



## **SEISMIC UPGRADING OF RC BUILDINGS BY MEANS OF ADVANCED TECHNIQUES: THE ILVA-IDEM PROJECT**

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### **SUMMARY**

The paper presents both the general planning and some preliminary results of a physical/numerical testing of a full-scale existing reinforced concrete building. The research investigates the efficiency of different advanced techniques for seismic upgrading/retrofitting. The building under study was designed and constructed at the end of 70s, for resisting mainly vertical loads and according to out-of-date technical codes. It is destined to be demolished because of the political decision to convert the ex-industrial area (ILVA steel mill), where the building is located (Bagnoli district of Naples, Italy), into a tourist and residential one. Thus, the idea was to carry out an 'intelligent demolition', from which the acronym of the project «ILVA Intelligent DEMolition» (ILVA-IDEM), by using the building as a full-scale specimen to be tested up to collapse. The research involves several universities, national institutions and industrial companies. Within the planned experimental investigation the following seismic upgrading/retrofitting systems are examined: 1. concentric buckling-restrained steel braces; 2. eccentric steel braces; 3. concentric shape memory alloy braces; 4. base isolation; 5. steel shear panels. Besides, a seismic repairing system, making use of carbon fiber reinforced polymers is under study.

### **INTRODUCTION**

Seismic upgrading of existing gravity-load designed (GLD) reinforced concrete (RC) buildings is a very important subject in the field of earthquake engineering. In fact, recent earthquakes (Northridge, U.S.A. 1994; Kobe, Japan, 1995; Izmit, Turkey, 1999; Athens, Greece, 1999; ChiChi, Taiwan 1999) clearly demonstrated the lack of adequate protection against both damage and collapse for this type of structures. Hence the need to improve the current structural design codes for seismic zones, in order to safeguard human lives, but also to limit damage and loss of functionality in buildings and facilities after a strong earthquake, has been strongly highlighted.

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Several technical solutions are currently available for the mitigation of earthquake risks, going from active to passive dissipating devices as well as base isolation. In general, seismic repairing/upgrading structural systems can be classified according to the following conceptual scheme:

1. Systems based on adding new structural elements, which directly operate at global level for improving the seismic response.
2. Systems based on repairing/upgrading existing structural elements, aiming at improving the global response by changing the local behaviour.

Type 1 systems are very useful for seismic upgrading in those situations characterised by the absence of purposely-designed lateral-load resisting structures, such as in the case of GLD buildings. A correct design of these systems is based on the idea to eliminate/reduce the plastic deformation demand to the existing structure by adding supplemental energy dissipating devices. Among type 1 systems, metal-based technologies are often considered as the most satisfactory technical solutions, because of the effectiveness, practicality and economy [1, 2, 3]. Metal solutions mainly consist in adding new structural elements in the form of braces, which collaborate with the existing structure, varying its static scheme and operating at global level as supplemental energy dissipation passive systems. The bracing systems are designed according to modern knowledge of earthquake engineering, so that they may significantly improve safety of existing buildings against lateral collapse. Steel-based solutions are very affordable, but, as they rely on steel yielding for dissipation, they are also affected by the problem of residual deformations of the structure after the earthquake. This drawback could be overcome by means of innovative shape-memory alloys (SMA) solutions, which, based on the super-elastic properties of such materials, allow a self-centring capacity of the structure after the earthquake [4]. In the latter case, the energy dissipation could be integrated through the addition of viscous damping devices. The effectiveness of many of such systems in protecting both structural and non-structural components has long been demonstrated by both theoretical and experimental studies. An overview of classic passive control systems is given in Kasai et al [5]. Among type 2 systems, a multitude of seismic rehabilitation/reparation techniques has been proposed and studied. With reference to the traditional systems, the following practices can be mentioned: a) epoxy injections; b) steel plating or concrete jacketing [6]. More recently, the use of fibre reinforced polymers is spreading [7].

Nowadays, a lot of both theoretical studies and experimental tests of reinforcing systems on structural elements and sub-structures have been performed [8, 9, 10]. Laboratory experiences are valuable for studying the intervention techniques, but they present important restrictions, concerning the difficulty to well reproduce the actual boundary conditions for the single structural element or sub-structure, sometimes the scale-effect, the difficulty to reproduce the actual RC structure defects (e.g. reinforcing bars corrosion and/or concrete degradation). For these reasons, the opportunity to perform collapse tests on existing structures must be considered a precious and unavoidable occasion to improve the knowledge on both design and analysis methods. What is more, the major part of recent studies mainly examines each technical solution independently from the others. Therefore the surplus value of the current experimental investigation consists in both the analysis of an existing building and the examination and comparison of different technologies for building upgrading. In this framework, the proposed research activity consists of a series of full-scale tests on a reinforced concrete (RC) building, located in Bagnoli (Naples, Italy), in the area where the plants of the previous steel mill named ILVA (former Italsider) have been destined to be demolished. Inspired from this occurrence, the acronym of the research project has been decided: «ILVA-IDEM (ILVA Intelligent DEMolition)». The aim of the research is to analyze the reliability of different advanced systems for seismic upgrading, by performing experimental tests until collapse of the structures under investigation. Details about this research are given hereafter.

## RESEARCH SUMMARY

### The building

The building under investigation is located in the Bagnoli district of Naples (Italy). In this site a very important industrial plant of the Italian steel producer, named “ILVA” (or “Italsider”), was installed at the beginning of the last century. After the decision of the European Community to reduce the Italian production of steel, many iron and steel mills have been closed, including the Bagnoli plant whose site was recognized as very attractive from the viewpoint of the tourist exploitation. So, the ex-industrial area of Bagnoli is now under reorganization, in order to convert it into a residential and tourist one. As a consequence, a lot of constructions located in Bagnoli have already been demolished or they will be in few years. However, several of such buildings possess cultural value from the perspective of the structural engineering, because they represent the construction practice for RC buildings during the 60s-70s in the South of Italy. They were designed and constructed for resisting mainly vertical loads, according to old seismic codes for constructions. Moreover, they often underwent material degradation because of aggressive environmental conditions. For such constructions the urgency of evaluating the seismic vulnerability and identifying the appropriate upgrading/retrofitting structural system exists. In particular, the examined building was designed and constructed at the end of the 70s, few years before the occurrence of the Campano-Lucano earthquake (Irpinia, Italy, 1980). At that time, the city of Naples was even not considered to be exposed to significant seismic actions, so that the practice was to design either without or with only very small attention to the horizontal load-resisting structural scheme. Figure 1 shows the building before the experimental investigation, together with its schematic plan and front views. The building has a rectangular lengthened plan shape (41.6m×6.50m) and it is on two floors with a first and second floor heights on the ground of 3.55m and 6.81m, respectively. Beams are set only along the building perimeter and they support hollow tiles mixed slabs. In the transverse direction, lateral strength is essentially provided by perimeter columns, which have 300mm×300mm square concrete sections, reinforced with four longitudinal steel bars ( $\Phi 12$ , where  $\Phi$  is the diameter in mm) placed at the corners of the section. Square steel stirrups ( $\Phi 8$ ) are placed in the columns with an approximate 300mm spacing. In order to increase the potential number of specimens and to test different upgrading solutions, slabs were cut at the first and second floor, in such a way to divide the whole building into six separate simple structures to be analysed. Figure 2 roughly shows this subdivision. Before the cutting of the slabs, both the internal partitions and the external claddings of the building were removed. Figure 2 illustrates the building at the end of such preliminary operations.

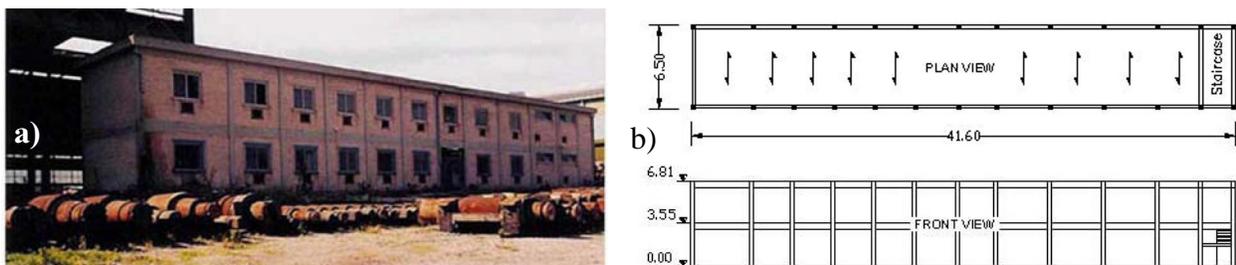


Figure 1. Global view of the original building (a) and schematic plan and front views (b).



Figure 2. The building subdivided into six independent structures.

## Research planning

The general planning of the research can be summarized by the following main 8 steps:

- Step 1 As-built data collection.
- Step 2 Identification of dynamic properties of existing structures by means of in-situ testing.
- Step 3 Static pushover test of structure n. 3 (to be used as reference response).
- Step 4 Modelling of the original structures (using data coming from steps 2 and 3).
- Step 5 Design and application of seismic repairing/upgrading systems;
- Step 6 Identification of dynamic properties of upgraded structures by means of in-situ testing.
- Step 7 Static pushover tests of the upgraded structures.
- Step 8 Modelling of the upgraded structures (using data coming from steps 6 and 7).

The seismic upgrading techniques to be tested are listed hereafter, each of them being associated to the corresponding structure numbered in Figure 2:

1. Base isolation (BI) – Structure n. 1.
2. Steel buckling-restrained braces (BRB) – Structure n. 2.
3. Carbon fiber reinforced polymers (C-FRP) – Structure n. 3.
4. Steel eccentric braces (EB) – Structure n. 4.
5. Shape memory alloy braces (SMA) – Structure n. 5.
6. Dissipative shear panels (SP) – Structure n. 6.

It is worth to underline that the composite materials (C-FRP) system has been designed as a seismic repairing technique for structure n. 3, which was previously tested, in its original conditions, under a lateral load monotonically increasing up to collapse, as described by Step 3.

Figure 3 shows all the structures indicating their dedicated seismic upgrading technique.

Some details about the 8 research steps listed previously, for each of the six structures with their seismic upgrading techniques, are given in the remaining of the paper.



**Figure 3. Techniques under study: 1. BI; 2. BRB; 3. C-FRP; 4. EB; 5. SMA; 6. SP.**

## Research affiliates

A number of both institutional and industrial partners are cooperating for the development of the ILVA-IDEM research activity. On the institutional side, three Italian Universities, one Italian public Institution and one Greek University are engaged. On the side of Industries, there are nine participants, which offer their economic and technological support. The research group components are listed in Table 1.

**Table 1. The ILVA-IDEM research group.**

INSTITUTIONAL PARTNERS	INDUSTRIAL PARTNERS	ROLE
University of Naples Federico II	Bagnoli Futura S.p.A	Work and safety coordination
University of Chieti G.D'Annunzio	Italrecuperi*	Demolition works
University of Basilicata	TIC	Steel systems
University of Thessaly (Greece)	Carannante	Steel systems
Italian Dept. of Civil Protection	TIS*	Special dissipative devices
	TECNO IN*	Experimental measurements
	MAC S.p.A.	Composite materials
	TECHNOBUILDING SERVICE*	Concrete rehabilitation

\* No profit cooperation

## STEP 1: AS-BUILT DATA COLLECTION

### Building configuration and material properties

The geometry of each structure has been measured in-situ and data about the structural member sizes, the slab arrangement and the steel reinforcements have been acquired. As an example, Figure 4 shows the detailed geometry of structure n.3.

Material properties have been measured both by means of in-situ non-destructive tests and laboratory tests on samples drawn out from the original building. Tables 1 and 2 give the main mechanical properties measured for both concrete and steel, respectively.

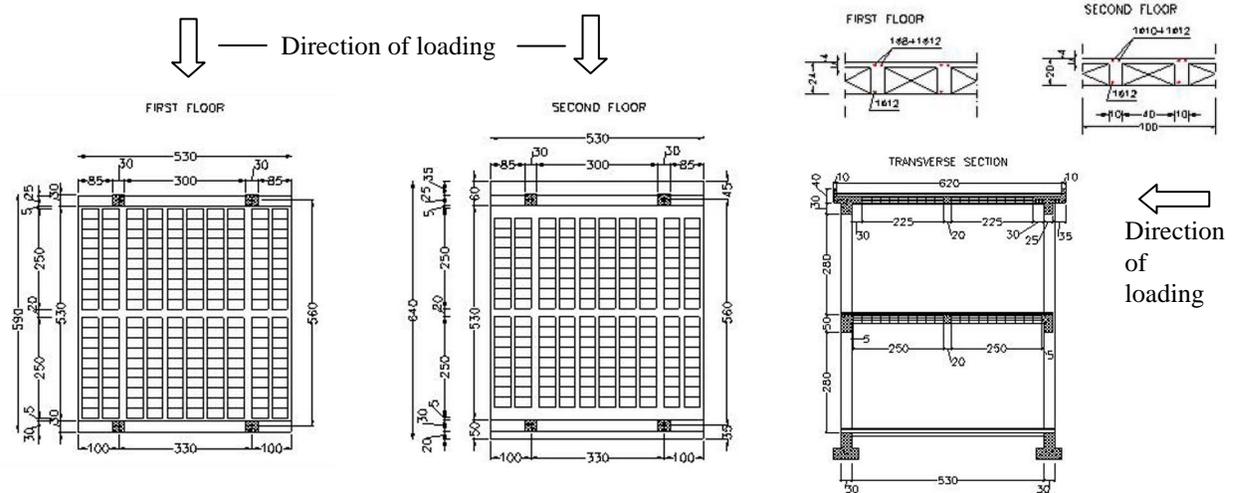


Figure 4. Measured geometry of structure n. 3.

Table 2. Measured concrete properties.

Specimen n.	Unit weight (kg/m <sup>3</sup> )	Elastic modulus (MPa)	Strength (MPa)
1	2244	17692.0	20.5
2	-	16666.7	21.0
3	2235	16129.2	19.9
Average	2239	16829.3	20.5

Table 3. Measured steel properties.

Specimen n.	Φ (mm)	Length (mm)	Yielding load (kN)	Ultimate load (kN)	Ultimate stress (MPa)	Yielding stress (MPa)
1	8	1040	29.0	33.0	656.5	576.9
2	8	975	-	41.0	815.7	-
3	8	500	23.1	33.4	664.5	459.6
Average					712.2	518.25
4	10	558	39.5	59.2	753.8	502.9
5	10	520	38.9	58.8	748.7	495.3
6	10	485	-	62.7	798.3	-
Average					766.9	499.1
7	12	850	44.1	73.8	652.5	389.9
8	12	570	53.1	82.2	726.8	469.5
9	12	860	53.0	79.0	698.5	468.6
Average					692.6	442.3

## STEP 2: DYNAMIC PROPERTIES OF THE ORIGINAL STRUCTURES

### Identification of the dynamic properties by in-situ testing

Dynamic properties of existing structures were measured through in-situ tests, by means of three techniques: 1. harmonic vibrations by means of a vibrodine; 2. impulsive loading by means of a special hammer; 3. vibrations induced by an heavy body impacting the ground close to the structure. At the time of this writing, measurements have been carried out on structures n. 2, 3 4 and 5 by the Italian Dept. of Civil Protection. They are going to carry out analogous tests also for structures n. 1 and n. 6.

Figure 5 shows the electronic devices used for measuring floor accelerations and their location on the structure. Some results in terms of frequencies for the first six modes of vibration of unit 2 through 5 are presented in Table 3. Figure 4 presents both frequencies and relative viscous damping identified for structure n. 2 by means of the impulsive hammer tests.

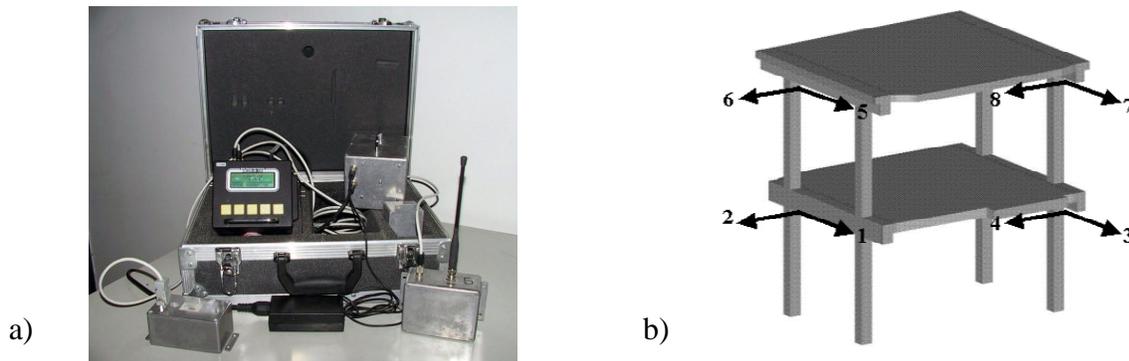


Figure 5. Data acquisition unit, transmitting/receiving device, accelerometer (a) and accelerometer location on the structure (b).

Table 3. Measured vibration frequencies.

Frequency (Hz)	Harmonic vibrations		Impulsive hammer	
	Structure n.2	Structure n. 3	Structure n. 4	Structure n. 5
$f_1$	1.48	1.60	1.80	1.60
$f_2$	-	1.88	1.96	1.80
$f_3$	2.06	2.25	2.47	2.20
$f_4$	4.29	4.80	5.12	4.80
$f_5$	5.20	5.38	5.92	5.38
$f_6$	6.58	6.80	7.00	6.80

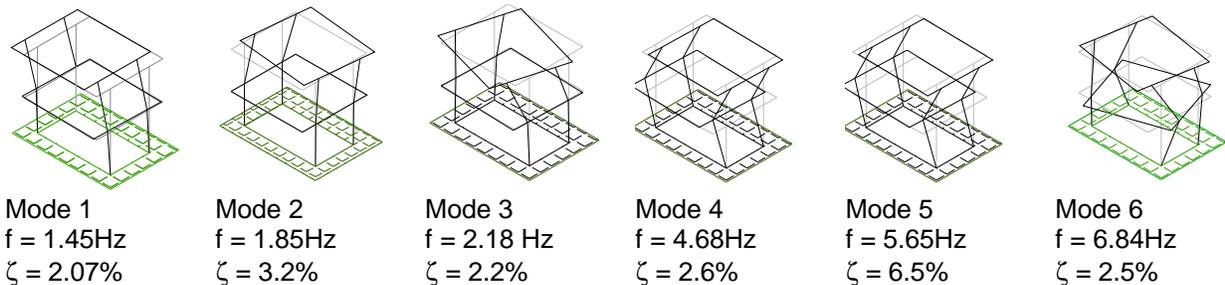


Figure 6. Main dynamic properties identified using the impulsive hammer for structure n. 2.

### STEP 3: STATIC PUSHOVER TEST ON STRUCTURE N. 3

At first, a static pushover test up to collapse was performed on structure n.3 (see Figure 4). A monotonically increasing lateral force was applied at the top slab of the structure, through the use of two hydraulic load actuators contrasted by means of the retaining structure shown in Figure 7a. It must be remarked that this retaining structure was constructed using materials found free of charge in the area of the old steel mill. This explains its non-engineered aspect. However, it efficiently performed its function. Lateral story displacements were measured by means of optical-electronic devices placed at the two floors of the structure, as shown in Figure 7b. Figure 7c highlights the second story sway collapse mechanism, which revealed the formation of plastic hinges at the top and bottom of each column of the second floor. Strong damage concentration, in terms of plastic bending curvature, was evidenced during the test, as clearly shown in Figure 7d: one single large crack formed for each plastic hinge. A visual inspection of the structure during and after the test highlighted that only a limited spalling of cover concrete took place on the compression side, while significant bond-slipping for the longitudinal steel rebars probably occurred. Figure 7e illustrates the experimental base shear vs. lateral displacements relationships, both for the first story and second (top) story. Results are reported up to the achievement of the maximum lateral force, because the test was load-controlled. It is interesting to note that some non-linear response occurred also in the first story of the structure, as it is evidenced by the appreciable non-linearity of the base shear vs. first story lateral displacement relationship. This is also apparent from Figure 7f, where the base shear versus interstory drift angles' relationships are drawn. The latter are measured as the ratio between the story drift (differential lateral displacement between adjacent stories) and the story height. Top story drift angle is defined as the ratio between the top lateral displacement and the top story height measured on the ground level.

A more detailed description of the pushover test is given in [11].

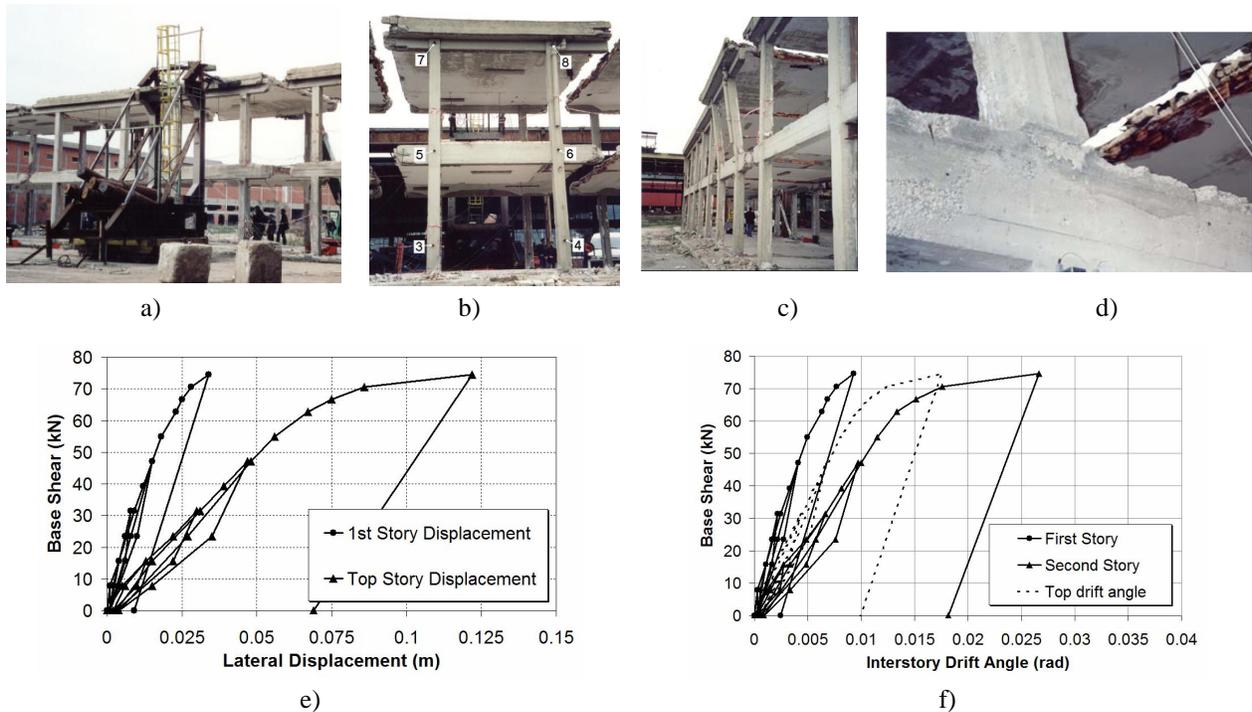
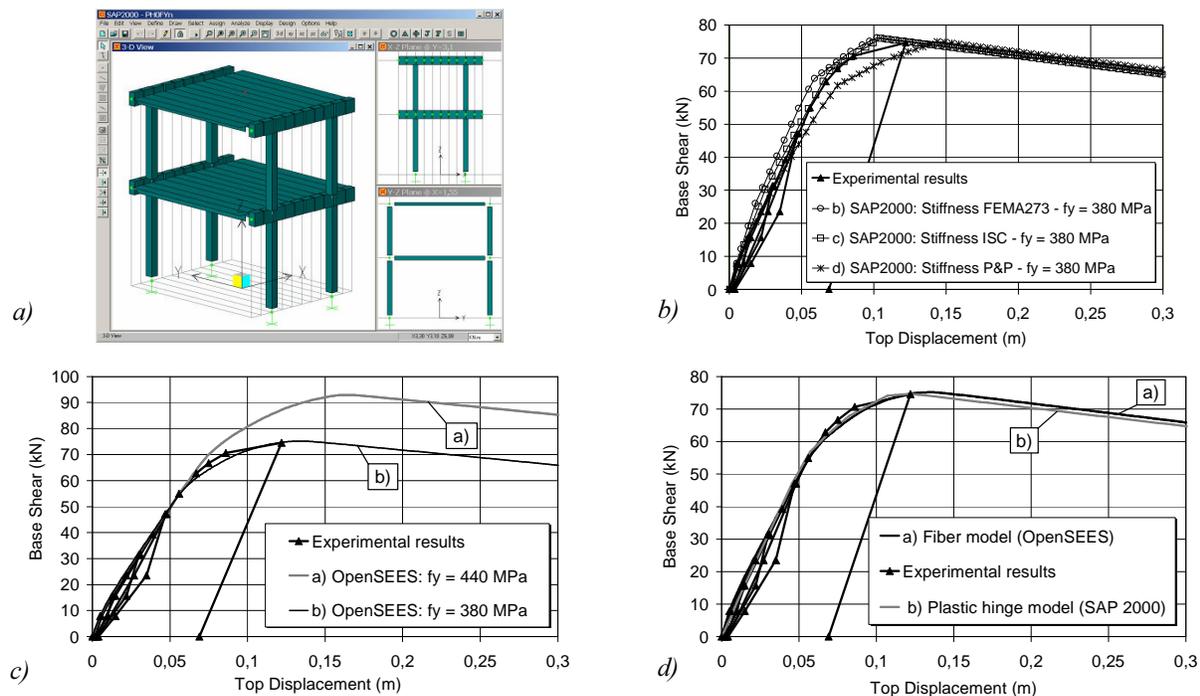


Figure 7. Summary of results of the pushover test on structure n. 3.

## STEP 4: MODELLING OF THE ORIGINAL STRUCTURES

Numerical models of the original structure have been developed. Both plastic hinge models and fiber beam-column elements have been alternately used.

Figure 8a shows the geometry of the numerical model, illustrating that the flexural contribution to the strain energy given by the reinforced concrete horizontal slabs was taken into account by approximating it with the bending of a number of horizontal girders having a T shape of the cross section. The plastic hinge model was implemented in the well-known commercial software SAP 2000NL v.7.12 [12]. Concrete cracking was indirectly taken into account by fictitiously reducing the moments of inertia of beams and columns, as suggested by the following technical recommendations: FEMA 273 [13], the recently proposed Italian Seismic code (ISC), Paulay and Priestley [14]. The strength properties of plastic hinges were computed using the average measured strength for concrete (see Table 2). On the contrary, a reduced value of the steel yielding strength was required in order to match the experimental results. Namely, a value of 380MPa was used instead of the average measured value of 442MPa (see Table 3, diameter 12mm). Figure 8b shows the comparison among the different numerical assumptions and the experimental results. The fiber model was implemented in the recently developed software platform named OpenSEES [15]. In this type of model, the tension strength of concrete was assumed as equal to zero, while its compressive behaviour was assumed according to different hypotheses, namely both considering and neglecting the effect of steel stirrups confinement. Finally, the steel yielding strength was assumed as coming from the calibration phase of the plastic hinge model. Figure 8c shows the effect of the reduced yielding strength and compares the numerical results with the experimental ones. Finally, Figure 8d illustrates the comparison between the physical test results and the two numerical models, showing the very good agreement that was achieved for both models with the experimental results. In particular, for the plastic hinge model, the moments of inertia of beams and columns were reduced by a factor equal to 0.4 and 0.7, respectively. Further details about the modelling of the structure and the calibration phase are given in reference [16].



**Figure 8. Numerical vs. physical test comparison.**

## STEP 5: DESIGN AND APPLICATION OF SEISMIC REPAIRING/UPGRADING SYSTEMS

Within the planned experimental investigation three seismic upgrading/retrofitting systems, which consist in different types of bracing, as well as a seismic repairing intervention by means of composite materials, are tested. Moreover dissipative steel shear panels and a base isolation system have been also taken in consideration. More in detail the examined and applied techniques are:

1. A base isolation (BI) system, using a relatively new type of high damping rubber bearing, with a ring shape. The latter originates from the need to have a stable bearing under lateral loading even if the plan size is small due to the low value of vertical loads. A horizontal steel bracing system assures the diaphragm effect at the base level (Figure 9).
2. A concentric bracing system, based on Buckling-Restrained Braces (BRB), obtained by inserting a steel rectangular plate between two rectangular hollow-section tubes, which have the only function to stabilise the internal plate from lateral buckling, thus allowing the yielding of the steel plate under external actions (Figure 10) [17].
3. A seismic repairing intervention, using Carbon Fiber Reinforced Polymers (C-FRP) for reinforcing the damaged columns of the structure already tested under monotonic loading conditions (Figure 11) [18].
4. An Eccentric Bracing (EB) system, with the link vertically placed and directly attached to the slab of the existing structure. Links have been properly designed for mainly undergoing shear deformation, i.e. “shear links” or “short links” (Figure 12) [17].
5. A concentric bracing system with braces made-up of Shape Memory Alloys (SMA), which exploits the super-elastic properties of such materials for permitting the self-re-centering of the structure after the earthquake (Figure 13).
6. Dissipative steel shear panels (SP). This part of the research is directly linked to another experimental activity, which is under development at the Dept. of Structural Analysis and Design of the University of Naples “Federico II” [19]. Here, pure aluminum shear panels are being tested. Pure aluminum, when heat-treated, exhibits low strength and large ductility, allowing energy dissipation in shear activated by the interstorey lateral displacements of the main structure (Figure 14).

With reference to Figure 3, the BI system, the BRB system, the C-FRP system, the EB system, the SMA system and the SP system have been applied to sub-structures n. 1, 2, 3, 4, 5 and 6 respectively.

Figures 9 through 14 give a general representation of the BI, BRB, C-FRP, EB, SMA and SP systems, respectively.

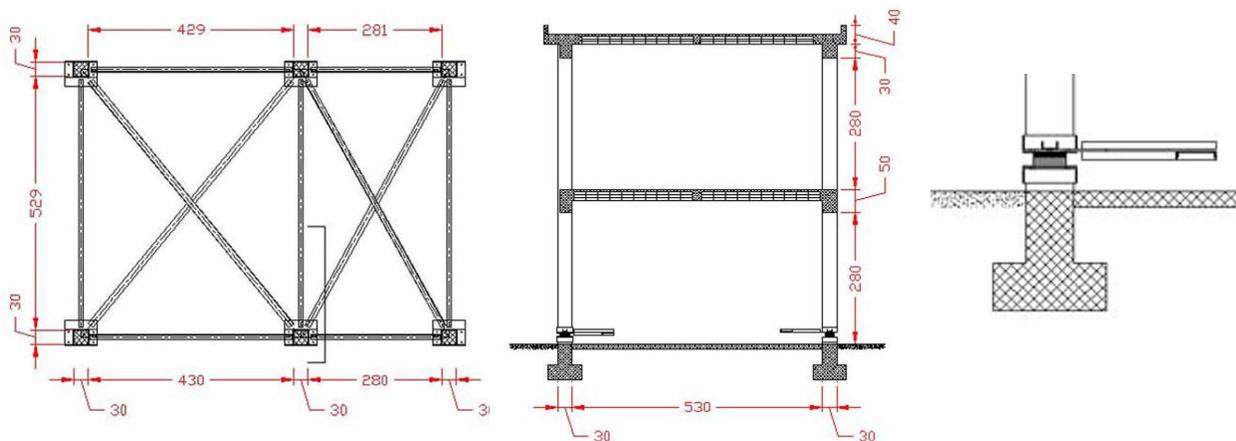
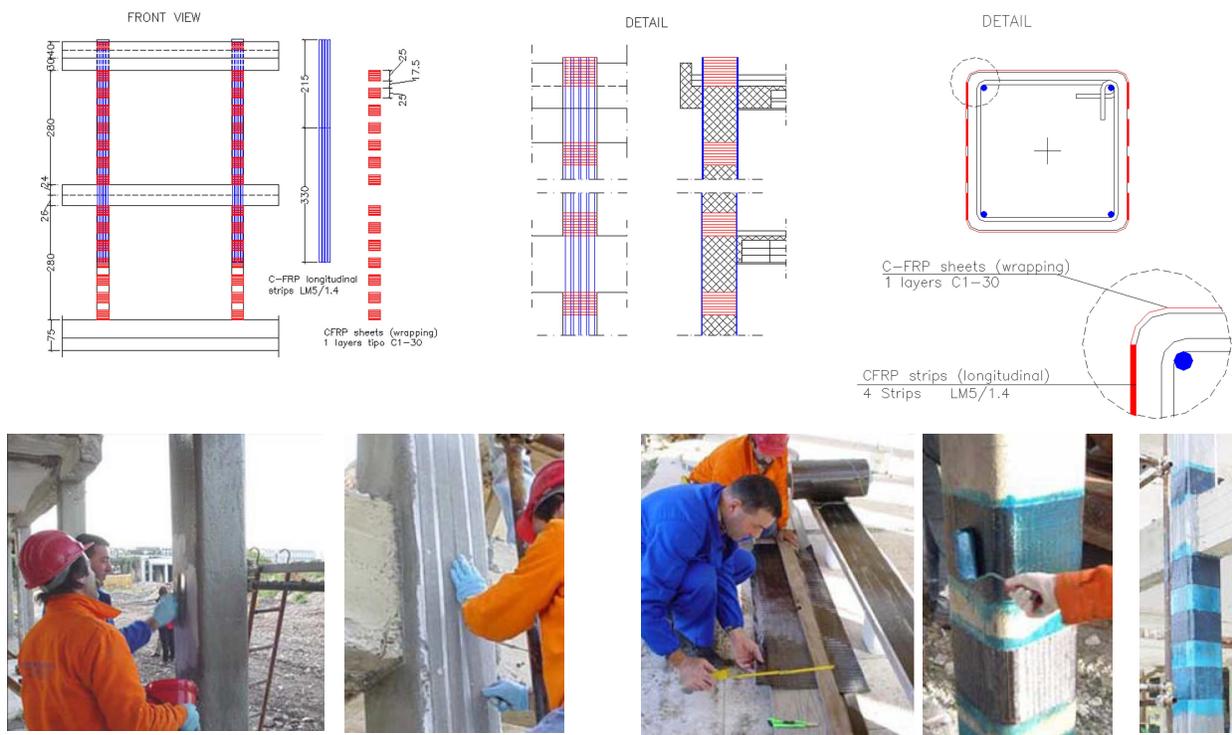


Figure 9. The base-isolation system (BI).



**Figure 10. The concentric buckling-restrained steel braces (BRB).**



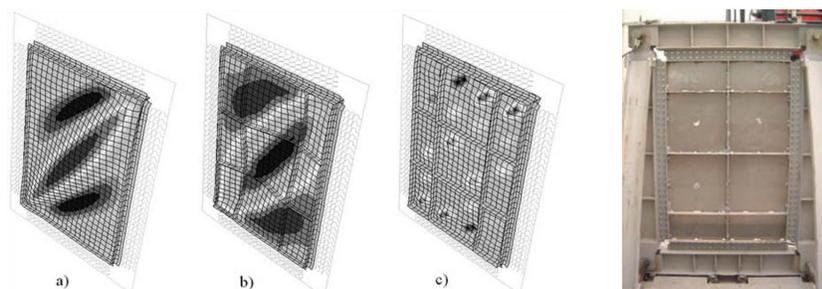
**Figure 11. Seismic repairing by means of composite materials (C-FRP).**



**Figure 12. The eccentric steel bracing system (EB).**



**Figure 13. The shape memory alloy braces (SMA).**

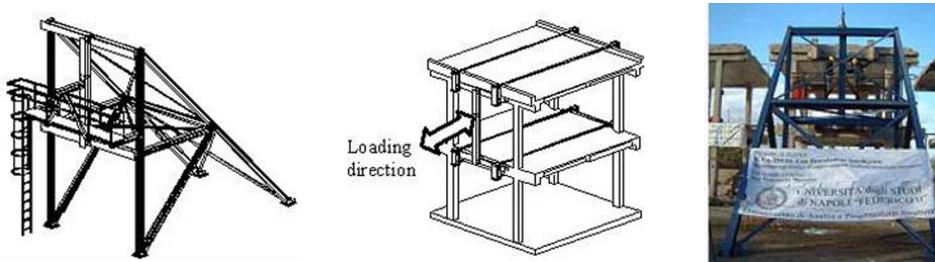


**Figure 14. Different types of dissipative shear panels and the pure aluminum panel tested (SP).**

### STEP 6 THROUGH 8: TESTS ON THE UPGRADED STRUCTURES

A summary of the progress state of the presented experimental activity is given in this section. The structure modified by means of the SMA system has already been tested and now results are going to be elaborated. Concerning the EB and the BRB systems, they have been already designed, constructed and erected in the existing structures [18]. Besides the C-FRP repairing of structure n. 3 has been already carried out [19]. The design of both the base isolation system and the dissipative shear panels is currently in progress. These seismic protection devices should be soon constructed and erected.

The above-mentioned seismic up-grading systems will be tested under cyclic loading conditions. To this purpose, a new, well-engineered, reacting structure has been designed. It is shown in Figure 15. As it can be seen, the lateral load will be applied by means of a single point load-actuator, contrasted against two vertical beams, one placed on the testing structure and the other on the reacting frame. This lateral force will be applied in such a way to have an inverted triangular lateral force distribution on the structure to be tested, in such a way to experimentally replicate the usual assumption of pushover studies.



**Figure 15. The reaction frame system.**

## ACKNOWLEDGEMENTS

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