combination coefficients. The varied properties obtained are reported in Table 1, together with isolation period, damping coefficient (with and without the sliders contribution) and spectral values in terms of pseudo-acceleration and displacement. All the verifications of the isolation system and of the superstructure are satisfied, thanks to the low variation of the displacements in the UB and LB conditions (due to the isolation period which always ranges within the constant displacement region of the spectrum) and the over-strength of the superstructure. Finally, Figure 3 reports a plan view and a longitudinal cross section of the releasing device used to perform the in-field tests and the relevant “reaction box”. The estimated maximum reaction force is about 5000 kN and all the nine piles of the box base slab collaborate in contrasting it.

	γ_{iso} [-]	G [N/m^2]	ξ [%]	ξ_{tot} [%]	T_{iso} [s]	η [-]	S_a [m/s^2]	S_d [m]
Nominal	1.74	0.39	9.12	11.17	3.63	0.79	0.73	0.244
UB	1.78	0.67	9.07	10.27	2.80	0.81	1.26	0.250
LB	1.70	0.30	9.12	11.84	4.13	0.77	0.55	0.239

Table 1: Nominal and varied properties in the UB and LB conditions and relevant characteristics of the isolation system



(a) (b)

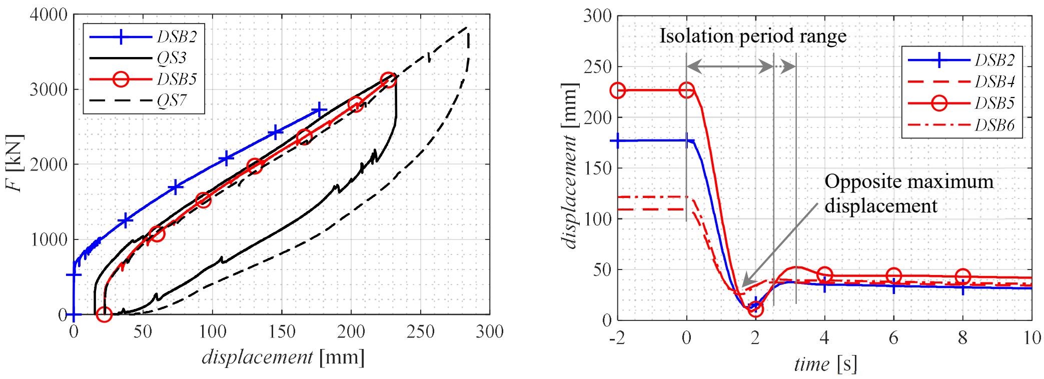
Figure 3: Lateral (a) and plan (b) view of the testing device and its “reaction box”

3 Results

In this section preliminary results of the in-field tests carried out on the building during its construction phase (when the structures were completed) are reported. In particular, a series of Dynamic Snap-Back (*DSB*) tests and Quasi Static (*QS*) tests have been performed by using the equipment described in Figure 3. Measurement instrumentations are placed on both the isolation system (displacement transducers) and the superstructure (accelerometers), but only results relevant to the isolation system are illustrated in this paper. The sequence of the tests, the maximum applied displacements and thrust forces are reported in Table 2. Residual displacements at long time (immediately before the subsequent test) are also reported in the last column of the table. It is worth to note that the last test (*QS7*), in which the maximum displacement has been imposed, shows the largest residual drift (31.4 mm) but a large part of it was recovered after few days from the test (final residual displacement equal to 25 mm). Figure 4 reports response curves in terms of loading force-displacement and displacement time-histories of some *DSBs* and the loading and unloading force-displacement curve of the two *QS* tests.

Test	Date	max displacement [mm]	max Force [kN]	residual displacement [mm]
Pre-test1	3rd July	0.0	518	0.0
DSB2	3rd July	177.3	2729	15.2
QS3	3rd July	232.4	3206	22.1
DSB4	6th July	109.4	1756	22.1
DSB5	6th July	226.9	3122	22.0
DSB6	6th July	121.8	1786	22.4
QS7	6th July	284.6	3834	31.4→25

Table 2: Sequence of the tests performed



(a) (b)

Figure 4: Force-displacement curves of the in-field tests (a) and displacements time-histories of in-field *DSB* tests (b)

From Figure 4a, the breakaway force and the dynamic friction force can be estimated, as illustrated in the graph. The estimated value of the breakaway force is about 700 kN for the first test (*DB2* test) and 500 kN for the following ones, whereas the dynamic friction force is nearly 200 kN. At the end of the *QS* tests the building does not restore its initial position, since the friction force is equilibrated by a residual force of the HDRBs. Once the dynamic friction force is deducted from the response curves, it is evident that the obtained curves are coherent with quasi-static type tests performed during the bearing production [2]. The role of the friction is also evident in Figure 4b, where the free vibration of the building is reported. It can be seen that the building oscillates between a non-zero displacement configuration, but a slow recentring displacement can be recognized by looking at the response after 4 s from the release, confirming the importance of the viscous component of HDRBs response [5]. The isolation period obtained from the tests, ranging between 2.5 s and 3.12 s, agrees with the design one, by considering the lower mass of the building during the tests with respect to the design one.

4 Conclusions and Contributions

In this paper the new research centre of the Camerino University has been described, for which a hybrid isolation system was adopted. The design of the building has been presented first, by highlighting procedures and strategies adopted to guarantee a high level of reliability, resilience and robustness. In particular, the large isolation period adopted in the design leads to drastically reduce the seismic actions on the superstructure and to the achievement of a structural system not very sensitive to the possible variation of HDRBs properties. Furthermore, a capacity sufficiently larger than the design demand in terms of both devices displacements and superstructure braces over-strength, permits to additionally increase the robustness of the building. Finally, the design of the in-field experimental campaign has been developed in parallel with the design of the building and its execution was planned at the end of the structural system construction, in order to verify the actual behaviour of the isolation system. In particular, a quadrilateral articulated steel strut element has been designed and used as releasing device, its location is in a reaction box, which has been realized close to the building and properly dimensioned. A pair of hydraulic jacks, whose force has been monitored through load cells, has been used for the pushing phase, while the displacements of the isolation system has been recorded thanks to horizontal and vertical transducers. Preliminary results, in terms of force-displacement response curves of quasi-static tests and displacement time-histories of dynamic snap-back tests have been showed and discussed. By analysing the force-displacement response curves of the quasi-static tests, both the static and dynamic friction force of FSBs has been estimated. Moreover, the velocity-dependent behaviour of the HDRBs has been observed too for the low velocity used for the quasi-static tests. Finally, the displacement time-histories of the snap-back tests have permitted to estimate the isolation period range and the recentring capacity of the isolation system.

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