REMOTELY-SHARED EXPERIMENTAL TESTS ON SEMI-PASSIVE DEVICES FOR SEISMIC PROTECTION OF SYSTEMS AND COMPONENTS FOR CIVIL APPLICATIONS, CULTURAL HERITAGE AND STRATEGIC INFRASTRUCTURES.

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ABSTRACT
Measuring the displacements during the shaking table earthquake tests is a crucial task for the numerical and experimental studies in structural dynamics, specially within the displacement-based approach in seismic design and calculations. The DySCo (Structural Dynamics, numerical Simulation, Qualification tests and vibration Control) Virtual Laboratory at the ENEA C.R. Casaccia is the first example in Italy of remotely-shared experimental facilities for seismic tests of civil applications, cultural heritage and strategic infrastructures – also nuclear – components and systems to be subjected to qualification tests. The data acquisition is performed by means of a new, innovative, high-resolution, motion-capture system called 3DVision. The experimental images and data are shared with remote users and exchanged in real time via Internet. The 3DVision system is able to track the 3D motion of several selected points of the structures in terms of displacement, speed and acceleration using a constellation of high-resolution Infrared Cameras to measure accurate 3-D positions of hundreds of markers placed on the structure during the seismic tests. In this paper are described the experimental tests shared within the DySCo Virtual Laboratory of the innovative semi-passive antiseismic devices EARLYPROT (made by steel, marble or ceramic) for seismic protection of nuclear system and components (device made by steel), sensitive equipments (devices made by ceramic) and art objects (devices made by marble) were tested in DySCo Virtual Laboratory.

KEYWORDS
Semi-passive, shared experiments, seismic, vibrations, qualification

1 INTRODUCTION

The main experimental facilities for vibration and seismic tests at the ENEA-MATQUAL (Qualification of Components and Systems) laboratories at the Casaccia Research Center of Rome, Italy, consist of two electrodynamics shakers and two high performance seismic tables for three axial seismic tests of structures up to 10 ton mass and 3g acceleration applied at the Center of Gravity at 1m from the base table. The shaking table tests can reproduce the real stress-strain field in the structures due to the dynamic loads induced by wind, traffic and earthquakes. The activities are principally devoted to the experimental studies of innovative systems for the seismic isolation and retrofitting of civil, industrial, and historical buildings, together with the seismic tests of sub-structures and scaled mock-ups, in order to evaluate their dynamic behavior, the

isolation/dissipation performance of the anti seismic devices and the failure modes of the structural parts.

Table 1. Test facilities at ENEA C.R. Casaccia laboratories

	Table 1 (Master)	Table 2	Shaker 1	Shaker 2
Table size	4m x 4m	2m x 2m	1.5m x 1.5m	0.6m x 0.6m
Degree of Freedom	6DOF	6DOF	1DOF	1DOF
Frequency range	0-50 Hz	0-100 Hz	5-2000 Hz	5-200 Hz
Acceleration	3g peak	5g peak	125g (0-peak)	100g(0-peak)
Velocity	0.5 m/s (0-peak)	1 m/s (0-peak)	2 m/s (0-peak)	1.2 m/s (0-peak)
Displacement	0.25 m (0-peak)	0.30 m (0-peak)	0.025m (peak-peak)	0.025m (peak-peak)
Mass/Force G.C. height	10ton 1m g.c. height	1 ton 1m g.c. height	145 KN Force 1m g.c.height	27 KN Force 1m g.c.height

Beside the traditional sensors (accelerometers, LVDT, strain gauges) normally used in dynamical tests, the data acquisition are also performed by a new, innovative, high resolution 3-D optical movement detection and analysis tool. Its purpose is to track the dynamic displacement of several selected points of the structures during the dynamic tests of natural (earthquake) and artificial (mechanical) induced vibrations. This system uses twelve high resolution Infrared Cameras to measure accurate 3-D positions of hundred of markers placed on the structure during the seismic tests (De Canio et all. 2008). The innovative monitoring technique allows measuring 3 axial absolute displacements with easy and fast test set-up, high accuracy and the possibility to link the 3D-motion time histories of the tracked markers with CAD drawings of the structure and validate the FE models in real time experimental data assimilation. The new monitoring system have been tested during several shaking table experiment on a masonry buildings representative of the historical houses still used for civil habitation in Italy and for the dynamic characterization of structures and components prior the seismic qualification tests of systems and components for mechanical, transportation and nuclear industry.

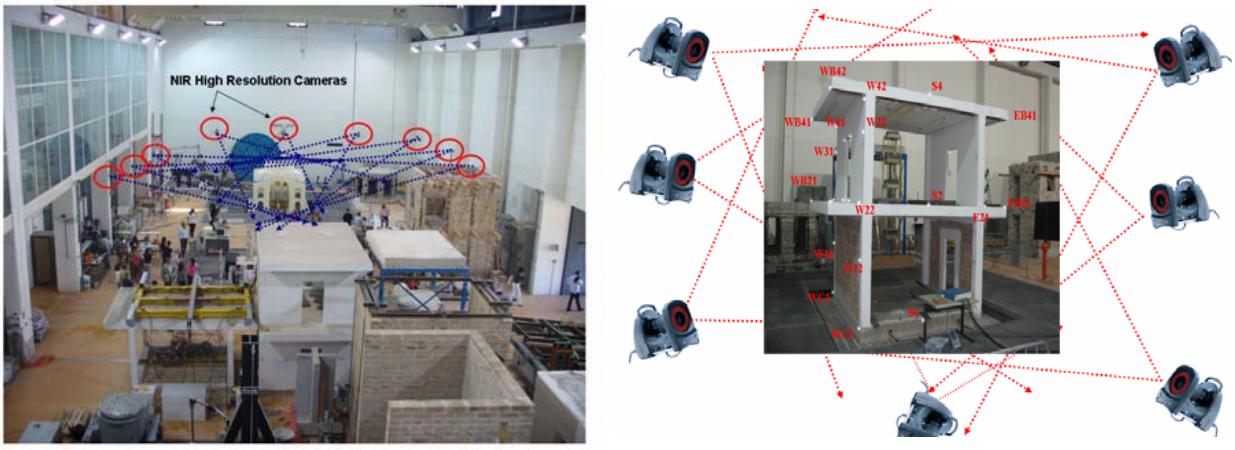


Figure 1. 3D_VISION system: position of the cameras to detect the motion of the markers.

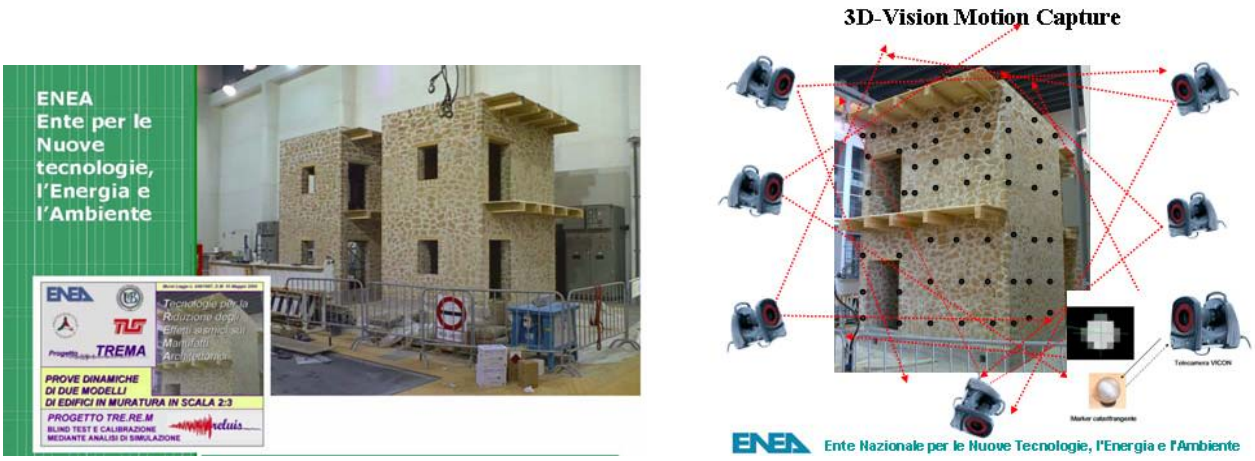


Figure 2. Project TRE_RE_M (TREMA_RELUIS_MASONRY), test on 1:1.5 model representative of the most typical historical buildings in Italy.

1.1 The DySCo Virtual Laboratory

The possibility to synchronize visible and infrared cameras allows the remote participation and control of the shaking table tests in a networking configuration of distributed experiments. In the following figure is showed the conceptual structure of this networking configuration within the virtual laboratory DySCo (structural **Dy**namic , numerical **S**imulation, qualification tests and vibration **Co**ntrol)

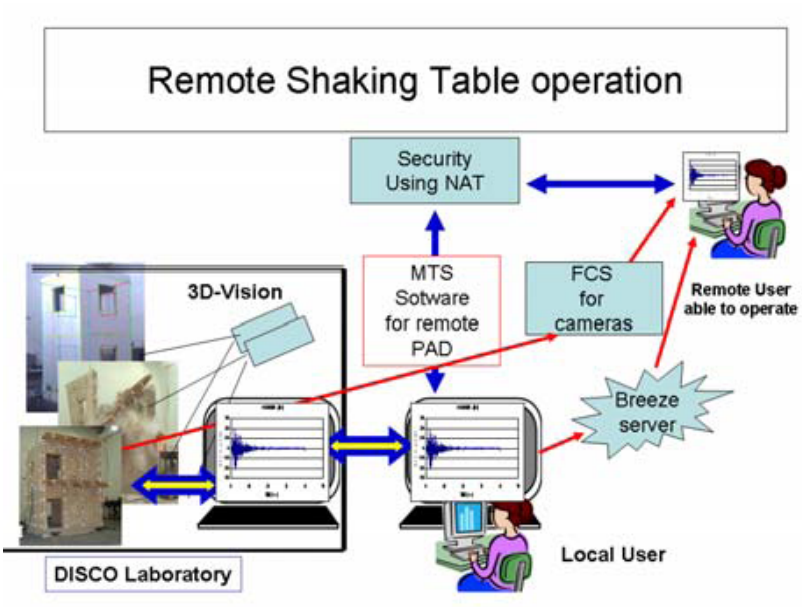


Figure 3. The possibility to synchronize visible and infrared cameras allows the remote participation to the shaking table tests in a networking configuration of distributed experiments.

As the experimentation goes on, remote users have the possibility to interact step by step with the experts of the DySCo laboratory, exchanging opinions about the results and, if necessary, agree the modifications in the subsequent steps of the experiment. The connection to DySCo is provided by the ENEA grid of numerical computation, the results are shared in real time via Internet among the

partners of the experiment and stored in ENEA web pages for future use and for every remote user who can visualize them by different access privileges.
Together with the Shaking Tables for seismic tests, the figure 4 show the other test facilities networked within DySCo, i.e. the CTM (Combined Temperature-Mechanical) test facility, the electro dynamic shakers for mechanical qualification and the reaction wall for quasi static pseudo-dynamic test .

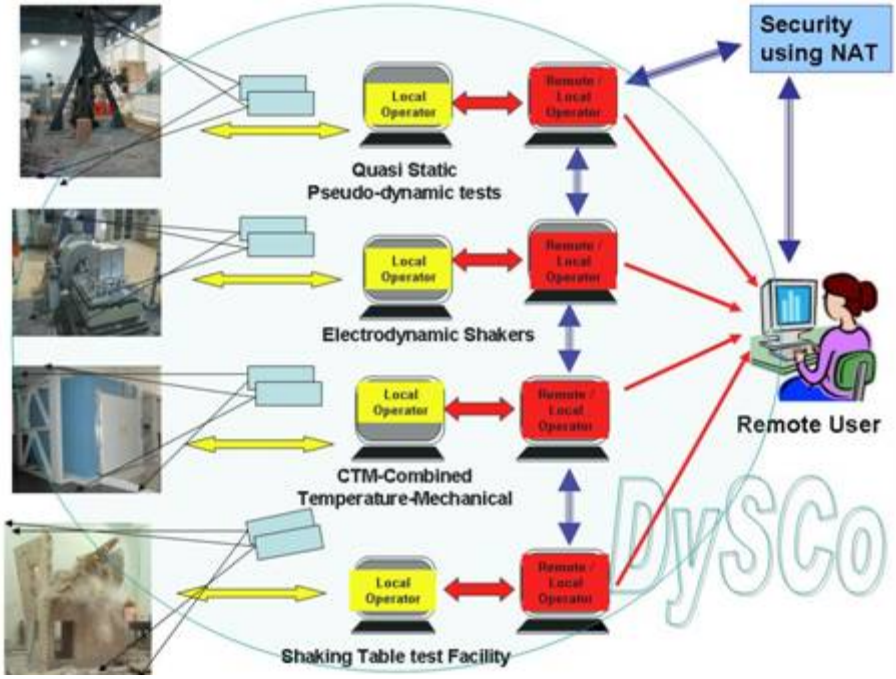


Figure 4. The possibility to synchronize visible and infrared cameras allows the remote participation and control of the shaking table tests in a networking configuration of distributed experiments with other laboratories.

One of the goals of this project is also to implement the process of vibration and seismic qualification for nuclear components and system: the remote control allows the customer to immediately analyze the results together with the ENEA scientists and visualize where the problem for a non-qualification notify is.
The DySCo Virtual laboratory comes from many research projects of seismic protection for civil structures like as: TREMA, RELUIS and TELLUS STABILITA.
The measure of the displacements is a crucial task for the numerical and experimental studies in structural dynamics, especially within the displacement based approach in seismic design and calculations. The ENEA grid and the CRESCO (Computational RESearch center on COmplex system) parallel computational system, give to the remote user the opportunity to run the heavy finite element structural analysis codes by the most important commercial software available by CRESCO.

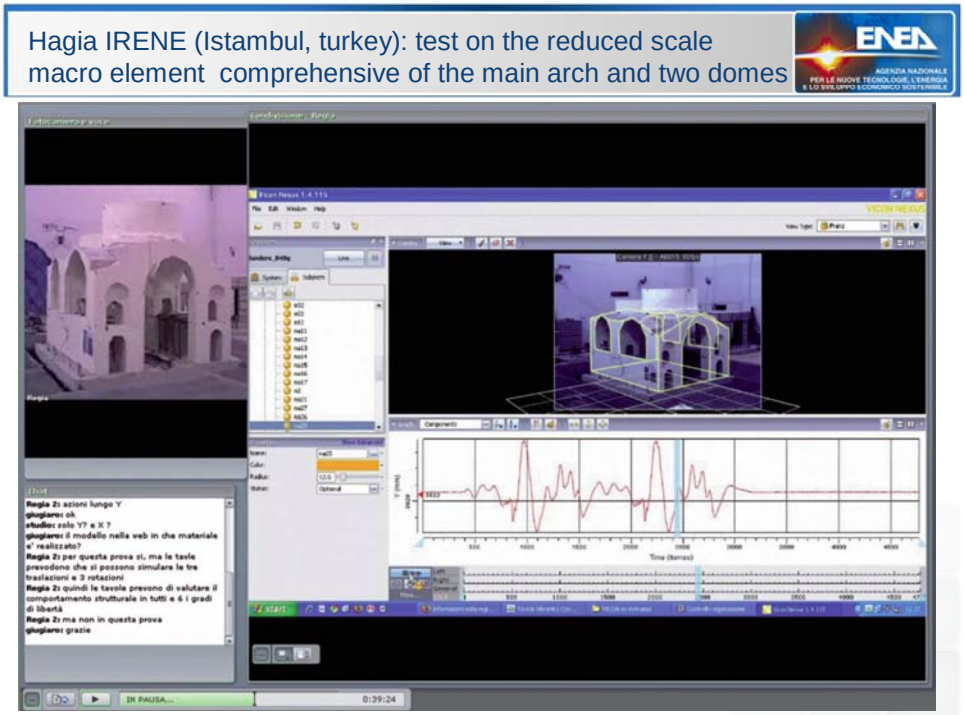


Figure 5. The remote user share data and images during the experiments and communicate with the ENEA scientists: example of remotely shared data during the test on a reduced scale mock-up of the most representative structural macro element of the Hajgia Irene Church in Istambul, Turkey.

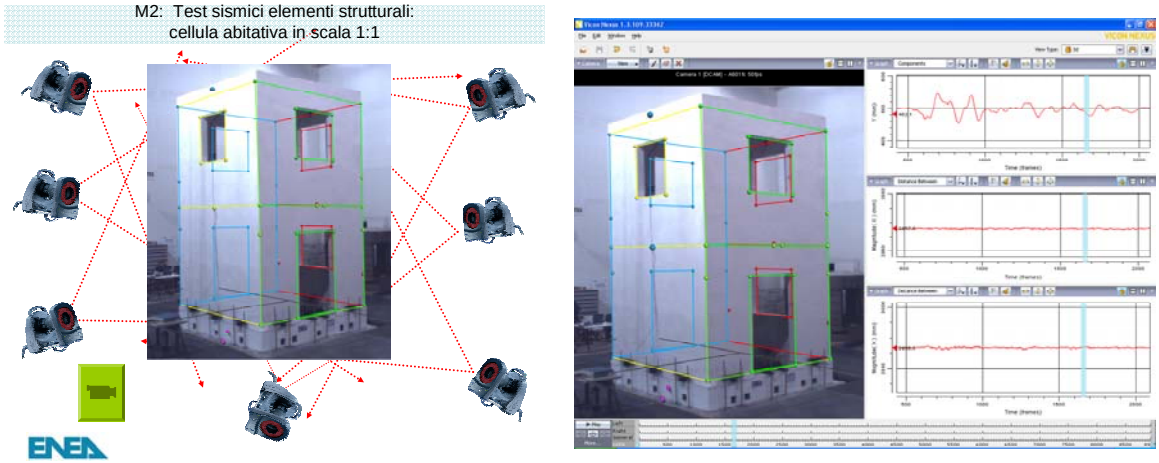


Figure 6. Remotely shared images and data during the Shaking table test on a 1:1 cell of modular building

The DySCo virtual laboratory is nested within the ENEA Grid of computational and experimental facilities: the Tokomak particle accelerator at the ENEA R.C. Frascati, the ABI Prism 3700 DNA sequence system at the ENEA R.C. Trisaia, the 300 KeV Electron microscope at the ENEA R.C. Brindisi .

1.2 Remotely shared tests on objects protected by the semi passive devices EARLYPROT

Other examples of remotely shared experiments are the seismic tests for historical statues and electrical cabinets for nuclear plants both protected by the "semi passive" isolators EARLYPROT made by marble (for the seismic isolation of statues) and steel (for the seismic isolation of industrial systems and components), blocked in normal conditions and activated by the early warning triggering signal (De Canio, 2008).

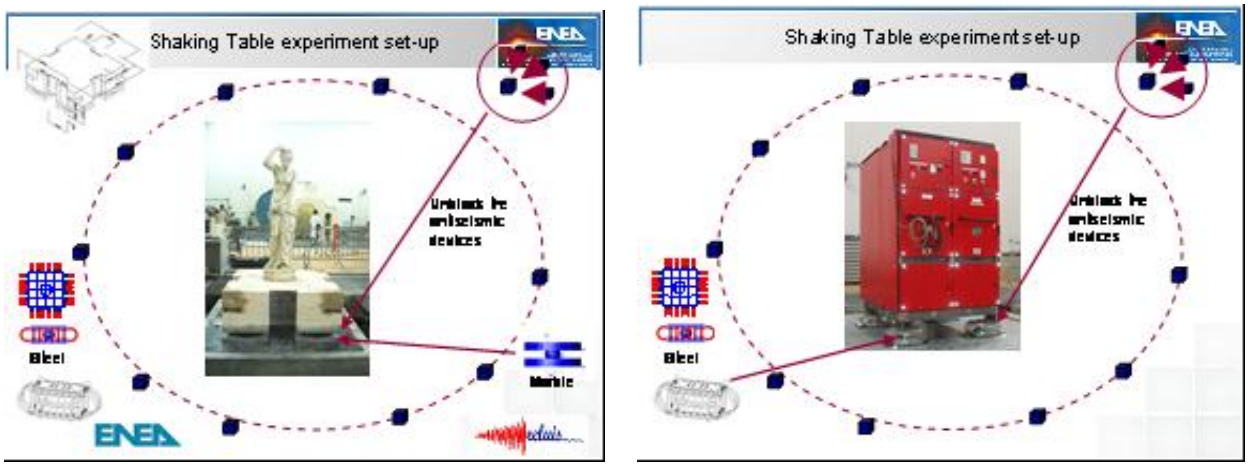


Figure 7. Example of a real time test on the innovative "semi passive" isolators "earlyprot" (made by marble, ceramics and/or steel) activated by the early warning signals, application for historical statues and strategic non structural components

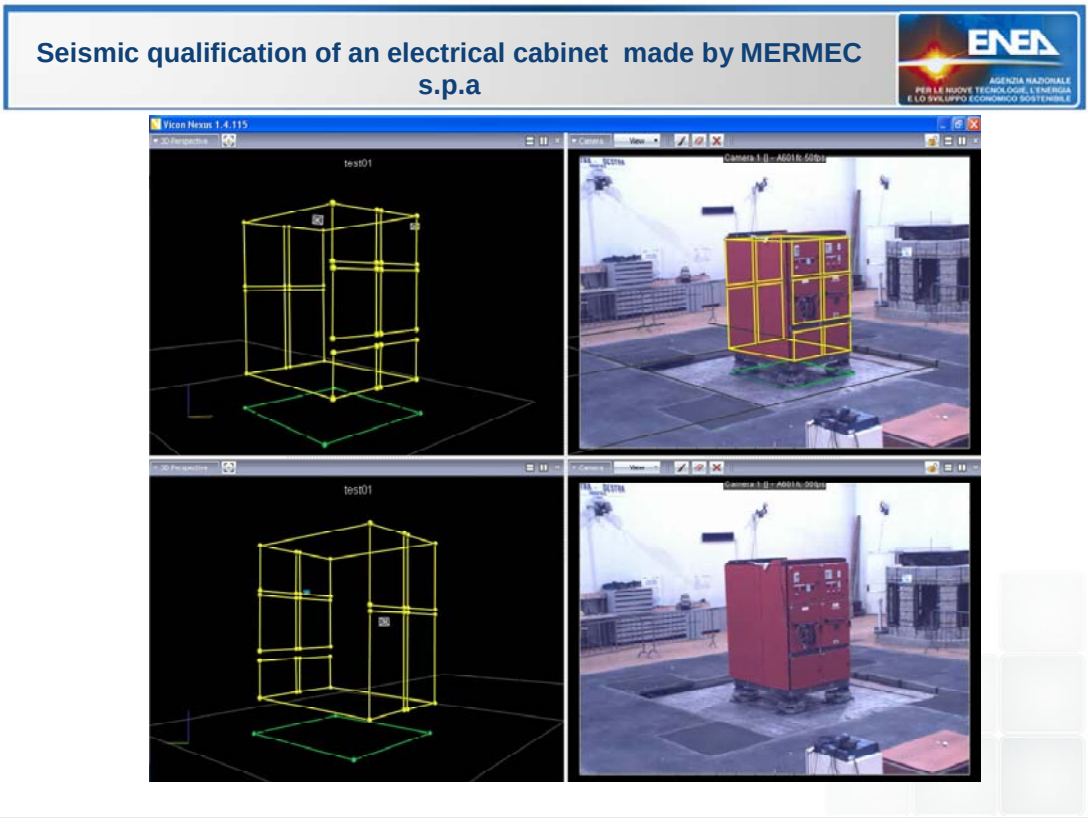


Figure 8. Remote shared images and data during the qualification tests of the class 1-E cabinet for nuclear plants.

The cabinet was protected by the isolators EARLYPROT. They are sliding-rolling (pendulum type) devices provided by dissipating cables limiting the displacements (see figure 9).
The characterization tests of the isolators was performed by the following sequence of tests:

- pull-release tests for the evaluation of stiffness and damping coefficients with two configuration of masses (34KN and 17 KN), and different number of dissipating cables (36, 32, 24, 16, 8, 0)
- frequency sweeping
- constant sine (0.5 Hz and 2 Hz)
- seismic tests using recorded time histories representative of the most typical earthquakes of Europe, Asia and America.

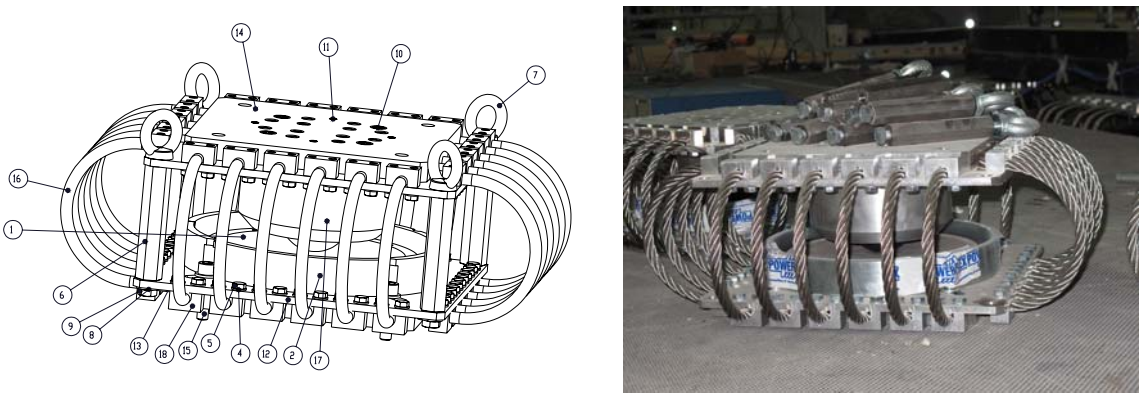


Figure 9. Semi passive seismic isolator EARLYPROT, blocked in normal condition and activated by an early warning triggering signal.

During the characterization tests the displacement signals have been detected by means of the 3D_vision system (see figure 10)

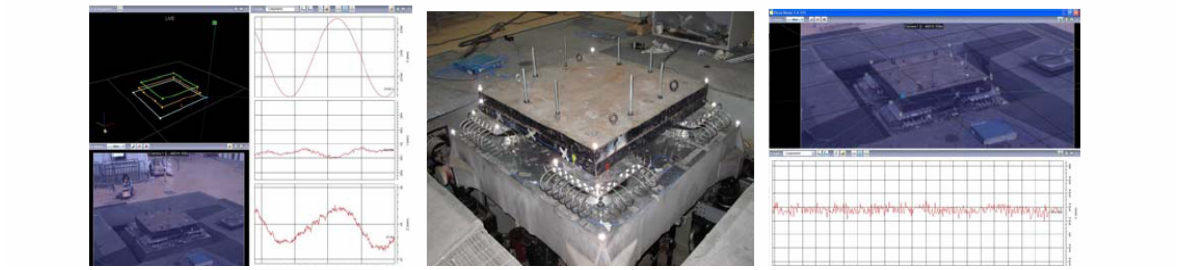


Figure 10. Sharing images and data during the tests of the semi passive seismic isolators EARLYPROT.

In this paper the preliminary results of the pull-release tests are presented; in the fogure 11 there are the displacement data recorded by the 3D_Vision system during the tests at different number of dissipating cables.

The analyses of figure 11 and table 2 show that the device has different behaviours at large and small displacements. The logarithmic decrements after each cycle are not constant: $\delta_1 < \delta_2 < \delta_3$ and the equivalent damping ξ span from ξ_{max}=64% (36 cables) to ξ_{min}=9.0% (0 cables) with a non linear dependency from the number of cables**.**

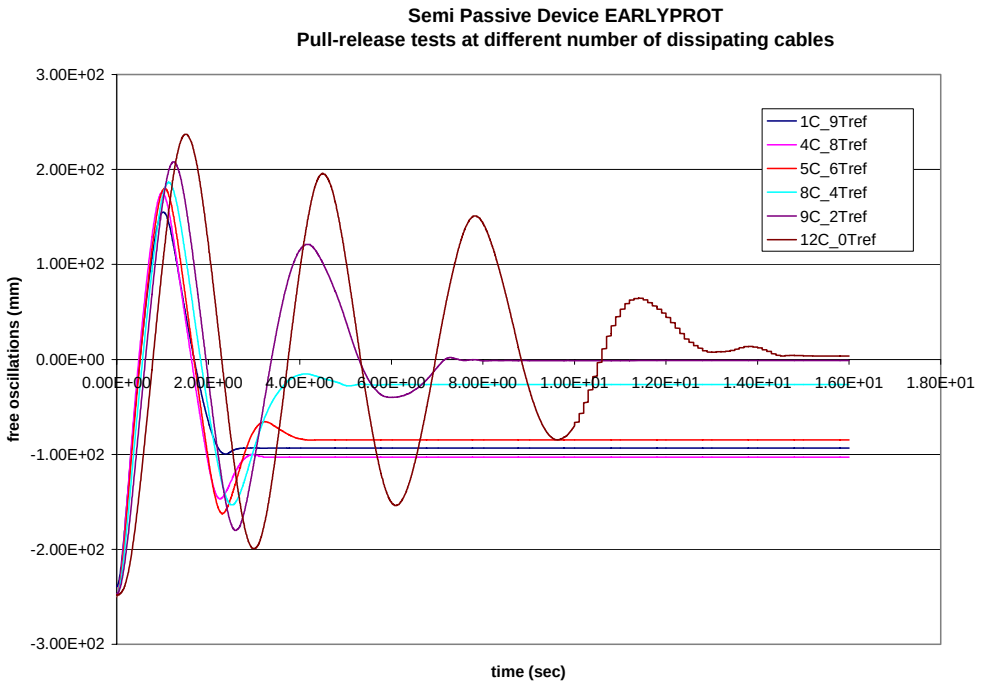


Figure 11. Pull-release tests of the semi passive device EARLYPROT at different number of dissipating cables, starting with 9 cables/side (e.g. 36 total) up to 0 cables/side. The displacements of the markers are detected by the 3D_Vision motion capture system

Table 2. Evaluation of the equivalent Damping coefficients

Test	Nc	Force KN	Ao	A1	A2	A3	t1	t2	t3	δ_1	δ_2	δ_3	$\tilde{\delta}$	ζ
1c	36	1.03	239.5	6.3	0.1	-	2.4	3.6	-	3.638	7.781	-	**5.7**	**0.64**
4c	32	1.07	249	44.0	0.2	-	2.3	3.3	-	1.733	7.127	-	**4.4**	**0.51**
5c	24	0.92	250	77.2	0.2	-	2.3	4.3	-	1.175	7.131	-	**4.1**	**0.47**
8c	16	0.81	249	126.4	0.4	-	2.5	5.0	-	0.678	6.434	-	**3.5**	**0.41**
9c	8	0.67	247.7	180.0	39.9	1.2	2.6	6.0	8.2	0.319	1.826	5.364	**2.5**	**0.33**
12c	0	0.21	248.8	199.0	154.0	83.1	3.0	6.1	9.6	0.223	0.48	1.097	**0.6**	**0.09**

Test= test name

Nc= number of cables

Ao = initial displacement at t=0

A1=A(t1) , A2=A(t2), A3=A(t3)… = peaks of displacements at time t1, t2, t3,….after each cycle of oscillation

δ_i = logarithmic decrement after i oscillations

$\tilde{\delta}$ = average logarithmic decrement

ζ = equivalent damping coefficient

Considering the hypothesis of Coulomb Damping, the physical behaviour is still non linear with respect the number of cables. In the figure 12 there is the comparison between the results of the pull-release tests on the devices with 0, 8 and 16 cables (i.e. 0, 2 and 4 cables/side)

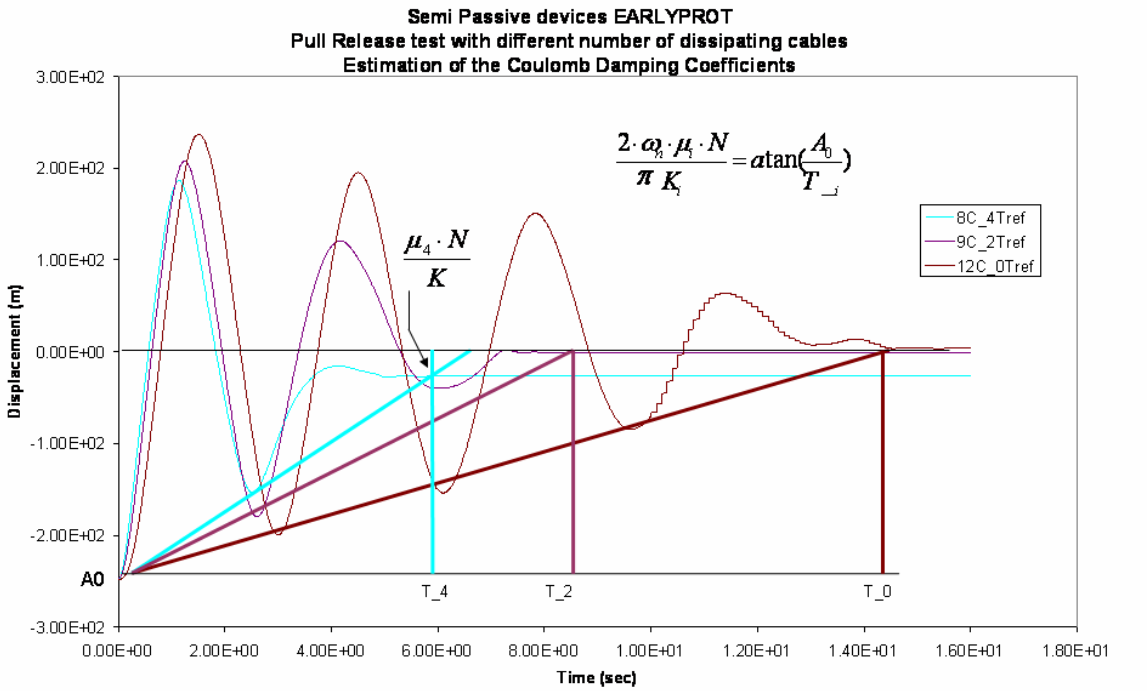


Figure 12. Coulomb damping estimation.

2 CONCLUSIONS

The use of the innovative 3D-vision capture motion allow the direct monitoring of the displacements of hundreds of point of a structure during dynamic tests. The possibility to assimilate these data in the FEM numerical model of the structure is useful for its reliable validation. The availability of the displacements data is important for the displacement based calculations in structural analysis. The 3D_vision data and images can be easily shared in the distributed experiments within a network of laboratories.

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4 REFERENCES

Gerardo De Canio, Michele Caponero, Alessandro Colucci, Ivan Roselli (2008). " Innovative high resolution 3-d vision and optical fiber sensors for data acquisition during experimental earthquake tests" *The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China.*

Gerardo De Canio (2008). Seismic early warning systems for strategic infrastructures and CUHES. *The 14th World Conference on Earthquake Engineering October 12-17, 2008,* Beijing, China.