Rete dei Laboratori Universitari di Ingegneria Sismica
Executive Project 2005–2008
Research Project N. 7

7. TECHNOLOGIES FOR THE SEISMIC ISOLATION AND CONTROL OF STRUCTURES AND INFRASTRUCTURES

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7.1. Introduction

The technologies for the control of the seismic structural vibrations have been greatly developed in the last decades, with several applications all over the world. Their effectiveness is proved by laboratory and field tests as well as by their excellent performances during recent earthquakes, especially in Japan. It is nowadays acknowledged that they allow structures to achieve higher safety levels than conventional structures, even when designed by using modern seismic criteria. Their diffusion, if favoured by reliable and optimised norms, would permit to achieve a sensible reduction of the seismic risk.
In Italy the development and the practical exploitation of the advantages of these technologies has been slowed down by the lack of a specific norm. The enforcement of the Ordinanza 3274, including two chapters on the seismic isolation of buildings and bridges, represented a turning point for their practical use, so that most of the new strategic buildings are now designed with seismic isolation. However there still are several problems to be further studied and better solved, to make applications more and more reliable and easy.

7.1.1 General Objectives

The general objective of the RELUIS research project N.7 is the improvement of the knowledge on some specific aspects of design and functioning of passive and semi-active systems for the control of seismic structural vibrations, as well as the general improvement and simplification of the design tools (norms, guidelines, analysis and experimental verification methods), in order to make easy, reliable and, wherever possible, economically convenient their application.
The concerned problems are relevant to the four main control techniques (seismic isolation, passive energy dissipation, tuned mass, semi-active control) as applied to structures with usual characteristics (R/C and steel buildings, bridges with R/C piers) or peculiar structures (R/C precast buildings, monumental masonry buildings such as churches and palaces, light structures). Almost all the currently used technologies are considered, both the well established ones (rubber and sliding isolators, viscous, visco-elastic and hysteretic energy dissipating devices) and the most recently proposed (shape memory alloy, magneto-rheological, wire rope devices). The design problems to be dealt with are relevant to both new and existing constructions. For these latter, particular attention is devoted to monumental buildings, deck bridges and the application of energy dissipating devices to R/C buildings. A specific aspect to be dealt with is the response of structures with seismic isolation or energy dissipation protection systems to near-fault earthquakes, with the aim of studying suitable provisions in the design of the devices or of the structure, as a second line of defence to guarantee adequate safety margin with respect to the total collapse of the structural system.

Specific aspects relevant to seismic isolation are:
- elastomeric isolators (buckling, tension, thermal effects, experimental and theoretical verifications), low cost isolation, combination with sliders, application potential for monumental buildings,
- modes and methods of application to monumental buildings,
- isolation technologies for light structures,
- simplified analysis methods (applicability and procedures), behaviour factor for linear analyses,
- deck-bridges with seismic isolation (3D effects, devices, design methods) [activity coordinated with RELUIS L.3]
- attenuation of irregular configuration effects in buildings and bridges, even related to the technology choice,
- optimal structural configuration for the use of different technologies,
- evaluation of the cost/benefit ratio when using the isolation technologies under study,
- effects of anomalous seismic actions and of their vertical component.

Specific aspects relevant to energy dissipation are:
- design criteria and simplified analysis methods (linear with behaviour factor, non linear – application potential and procedures),
- procedures for the experimental validation of the different device categories,
- application potential and procedures for pre-fabricated structures,
- effects of anomalous seismic actions and of their vertical component.

Specific aspects relevant to tuned mass systems are:
- application potential and procedures for variable mass systems, both in passive and semi-active control,
- design criteria and simplified analysis methods (behaviour factor for linear methods, non linear procedures),
- design and analysis methods of isolation – tuned mass combined systems.

Specific aspects relevant to semi-active control systems are:
- reliability in the long run of these technologies, functioning in passive control, functioning under service and seismic conditions, self-diagnosis and structural identification,
- behaviour analysis and evaluation of the effectiveness with respect to passive control systems,
- design criteria and methods,
- experimental evaluation procedures of different device categories.

7.1.2 Activities

The activities are carried out by 12 research units, three within RELUIS and 9 external to RELUIS, as reported in the following table:

	Institution	Responsible	Title
RELUIS			
R1	UNIBAS - University of Basilicata	M. Dolce	Passive control of buildings and bridges: experimental and numerical studies for the validation and improvement of the structural design, analysis and verification methods and of the device testing procedures
R2	UNINA_SE - University of Naples (Serino)	G. Serino	Design methods of buildings and bridges with viscous devices and of light structures
R3	UNINA_DL - University of Naples (De Luca)	A. De Luca	Seismic isolation of historical-monumental buildings
EXTERNAL			
E1	UNIPG - University of Perugia	A. Parducci	Design and architectural aspects in seismic isolation applications
E2	UNICAL - University of Calabria	A. Vulcano	Design of buildings with energy dissipatine braces and seismic isolation and near-fault effects
E3	POLITO – Technical University of Torino	A. De Stefano	Tuned mass systems and semi-active control for the reduction of the structural seismic response
E4	UNIUD - University of Udine	S. Sorace	Design and simplified analysis methods and experimental qualification procedures for seismic isolation and energy dissipation systems including viscous fluid devices
E5	UNISA - University of Salerno	B. Palazzo	Experimental validation of the combined base-isolation – mass damper control system
E6	UNICAM - University of Camerino	A. Dall'Asta	Dynamic response control of existing R/C frames using high damping rubber devices and buckling restrained braces
E7	UNIBO - University of Bologna	M. Savoia	Design methods and reliability of buildings with seismic energy dissipation
E8	UNIPARTH - University Parthenope of Naples	A. Occhiuzzi	Seismic vibration control through semi-active dampers
E9	UNIVAQ - University of L'Aquila	V. Gattulli	Integrated systems of control and self-diagnosis in semi-active seismic dampers

The project is organized in four main tasks, relevant to the considered control strategies, namely:
TASK 1 – Passive control with seismic isolation (Research Units: UNIBAS, UNINA_Se, UNINA_DL, UNIPG, UNICAL, UNIUD)
TASK 2 – Passive control by energy dissipation (UNIBAS, UNINA_Se, UNICAL, UNIUD, UNICAM, UNIBO)
TASK 3 – Passive control by tuned masses (POLITO, UNISA)
TASK 4 – Semi-active control (POLITO, UNIPARTH, UNIVAQ)

The activities include theoretical and experimental studies. The former ones include parametric investigations and single case study analyses, to set up design and verification methods of systems and devices as well as control algorithms. An extensive experimental program on large scale models in the RELUIS and in some external unit labs is the main coordination and comparison action of the project. Due to the high level of protection provided by the control systems, most of these tests can be carried out under design seismic actions without damage to the structure, thus providing important indications on the device and structure behaviour. Based on the experimental work, the working hypotheses and the theoretical results obtained in the different tasks can be evaluated.
Besides the experimental tests on large models, experimental investigations on devices for seismic isolation, energy dissipation and semi-active control are carried out. They are aimed at verifying the actual behaviour of the devices under different working conditions, improve the general design and verification rules, verify the behaviour of the devices to be installed into the mock up structures, improve the modalities of experimental verification procedures as given by the Italian and the international norms.
The coordination action is also aimed at making the results obtained by the various research units comparable and, then, at defining:

- uniform criteria for the evaluation of the seismic response of the structure and of the device behaviour,
- reference earthquakes to use in both the numerical analyses and in the experimental tests,
- reference case studies to apply the different systems,
- experimental model characteristics and test execution order and modalities, in order to maximise the information content of the results.

7.1.3 Final Products

- Guidelines and manuals with design indications and examples for buildings with energy dissipating bracing systems of the following types: hysteretic, fluid-viscous, visco-elastic, re-centring with or without viscous dissipation (UNIBAS, UNINA_Se, UNICAL, UNIUD, UNIBO, UNICAM).
- Design manual, with examples of applications, of dissipating systems for precast structures (UNIBO).
- Design manual, with examples of applications, of seismic isolation of light structures with *wire-rope* devices (UNINA_Se).
- Guidelines and design indications which integrate and improve the current norm, for the seismic upgrading of historical-monumental buildings through seismic isolation (UNINA_DL).
- Design manual with suggestions to integrate and improve the current norms on seismic isolation, for the use of the different seismic isolation technologies in relation with architectural aspects (UNIPG).
- Design manual, with real case applications, for the design of bridge structures with viscous and viscoelastic dampers [UNINA_Se].
- Design manual, with real case-sytudies, for seismically isolated structures with tuned mass [UNISA].
- Manual, with application examples, for tuned mass systems with uncertainties on the mechanical properties and with robust adaptive semi-active control (POLITO).
- Design manual for semi-active devices fo seismic applications: choice and design criteria, control algorithm, evaluation of the structural response for constructions endowed with semi-active devices, reliability of the technology and potential for the integration with monitoring and structural identification systems (UNIVAQ, UNIPARTH)
- Proposal of norms for buildings with energy dissipation systems (UNIBAS, UNINA_Se, UNICAL, UNIUD, UNIBO, UNICAM)
- Proposal for modifications of the seismic isolation norms for some aspects related to the simplified analyses of building and bridges (UNIBAS, UNINA_Se), to the experimental verification of the devices (UNIBAS, UNINA_Se, UNINA_DL, UNIUD), for the near-fault effects and the vertical component (UNICAL, UNIUD)

The intermediate and final results of the project will be also presented in congresses, workshop and publications on scientific reviews and on the WEB (www.reluis.unina.it).

7.2. Activities

7.2.1. TASK 1 – Passive control with seismic isolation - GENERAL

Some general aspects on the application of seismic isolation to any kind of structures are being dealt with, in order to find general results that can help in establishing design criteria and rules. During the first year the reduction factors for high-damping spectra, related to the application of simplified design methods, and the properties of viscous-recentring seismic isolation systems have been investigated. The results of these studies can be of use also for Task 2.

7.2.1.1. Reduction factors for high-damping spectra (R1_UNIBAS)

The main scope is to evaluate the accuracy of the current equations to reduce spectral ordinates when damping is greater than 5%, as normally happens to seismically isolated structures. Ten different equations, taken either from seismic codes or from the literature, have been compared. They provide considerably different values, thus emphasizing the importance of the problem. About 100 earthquake records, from magnitude 6 to 8, have been considered. Their individual and average spectra have been calculated for different damping ratio and then compared with the approximate damped spectra obtained with the use of the reduction factors.

7.2.1.2. Viscous-recentring seismic isolation systems (R1_UNIBAS)

This activity is aimed at verifying the advantages of coupling strongly re-centring devices, such as the ones based on Shape Memory Alloys, or linear elastic devices with viscous dampers, and to establish convenient ranges of the additional viscous energy dissipation. This coupling presents the advantage of not jeopardising the recentring capability while greatly reducing the displacements of the isolation system. A parametric investigation on a two horizontal DOF oscillator, subjected to a set of natural accelerograms compatible with the code spectra (see www.reluis.unina.it) and to near fault earthquake has been carried out. The model takes accurately account of the different behaviours of the devices composing the isolation system, including the sliding PTFE bearings. A viscous-recentring device will be tested within the JET-PACS program.

7.2.2. TASK 1 – Passive control with seismic isolation – BUILDINGS AND BRIDGES

Some general design aspects of seismic isolation for ordinary and monumental buildings and bridges, aimed at improving the design criteria and methods as well as simplifying and improving code specifications have been examined, especially related to general design problems of buildings involving architectural aspects, problems related to simplified analyses of isolated buildings and bridges, general and specific problems of churches (starting from the lateral load resistance assessment to the peculiar features of the isolation devices), economic comparative aspects of seismic isolation, experimental tests on bridge models.

7.2.2.1. Configuration aspects (E1_UNIPG)

Considerations of the architectural as well as the structural configurations of buildings have not significantly influenced the fundamental concepts of the architectural design so far. Analyzing the relations among architectural configuration, structural solution and seismic response of buildings equipped with innovative protection systems, leads to the outlining of new basic criteria in architectural conception. To identify optimal configurations of both the superstructure and the isolation system, the interaction among the building configuration, the seismic-resistant system configuration and the isolating system arrangement are to be considered.

The application of innovative principles of seismic protection makes some configurations of modern architecture acceptable, though they are usually considered as critical or incompatible with seismic safety. A typical example is given by the so called "pilotis" configurations. At present, the solution is penalized by code requirements, but the real problem is represented by the number of existing buildings in areas prone to seismic risk. Modern technologies can enhance the seismic performances through effective retrofitting without modifying the architectural features.

The following activities have been or are being carried out:

- Parametric analyses on simplified schemes to identify the criteria for the optimal distribution of the elevation mass and the isolator stiffness to reduce torsion. Basic in-plan building shapes have been considered: circular (C) and square (S). The isolation system consists of High Damping Rubber Bearings.
- Actual isolated buildings, designed respecting optimization criteria and currently under construction, have been used as case studies, by carrying out behaviour analyses and verifying the response.

- Sample structural systems, including different types of lateral-resistant systems, have been modelled to define criteria of optimum configuration with reference to overturning effects. They include:
  - seismic-resistant system consisting of 2-bay r/c frames alternated by plain r/c walls
  - seismic-resistant system consisting of dual-system alternated to frames
- a typical category of structural solutions, making configuration rules compatible with innovative solutions, is provided for the suspension of building parts or elements. Different structural scheme have been investigated, namely:
  - suspended buildings where energy dissipating devices are inserted between the oscillating floor block and the rigid core.
  - suspension of floor slabs connected to the main structure by means of dissipative devices.
  - "bridge buildings" where floors are suspended and laterally connected with dissipating devices.
- Solutions for the retrofit of the soft-first-story have been studied, where the pilotis story can be regarded as an equivalent configuration of base isolation.

7.2.2.2. Force distribution for the static analysis of buildings with different seismic isolation systems (R1_UNIBAS)

In the Italian code, as well as in many other codes, the equivalent static analysis is strongly limited due to the difficulty of defining a reasonably conservative distribution of inertia forces along the height of the building, as soon as the behaviour of the isolation system is non linear and/or the damping is high. The non linearities activate the higher modes of the building, thus increasing the acceleration at the upper stories. In the Japanese code a formulation of the problem relies upon an equation that describes the acceleration profile along the height, as a function of the viscous and hysteretic energy dissipation. The aim of this activity is to find a new and more accurate formulation, which accounts for the force-displacement shape relationships of the main types of isolation systems (rubber, lead-rubber, strongly re-centring, curved sliding devices, etc.). The actual force distribution will be evaluated on both experimental results drawn from past researches on large structural models tested on shaking tables or in pseudodynamic tests and on numerical results of dynamic non linear analyses. The results will be summarised through multivariate regression analysis to find a unique distribution equation to be included in seismic codes.

7.2.2.3. Assessment of the seismic safety of monumental buildings (R3_UNINA_DL)

The basilica churches have been selected as the building class to be studied with the purpose of assessing the BIS effectiveness in the seismic retrofit design due to the following considerations: (a) churches exhibit high seismic vulnerability, as shown in the 1998 Umbria-Marche earthquake; (b) churches are largely diffused in the Italian monumental patrimony; (c) churches show repetitive geometrical configurations and structural schemes, that suggest the possibility of extending the study results obtained on a limited number of examples to a larger sample.

The first step of the research activity has been the selection of a significant sample of monumental church buildings. 10 churches have been selected, all located in Naples. For each of them, the following information have been collected: historical data, graphic and photographic documentation, geometrical characteristics, material properties, damage patterns, architectural or structural interventions. The buildings have plan dimensions from 21×29m to 44×66m, heights from 14 to 47m, weights from about 2200 t to about 29500 t.

Typological and single macro-element analysis have been carried out for the selected buildings, to parameterize and define the variation range of the global and single macro-elements geometrical characteristics. The selected macro-elements classes are the apsidal macro-element, the first and second triumphal arch, the transverse section of the broad aisle, the façade, the longitudinal prospect and the longitudinal internal arcade.

Linear static and dynamic structural analysis have been carried out on the 3D models of the selected building, while non-linear static analyses have been carried out on the 2D models of the single macro-elements of each building. The analyses have been oriented to the evaluation of global and local structural properties, dynamic characteristics, behaviour under increasing horizontal loads (in plane and out of plane), and to the evaluation of ultimate strength and deformation capacity. The structural analysis activity is aimed at obtaining a simplified assessment of the building seismic safety / vulnerability.

7.2.2.4. Design procedures and simplified analysis methods for BIS in the retrofit of monumental buildings (R3_UNINA_DL)

From the analysis of existing applications of BIS and from previous studies , it has been pointed out that there are some problems not yet completely solved in the application of BIS to retrofit historical monuments, both related to the peculiarity of the upper structures (ancient masonry buildings, often characterised by complex geometry) and to the characteristics of the isolation devices required for this particular applications (high deformation capacity, lightness, etc.). The following aspects deserve consideration:

- Definition of a design procedure for the BIS, aimed to the optimization of different conflicting requirements: values of axial stresses due to gravity loads on devices from 6 to 10 MPa; first shape factor S_1 not less than 18; secondary shape factor S_2 not less than 3-4; achievement of the target isolation period in the range of 2.5 - 3.5 sec, in order to reduce the strength demand on the building to values comparable to the poor capacity of the superstructure; minimum eccentricities between the upper-structure masses and the isolation device stiffnesses; small range of variation of axial load on the devices due to seismic actions (+/- 30% of vertical load); adequate safety factor against critic load (>2).
- Definition and solution of the problems described at the previous point in the case of light structures (small churches or small historical structures), for which it can result particularly difficult, with a standard design procedure and with usual isolation devices, to get an isolation period larger than 2.5 sec.
- Evaluation of the isolated structure behaviour with and without a rigid slab above the isolation system; this aspect is important because in many cases the insertion of a rigid slab at the base of the structure is impossible for the presence of artistic elements and decorations.

For five churches (SI, SGM, SGMR, SPM and SGO), an isolation system has been designed and an improved optimization process (varying the shear modulus G, the system configuration and optimizing the position of the mass and stiffness centroids) has been studied and applied. The isolated structures have been analyzed through FEM, evaluating their seismic response through modal and time history analyses.

7.2.2.5. Computational models and design procedures for Base Isolation Supplemental Damping (BISD) systems and relevant structural installations (E4_UNIUD)

The implemented models concerned the classical installation of BISD systems, i.e., at the base of building structures, and a new field of application, represented by the incorporation of the system at the base of single floors, to specifically protect their contents (e.g., artworks, pictures and statues in museums and exhibition halls, machineries in industrial structures, special apparatuses in hospitals, shelves and stands in libraries, stores and commercial centres, etc).

The conceptual lines for the incorporation of the BISD system in seismically isolated floors were formulated and applied to the hypothesis of reconstruction of an ancient castle destroyed by the 1976 Friuli earthquake (Prampero castle in Manzano, near Udine). This hypothesis concerns the new use of the building as a museum, with two statues situated on the isolated ground floor. The response of the statues was analysed by including a first level of schematisation of their rocking effects into the computational model of the mobile floor. Various seismic isolation solutions were proposed, in addition to the BISD one, to obtain the greatest benefits as compared to the conventional fixed-base structural configuration.

7.2.2.6. Economic aspects (E1_UNIPG)

A thorough investigation of economic aspects in the application of innovative protection systems can provide substantial help in deciding the actual convenience and the real advantages of such systems with respect to conventional seismic design approaches. The problem is being addressed as follows:

- Preliminary definition of the correlations among the seismic hazard, the strength capacity level (design seismic intensity), expected damage levels (vulnerability), retrofitting costs (direct and indirect costs related to the damage scenarios), taking into account the new Italian seismic code.
- Definition of the analysis methodologies to evaluate the performance response.
- Set up of economic criterion for the actualization of the probable costs as a function of the discounting-back annual rate and the reference life time of the building.

The following activities have been or are being carried out:

- Deterministic definitions have been formulated of: seismic hazard, in terms of correlation between PGA and return period; vulnerability, in terms of correlation between PGA and ductility demand (damage indicator); costs, in terms of correlation between the damage indicator and the retrofitting costs.
- Preliminary analyses have been carried out on simple schemes of isolated buildings and bridges.
- Practical analysis methodologies using energy-based non linear static analyses, in substitution of direct time history analyses, have been conceived, applied and tested.
- State-of-the-art probabilistic definitions of the main correlations controlling the economic response of the constructions (return period and intensity parameter; intensity and damage index; damage index and retrofitting costs) have been formulated.
- Methodologies for the comparison of the actual performance of isolated and conventional constructions, when using the previously listed probabilistic definitions of the correlations, have been outlined.

7.2.2.7. Effects of near-fault earthquakes on isolated buildings (E2_UNICAL; E4_UNIUD)

Near-fault earthquakes are characterized by long duration pulses along horizontal directions, high-frequency motion along the vertical direction and large variability of the acceleration ratio α_{PGA} (i.e., the ratio between

the peak value of the vertical acceleration, PGA_V, and the analogous value of the horizontal acceleration, PGA_H), with values of α_{PGA} even larger than 1.
The effects of near-fault ground motions on the response of base-isolated framed buildings include: very large horizontal displacement of the isolators (e.g., high-damping laminated rubber bearings, HDLRBs) and interaction between their horizontal and vertical force-displacements laws; plastic hinges along the span of girders; variation of the axial force in the columns, producing undesirable phenomena (i.e., buckling, brittle failure of reinforced concrete columns, etc.). As a consequence, it is very important to check the effectiveness of the base isolation of framed buildings, considering the combined effects of the horizontal and vertical components of near-fault ground motions, in order to establish if additional code provisions are needed.
The first stage of the studies on the response of base-isolated structures under near-fault earthquakes was focused on the application of analytical pulse-type ground motions. Two “forward-and-back” single-sided pulse models were used, as formulated in [Hall and Ryan 2000] and [Makris and Chang, 2000], respectively. The numerical investigation was carried out by the model of the real structure equipped with the BISD system, mentioned in section 2.2, and a reinforced concrete structure incorporating HDRB isolators, assumed as a reference for the research developed in [Hall and Ryan 2000]. This section of activities will be completed in the second year of the Project by a supplementary numerical enquiry based on real near fault earthquake records.
The main characteristics (class of soil, distance from the fault, magnitude, peak values of the horizontal and vertical acceleration-components) and response spectra of strong near-fault earthquakes recorded in different countries were examined and compared. Then, attention was focused on strong ground motions recorded in Turkey (Izmit, 1999; Duzce, 1999), whose data are available in a european database (www.isesd.cv.ic.ac.uk/ESD).

7.2.2.8. Displacement and Force Control Design Procedures for Seismic Isolation of Bridges (R1_UNIBAS)

Two different procedures have been set up for the design of the IS’s. They are respectively aimed at getting either a given maximum force (design force approach) or a given maximum displacement (design displacement approach) in the IS. Both are based on the Capacity Spectrum Method, as defined in (ATC, 1996). The design force approach is particularly useful for the retrofit of existing bridges, while the design displacement approach is better suited for new bridges. Three different isolation systems are considered. All of them are made of steel-PTFE sliding bearings, to support the weight of the deck, and of auxiliary devices, based on different technologies and materials (i.e. rubber, steel and shape memory alloys), to provide re-centring and/or additional energy dissipating capability. A numerical simplified pier-deck model has been set up, where the pier is modelled as an elastic cantilever beam and the mass of the deck is connected to the pier through suitable non linear elements, simulating the behaviour of the isolation system.

7.2.2.9. Design procedure for isolated bridges with dampers (R2_UNINA_SE)

A literature state of the art have been accurately made on the design procedures of passive dissipators to be included between the pier and the deck in an isolated bridge. A methodology for determining the optimal values to be assigned to the damping and stiffness parameters has been defined, where the damping feature depends on the mechanical characteristics of passive control devices installed between the pier and the deck. Within this methodology, simple design spectra are proposed, which allow to determine the optimal damping parameter as a function of the stiffness parameter.

7.2.2.10. Design of an experimental bridge pier model (R1_UNIBAS)

The experimental tests on bridge sub-assemblages requires the design of a representative bridge-deck sub-assemblage that can permit to include the effects of seismic isolation systems on the behaviour of the structure. The tests will be carried out with the pseudo-dynamic method and the model is made of 1/3 scale pier and the deck segment corresponding to the cap size, including two bearings or isolators. The pier is designed considering only vertical loads, according to the usual criteria used in the eighties. Numerical simulations on the non linear behaviour of the pier-isolation-deck assemblage are in progress.

7.2.3. TASK 1 – Passive control with seismic isolation - DEVICES

Both experimental and numerical studies are envisaged in this section. They are relevant to rubber isolators (with or without dissipating insert inside), sliders, wire rope isolators and viscous devices for seismic isolations, and are aimed at improving the knowledge of some not well understood problems and to provide practical solutions.

7.2.3.1. Experimental tests on rubber isolators without or with lead or viscous insert (R1_UNIBAS)

Tests of several rubber and lead-rubber isolators are being carried out at the Lab of UR1 – UNIBAS. They are mainly aimed at evaluating their buckling resistance under high compression loads and their tensile resistance under tensile vertical loads, also applying different shear deformations. Also cyclic tests and relaxation tests will be carried out, in order to characterise their behaviour and extract some parameters that are useful for better modelling their seismic behaviour, including Mullin effect.

The tests are carried out on conventional and hollowed rubber isolators. This latter are filled with either lead or highly viscous material, in order to improve their energy dissipating capability.

7.2.3.2. Numerical analysis and experimental tests on rubber isolators (HDRB) for monumental buildings (R3_UNINA_DL)

Preliminarily to the experimental activity, a parametric numerical study has been carried out, through FE analysis, on a set of five HDRB models, characterized by different values of the primary shape factor (S_1 = 6, 12, 18, 24, 30). For each isolator, the analyses have been performed under different loading conditions, namely only vertical loads (3, 6, 9, 12, 15 MPa), only horizontal loads (horizontal displacement equal to 100, 200 e 300%), and vertical plus horizontal loads. The numerical results have been taken into account in planning the experimental activity on HDRBs. Furthermore, the specific application of HDRBs, i.e. retrofit of existing monumental buildings, has deserved some additional considerations, leading to the definition of some performance requirements, namely: lightness, high deformation capacity and durability.

Finally, for the HDRBs to be used in the seismic isolation of historical monuments, both traditional, steel reinforced, and innovative, composite reinforced, elastomeric bearings have been selected for a comparative assessment of the experimental behaviour. The composite reinforced elastomeric bearings are much lighter and durable than traditional bearings.

7.2.3.3. Variable stiffness model for rubber isolators (E2_UNICAL)

The response of a HDLRB under a lateral loading (F), acting simultaneously with a compressive or tensile axial loading (P), exhibits a vertical displacement (u_V) which is due to both axial deformability of the rubber and tilting of the middle layers of the isolator under shear deformations. Experimental results available in the literature have pointed out that the horizontal stiffness of a HDLRB (starting from the nominal value, K_{H0}) decreases with increasing vertical load (P), while the corresponding vertical stiffness (starting from the nominal value, K_{V0}) decreases with increasing lateral displacement (u_H).

The attention has been focused on the setting up of simple and reasonably accurate models that allows extensive analyses of base-isolated structures to be carried out with an affordable computational effort.

7.2.3.4. Mathematical models and instability considerations for rubber isolators (R2_UNINA_SE)

After an investigation of all the formulae of literature relative to the instability of reinforced elastomeric isolators, some of them, providing the value of the critical load, have been compared to the one defined by t UR2 – UNINA_Se and to the one contained in the new Italian Seismic Code, by applying them to some experimentally tested isolators. Moreover, a state of the art on the mathematical models developed to simulate the experimental behaviour of the rubber isolators has been carried out, to verify the most sophisticated models within the testing campaign performed during this project.

7.2.3.5. Numerical modelling of rubber isolator with viscous insert (R1_UNIBAS)

This study is aimed at developing detailed and simplified models for the analysis of some critical aspects of the behaviour of laminated rubber isolator with internal viscous insert. Three models will be studied:

- 3Dl models of the entire isolator under general loading conditions
- 3D models of the single rubber layer between two steel shims, under simplified loading conditions
- Mono-dimensional equivalent models of the entire isolator aimed at studying the buckling conditions.

The rubber behaviour is modelled with a hyperelastic non linear (neo-hokeano, Blatz and Ko, etc.). Both FEM numerical approaches (for 3D and 1D models of the entire isolator) and analytical approaches (for 3D models of the single layer and 1D models of the entire isolator) will be used.

Comparisons with the results of the experimental activity will be carried out.

7.2.3.6. Experimental tests on Steel-PTFE Sliding isolators (R1_UNIBAS)

Available studies on friction properties of sliding bearings have been mainly carried out on special arrangements of the sliding surfaces, not on real full scale devices. In this activity, the experimental tests are carried out on real sliding isolators with lubricated surfaces, typically used in Italy. Axial loads and speed are the two investigated parameters. Four devices have been tested, with compression stresses and speed in the ranges 6.6 - 26.4 MPa and 0.1 - 400 mm/sec., respectively.

7.2.3.7. Mathematical models and experimental tests for Wire-Rope devices (R2_UNINA)

Isolation systems of light structures based on *Wire-Rope* devices will be numerically and experimentally studied. Experimental tests will be carried out with a Machine, which has been used until now to test antivibration elastomeric pads and mats for railway tracks (RPMTM = Resilient Pad and Mat Testing Machine).

7.2.3.8. Analytical and computational models of FV devices (E4_UNIUD)

The analytical model of FV spring-dampers adopted in this research, formulated in [Peckan et al. 1995, Sorace and Terenzi 2001a, b], consists of a fractional power-velocity law, for the non-linear damping force component, and a Menegotto-Pinto-type relationship, for the non-linear elastic spring force component.
A reliable model of this type is especially interesting for possible qualification and acceptance tests of FV spring-dampers performed at lower velocities than the design ones. Reduced-velocity tests, indeed, are necessarily carried out in the case of very large devices, for which it can be difficult to provide the required maximum load/frequency combinations. These aspects will be further enquired in the last section of UNIUD activities, planned for the third year of the Project.

7.2.4. TASK 2 – Passive control by energy dissipation - GENERAL

7.2.4.1. State of the art and analytical modeling of dampers (E2_UNICAL)

The state of the art of buildings with damped braces was examined. A large variety of damped braces was found, depending on the arrangement of different systems and, especially, on the kind of dissipation. However, the attention was focused on the following kinds of dampers: hysteretic (friction and metallic-yielding), viscous and viscoelastic dampers, aiming to develop analytical models for simulating the cyclic response of these dampers.

7.2.4.2. Identification techniques of dissipation properties of structures with innovative protection systems (E7_UNIBO)

Main purpose of this study is the characterization of dynamic behaviour of seismic dissipation systems. When a dissipation system is adopted, the actual damping of the structure and the corresponding mitigation of seismic action depends on the structural behavior. A correct evaluation requires hysteretic damping produced by non linear material behavior of the structure be also taken into account in order to estimate energy dissipation. In order to estimate damping ratios of structures with innovative protection systems, dynamic identification processes have been developed. To this purpose, different methods in time and frequency domain have been compared.
Well-established techniques exist in the literature for parameter estimation of linear models in time domain (autoregressive models and subspace methods). Excitation of the structure by dynamic forces is required in order to apply frequency domain methods. Forces may be imposed, for example, by means of a mechanical shaker. On the contrary, time domain methods are more flexible since every kind of dynamic excitation can be used, such as noise excitations or forces induced by impact of weights on the structure.
Techniques for non-linear identification are required in the case of high damping systems. Methods such as NARMAX (Nonlinear Autoregressive with Exogenous Input) can be used when non-linear behaviour of structure requires more robust algorithms. Nonlinear Autoregressive models must be supported by non-linear optimization procedures, because several parameters must be usually optimized simultaneously. To solve this problem, Evolutionary and Genetic Algorithms have been adopted in the present research.

7.2.4.3. Methods for reliability estimate of innovative systems for seismic mitigation (E7_UNIBO)

The estimate the reliability of a seismic protection system is a very important problem from the technical point of view. A protection system must be effective for different possible earthquakes originated close to a given site, and even if some small localized damages of protection system occurred after the last maintenance control. In the first year of the research, reliability estimate methods have been studied and implemented. Those methods give fragility curves of a given structure, considering the variability of seismic action and of mechanical properties of the structure. Sets of earthquake accelerograms can be selected from natural records or artificial records generated with probabilistic criteria. As for structural mechanical properties, existing structures are considered, with concrete strength, steel yielding and mass distributions defined according to probability criteria. Response surface method and central composite design for selection of simulation tests are used to construct fragility curves, and failure probability of the structure is estimated by FORM or SORM methods.

7.2.5. TASK 2 – Passive control by energy dissipation - BUILDINGS

Attention has been focused mainly on the numerical modeling, experimental analysis and the development of design procedures for buildings equipped with several different kinds of energy dissipation devices. Both traditional and new conception dissipative bracing systems have been considered. The possibility of applying non invasive energy dissipation systems to masonry structures is also being studied.

7.2.5.1. Computational models and design procedures for viscous fluid dissipative bracing system and relevant structural installations (E4_UNIUD)

The computational model of this protective technology was obtained by assembling the models of the two interfaced spring-dampers placed atop the supporting steel braces, or over a central steel column, as proposed for a new mounting scheme developed for the semi-active braces within this research. Two typologies of application of the protective system were analysed: a) a complete installation over the height of standard buildings, and b) an installation limited only to the ground floor, in the case of buildings with "pilotis" (largely diffused in the Italian architecture of the Seventies and Eighties). A pre-normative steel school building in Florence, characterised by the high seismic vulnerability that is typical of many similar structures in the Italian territory; and a reinforced concrete residential building in Udine, well representative of the "pilotis"-ground floor configuration, were selected as demonstrative case studies. Relevant computational models were completed within the first year, and some preliminary results presented for the second case study building.

7.2.5.2. Computational models and design procedures for the damped cable system and relevant structural installations (E4_UNIUD)

A new computational model of the damped cable system was implemented during the first year activities, with special regard to the sliding contacts between prestressed cables and floors. The model consists in an elastic connection between the cable-floor interfacing joint and the centre of curvature of the cable deviator, and a rigid-body constraint imposing a displacement trajectory equal to the deviator shape to the interfacing joint. This scheme was described in detail in [Sorace and Terenzi 2006a], where the response of the new computational model was compared to the one of an analytical model developed and experimentally validated in previous studies [Sorace and Terenzi 2003b]. A remarkable correlation of the two responses was observed for the reference frame structures examined in this analysis.
The previously proposed design procedure of the system was reassessed and applied to two hypotheses of installation, represented by the same pre-normative steel school building considered for a dissipative bracing-based retrofit solution, mentioned in section 2.3, and a reinforced concrete hospital building in Latisana, in the province of Udine.

7.2.5.3. Design procedure for displacement-dependent non linear bracing systems (R1_UNIBAS)

This activity is aimed at setting up a non linear static procedure for the design and safety verification of displacement-dependent non linear bracing systems, as well as simplified elastic design methods based on the use of the behaviour factor (q-factor).
The non linear static procedure is based on the following steps:

1. Definition of the characteristics of the structure, using push-over analysis and SDOF reduction
2. Evaluation of the characteristics of the equivalent brace, for a pre-assigned ductility
3. Distribution of such characteristics at the stories, assuming constant stiffness ratio between the structure and the story brace
4. Safety verification with the N2 method and evaluation of the q-factor.

7.2.5.4. Design criteria for viscous dampers (E7_UNIBO)

The main objectives of the research activity performed during the first year were the acquisition of a complete bibliography concerning the use of viscous dampers for mitigation of seismic actions for building structures and the definition of design procedures for optimal position of viscous dampers in building structures. Three main goals have been pursued: 1) Definition of the physical/mathematical approach most suitable to identify the system of added viscous dampers leading maximum efficiency in terms of energy dissipation; 2) Once obtained physical characteristics of the "optimal" viscous damper system, definition of a design procedure giving characteristics of dampers to be required to the manufacturer; 3) Design of mechanical systems suitable for practical insertion of such devices in building structures (with special attention to reinforced concrete buildings).

7.2.5.5. Design procedure for visco-elastic bracing systems for buildings structures (R1_UNIBAS)

This activity is aimed at setting up a static procedure for the design of visco-elastic bracing systems, assuming the loss factor, the damping ratio and the strain amplitude of the visco-elastic material as unknown variables. The procedure is based on the following steps:

1. Analysis of the structure to evaluate its story stiffness characteristics
2. Design of the story bracing stiffness, assuming constant stiffness ratio between the structure and the story brace
3. Iterative design of the dissipating device, once temperature, strain amplitude and period are fixed.
4. Evaluation of the capacity curve of the braced structure and SDOF system reduction.
5. Evaluation of the equivalent damping of the braced structure and search for the performance point.
6. Verification of the strain amplitude of the visco-elastic material.

7.2.5.6. Design procedure for buildings with viscous and visco-elastic dampers (R2_UNINA_SE)

A literature state of the art have been accurately made on the design procedures of passive bracing systems including viscous and visco-elastic devices for a new structure in its design phase or for an existing structure in its rehabilitation phase. A methodology has been defined for determining the optimal values to be assigned to the damping and stiffness parameters, where the damping feature depends on the mechanical characteristics of passive control devices installed between the braces and the structure. Within this methodology, simple design spectra are proposed, which allow to determine the optimal damping parameter as a function of the stiffness parameter. The design procedure has been applied and further investigated for the mock up steel frame structure which will be tested at the structural Laboratory of UR1 – UNIBAS with passive and semi-active bracing systems installed in different configurations (JET-PACS program).

7.2.5.7. HDR and BRB braced systems: analysis methods and design procedures (E6_UNICAM)

Existing framed structures with limited stiffness and ductility are considered, in which the introduction of dissipating braces permits remarkably improving the global seismic response. Two particular kinds of dissipation devices are analyzed. The first consists of dampers based on High Damping Rubber (HDR) and the second consists of buckling restrained braces (BRB) based on elasto-plastic materials. The project includes both theoretical and numerical investigations aimed at defining reliable analysis methods and design criteria as well as an experimental campaign on a real scale, one storey R/C mock-up, equipped with dissipation devices, carried out in order to validate the results of the numerical analyses.
The influence of the inelastic behaviour characterizing the HDR dissipation devices on the dynamics of a S-DoF system has also been studied. This activity may be considered as a basic step for understanding the M-DoF system behaviour. The attention has been focused in defining equivalent linear systems in order to make it possible performing linear analyses very useful in design procedures.

7.2.5.8. Re-centring and dissipating system for masonry structures (R1_UNIBAS)

The attention has been focused on the conception and design of an energy dissipating and re-centring system for masonry monumental structure. In case of regularly pierced walls with slender panels, the rocking mechanism of each panel, combined with the effect of the vertical loads, gives rise to a re-centring global mechanism, whose behaviour can be described as nonlinear elastic. It can be combined with energy dissipation elements suitably positioned at the four panel corners. The retrofit has been designed with reference to a 1/6 scale model of the structure of the tambour of the dome of the S.Nicolò's Church of Catania. The real model will be tested in December 2006 at the ENEA-Casaccia Shaking table, for an external experimental project.

7.2.5.9. Design and set up of the mock up for the Joint Experimental Tests of Passive and semi-Active Control Systems (JET-PACS program)

Several different passive and semi-active control devices will be tested in a mock up structure at the structural Laboratory of UR1_UNIBAS. The mock up structure is a 2/3 scale 2 story one by one bay steel frame, already available from a previous project. The tests will be carried out under dynamic conditions, by putting the base of the frame on guides and by driving it with a dynamic 500 kN force, 500 mm stroke actuator. The frame has to be checked and modified in order to better fit the requirements of the testing program and to be driven by the dynamic actuator.
The research unit UR2_UNINA_Se has worked on the preparation of the experimental testing campaign which will be carried out at the structural Laboratory of UR1_UNIBAS on the mock up structure equipped

with passive and semi-active bracing systems. After a dimensional analysis of the mock up structure, a 3D complete finite element model of the structure has been constructed for obtaining the modal frequencies and shapes of the structure, together with some simplified numerical models that are suited to make some design considerations of the control bracing systems. It has been defined how to perform the dynamical characterization tests needed to determine the resonance frequencies and damping coefficients of the structure, and the different passive and semi-active devices to be installed on the mock up have been examined with their technical characteristics. A scheme of the testing configurations has been prepared, including a non controlled configuration, a passive control configuration and a semi-active control configuration, with two possible types of braces (rigid and flexible); moreover, different already experimented connecting systems have been considered for the link of the dampers to the structure and to the braces. Finally, a detailed definition of the instrumentation (transducers, hardware and software) needed for the tests has been made, either that one to be used for the tests in the non controlled and passive control configurations, or the one to be arranged for the tests in semi-active control configuration.

7.2.5.10. Full-scale experimental test on precast concrete frame with innovative protection system (E7_UNIBO)

A full-scale precast concrete frame has been designed and will be realized in collaboration with a company producing precast structural elements. The structure will be used by the Research Unit to test viscous damper systems, but also other Research Units will be able to test different innovative systems.
A number of numerical tests has been performed in order to verify the versatility of the structure. Experimental tests have been designed, with different experimental setups and kinds of excitation.
Three different excitation methods will be adopted: ambient vibrations will be used to for dynamic modal analysis of the structure in the linear range; then, dynamic tests will be carried out by means of a mechanical shaker or free vibrations will be recorded after releasing in different configurations.

7.2.6. TASK 2 – Passive control by energy dissipation - DEVICES

The activities performed were all aimed at proving the effectiveness of new type of energy dissipation devices and defining reliable constitutive models of their dynamic behaviour through the execution of experimental tests. Both experimental and numerical studies are therefore envisaged in this section, all directed to provide practical solutions to improve their applications.

7.2.6.1. Hysteretic numerical models for fluid viscous dampers (E7_UNIBO)

Numerical models have been developed for fluid viscous dampers. Different models proposed in the literature have been considered (classical Maxwell model, Standard mechanical model, fractional derivative model and modified power law). Their potentialities have been compared with reference to sets of experimental data reported in the literature. Between them, standard mechanical model has been considered as the more powerful method.
The objective of the study is mainly the definition of a numerical model for structural dynamic analysis, but also a method to detect the presence of damage in fluid viscous dampers for dynamic tests.

7.2.6.2. Combined Viscous-SMA device for the JET-PACS program (R1_UNIBAS)

R1_UNIBAS will contribute to JET-PACS by testing strongly recentring Shape Memory Alloy devices, combined with viscous non linear devices to increase their energy dissipation capability. The viscous devices have been conceived, designed, realised and tested, Their shape and size is such that they can be incorporated in SMA devices. The number of SMA wires to get the optimal value of force must be recalibrated, according to the design objectives of the strengthening system.

7.2.6.3. Experimental Tests of Fluid Viscous devices for the JET-PACS program (R2_UNINA_SE)

The research unit UR2_UNINA_SE has worked on the preparation of the experimental tests to be performed on the viscous and magnetorheological dampers at the structural Laboratory of UR2 – UNINA_Se. For both for the viscous dissipators and the magnetorheological devices, UR2 has thought how to connect the devices to the Testing Machine present in the Laboratory and has defined the instrumentation needed.

7.2.6.4. Definition of reliable models for dissipation devices (E6_UNICAM)

The analysis of the existing scientific literature demonstrates that the behaviour of BRB devices is widely investigated. On the other hand a lack of information exists about the behaviour of HDR devices under shear loads. It should be noted that the use of rubber with enhanced dissipating properties is not new in the mitigation of seismic effects but, up to now, it has been adopted almost exclusively in the seismic isolation. In

this case the dissipative properties of the material may be considered as a secondary effect and very simplified models may be acceptable for the design.
In the case of dissipation braces within framed structures simplified models do not furnish an adequate description of the dynamic behaviour of HDR devices. Consequently, the first activity carried out in the project is to define a constitutive model able to describe all the main phenomena occurring on HDR dissipation devices subjected to shear strains. This activity is based on the results available from experimental tests carried out in the past, which pointed out that, under cyclic loads, the material behaviour is characterized by an important transient contribution (Mullins effect) which is strain rate and strain amplitude dependent. Once the transient response has disappeared, the material exhibits stable loops which are also strain-rate and strain amplitude dependent. The transient response does not occur only in the virgin material, because the rubber showed important recovery properties.

7.2.7. TASK 3 – Passive control by tuned masses

The evaluation of the possibilities offered by Tuned Mass Dampers (TMDs) and Tuned Liquid Dampers (TLDs) for seismic response reduction as well as their actual implementability in real structures is the main scope of this task (E3-POLITO, E5_UNISA). The development of analytical and numerical tools for studying their effectiveness and robustness also in combination with base isolation has been carried out during the first year of the research, while experimental activities are going to be perfomed by the E5_UNISA Unit in the subsequent years. A cooperation is envisages with the R2_UNINA_SE Unit regarding the adoption in the experiments as supporting elements of the tuned masses of Wire Rope isolators, which combine the restoring and damping functions in one single element and are particularly suited for light masses as those necessary in TMDs.

7.2.7.1. Development of analytical and numerical tools for tuned mass dampers (E3_POLITO)

After a state-of-the-art and a state-of-the-practice of Tuned Mass Dampers (TMD) and Tuned Liquid Dampers (TLD), the development of analytical and numerical tools for studying TMDs' and TLDs' effectiveness and robustness as passive structural control systems for the seismic protection of buildings has been carried out. Stemming from the knowledge collected through the foregoing literature review, the idea of a new type of mass-uncertain TMD has been proposed and the corresponding analytical and numerical models developed, thus providing with the basic tools for more generally investigating into the effectiveness and robustness of TMDs for seismic response mitigation.
While looking for new motivations which could possibly increase the seismic benefit of TMDs, the activity stems from the idea of turning into TMDs those non-structural masses, such as roof gardens, tanks or technical installations, which are normally placed on top of buildings, in order to obtain a structural control system having low cost and minimal impact. Since such installations are susceptible of varying their mass (e.g. due to changes in the soil water content in the case of a roof-garden TMD), and therefore potentially their frequency and damping, assessing and enhancing robustness against mistuning is identified as a crucial issue for these new family of 'mass-uncertain TMDs'.
Hence, the activity can be summarized as follows: a) an innovative robust design has been formulated in the framework of a worst-case H_∞ approach as the necessary substitute for the classical nominal design, automatically providing the optimal selection of multiple TMDs' parameters for controlling single degree of freedom systems; the developed procedure has allowed on the one hand the robust analysis of systems with parametric uncertainties (both in the main structure and in the oscillators) and on the other the comparison between two alternative paradigms of single and multiple TMDs, namely the classic translational absorber and a new version of pendulum TMD, this latter configuration being preferred owing to the advantage of keeping its natural period unchanged under mass variations; b) such new version has been conceived as a rolling pendulum device specifically proposed by this Unit to minimize the non-linearity inherent in rolling systems undergoing large oscillations; to this purpose, analytical and numerical methods have been derived to divine the optimal iso-periodic rolling shape, both in 2 and 3 dimensions, resulting in the proposal of the 2d elliptical optimal profile and the 3d ellipsoidical optimal surface as the distinctive ingredients of the new device; c) numerical simulations under different excitation conditions have been conducted to evaluate effectiveness and assess the applicability range of the new device; the superior robustness of the pendulum system against uncertainty in the oscillating mass has been demonstrated with respect to the translational TMD through a parametric study; the results have shown that a translational TMD can still provide acceptable robustness only if its mass uncertainty is not too large and its mass ratio not too small; in all other cases, the pendulum system should be adopted; d) a study has been conducted to demonstrate that the geometrical constraints inherent in a pendulum solution do not prevent a seismic application of the device under the seismic levels prescribed by the European Seismic Code; e) the benchmark problem proposed by Narasimhan et al. (2002) has been adopted in conjunction with Salerno Research Unit as a common object

to evaluated the seismic performance of combining Base Isolation with mass-uncertain TMD control (BI-TMD).

7.2.7.2. Base isolation and tuned mass damper combined strategy (E5_UNISA)

Base isolation has been widely viewed as an effective strategy to protect structures subjected to seismic excitations. However, it has been shown that, in the case of seismic excitations with high energy content at low frequencies, i.e. a near-fault event or a seismic wave propagating itself through alluvial soil, isolation bearings may undergo gross deformations. By increasing the isolation layer damping, base displacements can be reduced, but, high damping in the isolation layer unfavourably affects the behaviour of the superstructure due to spill-over effects.

By observing that seismic response of a well-isolated systems is dominated by the first-modal contribution and that Tuned Mass Dampers (TMD) are able to reduce the fundamental vibration mode, a new idea is to combine both properties into a single system. Considering the base isolated (BI) structure as a single-degree-of-freedom equipped with a TMD, and subsequently by applying the Laplace transform to the motion equations, it is possible to prove that the TMD works as a closed loop control on the isolation layer.

The objective of the proposed combined system is to control the system response by only reducing the fundamental modal contribution which is dominant in such systems. This positive behaviour is due to the appropriate combination of three fundamental properties of the original systems: the reduction in ground motion transmission to the superstructure, the vibration mode modification due to the BI and the first vibration mode reduction by means of the TMD at this frequency.

The research activity has been focused on the effectiveness of the BI&TMD control strategy, and, in particular, the seismic response of a three-dimensional base isolated benchmark structure equipped with a TMD system has been investigated with the aim of evaluating the effect of the mass damper parameters on the seismic response of the isolated system. The benchmark structure, defined by Narasimhan et al. in 2002, is a base-isolated eight-storey, steel-braced frame building, 82.4 meters long and 54.3 meters wide, similar to existing buildings in Los Angeles, California. The floor plan is L-shaped and the superstructure bracing is located at the building’s perimeter. The superstructure is modelled as a three-dimensional linear elastic system and the floor slabs and the base are assumed to be rigid in plane. The superstructure and the base are modelled by using three master degrees of freedom (DOF) per floor at the centre of the mass. The combined model of the superstructure (24 DOF) and isolation system (3 DOF) consists of 27 degrees of freedom. All twenty four modes in the fixed base case are used in modelling the superstructure. The superstructure damping ratio is assumed to be 5% in all fixed base modes.

Wide-ranging numerical experimentation on the dynamic response of base-isolated benchmark structures equipped with optimal Tuned Mass Dampers to a significant set of bi-directional recorded seismic inputs has been carried out. A set of performance indexes to describe the effect of the control system on the isolated benchmark are evaluated for each of the recorded events taken into consideration. Such indexes concern both maximum displacements and accelerations of isolation level and superstructure, allowing for a comprehensive analysis of the effectiveness of the proposed control strategy. Our results have been compared with the seismic response obtained by applying time and frequency analysis method.

In addition, preliminary studies on the BI&TMD control strategy robustness with regard to the TMD system’s parameters were also carried out.

7.2.8. TASK 4 – Semi-active control - BUILDINGS

The evaluation of the possibilities offered by semi-active control for seismic response reduction as well as their actual implementability in real structures is the main scope of this task (E8UNIPARTH, E9_UNIVAQ). Although the first application of a semi-active control system on a real-scale buildings date back to the 1993 as shown by Kobori et al. (1993), and a second remarkable example is described by Patten et al. in 1999, the number of structures protected by these systems is quite low, at the moment. These first applications adopted viscous dissipaters able to modify their mechanical parameters through the operations of added hydraulic circuits featuring one or more servo-valves. Therefore, these systems shared the common difficulty of dealing with electronic, mechanical and hydraulic parts, so that the time needed to adjust the parameters of the dampers was comparable to the structural natural period and, in turn, too long to achieve optimal performances. For this reason, a new generation of semi-active dampers based on the properties of magnetorheological (MR) fluids have attracted the attention of many researchers. A MR dampers may vary its mechanical properties in the time interval needed to modify the magnetic field in which the fluid is immersed: this time interval may be as short as few milliseconds. Due to this attractive behaviour, MR dampers seem to be the most effective way to introduce a semi-active control system in civil structures. Many laboratory and/or prototype applications have been manufactured and tested so far, and two remarkable real-scale applications have been described by Chen et al. in 2004, and Spencer and Nagarajaiah in 2004, respectively for a bridge and a building structure.

7.2.8.1. Semi-active MR dampers for seismic protection of buildings (E9_UNIVAQ)

The remarkable potentialities of semi-active control systems for seismic protection of civil structures can be largely underemployed, or even invalidated, due to the long time intervals in which they are forced in rest conditions, waiting for of an earthquake event. An objective of the research is the overcoming of such problem, designing the control devices against both recurrent dynamic actions (traffic, rotating machines, wind), and simultaneously for exceptional seismic actions.

A wide theoretical literature exists on the potential skills of semi-active control systems in the protection of building from seismic actions. Nevertheless, only a few experimental applications on laboratory specimens are currently known, and even less real scale realizations have been completed, neither advanced guide lines exists in the national codes. On this respect, more insight is still necessary in evaluating the benefits of the different implementation techniques, in employing effective bivalent solutions for operational and seismic conditions, in developing robust control algorithms, and finally improving the reliability of the devices. Moreover, a quite unexplored field is nowadays represented by the fusion of control methodologies with real time structural monitoring and self-diagnosis for a twofold beneficial effect on the equipped buildings.

7.2.8.2. Effect of damping devices on the structural dynamic behaviour (E8_UNIPARTH)

The design of a semi-active control systems includes a number of different issues:

- type of technology (kind of devices to use);
- number and locations of the devices;
- control algorithm.

The research program includes both viscous and MR semi-active dampers, even if the latter show superior performances. The design of the optimal number and positioning of semi-active dampers is based on concepts similar to the case of passive dampers, and it is widely described in the scientific literature. However, by writing the equations of the motion in the state space it has been possible to directly observe the influence of any single damping device on the damped frequency and on the damping ratio of any single modal shape, also in the range of high damping ratios, thus allowing a deeper insight of the effects of different damping strategies.

7.2.8.3. Control algorithms for semi-active MR dampers (E8_UNIPARTH)

Once a given number of a selected kind of semi-active damper have been chosen to protect a structure, the possibility of having time-varying dynamic properties has to be exploited by an operation logic, i.e., a control algorithm. In the few real-scale applications and in the majority of laboratory implementations, control algorithms based on or derived from the classical theory of optimal control have been utilized. This kind of algorithms rely on a robust and consolidated theory, but they need a real time knowledge of the whole system state, i.e., the displacements and the velocities of all of the degree of freedom of the controlled structure have to be measured and fed to the control algorithm at any time. In the case of structural systems, real-time measurement of displacements and velocities yields a number of different problems that can be too hard to solve. Therefore, a control algorithm which requires a limited number of real-time measurements has been developed for semi-active MR dampers. Furthermore, the measurements needed are forces and relative velocities, which are relatively easier to acquire.

7.2.8.4. Numerical modelling of semi-active MR dampers (E8_UNIPARTH)

MR dampers are usually modelled in numerical codes according to a phenomenological scheme originally proposed by Spencer et al. in 1997. This model is based on the Bouc-Wen evolutionary scheme and requires 10 parameters to describe the behaviour of a MR damper. The number of parameters increases to 14 when the fluctuation of the magnetic field inside the dampers is taken into account. Such a complex model is hard to include in more general numerical codes where both the dampers and the hosting structure should be described. Therefore, a simpler, 4-parameter model (7-parameter including the effects of a fluctuating magnetic field) has been developed and validated, based on the results of a past experimental campaign on a prototype MR damper.

7.2.8.5. Organization of experimental set up for the mock up of the Joint Experimental Tests of Semi-Active Control Systems (JET-PACS program) (E8_UNIPARTH)

The research program includes some experimental tests on a mock-up steel structure, which will be equipped with different damping system, either passive or semi-active. As for the semi-active ones, the experimental activities need the additional testing set up related to the acquisition-process-command loop of the control system. Therefore, the hardware and the related software needed to said experimental activities has been specified and acquired during the first year of the project. In particular:

- The MR damper have been designed and are currently being developed by the manufacturer;
- The measuring instrumentation has been defined and acquired in cooperation with the UR2_UNINA_SE;
- The hardware for real-time processing and commanding, and its related operating environment has been acquired;
- The power suppliers for proper operations of the MR dampers have been acquired.

7.2.9. TASK 4 – Semi-active control - CABLES

7.2.9.1. Semi-active MR dampers for cable oscillation reduction (E9_UNIAQ)

Stay cables are critical structural components in cable-stayed structures. Owing to their large flexibility, relatively small mass and extremely low damping, stay cables are susceptible to large-amplitude vibration caused by wind, rain and support motion. Theoretical and experimental studies of pure passive of active control of cable vibration through stiffness and tension control have shown great application shortcomings, while only recent research attention has being paid to semi-active control of cable vibration, mainly by using magneto-rheological (MR) dampers. Many studies indicated that appropriately implemented semi-active control systems using MR damping devices perform significantly better than passive devices and have the potential to achieve almost the same performance of fully active systems. Moreover, semi-active ER/MR dampers offer the adaptability of active control devices without requiring the associated large power sources neither presenting their technological difficulties of installation. Nonetheless, as a type of fail-safe device, MR dampers can also serve as passive dampers in the case of small-amplitude cable vibration and be activated when large vibration is coming. To enhance the semi-active control performances, the modelling of the interaction between the cable dynamics geometric nonlinearities and the MR damping material ones is still an open research topic.

7.3. Results

7.3.1. TASK 1 – Passive control with seismic isolation - GENERAL

7.3.1.1. Reduction factors for high-damping spectra (R1_UNIBAS)

The results have shown that any reduction factor can be used for average or envelope spectra but not for single earthquakes, for which large errors can occur. the EC8 equation (the same as in the Italian Code) provides acceptably conservative results in the range 0.2-3.0 secs, while the equation provided by the Japanese code provides underestimates of the response of the order of 10-30%, depending on the damping ratio. Better estimates for periods greater than 3.0 secs. can be obtained by assuming expressions where the reduction factor is a function of the period also, such as those proposed by Lin and Chang and by Wu and Hanson. A paper will be presented at the next Italian ANIDIS conference.

7.3.1.2. Viscous-recentring seismic isolation systems (R1_UNIBAS)

An optimal value of the additional viscous damping has been found as the one that reduces both displacement and forces. It is of the order of 10-20%. Non linear recentring devices coupled with viscous devices produce better results than linear elastic devices, both in terms of force and displacement limitation.
A paper will be presented at the next Italian ANIDIS conference.

7.3.2. TASK 1 – Passive control with seismic isolation – BUILDINGS AND BRIDGES

7.3.2.1. Configuration aspects (E1_UNIPG)

Parametric analyses on simplified schemes have given first indications on the optimal distribution of building mass and system stiffness.
The goal of reducing overturning effects can be achieved by complying with the following criteria:

- decreasing the number of isolators, to increase their static compression force and positioning them at the boundary of the building, to reduce the axial variation due to horizontal overturning forces;
- arranging the columns of the first floor to re-direct the compression forces due to vertical loads in those isolators having the maximum overturning forces;

Taking into account these results, some schemes have been devised and analysed. Rough criteria for the selection of configurations and the assessment of dimensions have been formulated.

Optimal structural configurations have been identified for buildings characterized by the suspension of sections or elements. Rules for the shape and the distribution of isolating and dissipating elements have been proposed.

- Arrangements of the top connection and rules for the bottom dissipating connection between the oscillating floor block and the rigid core have been found for seismically isolated suspended buildings.
- Optimum arrangement of isolated and dissipated solutions have been compared for the suspended floor slabs.
- Pre-dimensioning and optimum structural schemes of the main frame in "bridge buildings" have been defined. Optimum distribution of dissipating connecting elements have been proposed.

Effective seismic retrofitting of "pilotis" buildings has been outlined by enhancing its spontaneous "isolated" behaviour, through a special compound energy dissipating system, consisting of dissipating devices (primary system) placed among the columns of the framed elements supporting the building and the ductility enhancement in critical zones of all the columns (secondary system), e.g. by replacing the concrete cover with high ductile concrete and by confining the columns ends.

7.3.2.2. Force distribution for the static analysis of buildings with different seismic isolation systems (R1_UNIBAS)

Only intermediate results are available. The available experimental results have been re-evaluated and the relevant force distributions leading to the maximum shear forces experienced during the earthquakes have been fitted with linear and parabolic functions. The numerical parametric analysis is still being executed.

7.3.2.3. Assessment of the seismic safety of monumental buildings (R3_UNINA_DL)

From the structural analyses results, the most vulnerable macro-element classes have been identified, i.e. the triumphal arches and the elements of the broad aisle; these elements have shown high demand and low capacity. The results also show high stress concentrations at the intersection of the macro-elements, high stresses in the principal façade and longitudinal prospect macro-elements. Globally, the most vulnerable buildings are San Paolo Maggiore e San Giovanni Maggiore churches (both characterized by large mass and size), but, generally speaking, all the examined churches are highly vulnerable to seismic actions.

7.3.2.4. Design procedures and simplified analysis methods for BIS in the retrofit of monumental buildings (R3_UNINA_DL)

A specific design procedure for the isolation system of existing monumental building has been defined and applied to five churches. It has been noticed that some difficulties in reaching the target isolation period arise for light-weight structures, for which sliders can be coupled to rubber isolators. Different problems, mainly related to the difficulty in verifying the device performance limits for the devices (critical load, maximum shear strain), arise in large-size structures.

Response parameters (shear demand in the upper structure, accelerations, base displacement, inter-story drift, etc.) of the retrofitted buildings have been obtained from numerical analyses, showing the effectiveness of BIS in reducing the demands in the upper-structures. The analysis results have also shown that the presence/absence of the rigid floor at the isolation level does not imply variations in terms of accelerations, displacements and forces in the upper part of the construction, but only different values of the axial stress on the isolators in the gravity load condition. This aspect is strictly related to the deformability, and, consequently to the geometry, of the upper-structure; simplified models which takes into account this effect have been proposed.

7.3.2.5. Computational models and design procedures for Base Isolation Supplemental Damping (BISD) systems and relevant structural installations (E4_UNIUD)

A real case study designed during the first year of the Project, representing the first application of this technology in Italy, was particularly examined. Deep details were provided on the practical use of the reassessed design procedures of the BISD system to this representative case study, on the modelling phases, as well as on the practical implementation and experimental qualification of the steel-Teflon sliding bearings and FV spring-dampers.

Almost complete results were obtained also in the study of the incorporation of the BISD system in seismically isolated floors.

7.3.2.6. Economic aspects (E1_UNIPG)

The following results have been obtained:

- Outlining a deterministic methodology for a performance-based cost assessment of constructions.

- Graphs allowing simple cost comparisons at the design stage between base-isolated and fixed-base solutions.
- Outlining a probabilistic methodology for a performance-based cost assessment of constructions.

7.3.2.7. Effects of near-fault earthquakes on isolated buildings (E2_UNICAL; E4_UNIUD)

The results relevant to the first case study subjected to analytical pulse-type ground motions has shown a high performance-demand for the protective system by the pulse-type ground motions.

The nonlinear seismic response of five-storey r.c. base-isolated framed structures, designed considering (besides the gravity loads) the horizontal seismic loads acting alone or in combination with the vertical seismic loads, was studied under the horizontal and vertical components of natural near-fault ground motions. The following main conclusions were drawn:

- for structures designed for only horizontal seismic loads, the ductility demand of the girders, especially for increasing values of the nominal stiffness ratio of an isolator (α_{K0}=K_{V0}/K_{H0}) was significantly larger when the vertical component of the ground motion was considered simultaneously with the horizontal component; the effects were rather evident at the end and mid-span sections, especially at the top floor;
- he vertical motion induced variation of the axial force in columns, producing in many cases even tension or a compressive force larger than the balanced-failure force, especially for increasing values of α_{K0};
- the superstructure should be designed accounting also for the vertical ground motion, especially with regard to the girders at the upper storeys when assuming a rather high value of α_{K0}, for which the superstructure behaved like a fixed-base structure in the vertical direction;
- alternatively, for a rather low value of α_{K0} the superstructure behaved as being also vertically isolated, but the effects of the rocking motion should be carefully examined;
- the use of an isolator model accounting for the variation of the stiffness properties could lead to numerical results rather different than those obtained assuming the nominal horizontal and vertical stiffnesses;
- the horizontal stiffness of the exterior isolators could undergo significant variations for lower α_{K0} values, leading to a shift of the fundamental (horizontal) vibration period and, then, to significant effects on the superstructure.

7.3.2.8. Displacement and Force Control Design Procedures for Seismic Isolation of Bridges (R1_UNIBAS)

An extensive numerical investigation has been carried out in order to (i) assess the reliability of different design approaches, (ii) compare the performances of different types of isolation systems, (iii) evaluate the sensitivity of the structural response to friction variability due to bearing pressure, air temperature and state of lubrication and (iv) identify the response variations caused by changes in the ground motion, bridge and isolation characteristics.

7.3.2.9. Design procedure for isolated bridges with dampers (R2_UNINA_SE)

A design procedure has been developed for bridges and included in a paper presented at the ERES 2005 conference. This methodology has provided some suggestions for the selection of the optimal values to be assigned to the damping and stiffness parameters of the bridge isolation system.

7.3.2.10. Design of an experimental bridge pier model (R1_UNIBAS)

The testing set up has been conceived. The seismic action is applied through actuators with the pseudodynamic method, while the vertical static load is applied through a force-controlled vertical jack contrasting against a vertical prestressing cable passing through the deck segment and the pier. The design drawings of the pier-deck subassemblage and the test set-up are being completed.

7.3.3. TASK 1 – Passive control with seismic isolation - DEVICES

7.3.3.1. Experimental tests on rubber isolators without or with lead or viscous insert (R1_UNIBAS)

Tests on rubber, lead–rubber, ADRI isolators have been carried out to evaluate their cyclic behaviour under different compressive load, up to nearly buckling condition. The influence on energy dissipation and stiffness has been evaluated. Tests to evaluate buckling and tensile resistance are in progress.

7.3.3.2. Numerical analysis and experimental tests on rubber isolators for monumental buildings (R3_UNINA_DL)

From the results of the numerical analyses the following results have been derived: the value of the first shape factor S1=18 is a threshold value, separating acceptable from undesirable behaviour: for devices with

S1 values larger than 18 the stress state closely approximates the hydrostatic one, as hypothesized in the theory at the basis of the widely used design formulae; further, the stress concentrations and the edge effects become negligible. Shear strains induced by vertical load strictly depend on the shape factor, show a strong nonlinear variation with the applied vertical pressure and can assume very large values in low shape factor bearings. Design guidelines for rubber isolators should include the above results, though in a simplified form, by explicitly defining appropriate limit values of the long and short term compressive stress as a function of the primary shape factor S1. Missing such indications, local failure in the rubber as well as at the rubber steel interface can occur in the isolator, driving to dangerous drop of the load bearing capacity and of the efficiency of the isolation system.
Two sets of HDRBs (steel and composite reinforced) have been designed for the experimental activity; both the sets of bearings are identical in geometry and rubber properties, only varying the material of reinforcing plates. In particular Ø400mm bearings, all characterised by first shape factor equal to 20 and by different values of the second shape factor (from 1.5 to 6) have been defined.
Experimental results will be available at the end of the second year of the research program, according to the program schedule.

7.3.3.3. Variable stiffness model for rubber isolators (E2_UNICAL)

A two-spring-two-dashpot model, made up of a spring acting in parallel with a linear viscous dashpot both in the horizontal and vertical directions has been set up. Two nonlinear laws accounting for the observed behaviour were adopted to simulate the isolator response: one law accounts for the variation of the horizontal stiffness due to the vertical load (P), while the other law accounts for the variation of the vertical stiffness depending on the horizontal displacement (u_H); the damping contribution is taken into account simply by a linear viscous damping.

7.3.3.4. Mathematical models and instability considerations for rubber isolators (R2_UNINA)

Some formulae for the instability of reinforced elastomeric isolators have been set up and compared to the expressions of the critical load to some relations found in literature, by using them for some isolators experimentally examined. The expression of the critical load in the Norm provides a value much higher than the values assumed by the other literature relations.

7.3.3.5. Numerical modelling of rubber isolator with viscous insert (R1_UNIBAS)

Up to now the following models have been set up:

- Semi-analytical 3D model for single layer, with neo-hokean constitutive law
- FEM 1D beam model for large shear deformations for buckling analyses with a step-by-step strategy

The FEM 3D modelling studies for the entire isolators are in progress.

7.3.3.6. Experimental tests on Steel-PTFE Sliding isolators (R1_UNIBAS)

The tests have shown a very good reproducibility of the frictional behaviour, a very low friction coefficient, ranging between 0.3% and 1.2%, an increasing trend with the speed, except for the very low speed values, and a decreasing trend with the compression stress.

7.3.3.7. Mathematical models and experimental tests for Wire-Rope devices (R2_UNINA_Se)

A state of the art has been made on the experimental tests, the mathematical models and the design procedures of implemented in the seismic isolation system of light structures, like electric equipments. The experimental cyclic behaviour of the isolators for different stresses (tensile-compression, shear, roll) has been characterised. The cyclic behaviour for tensile-compression has been reproduced by the classical Bouc-Wen model, modified to take into account the asymmetrical behaviour. The cyclic behaviour for shear stress is symmetric and has been simulated by the hysteretic Bouc-Wen model.
The modifications of the Laboratory Machine have been designed. The modified machine is able to carry out different tests for shear stress in two directions and for tensile-compression stress on *Wire-Rope* devices with different dimensions. A report has been drafted describing all the modifications to be made.

7.3.3.8. Analytical and computational models of FV devices (E4_UNIUD)

The analytical model of FV spring-dampers has been further validated on the results of cyclic and pseudodynamic tests carried out over an expanded time-scale, confirming a remarkable level of correlation with the experimental results, as already observed in the case of real-time tests. The considered behavioural laws were transferred into the corresponding computational model, as well as of the examined case study structures. The computational model was obtained by a proper assembly of nonlinear “link” elements (a dashpot, a spring, a gap, and a hook elements placed in parallel), and the introduction of a thermal variation apt to reproduce the static preload of devices.

7.3.4. TASK 2 – Passive control by energy dissipation - GENERAL

7.3.4.1. State of the art and analytical modeling of dampers (E2_UNICAL)

Besides the State-of-the-Art, the analytical models which were developed in order to simulate the cyclic response of the dampers considered in the first year of the activities are as follows:
- a bilinear law for a hysteretic damper;
- a velocity-dependent linear law for a viscous damper;
- a "generalized model" (i.e., a combination of Kelvin and Maxwell models) for a viscoelastic damper.

These models are almost ready to be incorporated in the analysis of framed buildings with damped braces.

7.3.4.2. Identification techniques of dissipation properties of structures with innovative protection systems (E7_UNIBO)

Different algorithms for identification of dynamic characteristics of r.c. structures have been developed and implemented. Methods in time domain (ARMA and ARMAV models) and frequency domain (Circle-fit-Method) have been tested with reference to numerical simulations of dynamic tests as well as in-situ recorded experimental data. In the linear field, these methods have been used to identify modal frequencies and corresponding damping ratios. Parameter identification has been performed making use of Evolutionary and Genetic Algorithms.
First results of the extension of these methods for non-linear identification have been obtained. Non-linear behavior may be due to hysteretic behavior of.r.c. structure or to very high damping, possibly depending on velocity, as in the case of viscous damper systems.

7.3.4.3. Methods for reliability estimate of innovative systems for seismic mitigation (E7_UNIBO)

A procedure has been developed for reliability estimate of structures subject to seismic risk. Hazard and fragility analysis of the structure are carried out separately. A technique to define Response Surface (RS) model with block effects is developed. Accordingly, some variables are considered explicitly in definition of RS, whereas variability of seismic action and mechanical properties over the structure are considered as implicit variables. As for seismic action, natural or artificial time-histories are considered. In the second case, the method proposed by Sabetta and Pugliese (1996) is adopted. As for concrete strength in RC structure, it is defined as the product of a random variable giving the mean strength, and a random field with prescribed variance and correlation matrix. RS is then calibrated through data obtained by non linear dynamic numerical simulations corresponding to given sets of ground motions, strength distributions and values of other random variables. Input data sets are defined according to Central Composite Design (CCD) technique with block effects, associated with different earthquake time histories and strength distributions.
The method will be used in the second year for reliability analysis of r.c. structures with innovative protection systems, in order to verify their robustness with respect to variability of seismic excitation and possible damage of some protection elements.

7.3.5. TASK 2 – Passive control by energy dissipation - BUILDINGS

7.3.5.1. Computational models and design procedures for the dissipative bracing system and relevant structural installations (E4_UNIUD)

Relevant computational models were completed within the first year, and some preliminary results presented in [Sorace, Terenzi e Bandini 2006] for the second case study building. Therein, a general modelling strategy for dynamic problems characterised by a limited number of non-linear degrees of freedom – typically represented by structures incorporating seismic protection devices – was theoretically discussed, with special reference to the options offered by the SAP2000NL finite element program. Complete results will be summed up in the manual for designers dedicated to the energy dissipating bracing systems, as well as in a paper under preparation for the Sixth International Conference on Steel and Aluminium Structures – ICSAS '07, which will be held in Oxford on July 2007. The design procedure of the system originally outlined in [Sorace e Terenzi 2003a] was reassessed and upgraded during this first year activities. This more advanced formulation was reported in the above-mentioned paper accepted for publication in the Journal of Structural Engineering – ASCE, that will appear on 2007. Its demonstrative application to the two selected case studies will be presented in the manual for designers as well as in the ICSAS '07 paper.

7.3.5.2. Computational models and design procedures for the damped cable system and relevant structural installations (E4_UNIUD)

The proposed design procedure of the system was reassessed and applied to two hypotheses of installation, represented by the same pre-normative steel school building considered for a dissipative bracing-based retrofit solution, mentioned in section 2.3, and a reinforced concrete hospital building in Latisana, in the province of Udine. Relevant elaborations will be reported in the above-mentioned ICSAS '07 paper (steel building), and a paper presented at the 12th Italian Conference on Earthquake Engineering (reinforced concrete building), which will be held in Pisa on June 2007, and then collected in the dedicated report of the Project.

7.3.5.3. Design procedure for displacement-dependent non linear bracing systems (R1_UNIBAS)

Up to now the following models have been set up:

- Semi-analytical 3D model for single layer, with neo-hokean constitutive law
- FEM 1D beam model for large shear deformations for buckling analyses with a step-by-step strategy

The FEM 3D modelling studies for the entire isolators are in progress. A paper has already been presented at the AIMETA congress and another will be presented at the ANIDIS congress.

7.3.5.4. Design criteria for viscous dampers (E7_UNIBO)

A complete bibliography has been collected and rationally assembled so that the scientific contributions could be organized in groups of homogeneous research topic. Several approaches for identification of the "optimal" (in terms of efficiency in energy dissipation) systems of added viscous dampers have been compared. Among these approaches: (1) numerical optimisation algorithms based upon the minimization (or maximization) of given performances indexes and (2) physical approaches based on properties of Classical Damping (Rayleigh damping).
Results have been obtained with reference to response of dynamic systems to both stochastic and natural acceleration time histories, showing that physical approach lead to more "stable" results Numerical approaches, on the contrary, exhibited a number of drawbacks in real applications (such as the presence of local minima/maxima). With reference to a real case, techniques for physical insertion (connection) of viscous damper systems in a mixed (steel + reinforced concrete) building structure have been also developed.

7.3.5.5. Design procedure for visco-elastic bracing systems for buildings structures (R1_UNIBAS)

The procedure has been set up and initially applied to a benchmark structure (Bonefro building). The results have been checked with non linear dynamic analysis. It will be applied to some structures of school buildings, in order to evaluate its applicability and to set up a simplified method relying on linear dynamic analyses only

7.3.5.6. Design procedure for buildings with viscous and visco-elastic dampers (R2_UNINA_SE)

A design procedure has been developed and design indications for non-linear viscous devices are given in a paper presented at 2nd FIB Congress in 2006. The research unit R2_UNINA_SE has applied and further developed its design procedure for the dissipative bracing systems of the mock up steel frame structure which will be tested at the structural Laboratory of UR1 – UNIBAS. This methodology has provided some suggestions for the selection of the optimal values to be assigned to the damping and stiffness parameters of the control bracing systems. A paper on these developments will be presented at the next Italian ANIDIS Conference.

7.3.5.7. HDR and BRB braced systems: analysis methods and design procedures (E6_UNICAM)

The results of the harmonic analysis have been examined and the main effects of the non linear behaviour of HDR dissipation devices have been evaluated. Also the response under impulsive excitations has been analyzed and the influence of the Mullins effect has been quantified in terms of stiffness and dissipation capacity. The seismic response of the system under a given ground motion confirms the importance of the transient behaviour connected to the Mullins effect.
In order to define the linear models equivalent to the stable and transient behaviour, two conditions must be enforced for each model. The linear models have been defined by evaluating the most convenient equivalence conditions.
The seismic response of the S-DoF system has been compared with the responses obtained by using the simplified linear models. The results show that the linear models proposed permit to obtain the bounds of the response in terms of forces and displacements. This is valid only if the maximum strain obtained is equal to the design strain at which the linear models are calibrated.

7.3.5.8. Re-centring and dissipating system for masonry structures (R1_UNIBAS)
The retrofit has already been designed and implemented on the experimental model, waiting for the test, and several numerical simulation analyses have been carried out, demonstrating the excellent behaviour of the model up to 0.5 g PGA of the Colfiorito Earthquake.

7.3.5.9. Design and set up of the mock up for the Joint Experimental Tests of Passive and semi-Active Control Systems (JET-PACS program)
The research unit UR2 – UNINA_Se has drafted a Report on the preparation of the experimental testing campaign which will be performed at the structural Laboratory of R1_UNIBAS on the mock up structure equipped with passive and semi-active bracing systems: dimensional analysis of the mock up structure, 3D complete finite element model and simplified numerical models of the structure, dynamical characterization tests, passive and semi-active devices to be installed on the mock up, scheme of the testing configurations, types of braces, connecting systems of the dampers to the structure and to the braces, instrumentation (transducers, hardware and software) needed for the tests.
The mass has to be increased from about 6 to about 12 tons, the bracing system that can include any type of devices to be tested and the basement strengthening has been designed. A set of 7 accelerograms, overally consistent with the soil B spectrum, has been selected for the tests from the RELUIS WEB site, along with an additional artificial accelerogram, strictly consistent with the same spectrum. All the design drawings of the modifications and additions of the mock up structure have been completed and distributed to the other research units taking part to JET-PACS, along with the accelerograms for the tests, in order to allow them to design and realise the devices and the joint details.

7.3.5.10. Full-scale experimental test on precast concrete frame with innovative protection system (E7_UNIBO)
A full-scale precast concrete frame has been designed. The designed test structure has two floors and one span. The structure will be used by the Research Unit to test viscous damper systems, but also other Research Units will be able to test different innovative systems. A number of numerical tests has been performed in order to verify the versatility of the structure. Experimental tests have been designed, with different experimental setups and kinds of excitation. Two main structural configuration have been planned, the structure without seismic devices and a second configuration where dampers are placed between floors.

7.3.6. TASK 2 – Passive control by energy dissipation - DEVICES

7.2.6.1. Hysteretic numerical models for fluid viscous dampers (E7_UNIBO)
Different numerical models for hysteretic behavior of fluid viscous dampers have been implemented, such as classical Maxwell model, Standard mechanical model, fractional derivative model and modified power law. These models have been applied to a set of experimental data. With reference to Standard Mechanical Model, damper and stiffness parameters have been calibrated, using identification methods described in 7.3.4.2.

7.3.6.2. Combined Viscous-SMA device for the JET-PACS program (R1_UNIBAS)
The tests on the viscous devices have been carried out at different temperatures and loading frequencies, showing a substantial independence from temperature, when it is varied between -10 and 50°C, and, obviously, a strong dependence on speed. At 3 Hz frequency each device is able to provide 4 kN maximum viscous force, which turns to an additional equivalent damping of the order of 10%.

7.3.6.3. Experimental Tests of Fluid Viscous devices for the JET-PACS program (R2_UNINA_SE)
The research unit UR2_UNINA_SE has defined some issues for carrying out the experimental tests on the viscous and magnetorheological dampers at the carried structural Laboratory of UR2 – UNINA_Se. For both the types of devices, UR2 has examined the connection of the devices to the Testing Machine of the Laboratory and has defined the equipment to be predisposed.

7.3.6.4. Definition of reliable models for dissipation devices (E6_UNICAM)
The response of the material has been decomposed into two components: the former exists for every strain history and the latter describes the transient response (Mullins effect) which degenerates as the strain history progresses. Some internal variables are introduced in order to reproduce all phenomena experimentally observed. In particular some of these describe the inelastic, strain-rate dependent, strains which occur in the material, while the others are damage parameters which permit describing the transient

response due to the Mullins effect. The parameters which appear in the evolution laws of the internal variables are calibrated by means of the experimental data. The accordance obtained between the experimental and numerical results is satisfactory in describing both the transient and the stable responses in the range of strain rate and strain amplitude of interest for practical applications.

7.3.7. TASK 3 – Passive control by tuned masses

7.3.7.1. Development of analytical and numerical tools for tuned mass dampers (E3_POLITO)

The main achievements are the following:

1. state-of-the-art report on passive and semi-active control through TMD and TLD;
2. development of analytical and numerical models, design procedures, home-made software (in MATLAB), together with the proposal of innovative technological configurations of TMDs (mass-uncertain rolling pendulum TMD), which has made the aforementioned first year activity possible and which will allow in-depth future studies of the effectiveness and robustness of tuned mass dampers for the mitigation of seismic response of building structures.

In particular, as to point 2), linear and non linear analytical and numerical models of multiple tuned mass dampers of either translational, pendulum or rolling pendulum types, in either 2 or 3 dimensions have been developed and mounted on single or multiple degrees of freedom structures. Non linearity is either connected with large amplitude motion of the pendulum and rolling pendulum configurations or with the rolling friction dissipation mechanism typical of the rolling pendulum TMD when rubber sheets are used at the interface between the rolling sphere and the supporting surface. Uncertainty in the oscillator or in the structural parameters can be introduced in terms of a worst-case scenario and branch & bound numerical optimization algorithms have been integrated with the finite element programme so as to provide the optimal robust design in the face of the expected uncertainty. Numerical simulations of the seismic response of simple structures equipped with TMD have allowed to evaluate and circumscribe the efficiency of this control strategy, and particularly that of the rolling pendulum type. A robust criterion for the design of mass-uncertain tuned mass damper against wind action has been proposed by A. De Stefano and E. Matta in a paper recently published in Proc. CTS 2006.

7.3.7.2. Base isolation and tuned mass damper combined strategy (E5_UNISA)

The results obtained from numerical experimentation leads to the following considerations on the effectiveness of the proposed control strategy:

- TMD on BI designed according to the proposed methodology improves the seismic behaviour of the benchmark isolated structure in respect of all considered performance indexes and recorded seismic events;
- With regard to the two indexes related respectively to the peak base displacement and the Root Mean Square (RMS) base displacement, the seismic response presents lower values when compared to the other indexes. This is consistent with the design target to minimize the isolation bearing displacements. Moreover, the superstructure absolute acceleration, in terms of root mean square is also strongly reduced;
- The proposed strategy to reduce isolator displacement presents different effectiveness levels on varying the dynamic characteristics of the seismic event. High performances were obtained for the El-Centro earthquake, more than 50% reduction in RMS base displacement, whilst for the Jiji earthquake slightly less than 10% reduction has been observed;
- TMD on BI appears to be very effective in reducing the RMS seismic response of the isolators. Its effectiveness is reduced if referred to the isolators peak displacement control.

These considerations derive precisely from the dynamic features of mass damping devices. The inertia of TMDs does not allow devices to be immediately effective in the application of the control actions. Therefore, in the case of "near fault" seismic events, characterized by a sort of input energy impulse during the first few seconds of the earthquake, mass damping shows itself to be an ineffective system in controlling seismic response peak values. Otherwise, high effectiveness in reducing both base level peak displacement and RMS is observed for “far fault” seismic events. Similar experimentation should be carried out for superstructure absolute acceleration.
Another design factor to be considered concerns the TMD’s dynamic. TMD maximum displacement appears to be generally compatible with the “rolling pendulum” technological solution proposed by the E3_POLITO research group with whom further collaboration is foreseen.
In terms of robustness, the obtained results show that a TMD system when applied to the base level of an isolated structure is much less sensitive to mis-tuning effects compared to the classical application of a TMD at the roof level of a fixed-base structure.

7.3.8. TASK 4 – Semi-active control - BUILDINGS

7.3.8.1. Semi-active MR dampers for seismic protection of buildings (E9_UNIAQ)

A wide research in the currently available solutions for overcoming the problem related to design semi-active control systems against recurrent dynamic actions, and simultaneously against exceptional seismic actions, has been performed. A detailed literature state-of-art on the experimental applications of semi-active control by means of MR dampers, focused on laboratory large-scale applications worldwide, has been completed. The research has evidenced that the three-dimensional behaviour of the tested structures is a deficient modelling aspect, due to the preference for simpler planar model. In order to reduce this deficiency in the incoming program of experimental tests on a benchmark two store reduced scale (2:3) building, different three-dimensional analytical and numerical finite elements models have been formulated in order to verify how the different element flexibility influence the system spectral properties. Once verified the spectrum sensitivity of the column-beam nodes flexibility, a static condensation procedure has been performed in order to both account for the nodes stiffness, and to simultaneously reduce the total number of Lagrange displacement parameters. The resulting 6 degrees of freedom model has been formulated in a completely symbolic manner, useful for future updating to include the effects of control thanks to semi-active MR bracers, and its accuracy has been fully validated by excellent agreement with the numerical solutions. Two Lord RD-1005-3 MR dampers have been purposely acquired for future tests on the benchmark building. A research report has been published on the work.

7.3.8.2. Effect of damping devices on the structural dynamic behaviour (E8_UNIPARTH)

The research activity of the 1st year of the project has led to a procedure to analyze the influence of any single damping device on the damped frequency and the damping ratio of any single modal shape. The procedure utilizes the mass, damping and stiffness matrices of a structural system to write the equations of the motion in the state space. The analysis of the migration of the poles of the system in the complex plane due to the addition of one or more dampers in the structure allows a better understanding of the effect of the dampers on the global dynamical behaviour of the structure.

7.3.8.3. Control algorithms for semi-active MR dampers (E8_UNIPARTH)

A comprehensive analysis of the control algorithms utilized in many existing applications (real-scale and laboratory) of semi-active control systems has led to a critical analysis of their weakness, mainly due to the need of a large number of real-time measurements. Therefore, an innovative control algorithm based on a limited number of measurement has been developed for semi-active control systems based on MR dampers.

7.3.8.4. Numerical modelling of semi-active MR dampers (E8_UNIPARTH)

A new numerical model able to represent the behaviour of MR dampers and based on a limited number of parameters has been developed and validated. The model is able to effectively represent the combined viscous+friction behaviour of MR dampers and exploits a power law refinement of the Bingham model.

7.3.8.5. Organization of experimental set up for the mock up of the Joint Experimental Tests of Semi-Active Control Systems (JET-PACS program) (E8_UNIPARTH)

The experimental activity due in the second and third year of the project needs some dedicated hardware and software. Therefore, the measuring instrumentation, the power suppliers and the real-time processing units needed to the experimental tests with the semi-active devices have been specified and acquired, either by this UR or in co-operation with the UR UNINA-DAPS.

7.3.9. TASK 4 – Semi-active control - CABLES

7.3.9.1. Semi-active MR dampers for cable oscillation reduction (E9_UNIAQ)

A large literature state-of-art has been collected on theoretical and experimental applications of cable semi-active control by means of MR dampers. Some preliminary results have been obtained in the closed form evaluation of the complex modes and frequencies characterizing a taut string equipped with a transversal MR damper, using a reduced order analytical model with 4 Ritz-Raleigh degrees-of-freedom. The analytical model is formulated in order to reproduce the experimental behaviour of a specimen made up of a 19 wires strand equipped with a purposely acquired Lord RD-1097-01 MR damper, which has been installed at the Laboratory for Nonlinear Dynamics of the DISAT, University of L’Aquila.

7.4. Conformity to the program

7.4.1. TASK 1 – Passive control with seismic isolation

7.4.1.1. Contribution of R1_UNIBAS

Generally speaking the activities related to seismic isolation are in line with the program for the first year. The execution of the numerical studies and of the simplified procedure setting up anticipates the activities of the second year. The experimental studies are correctly in progress. The ones concerning devices are being carried out, their progress depending on the availability of the devices to be tested. Some delay has occurred because of the need of improving the performances of the testing apparatus of seismic isolators. The studies concerning large models are concerned, at this moment, with the design of the models and of the tests, as in the program.

7.4.1.2. Contribution of R2_UNINA_SE

The activities related to seismic isolation are approximately in line with the program for the first year. The execution of the numerical studies is correctly in progress. The experimental studies for the preparation of the tests on the *Wire-Rope* devices and the examination of the devices are being carried out, their progress depending on the availability of the devices to be tested. Some delay has occurred because of the need of modifying the testing apparatus.

7.4.1.3. Contribution of R3_UNINA_DL

The activities related to the assessment of the seismic safety of monumental buildings are in line with the ones anticipated in the program; the structural analyses and the assessment of the seismic safety of the buildings, scheduled for the second year, have been already developed. The activities related to the design procedures and simplified analysis methods for BIS in the retrofit of monumental buildings are well in line with the program contents and proceed faster than the schedule. The activities related to the experimental tests are in line with the program contents and schedules. Additional numerical studies, not included in the program, have also been developed as a basis for the definition of the experimental tests. According to the program schedule, the dissemination of the research results (Design Manual) will start in the second year of the research program.

7.4.1.4. Contribution of E1_UNIPG

The activities have been carried out within the programme outlined at the beginning of the project. The analyses carried out on the aspects concerning the structural configuration and architectural morphology of earthquake resistant constructions equipped with isolating or dissipating devices allow to draw up a draft version of a report on the subject. First significant results are also available concerning the economic aspects of isolated constructions based on deterministic definitions of the performance controlling parameters.

7.4.1.5. Contribution of E2_UNICAL

After preparing a numerical model for simulating the nonlinear seismic response of framed structures, it was thought advantageous to test this model by analyzing the dynamic response of framed structures subjected to horizontal and vertical components of near-fault ground motions (Mazza and Vulcano, June 2006).
Then, after evaluating the state of the art of buildings with damped braces or base-isolation, it was considered opportune to study first the nonlinear dynamic response of base-isolated structures, which might undergo many drawbacks under near-fault earthquakes. For this purpose a numerical model accounting for the variation of the isolator stiffness properties was developed and incorporated in the computer code previously prepared for simulating the nonlinear seismic response of a framed structure.
The first results obtained for base-isolated structures emphasized the need of a more extensive investigation to obtain useful information for the design of these structure in regions were near-source earthquakes are expected.

7.4.1.6. Contribution of E4_UNIUD

The activities developed during the first year of the Project pursued the defined objectives. In particular, the activities related to this task are in line with the original programme for the first year.

7.4.2. TASK 2 – Passive control by energy dissipation

7.4.2.1. Contribution of R1_UNIBAS

Generally speaking the activities related to energy dissipation are well in line with the program for the first year and even more advanced. The setting up of simplified methods and the execution of the numerical studies partially anticipate the activities of the second year. The experimental studies are correctly in progress. Most of the energy have been dedicated to the setting up of the joint testing program (JET-PACS), to design the model and testing set up, and to coordinate the activities of the participating research units.

7.4.2.2. Contribution of R2_UNINA_SE

The activities related to energy dissipation are well in line with the program for the first year. The setting up of design methodology and the execution of the numerical studies is correctly in progress. The experimental studies for the preparation of the tests on the mock up structure within the joint testing program (JET-PACS) are being carried out, while the progress of the experimental studies for performing the tests on the devices depends on the availability of the devices to be tested. Most of the energy have been dedicated to the preparation of the tests within the joint testing program (JET-PACS) and to coordinate the activities of the participating research units.

7.4.2.3. Contribution of E2_UNICAL

According to the program of the first year, the state of the art of buildings with damped braces was evaluated, focusing the attention on hysteretic (friction and metallic-yelding), viscous and viscoelastic dampers. Analytical models for simulating the cyclic response of these dampers were prepared and are almost ready to be incorporated in the analysis of framed buildings with damped braces.

7.4.2.4. Contribution of E4_UNIUD

The activities developed during the first year of the Project pursued the defined objectives. Concerning the development and application of the finite element structural models of the case studies relevant to the dissipative bracing system and the damped cable system, the assumed objectives were overcome, arriving at the complete generation of these models within the end of the first year. The remaining activities are in line with the original programme for the first year.

7.4.2.5. Contribution of E6_UNICAM

Generally, the activities are well in line with the program for the first year . The definition of simplified models for the simulation of the behaviour of system endowed with HDR dissipation devices partially anticipate the activities of the second year. The experimental activity is programmed for the second and third year, but preliminary analysis aimed at defining the experimental tests set-up are currently in progress.

7.4.2.6. Contribution of E7_UNIBO

Activities on identification techniques and numerical modeling are in agreement with the original research plan. Numerical hysteretical models for fluid dissipation devices are ready to be implemented in structural FE models. Time domain and frequency identification techniques are very advanced, and have been validated with reference to numerical and experimental data.

Activities related to design criteria are well in line with the original program and even more advanced. Complete bibliographic work has been performed, and different methods have been implemented and tested with a set of benchmark problems. Those methods are now ready to be used for real design problems.

Reliability methods are also very advanced and tested in a number of conventional problems.

The experimental program is in line with the program for the first year. The full-scale prototype has been carefully designed and numerically tested. The next step will be the executive design of the systems for the application of dynamic loads and different seismic protection systems.

7.4.3. TASK 3 – Passive control by tuned masses

7.4.3.1. Contribution of E3_POLITO

The subscribed original programme provided the following activities during the first year:

1. first semester: state of the art on:
   - passive control through TMD and TLD
   - semi-active control of tuned absorbers
2. second semester: investigation of TMDs’ and TLDs’ (passive single or multiple oscillators) effectiveness in the presence of parametric uncertainties (passive robust analysis and synthesis).

As pointed out above, the aforesaid activities have been substantially complied with by this Research Unit. Moreover, the research collaboration recently activated on BI/TMD control system together with the Unit of Salerno constitutes a promising extra-programme for future work.

7.4.3.2. Contribution of E5_UNISA

Results obtained in this first part of the research activity show the effectiveness and the robustness of the proposed BI&TMD control strategy with regards to both displacement and acceleration of isolation layer and superstructure.
The ongoing research issue concerns numerical experimentation in order to evaluate the optimal positioning of a TMD system, as well as different strategies to improve the seismic performance of BI&TMD control systems in the case of near-fault events.
Moreover, in the second year of the ReLuis project, a broad-ranging laboratory experimental program is scheduled. In particular, the dynamic behaviour of a base isolated small-scale model will be investigated by using a shake table, and the effect of both passive mass dampers and active mass dampers on such a model will be analyzed and modelled.

7.4.4. TASK 4 – Semi-active control

7.4.4.1. Contribution of E8_UNIPARTH

The research activities described above have been performed on time with respect to the time schedule of the project. The analysis of existing applications have been close during the first semester of the 1st year. In the second semester, activities related to the design of semi-active control systems and to modelling of MR dampers have been concluded. The research activities about the control algorithm are still open, even if a new control algorithm is ready to be implemented on the mock up structure during the next two years of the project, for which the special instrumentation associated to the semi-active control scheme has been already acquired and is ready to use.

7.4.4.2. Contribution of E9_UNIAQ

Generally speaking the activities related to semi-active control are in line with the program for the first year. The state-of-art of the available methodologies in this field have been conducted with extreme accuracy due to the inherent novelty of the technology. With a similar approach also the numerical and analytical studies regarding two prototype experiments, a cable and a frame structure equipped with semi-active MR dampers, have been carried out. An analytical model for the joint testing program (JET-PACS) have been derived in a completely symbolic manner, useful for future updating after a preliminary identification test campaign. The dynamical model is strongly useful to design the control semi-active feedback algorithms, however can be utilized for preliminary simulation of any dissipation strategies proposed for the prototype steel frame. Finally, three dampers for the two different set of experiments have been acquired by the UR of L'Aquila.

References

TASK 1 – Passive control with seismic isolation

M. Dolce, D. Cardone, A. Lorenzo, 2007, Dissipazione viscosa nei sistemi di isolamento ricentranti, XII Italian Conference on Earthquake Engineering – ANIDIS, Pisa.

M. Dolce, D. Cardone and M. Rivelli, 2007, Fattori riduttivi per la determinazione di spettri elastici ad alto smorzamento, XII Italian Conference on Earthquake Engineering – ANIDIS, Pisa.

M. Dolce, C.Moroni, A. Mossucca, D. Nigro, Valutazione sperimentale dell'instabilità di isolatori in gomma soggetti a compressione e taglio, XII Italian Conference on Earthquake Engineering – ANIDIS, Pisa.

M. Dolce, C.Moroni, A. Mossucca, D. Nigro, 2007, Valutazione sperimentale del comportamento sismico di isolatori elastomerici soggetti a trazione

M. Dolce, D. Cardone, G. Palermo, Design Procedures and Seismic Performances of Isolation Systems for Bridges Based on Flat Sliding Bearings, Submitted to Bulletin of Earthquake Engineering

A.D. Lanzo, A. Bilotta, 2006, Un approccio misto per l'analisi path-following di telai elastici piani geometricamente nonlineari a grande deformabilità tagliante, Convegno Gimc- AIMETA

A.D. Lanzo, 2007, Modellazione elastica nonlineare per isolatori elastomerici armati con nucleo in materiale viscoso: valutazione della rigidezza assiale, ANIDIS, Pisa.

Marsico M.R. and Serino G. (2006). Modifications and additions to be made to the Resilient Pad and Mat Testing Machine (RPMTM) to test Wire Rope devices (*in Italian*). ReLUIS Line 7 project report.

Spizzuoco M., Serino G. and Onorii C. (2005). Seismic protection of bridges using passive control. 5th International Conference on Earthquake Resistant Engineering Structures (ERES), Skiathos.
Spizzuoco M. and Serino G. (2006). Design indications for non-linear viscous devices applied to r.c. structures. 2nd International FIB Congress, Naples, June 2006.
Spizzuoco M. and Serino G. (2007). A design methodology for dissipative braces (*in Italian*) . XII Italian Conference on Earthquake Engineering – ANIDIS Pisa.
Spizzuoco M., Serino G. and Marsico M.R. (2006) Organizational report for the tests on the 1:1,5 scale frame (*in Italian*) . ReLUIS Line 7 project report.
A. Giordano, A. De Luca, E. Mele, A. Romano. 2006. A simple formula for predicting the horizontal capacity of masonry portal frames. Accepted for publication on Engineering Structures.
G. Cuomo, A. De Luca, E. Mele and A. Romano. 2006. Design aspects in seismic isolation churches. Structural Analysis of Historical Constructions - SAHC2006, New Delhi.
A. Giordano, A. De Luca, G. Cuomo, E. Mele and A. Romano. 2006. Limit analysis of multiple span masonry portal frames. Structural Analysis of Historical Constructions - SAHC2006, New Delhi.
G. Cuomo, A. De Luca, and E. Mele. 2006. Seismic rehabilitation of cultural heritage through timber slabs and ties. Structural Analysis of Historical Constructions - SAHC2006, New Delhi.
A. Giordano, A. De Luca, E. Mele and A. Romano. 2006. Simplified evaluation of the horizontal capacity of masonry arches. Structural Analysis of Historical Constructions - SAHC2006, New Delhi.
Giordano A., Cuomo G., De Luca A., Mele E. 2007. Analisi limite sotto azioni orizzontali di portali ed archi in muratura a campata multipla. XII Italian Conference on Earthquake Engineering – ANIDIS, Pisa.
De Luca A., Mele E., Cuomo G. 2007. Isolatori elastomerici: analisi FEM ed implicazioni progettuali. XII Italian Conference on Earthquake Engineering – ANIDIS, Pisa.
Brandonisio G., Cuomo G., De Luca A., Mele E. 2007. Aspetti progettuali nell'isolamento sismico di chiese in muratura. XII Italian Conference on Earthquake Engineering – ANIDIS, Pisa.
A. Parducci, F. Comodini, M. Lucarelli "A Synergic Dissipation Approach to Retrofit Framed Structures with a Soft First Storey", 9th World Seminar on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures, Kobe, Japan, 2005.
M. Mezzi, A. Parducci "Preservation of Existing Soft-First-Story Configurations by Improving the Seismic Performance" 3rd Spec.Conf on The Conceptual Approach to Structural Design. Singapore, 2005.
M. Mezzi, A. Parducci "Conceptual seismic design and state-of-the-art protection systems" 8th U.S. National Conference On Earthquake Engineering. San Francisco (California). 2006.
M.Mezzi "Configuration and Morphology for the Application of New Seismic Protection Systems" 1st European Conference on Earthquake Engineering and Seismology. Geneva, Switzerland, 2006.
A. Parducci, F. Comodini, M. Lucarelli, M. Mezzi, E. Tomassoli "Energy-Based Non Linear Static Analysis" 1st European Conference on Earthquake Engineering and Seismology. Geneva, Switzerland, 2006.
M. Mezzi, F. Comodini, M. Lucarelli, A. Parducci, E. Tomassoli "Pseudo-Energy Response Spectra for the Evaluation of the Seismic Response from Pushover Analysis" 1st European Conference on Earthquake Engineering and Seismology. Geneva, Switzerland, 2006.
M. Mezzi "Enhancing the Seismic Performance of Existing "Pilotis" Configurations" IABSE 2006 Symposium. Budapest, Hungary, 2006.
Mazza, F. and Vulcano, A., 2006 (18-22 April), Seismic response of base-isolated buildings under horizontal and vertical near-fault ground motions, Proceedings of the 8th U.S. National Conference on Earthquake Engineering,100th Anniversary Earthquake Conference Commemorating the 1906 San Francisco Earthquake, 2006, San Francisco, California, paper n. 485.
Mazza, F. and Vulcano, A., 2006 (5-8 June), Nonlinear Dynamic Response of R.C. Framed Structures Subjected to Near-Source Ground Motions: Effects of the Vertical Component, Fédération Internationale du Béton, Proceedings of the 2nd International Congress, Naples, Italy, paper n. 8-24.
Mazza, F. and Vulcano, A., 2006 (3-8 September), Nonlinear response of base-isolated buildings under near-fault ground motions, Proceedings of the First European Conference on Earthquake Engineering and Seismology (a joint event of the 13th ECEE & 30th General Assembly of the ESC), Geneva, Switzerland, paper n. 481.
F. Mazza , A. Vulcano, 2007, Risposta dinamica non lineare di strutture intelaiate in c.a. isolate alla base soggette a terremoti "near-fault", XII Italian Conference on Earthquake Engineering – ANIDIS, Pisa.
F. Mazza , A. Vulcano, 2007, Effetti della componente verticale di terremoti "near-fault" sul comportamento sismico di strutture intelaiate in c.a., XII Italian Conference on Earthquake Engineering – ANIDIS, Pisa.
Sorace, S., Terenzi, G. (2005). "Application of a combined base isolation/supplemental damping seismic protection strategy to a public building in Florence." Proc., International Conference "250th Anniversary of the 1755 Lisbon Earthquake", Lisbon, Portugal, November 2005, LNEC Press, Lisbon, 481-486.

Sorace, S., Terenzi, G. (2006b). "Response of base-isolated buildings incorporating fluid viscous devices to near-fault earthquakes." Proc., 1st European Conference on Earthquake Engineering and Seismology, Geneva, Switzerland, September 2006, Paper No. 50, CD-ROM.
Sorace, S., Terenzi, G., Magonette, G., Molina, F. J. (2006). "Substructured pseudodynamic and cyclic tests on a seismic protection system including steel-Teflon bearings and fluid viscous devices." Proc., 6th World Conference on Joints, Bearings, and Seismic Systems for Concrete Structures, Halifax, Nova Scotia, Canada, September 2006, Paper No. 41, CD-ROM.
A. Dall'Asta and L.Ragni, 2007, Nonlinear effects in structures isolated with HDR bearings, XII Italian Conference on Earthquake Engineering – ANIDIS, Pisa.

TASK 2 – Passive control by energy dissipation

F. C. Ponzo, G. Vigoriti, G. Arleo, M. Dolce, 2007, Progettazione di controventi dissipativi a comportamento dipendente dagli spostamenti, XII Italian Conference on Earthquake Engineering – ANIDIS, Pisa.
F. C. Ponzo, G. Vigoriti, D. Sileo, M. Dolce, 2007, Progettazione di controventi dissipativi a comportamento visco-elastico, XII Italian Conference on Earthquake Engineering – ANIDIS, Pisa.
M. Dolce, M. Di Croce, 2007, Intervento di rafforzamento di una struttura monumentale mediante un sistema dissipativo-ricentrante, XII Italian Conference on Earthquake Engineering – ANIDIS, Pisa.
Sorace, S., Terenzi, G. (2006a). "Modellazione analitica e computazionale dei contatti scorrevoli di piano nel sistema a cavi smorzanti." Atti del 16° Convegno Nazionale di Meccanica Computazionale – GIMC 2006, Bologna, giugno 2006, Articolo 45, CD-ROM.
Sorace, S., Terenzi, G., Bandini L. (2006). "Le potenzialità della "FNA" nell'analisi dinamica non lineare di strutture dotate di sistemi avanzati di protezione sismica." Atti del 16° Convegno Nazionale di Meccanica Computazionale – GIMC 2006, Bologna, giugno 2006, Articolo 46, CD-ROM.
F. Bartera and R. Giacchetti, 2004. Steel dissipating braces for upgrading existing building frames. J. Constructional Steel Research, 60(3), 751-769.
A. Dall'Asta, L.Dezi, R. Giacchetti, G.Leoni and L.Ragni, 2005. Cyclic behaviour of HDR dissipating devices: experimental tests and analytical model - Proceedings of the 9th World Seminar on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures – Kobe – Japan, 13-16 June 2005, 283-290.
A. Dall'Asta, L.Dezi, R. Giacchetti, G.Leoni and L.Ragni, 2005. Dynamic response of composite frames with rubber-based dissipating devices: experimental tests - Proceedings of ICASS05 – Fourth International Conference on "Advances in Steel Structures" – Shanghai – China, 13-15 June 2005, 741-746.
A. Dall'Asta, L.Dezi, R. Giacchetti, G.Leoni and L.Ragni, 2006. Application of HDR devices for the seismic protection of steel concrete composite frames: experimental results. STESSA 2006 – 5th International Conference on the Behaviour of Steel Structures in Seismic Areas – Yokohama – Japan, 14-17 August 2006, 587-592.
A. Dall'Asta, L.Dezi, R. Giacchetti, G.Leoni and L.Ragni, 2006. Seisimic design of composite frames endowed with HDR devices - Proceedings of STESSA 2006 – 5th International Conference on the Behaviour of Steel Structures in Seismic Areas – Yokohama – Japan, 14-17 August 2006, 593-598.
A. Dall'Asta and L.Ragni, 2006 Experimental tests and analytical model of High Damping Rubber dissipating devices, Engineering Structures, 28, 1874-1884.
A. Dall'Asta, L.Dezi, G.Leoni and L.Ragni, 2007, Response spectra of braced frames with HDR devices, XII Italian Conference on Earthquake Engineering – ANIDIS, Pisa.
Vincenzi, L. & Savoia, M., 2006. Identificazione dinamica attraverso algoritmi di ottimizzazione evolutiva - GIMC-XVI Convegno Italiano di Meccanica Computazionale, Bologna, 26-28 June.
Vincenzi, L., Mazzotti, C. & Savoia, M., 2006. Modal identification of a TAV viaduct using subspace models - 2nd International FIB Congress, Naples, 5-8 June.
Savoia, M. & Vincenzi L., Differential Evolution Algorithm for Dynamic Structural Identification - submitted for publication.
Silvestri S., Trombetti T., Gasparini G. 2006. Effectiveness of inserting dampers between frames and lateral-resisting elements for the mitigation of the seismic effects - Paper n. 1182, Proceedings of the 100th Anniversary Earthquake Conference, EERI's Eight U.S. National Conference on Earthquake Engineering, 8NCEE, April 18-22.
Silvestri S., Trombetti T., Gasparini G. 2006. Seismic design of pre-cast reinforced concrete structures using additional viscous dampers - Paper No. 942, Proceedings of the "First European Conference on Earthquake Engineering and Seismology", Ginevra, Svizzera, 3-8 September.
Gasparini G., Silvestri S., Trombetti T. 2006. Optimal insertion of viscous dampers into torsionally coupled structures - Paper No. 949, Proceedings of the "First European Conference on Earthquake Engineering and Seismology", Ginevra, Svizzera, 3-8 September.
Ceccoli C., Trombetti T., Silvestri S., Gasparini G. 2006. Seismic design of pre-cast reinforced concrete structures using additional viscous dampers - Paper No. 000149, Proceedings of the "The Eighth

International Conference on Computational Structures Technology", Las Palmas de Gran Canaria, Spain, 12-15 September.
Trombetti T., Silvestri S., Gasparini G., Bottazzi M. 2006. Use of toggle brace system for the amplification of seismic damper motion in building structures", Paper No. 000150, Proceedings of the "The Eighth International Conference on Computational Structures Technology", Las Palmas de Gran Canaria, Spain, 12-15 September.
Gasparini G., Trombetti T., Silvestri S., Ceccoli C. 2006. A case study for seismic dampers placed between non moment resisting steel frame structures and lateral resisting concrete cores - Paper No. 000160, Proceedings of the "The Eighth International Conference on Computational Structures Technology", Las Palmas de Gran Canaria, Spain, 12-15 September.
Trombetti T., Gasparini G., Silvestri S. 2006. Insertion of additional viscous dampers for the seismic design of a pre-cast reinforced structure - Proceedings of the "The Tenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-10)", Bangkok, Thailand, 3-5 August.
Buratti, N., Ferracuti, B. & Savoia, M., 2006. Seismic Risk Assessment of R/C Structures Through Response Surface Method - ECCM-III European Conference on Computational Mechanics, Lisbon, 5-9 June.
Buratti, N., Ferracuti, B. & Savoia, M. 2006. Reliability of r.c. structures against seismic action: response surface approach - GIMC-XVI Convegno Italiano di Meccanica Computazionale, Bologna, 26-28 June.
Buratti, N., Ferracuti, B. & Savoia, M. 2006. Seismic fragility of existing RC structures by Response Surface Method - ECEES - First European Conference on Earthquake Engineering and Seismology, 3-8 September.

TASK 3 – Passive control by tuned masses

De Stefano A., Matta E., 2006. Robust Design of Mass-Uncertain TMD on Building Structures - Proceedings of the Eighth International Conference on Computational Structures Technology (CST 2006) - Las Palmas de Gran Canaria, Spain, 12-15 September 2006.
De Stefano A., Matta E., 2006. General concepts on TMD and TLD (*in Italian*) . ReLUIS Line 7 project report.
De Stefano A., Matta E., 2006. State-of-the-art of tuned mass dampers and references. ReLUIS Line 7 project report.
Palazzo B., Petti L., De Iuliis M., Sguazzo S., 2006. Seismic response of base-isolated benchmark building model controlled by Tuned Mass Dampers - Proceedings of the 4th World Conference on Structural Control and Monitoring, 11-13 July 2006
Palazzo B., Petti L., De Iuliis M., 2006. Tuned Mass Dampers to control the base-isolated benchmark building model - Proceedings of the First European Conference on Earthquake Engineering and Seismology, 3-8 September 2006
Palazzo B., Petti L., Sguazzo S., 2006. Strategia di controllo innovativa per l'adeguamento sismico di strutture strategiche: isolamento alla base e smorzamento di massa, Ingegneria Sismica, in press.

TASK 4 – Semi-active control

Occhiuzzi A., Spizzuoco M., Caterino N. (2006) Experimental tests and numerical modeling of magnetorheological dampers: the influence of model parameters, Sperimentazione '06.
Occhiuzzi A. (2007) Control algorithms for semi-active structural systems: do they really matter?, World Forum on Smart Materials and Smart Structures Technology (SMSST '07), China.
Occhiuzzi A. (2007) L'efficacia degli algoritmi nei sistemi di controllo semiattivo, XII Italian Conference on Earthquake Engineering – ANIDIS, Pisa.
Caterino N., Iervolino I., Occhiuzzi A., Manfredi G., Cosenza E. (2007) Sistemi di dissipazione passiva nella selezione dell'intervento di adeguamento sismico di un edificio in c.a. mediante analisi decisionale multicriterio, XII Italian Conference on Earthquake Engineering – ANIDIS, Pisa.
Contento A., Gattulli V., Lepidi M., Potenza F., Identificazione di modelli per un prototipo sperimentale di telaio tridimensionale con controventi semi-attivi. Report DISAT 2/2006, Luglio 2006.