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Seismic isolation of La Meynard Hospital, Martinique

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Abstract

The new technical support center of La Meynard hospital is meant to be operational just after an earthquake. This lead to design an isolation system. Rubber bearings have been used together with viscous dampers, which enable to decrease the building acceleration from 12.6 m/s² down to 1.6 m/s². A non-linear time history analysis of a simplified model was used to pre-design the isolation and damping system. The detailed calculations, was done by the company NECS on a 3D finite elements model of the structure, which took into account isolators and dampers. This analysis enabled to improve the design, particularly concerning the dampers orientation. The devices were manufactured by Freyssinet and tested according to NF EN 15129 standard. The installation of the devices was performed at the beginning of the construction. Works will last forty months starting from 2013.

Keywords: Hospital; seismic isolation; NF EN 15129; finite elements; time history analysis

1. Introduction

Pierre Zobda-Quitman Hospital, also known as La Meynard hospital, is located to the north-east of Fort-de-France. It was completed in 1984 to a design in accordance with French seismic design code PS69. Diagnostic work carried out in 2003 confirmed that it would be able to withstand a major seismic event, but that it would no longer be operational for the treatment of patients after the earthquake. The 2010 Haiti earthquake was an electroshock that made the project being launched to enable:

- operability immediately after an earthquake,
- compliance with PS92 and Eurocode 8 [1],
- compliance with fire safety standards.

A new 28,788 m² building is being constructed to house the new clinical support block, together with in-patient units, an elevated heliport and a car park. The estimated budget is €169 million, with 55% of the funds coming from the French government, 20% from the European Union, 15% from the hospital and 10% from the regional authorities. The contract is being performed by a consortium of designers - SCAU/SNCL - and construction companies, Sogéa Martinique (lead contractor) and SIMP (Vinci Construction Dom-Tom), in partnership with Cegelec (Vinci Energies). The earthquake expert is Victor Davidovici. The work is taking place over a period of 40 months, involving 50 contractors and requiring 80,000 m3 of earthworks, 32,000 m3 of concrete, 3,200 t of steel and up to 250 workers on site.

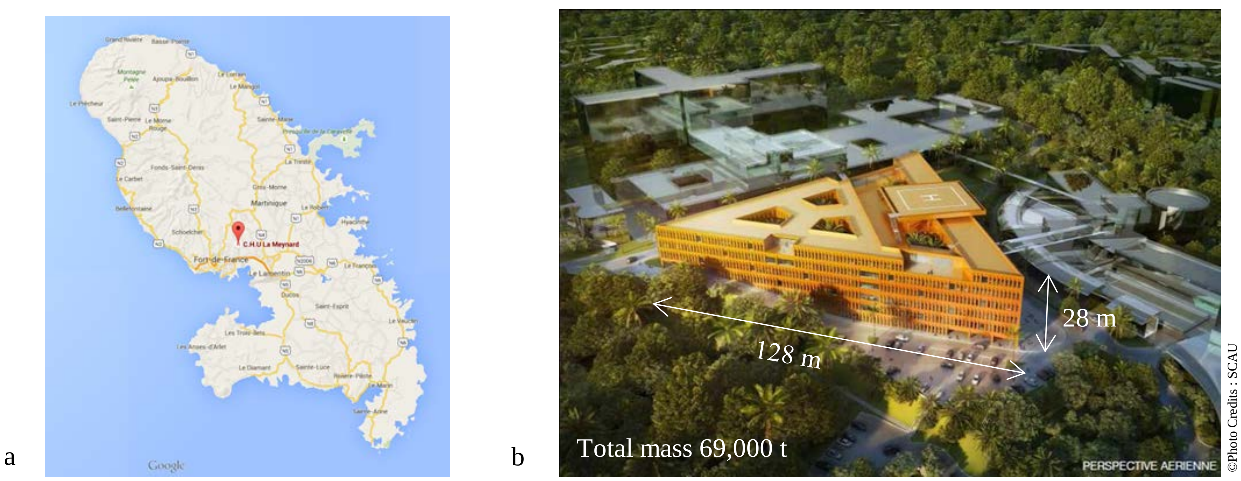
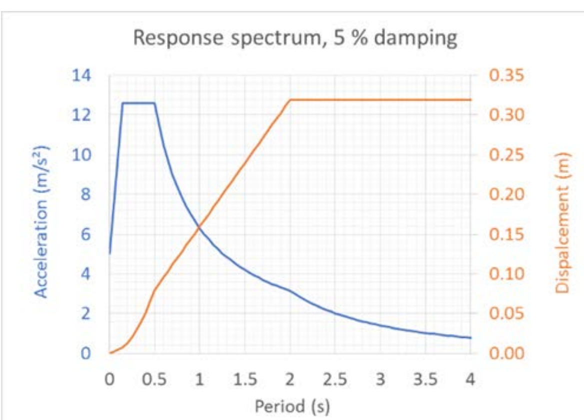


Fig. 1 – (a) Location of the hospital, (b) aerial view, dimensions and mass of the building



Seismic zone	5
Rock acceleration	3 m/s²
Importance factor	$\gamma_I = 1.4$
Topographic amplification	$S_T = 1$
Soil class	B

Fig. 2 – Acceleration and displacement response spectra specified for the project

The importance category IV building is located in a high seismic risk zone (zone 5). As the stability and integrity of the structure cannot be guaranteed at a reasonable cost using a conventional foundation system, the decision was made to isolate the building. The combination of laminated elastomeric isolators and dampers has reduced the acceleration of the isolated system to 1.6 m/s² and limited its displacement to 210 mm.

2. Preliminary design

A non-linear time-history analysis of a simplified model was used to produce a preliminary design for the isolation and damping system. The building was represented by a rigid mass with one degree of freedom. It translates parallel to the load, which is horizontal. The time-history response of the structure was calculated with Newmark's algorithm. The mean of the results obtained with nine artificial accelerograms was applied to determine the acceleration and displacement of the structure in the load direction.

A series of analyses of the isolation system was performed, gradually increasing the total damping coefficient brought by the dampers. The displacement decreases the more the damping increases. However, an optimum damping is found in order to minimise acceleration. It is not possible to completely cancel out the acceleration by increasing the damping, as an over-damped system behaves as if it were fixed to the ground. Its acceleration would therefore be greater than if it was simply isolated without any dampers. The figure below shows the changes in displacement and acceleration as a function of the ratio between the damping coefficient C of the dampers in the load direction and the mass M of the building. In this study, the optimum size is equal to approximately 10% of the mass.

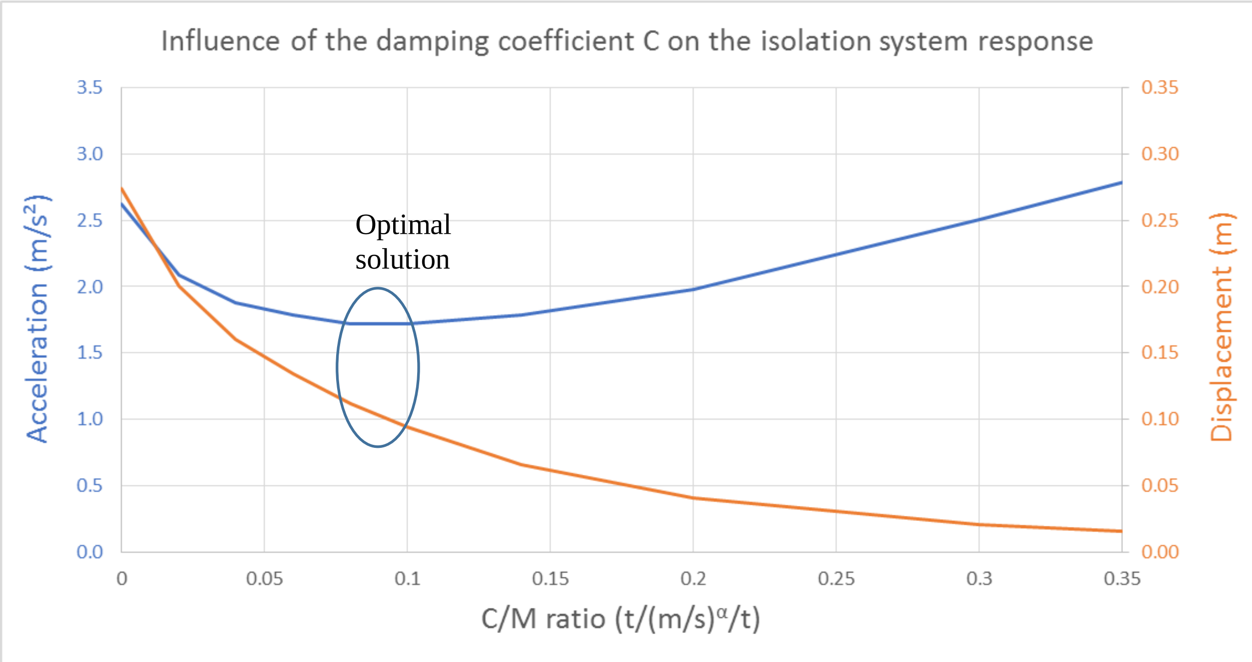


Fig. 3 – Influence of damper size on the response of the isolated system

Table 1 – Response of the bare building and the damped, isolated building

	Unit	Isolation and damping	Without isolation
Period of the first mode of vibration	[s]	2.0	0.27
Maximum acceleration at centre of gravity	[m/s²]	1.8	12.6
Maximum relative displacement of centre of gravity	[mm]	152	20

The various analyses performed during the preliminary design phase were used to define period and damping targets to limit displacement and minimise acceleration. These parameters then had to be confirmed by longer, more detailed calculations.

3. Construction design

The construction design of the structure was performed by design firms ITC and NECS, with ITC producing the detailed calculations and construction drawings and NECS the dynamic earthquake response calculations for the structure. The interaction between the two design firms was handled as follows: each design firm produced a structural model appropriate to its task. NECS produced the seismic design and gave ITC the interface data it needed to model the seismic action on its own model, namely the equivalent acceleration on each floor for the superstructure design, and the loads carried to the ground on each of the bearings (isolators and dampers) for the infrastructure design.

Given the highly non-linear behaviour of dampers, which have an $F = C\ V^{0.1}$ type behaviour law, the calculation of the structure's earthquake response requires the use of a non-linear transient analysis. In this regard, various numerical methods are possible. The most common is the method of directly solving the equation of motion ($M\ \ddot{U} + C\ \dot{U} + K\ U = -M\ \Delta\ \gamma(t)$), with an implicit or explicit integration scheme. There are two main drawbacks to this method: it is costly in terms of calculation time, and requires the construction of a damping matrix the representativeness of which is not easy to ensure. In this design, the behaviour of the structure was assumed to be linear-elastic, and the only non-linearity lies in the behaviour of the dampers. Under these conditions, it is possible to represent the dynamic behaviour of the structure by modal decomposition, which considerably reduces the calculation time and makes it possible to process damping on the modal basis. The non-linear loads introduced into the structure by the dampers are then modelled as external forces in the second member of the equation.

The finite element model used for the transient analysis is shown in Fig. 4. It is a detailed model of the whole structure: infrastructure, superstructure, isolators and dampers. The soil-structure interaction is taken into account by means of springs distributed over the surface of the footings and foundation slabs, restoring the three stiffness components of the foundation soil (K_X, K_Y, K_Z).

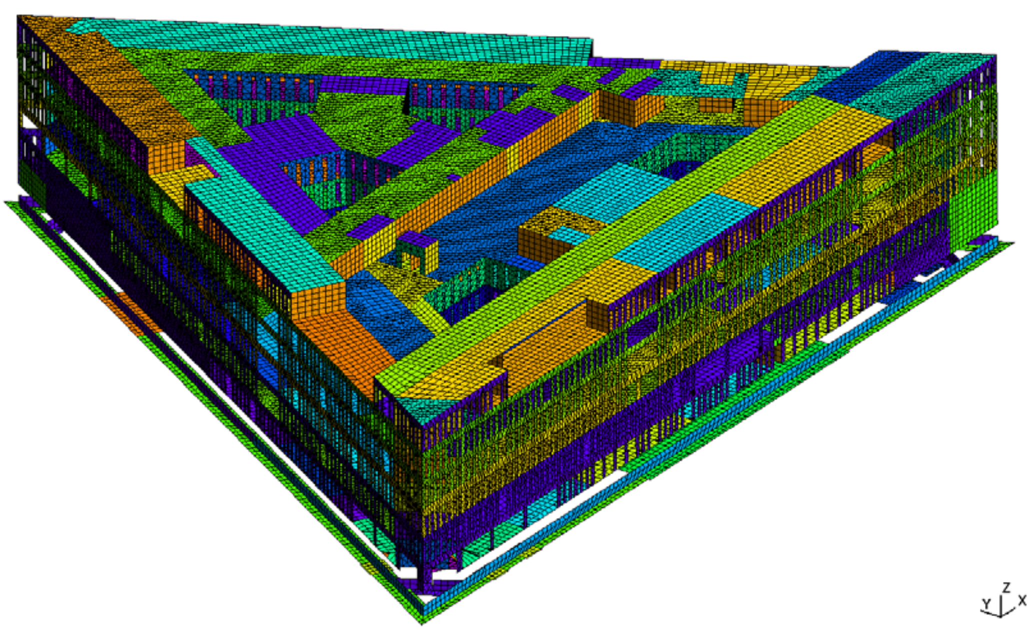
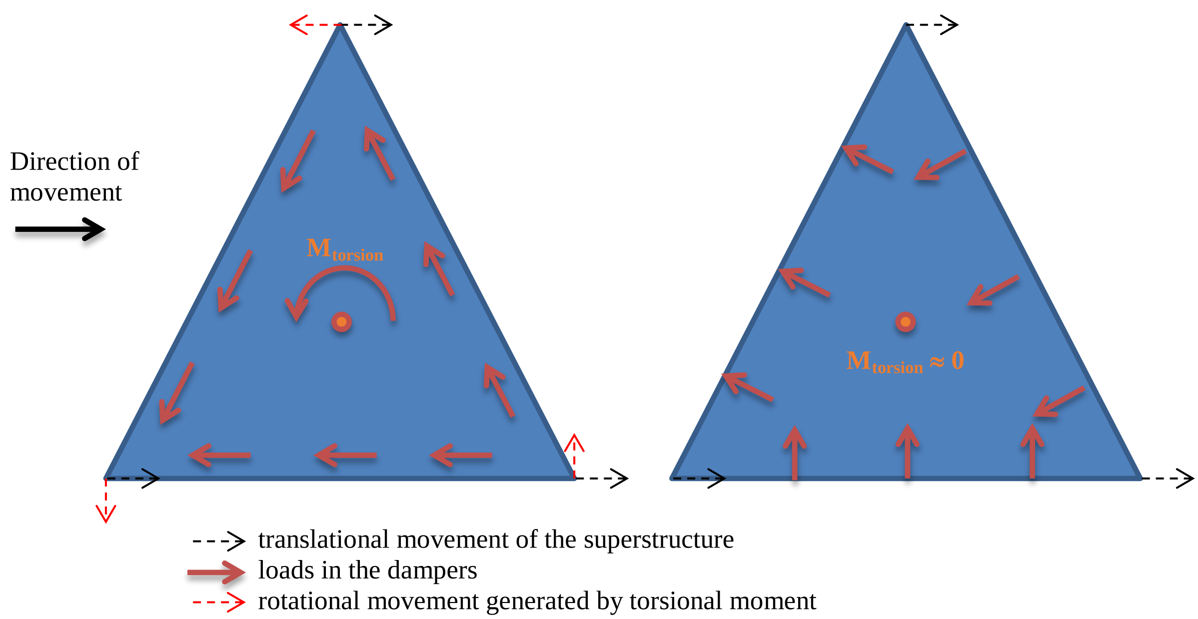


Fig. 4 – General view of the finite element model of the building

The location of the dampers is shown in Fig. 5. The initial design (a) included 36 dampers distributed mainly along the three façades, and oriented parallel to the façades. The first calculations done for this configuration revealed a non-uniform response of the structure, with horizontal displacements varying by 40% from one end of the building to the other. An analysis of the results showed that this damper arrangement generated large torsional moments due to the triangular shape of the building, as illustrated by Fig. 6. These conclusions lead to a re-evaluation of the location of the dampers, and particularly their orientation. The arrangement finally selected (Fig. 5b) is made up of 36 dampers oriented perpendicular to the façades, and located symmetrically relative to the axes of the building, which considerably reduces the torsional moments (by a factor of around ten).

(a) Initial design: dampers // façades (b) Optimised design: dampers ⊥ façades

Fig. 5 – Damper location

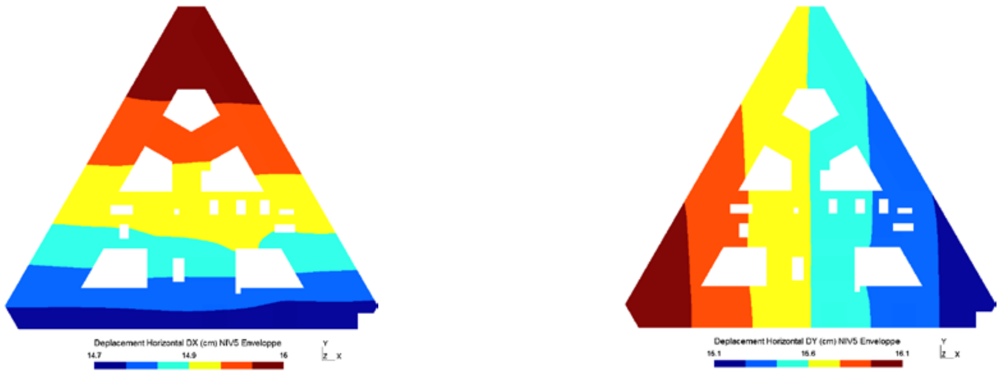


(a) dampers parallel to façades (b) dampers perpendicular to façades

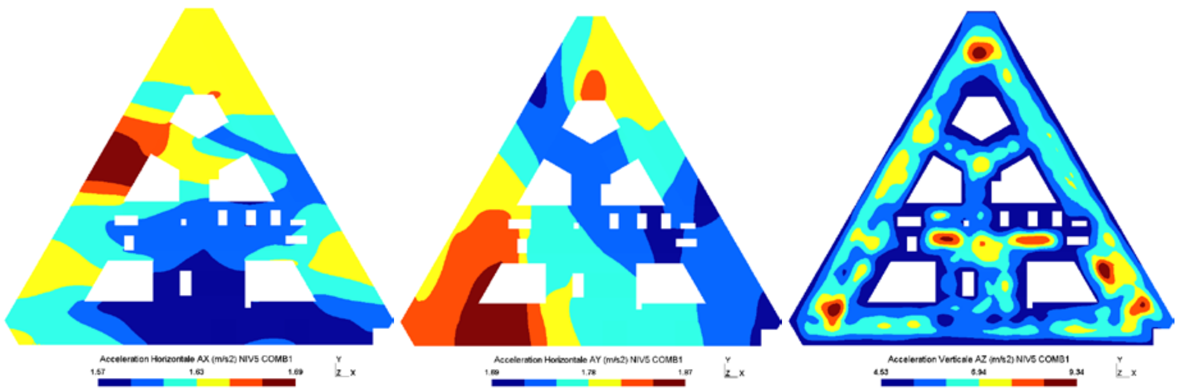
Fig. 6 – Influence of damper orientation on torsional moments

Once the solution had been optimised, the non-linear transient analysis was performed using the Code_Aster software package, for three sets of uncorrelated accelerograms set to the regulatory spectrum. The natural horizontal vibration frequencies of the building on isolators are around 0.44 Hz (giving a period of 2.3 s). The main results are summarised below and illustrated in Fig. 7. The overall displacement of the building is approximately 15 cm. The total horizontal load at the base of the structure is a maximum of 113 MN in one direction and 117 MN in the other, which represents mean equivalent horizontal acceleration of 0.15 to 0.16 g.

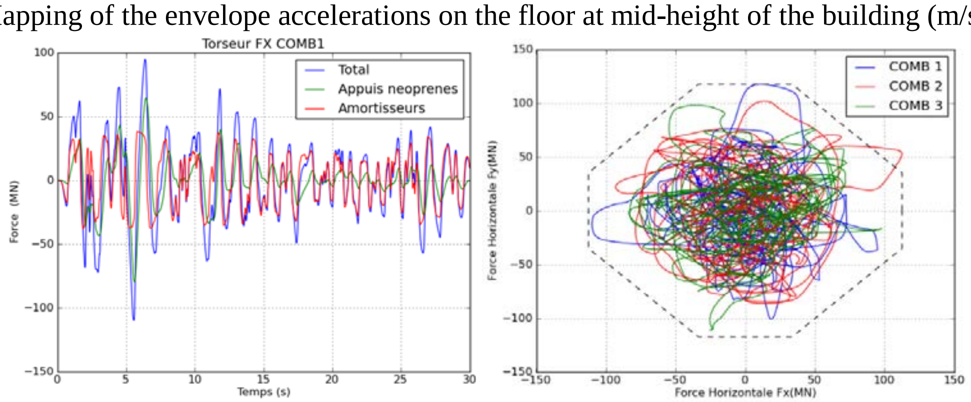
The torsional moment is small (137 MN.m maximum), corresponding to an eccentricity of the resultant of around 1 m. The additional accidental torsional effects are taken into account by means of additional static loading representing a torsional moment of 720 MN.m.



Mapping of the envelope horizontal displacements at mid-height of the building (cm)



Mapping of the envelope accelerations on the floor at mid-height of the building (m/s²)



Total load graphs: $F_X(t)$ (comb. 1), F_X-F_Y (comb. 1 2 3)

Fig. 7 – Extracts from the results of the non-linear transient analysis

The results obtained confirmed the efficiency of the seismic isolation system formed by the laminated elastomeric bearings and the viscous dampers, and were used to define the loads for the verification of the isolators and dampers, and the seismic design of the building's structure.

Table 2 – Main characteristics of the devices selected following the construction design

Device	**Type 1 isolator**	**Type 2 isolator**	**Type 3 isolator**	**Type 4 isolator**	**Damper**
Characteristics	Ø = 650 mm H = 296 mm G = 0.9 MPa	Ø = 700 mm H = 276 mm G = 0.9 MPa	Ø = 750 mm H = 276 mm G = 0.9 MPa	Ø = 850 mm H = 276 mm G = 0.9 MPa	C = 2,100 kN/(m/s)$^{\alpha}$ α = 0.1 V_{max} = 0.7 m/s
Quantity	194	46	39	9	36

4. Production and testing

The devices are Isosism® HDRB (High Damping Rubber Bearings) and Isosism® FD (Fluid Dampers), produced by Freyssinet. They are tested in accordance with European standards [2] and [3]. For the isolators, the vertical and horizontal stiffness has been checked. The tests on dampers are used to check the low-speed resistance, behaviour law, damping efficiency and wear resistance of the seals. The products are only installed on the building if they are found to be compliant.

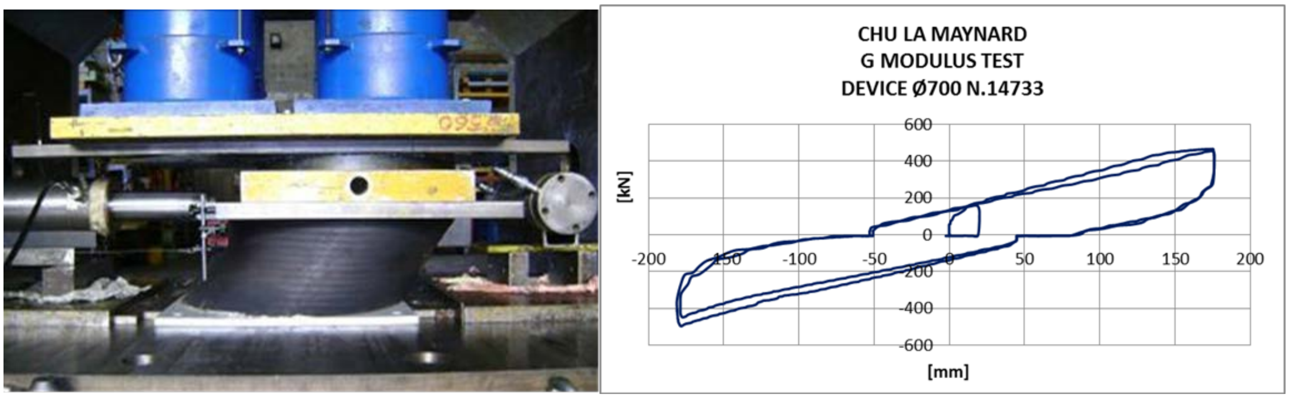


Fig. 8 – Isolator undergoing a distortion test and response curve

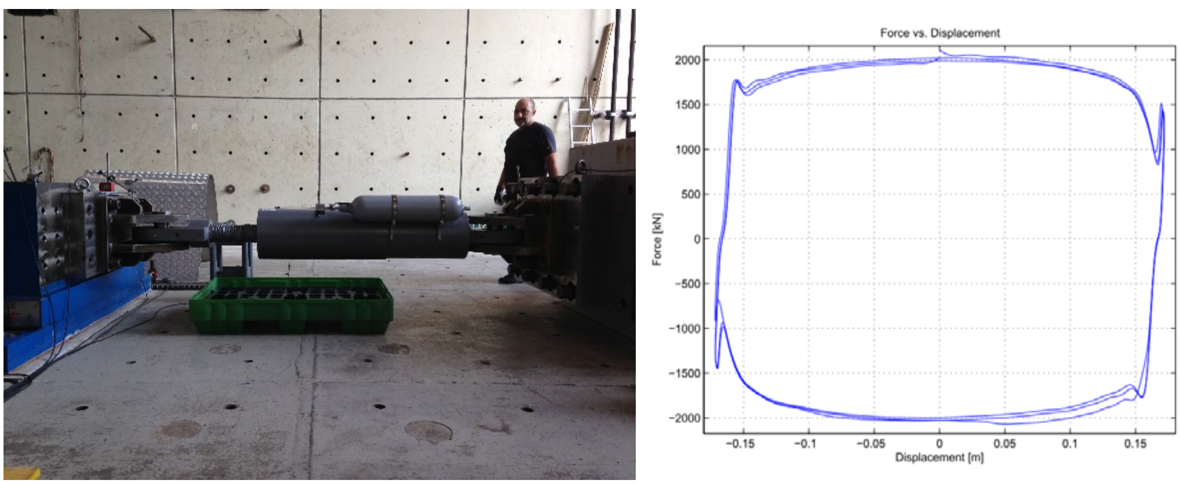


Fig. 9 – Viscous isolator in position for dynamic testing and response curve

5. Installation

The devices were installed at the beginning of construction, which is taking place over a period of forty months between 2013 and 2016.

Fig. 10 – Views of the site after installation of the isolators and dampers

The building has been constructed without any internal expansion joints to ensure health security (joints can be a place where bacteria proliferate). The consortium planned the construction phasing so that the instantaneous shrinkage took place during the construction phase. Keying strips were put in place to split the structure into five standard-sized blocks.

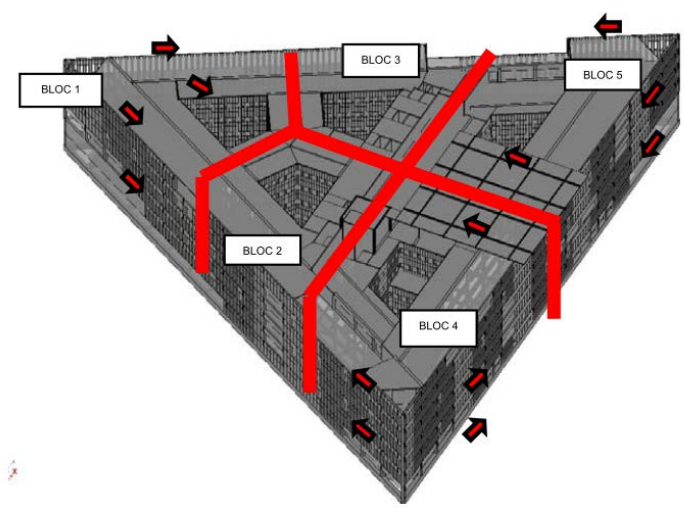


Fig. 11 – Keying strips used to construct the building without expansion joints

6. Conclusion

The consequences of the 2010 Haiti earthquake were a reminder of the importance of having a hospital theatre and clinical support block that is operational immediately after a seismic event. A financial analysis guided the designers of the new theatre and clinical support block at La Meynard hospital towards seismic isolation. Compared to an initial solution without isolation, the saving on quantities of concrete and rebars obtained with a base isolation could exceed and compensate the additional cost corresponding to the isolators supply, which represents about 2% of the total.

The combined use of isolators and dampers made it possible to efficiently reduce the acceleration of the building during a seismic event and limit the displacement of the isolated system. After testing to confirm their compliance, the isolators and viscous dampers were installed in the structure, which should be completed in 2016.

Base isolation is applicable to any building that has a 1st mode period smaller than 1.5 s, and that is not adjoining neighboring structures. It is even more appropriate to buildings such as hospitals, where the non structural components and equipement shall be protected as well. It will drastically reduce repair works in case of seismic occurrence and the serviceability will be maintained.

7. References

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