# PROHITECH

## Earthquake Protection of Historical Buildings by Reversible Mixed Technologies

Contract No.: **INCO-CT-2004-509119**
Duration: 36 + 12 months

## Final Report

by

## Project Steering Committee

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Date of preparation: 15th November 2008
Period covering 1st October 2004 – 30th September 2008

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# 1 Introduction

## 1.1 General

The research project PROHITECH is framed within the INCO thematic areas which are devoted to the "Protection and conservation of cultural heritage" in the Mediterranean area. The project tackles the very important subject of the seismic protection of historical and monumental buildings, namely of constructions dating back from the ancient age up to the mid of the 20$^{th}$ century. Its main objective is to develop sustainable methodologies for the use of reversible mixed technologies in the seismic protection of existing constructions, with particular emphasis to buildings of historical interest. Reversible mixed technologies exploit the peculiarities of innovative materials and special devices, allowing ease of removal if necessary. At the same time, the combined use of different materials and techniques yields an optimisation of the global behaviour under seismic actions. The endpoint of the research is be a proposal of codification for the use of such technologies in the seismic protection of existing constructions, which will meet the most up-to-dated codification issues at European level and will comply with layout, language and philosophy of structural Eurocodes.

The research program involved 16 academic institutions coming from 12 Countries mostly belonging to the South European and Mediterranean area (see list of partners). The work plan was based on 12 scientific workpackages, plus 3 management workpackages. 12 scientific deliverables were prepared. The scientific activity was broken down into 4 main parts, aiming at producing 4 main deliverables, developed in 4 years (initially 3 years were foreseen, but a prolongation of one year proved to be necessary and it was accepted by EC), which were intended to yield a significant advancement of the state of the art in the field of seismic protection of historical buildings. An intense activity of result dissemination at International level has been carried out. A total cost of 2739 k€, including contribution by Partners applying the Full Cost Model, was estimated for the research, corresponding to a global workmanship power of 1129 person/months. This figure includes the contribution of permanent (non additional) staff members. A financial support of 2400 k€ was agreed by EC.

*List of partners:*

| Partic. Role* | Partic. no. | Participant name | Participant short name | Country | Date enter project | Date exit project |
|---|---|---|---|---|---|---|
| CO | 1 | UNIVERSITY OF NAPLES FEDERICO II - ENGINEERING | UNINA | Italy | 1 | 48 |
| CR | 2 | UNIVERSITY OF LIÈGE | B | Belgium | 1 | 48 |
| CR | 3 | UNIVERSITY "Sts. CYRIL AND METHODIUS" OF SKOPJE | MK | Macedonia | 1 | 48 |
| CR | 4 | NATIONAL TECHNICAL UNIVERSITY OF ATHENS | GR | Greece | 1 | 48 |
| CR | 5 | UNIVERSITY OF NAPLES FEDERICO II - ARCHITECTURE | NA-ARC | Italy | 1 | 48 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **CR** | **6** | **INSTITUTO SUPERIOR TÉCNICO OF LISBON** | **P** | **Portugal** | **1** | **48** |
| **CR** | **7** | **THE " POLITEHNICA " UNIVERSITY OF TIMIŞOARA** | **ROPUT** | **Romania** | **1** | **48** |
| **CR** | **8** | **TECHNICAL UNIVERSITY OF CIVIL ENGINEERING - BUCHAREST** | **ROTUB** | **Romania** | **1** | **48** |
| **CR** | **9** | **UNIVERSITY OF LJUBLJANA** | **SL** | **Slovenia** | **1** | **48** |
| **CR** | **10** | **BOĞAZİÇİ UNIVERSITY** | **TR** | **Turkey** | **1** | **48** |
| **CR** | **11** | **TECHNION - ISRAEL INSTITUTE OF TECHNOLOGY, HAIFA** | **ISR** | **Israel** | **1** | **48** |
| **CR** | **12** | **ENGINEERING CENTER FOR ARCHAEOLOGY AND ENVIRONMENT (ECAE) – FACULY OF ENGINEERING - CAIRO UNIVERSITY** | **EG** | **Egypt** | **1** | **48** |
| **CR** | **13** | **NATIONAL SCIENTIFIC AND TECHNICAL RESEARCH CENTRE** | **M** | **Morocco** | **1** | **48** |
| **CR** | **14** | **SECOND UNIVERSITY OF NAPLES** | **SUN** | **Italy** | **1** | **48** |
| **CR** | **15** | **FACULTE DE GENIE CIVIL, UNIVERSITE DES SCIENCES ET DE LA TECHNOLOGIE, (USTHB) ALGIERS** | **AL** | **Algeria** | **5** | **48** |
| **CR** | **16** | **UNIVERSITY OF CHIETI/PESCARA** | **UNICH** | **Italy** | **1** | **48** |

## 1.2 Motivation of the study

As well known, several Countries and many cities in the southern part of Europe, namely the Mediterranean and Balkan area, are greatly exposed to seismic hazard, which causes its large and valuable building heritage to be strongly at risk of severe damage or even destruction due to earthquake occurrences. This problem mostly stands for historical and monumental constructions, due to the fact that most of them frequently lack basic anti-seismic features and/or were never fitted with adequate provisions against earthquake actions. The latest seismic events (Friuli-Italy, 1976; Vrancia-Romania, 1977; Campania and Basilicata-Italy, 1980; Spitak-Armenia, 1988; Banat-Romania,1991; Erzincam-Turkey, 1992; Dniar-Turkey, 1995; Umbria-Italy, 1997; Adana-Turkey, 1998; Iznit and Duzce-Turkey, 1999; Athens-Greece, 1999, to say the most important only) showed that the degree of seismic protection in these parts of Europe is largely unsatisfactory: too many constructions, particularly old masonry structures, very common in stricken Countries, poorly collapsed because of clear reasons, like degradation in quality of materials, lack of appropriate maintenance but, most of all, absence of elementary anti-seismic provisions.

This evidence, that confirms historical constructions to be by far the most vulnerable from the seismic point of view, demands for the definition of urgent strategies for the protection of the cultural heritage from seismic hazard. As a consequence, new technological systems are needed, able to provide a solution not only for specific structural or architectural problems, but also aiming at improving the global performance of the construction, intended as a "system". Similarly, great attention is paid not only to reliability and durability of intervention methods, but also to the possibility to be easily monitored and removed if required, according to the widely shared policy, aiming at the safeguard of existing buildings, in particular in case of historical and monumental works, from inappropriate restoration operations. At the same time, seismic events demonstrated that the use of modern constructional systems provided a satisfactorily good performance everywhere, with a very limited number of damaged and total absence of collapsed constructions. This evidence slowly started to produce a continuous increasing of the sensitivity to the use of more advanced technologies in the seismic protection policy, first of all by acknowledging the very good performance of innovative materials and further on, in a step by step process, by recognising the potential advantages of using special techniques for seismic resistant structures. This trend, initially concerned with new buildings for which a particular degree of seismic protection is required, represents today a further emerging activity in the field of seismic rehabilitation of existing buildings, including those having monumental features and historical interest.

Within the technical field of seismic rehabilitation, two aspects are receiving an increasing attention by engineers and researchers, namely:

- Preservation of Structural Integrity of existing buildings under severe or exceptional seismic actions (SI).
- Improvement of building seismic performance by means of Reversible Mixed Technologies (RMT);

Both these aspects are closely interrelated between each other, in the sense that the application of Reversible Mixed Technologies is, in some cases, the only tool to achieve a satisfying level of Structural Integrity under severe earthquake actions. The concept of Structural Integrity relies on the necessity to ensure seismic protection against collapse also in case of destroying events. In this view, it can be properly framed within the advanced concept of Performance Based Design (PBD). As well known, the Performance Based Design is a new way to approach the structural design against seismic actions, having the purpose to ensure a proper degree of structural reliability under any specified working conditions, including both serviceability and ultimate limit states. Till now, the Performance Based Design has been applied only to new structures, which can be easily designed complying with relevant behavioural thresholds set by PBD itself. No applications exist in the field of existing constructions, yet. In particular, neither criteria nor methodologies are available for achieving a satisfying design level against strong intensity earthquakes. This is indirectly confirmed by most of national seismic codifications, which, as a matter of fact, allow to avoid a rigorous seismic retrofit in case of historical constructions. This approach, of course, tends to preserve the monumental value of the construction, but causes this to be not adequately protected against severe earthquakes. It is evident as this aspect deserves great attention not only in the perspective of saving human lives, but also in the light of preserving invaluable artefacts from complete destruction. The use of innovative materials and Mixed Technologies is the most appropriate answer of ensuring an adequate performance, and hence the Structural Integrity, under strong seismic actions.

Reversible Mixed Technologies (RMT) are based on the integration of structural members of different materials and/or construction methods into a single construction. The basic feature of RMT is that their application should be always completely recoverable, that is reversible, if required. This is considered as an essential design requirement in order to prevent historical and monumental buildings from unsuitable rehabilitation operations. The main aim of RMT is the best exploitation of material and technology features, in order to optimise the structural behaviour under any condition, including very severe limit states involved by strong seismic actions. This practice, initially concerned with new, technologically advanced buildings, is now being looked up with increasing interest in the field of structural rehabilitation, too, due to the greatest possibilities of structural optimisation and, hence, performance improvement, achieved for thanks of mixed technologies. In a few words, the use of reversible mixed technologies would involve the best exploitation of each material and/or technology used in the intervention, providing in such a way the best performance from both technical and economical point of view.

### 1.3 Objective of the study

The main subject of the research is represented by buildings erected from the ancient age to the first half of the 20$^{th}$ century, all of which can be considered, with good conscience, as belonging to the cultural heritage of involved Countries. Such buildings cover a wide and diversified range of structural categories, including both masonry and reinforced concrete buildings and also some steel constructions, needing to be fitted with adequate anti-seismic provisions. As the intended activity is mostly focused on the use of innovative technologies, namely those relying upon mixed systems, an urgent necessity for a more advanced understanding of both material and device behaviour, as well as for a deeper insight into the seismic response of constructions is felt. This means specific objectives to be pursued, aimed at:

1. Drawing the attention of industry, research centres, engineers and competent authorities of European and Mediterranean Countries on the problem of safeguard of construction heritage from seismic risk, in particular when historical buildings are concerned;
2. Improving the awareness of operators listed above about the importance of using advanced materials and technologies in the seismic up-grading of constructions;
3. Improving the average knowledge of practising engineers about innovative systems of seismic protection, so as to contribute to the institution of specialised skills in the field of seismic rehabilitation;
4. Promoting the use at a wide scale of reversible and environmentally friendly technologies, in order to fit existing constructions with easily removable and modifiable seismic protection systems;

5. Supporting the adoption of "smart" materials and special techniques for the seismic protection of constructions as a cheap and effective alternative to traditional, highly intrusive strengthening methodologies, especially when historical constructions are faced;
6. Advancing the state-of-the-art in the field of seismic protection of constructions, by adding new information about the behaviour of structures fitted with special systems and/or using advanced materials or devices for improving the seismic performance;
7. Allowing engineers to use simple and reliable tools for analysing the behaviour of constructions provided with advanced systems for seismic protection, as well as for detailing up-grading interventions;
8. Developing advanced, PBD-complying guidelines for the practical application of innovative materials and technologies in the field of seismic restoration.

The whole of activity can be subdivided into five parts, outlined in the following table:

| Part | Title | Type of activity | Start month | End month | Deliverable |
|---|---|---|---|---|---|
| **Part R1** | Intervention strategies | Scientific overview | 2 | 11 | D-I |
| **Part R2** | Selection of materials and technologies | Research | 2 | 18 | D-II |
| **Part R3** | Experimental and numerical research | | 7 | 42 | D-III |
| **Part R4** | Set-up of codification rules | Technological development/innovation | 13 | 48 | D-IV |
| **Part M** | Scientific coordination and project management | Management | 1 | 48 | D-M |

These objectives have been achieved through **12 different scientific workpackages** aimed at the production of **four main deliverables (D-I, D-II, D-III, D-IV)**. Therefore, the achievement of both main and workpackage deliverables has been used as a suitable criterion for verifying and measuring such objectives.

The following table shows the list of the participants, together with the related responsible persons and the roles played in the project workpackages.

| Partic. no. | Participant short name | Responsible person | Role |
|---|---|---|---|
| 1 | UNINA | Federico M. Mazzolani | General Coordinator |
| 2 | B | Jean-Pierre Jaspart | WP11 Leader |
| 3 | MK | Kiril Gramatikov | WP7 Leader |
| 4 | GR | Ioannis Vayas | WP10 Leader |
| 5 | NA-ARC | Raffaele Landolfo | WP8 Leader |
| 6 | P | Luìs Calado | WP5 Leader |
| 7 | ROPUT | Dan Dubina | WP9 Leader |
| 8 | ROTUB | Dan Lungu | WP4 Leader |
| 9 | SL | Darko Beg | WP6 Leader |
| 10 | TR | Gulay Altay Askar | WP2 Leader |
| 11 | ISR | Avigdor Rutenberg | WP12 Leader |
| 12 | EG | Mohamed El Zahabi | - |
| 13 | M | Ahomar Iben Brahim | WP3 Leader |
| 14 | SUN | Alberto Mandara | WP1 Leader |
| 15 | AL | Mohamed Chemrouk | - |
| 16 | UNICH | Gianfranco De Matteis | Technical Coordinator |

It is important to note that, as respect to the original planning, the WP10 (validation of innovative solutions and procedures) has been moved from Part R3 to Part R4, as proposed during the 1st WP8 special meeting held in Naples on February 23 and 24, 2006 and stated during the 4th general meeting held in Istanbul on April 6 and 7, 2006, according to the updated timetable. Figure 1 shows the interconnection between workpackages and deliverables, whereas Figure 2 shows the project timetable.

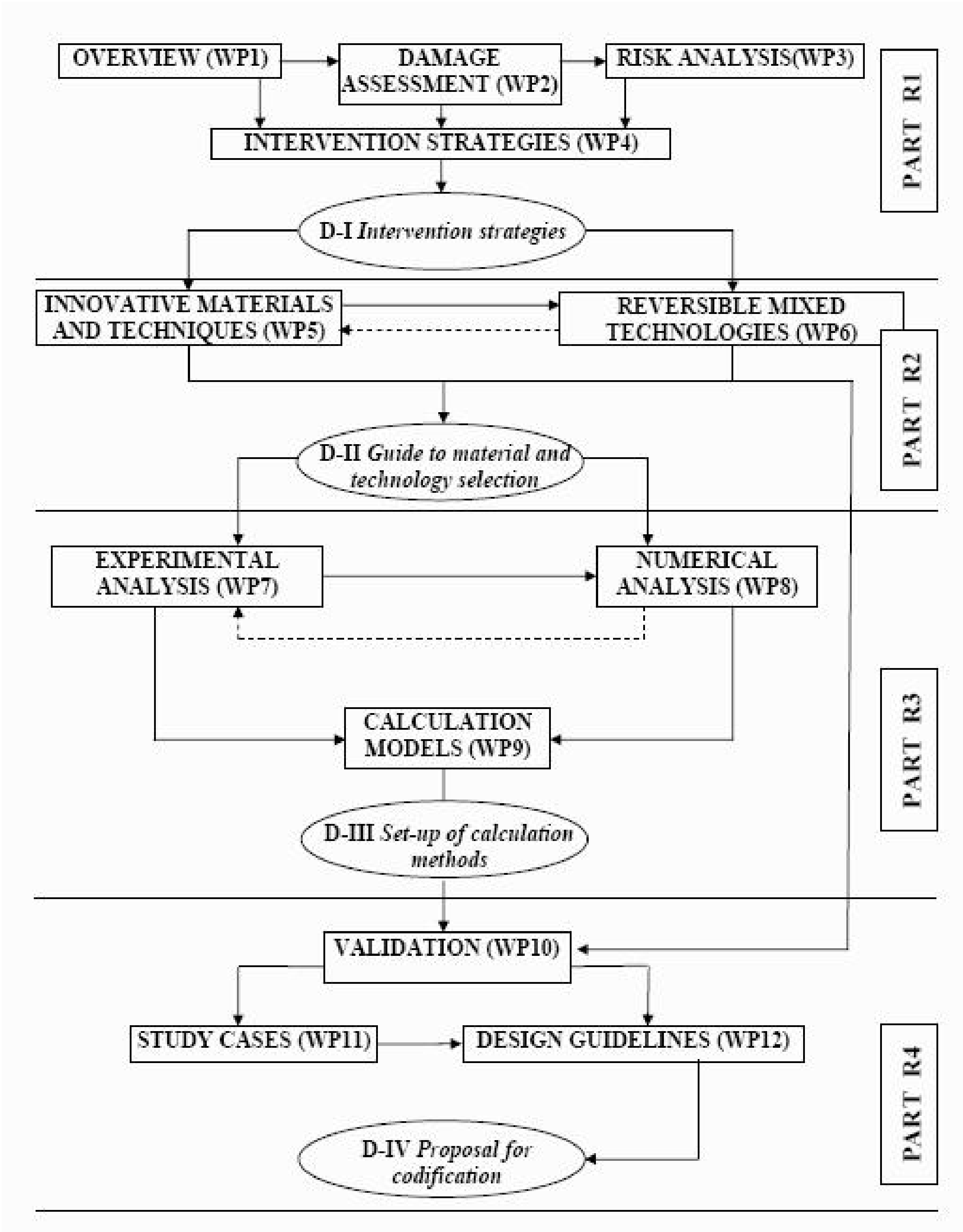



Figure 1. PROHITECH interconnection diagram

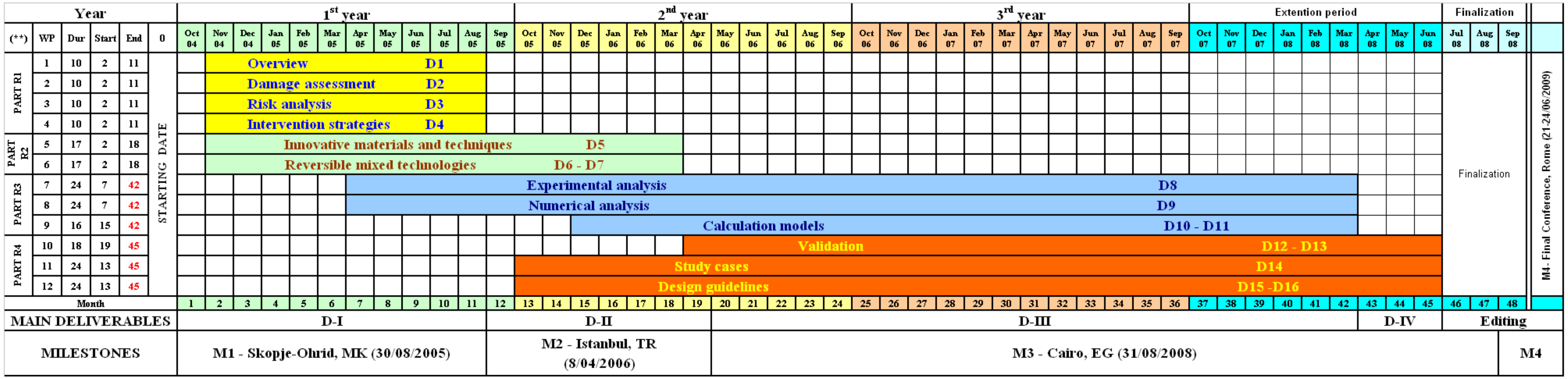



Figure 2. The PROHITECH timetable

# 2 Project objectives and major achievements

All the documents developed within PROHITECH are available on the website related to the research project: www.prohitech.com.

**PART R1**

The activities concerning the part R1 of PROHITECH project have been developed and concluded during the first year. In particular, within the Workpackages from 1 to 4, four project deliverables (D1-to-D4) have been produced. Moreover, the First Main Deliverable D-I has been completed, in which, with respect to its first version, additional information proposed by Partner No. 13 have been included.

In the following, the titles and contents of the deliverables produced during the first year activity, within the Part R1 of the project, are listed.

**Project deliverables:**

*D1 Overview of traditional technological systems adopted for seismic rehabilitation of historical buildings in European and Mediterranean Countries*

1. General overview
2. Consolidation levels
3. Strengthening techniques
4. Conclusions
5. References

*D2 Assessment of earthquake-induced structural damage in historical buildings of the Mediterranean area*

A. Introduction
B. Seismicity and building stock
C. Damage assessment
D. Common damage patterns
E. Damage statistics
F. Ancient monuments
G. Performance assessment
H. Conclusive remarks
I. Appendix I: damage assessment forms
J. References

*D3 Assessment of seismic risk maps and evaluation of seismic vulnerability of historical building heritage in the Mediterranean area*

A. Introduction
B. Seismic hazard
C. Seismic vulnerability
D. Conclusions
E. References
F. Appendix

*D4 Definition of methodologies for seismic up-grading of constructions based on both strengthening of structural elements and control of the seismic response*

1. General & terminology
2. Intervention solutions and criteria for seismic upgrading & rehabilitation of constructions
3. Options for intervention strategy
4. Country seismic legislation & actions for seismic intervention on constructions
5. Successful reversible intervention for cultural heritage constructions

   References

**Main deliverable:**

*D-I Assessment of intervention strategies for the seismic protection of historical building heritage in the Mediterranean basin*

- Chapter 1 SEISMIC HAZARD IN THE PROHITECH COUNTRIES
- Chapter 2 DAMAGE ASSESSMENT
- Chapter 3 SEISMIC VULNERABILITY ASSESSMENT
- Chapter 4 OVERVIEW OF EXISTING TECHNIQUES
- Chapter 5 INTERVENTION STRATEGIES

The Main Deliverable D-I is planned to be published with the following title:

*Intervention strategies for the seismic protection of historical building heritage in the Mediterranean basin (Volume I)*

**PART R2**

The activities concerning the part R2 of PROHITECH project have been developed during the first two years and they have been concluded in the second year. In particular, within the Workpackages 5 and 6, three project deliverables (D5-to-D7) have been produced. Moreover, the Second Main Deliverable D-II has been completed.

In the following, the titles and contents of the deliverables produced during the second year activity, within the Part R2 of the project, are listed.

**Project Deliverables:**

*D5 Identification of innovative materials and special devices to be used for reversible mixed technologies in structural rehabilitation*

1. Introduction
2. Materials
3. Devices

(It has to be underlined that deliverables D6 and D7 are arranged as a unique volume)

*D6 Development of reinforcement procedures for structural elements based on the use of reversible mixed technologies*
*D7 Set-up of seismic protection systems based on the dissipation of seismic input energy*

1. Introduction
2. Examination of materials
3. Examination of devices
4. Set-up of seismic protection systems
5. Conclusions

**Main Deliverable:**

*D-II Reversible mixed technologies for seismic protection: guide to material and technology selection*

- Chapter 1 INTRODUCTION TO REVERSIBLE MIXED TECHNOLOGIES
- Chapter 2 MATERIALS
- Chapter 3 DEVICES
- Chapter 4 SEISMIC PROTECTION SYSTEMS

The Main Deliverable D-II is planned to be published with the following title:

*Reversible mixed technologies for seismic protection: guide to material and technology selection (Volume II)*

**PART R3**

The activities related to Part R3 have been developed starting from the first year of the project, up to its end. In particular, within the Workpackages 7, 8 and 9, four project deliverables (D8-to-D11) have been produced. The Third Main Deliverable D-III is based on a synthetic editing of the above project deliverables.

In the following, the titles and contents of the deliverables produced within Part R3 of the project are listed.

**Project deliverables:**

*D8 Experimental assessment of the behaviour of true-scale structural elements strengthened with innovative reversible mixed technologies*

1. Tests on materials and elements
2. Tests on devices
3. Tests on sub-systems
4. Large scale model tests
5. Full scale tests

*D9 Calibration of numerical procedures for the analysis of strengthened structural elements on the basis of experimental results*

1. The benchmark study
2. Materials and elements
3. Devices
4. Sub-systems
5. Large scale models
6. Full scale buildings

*D10 Set-up of analytical models for special materials and special devices for the seismic structural control*

1. Models and performance criteria for structural elements of different materials
2. Models and performance criteria for devices
3. Models and performance criteria for sub-systems

*D11 Development of simplified models for the global seismic analysis of historical constructions*

4. Models for global analysis

**Main Deliverable:**

*D-III Reversible mixed technologies for seismic protection: experimental and numerical activity versus calculation models*

Due to the large amount of work carried out in Part R3, and the related outputs, the Third Main Deliverable is planned to be published arranged into two volumes, as follows:

*Reversible mixed technologies for seismic protection: experimental activity (Volume III)*

- Chapter 1 TESTS ON MATERIALS AND ELEMENTS
- Chapter 2. TESTS ON DEVICES
- Chapter 3. TESTS ON SUB-SYSTEMS
- Chapter 4. LARGE SCALE MODEL TESTS
- Chapter 5. FULL SCALE TESTS

*Reversible mixed technologies for seismic protection: numerical activity versus calculation models (Volume IV)*

Part I

- Chapter 1 THE BENCHMARK STUDY
- Chapter 2. MATERIALS AND ELEMENTS
- Chapter 3. DEVICES
- Chapter 4. SUB-SYSTEMS
- Chapter 5. LARGE SCALE MODELS
- Chapter 6. FULL SCALE BUILDINGS

PART II

- Chapter 1. MODELS AND PERFORMANCE CRITERIA FOR STRUCTURAL ELEMENTS OF DIFFERENT MATERIALS
- Chapter 2. MODELS AND PERFORMANCE CRITERIA FOR DEVICES
- Chapter 3. MODELS AND PERFORMANCE CRITERIA FOR SUB-SYSTEMS
- Chapter 4. MODELS FOR GLOBAL ANALYSIS

**PART R4**

The activities related to Part R3 have been developed starting from the second year of the project, up to its end. In particular, within the Workpackages 10, 11 and 12, five project deliverables (D12-to-D16) have been produced. Moreover, the Fourth Main Deliverable D-IV has been completed.

In the following, the titles and contents of the deliverables produced within Part R4 of the project are listed.

**Project deliverables:**

*D12 Validation criteria for restoration interventions*

1. Principles for restoration interventions on monumental and historical buildings
2. Performance vs. Rehabilitation levels
3. Rehabilitation strategies: Design criteria for structural interventions
4. Analysis criteria
5. Safety verification
6. Validation criteria

*D13 Validation of existing rehabilitation interventions*

1. Acropolis Athens
2. St. Sofia Church, Ohrid
3. El-Mardani Mosque, Cairo
4. Le Bastion, Algiers
5. Diplomatic hall royal Palace, Naples
6. St Giovanni Battista Church, Carife
7. “Baroc” Palace, Timisoara
8. Manor House, Banloc
9. Palace of Justice, Bucharest
10. Trajan Market Hall, Bucharest
11. Municipal Market Karditsa
12. Bedouins children School, Beer-Ssheva
13. Church of Holy Spirit, Javorka
14. Deutsche Bank, Naples
15. Jolly Hotel, Caserta
16. West University, Timişoara

*D14 Selection of study cases belonging to the historical building heritage of the Mediterranean area: analysis of feasibility of interventions based on the use of innovative reversible mixed technologies and relevant design of seismic retrofit*

1. Objectives
2. Partners
3. Proposed study cases
4. Selected study cases
5. Working procedure

6. Study case investigations
7. General conclusions
8. Technical annexes

*D15 Codification rules for the design of seismic protection interventions based on innovative reversible mixed technologies*

1. Introduction
2. Traditional techniques
3. Fibre Reinforced Polymers (FRP)
4. Seismic isolation
5. Energy dissipation
6. PROHITECH Countries national practice
7. Recommended codes, criticism and suggestions for improvement
8. References and bibliography

   Appendices

*D16 Preparation of an operational manual for the practical implementation of proposed procedures*

Some significant examples of application have been developed.

1 – Why reversible mixed technologies?
2 – Seismic protection systems for existing structures: principles & design considerations
3 – Design numerical examples
4 - Appendices
5 - References

**Main Deliverable:**

*D-IV Proposal of codification on the use of reversible mixed technologies in the seismic protection of historical buildings*

Due to the large amount of Part R4 outputs the Fourth Main Deliverable is planned to be published arranged into two volumes, as follows:

*Seismic protection of historical buildings: guidelines (Volume V)*

- Chapter 1 OVERVIEW OF RELEVANT CODES AND GUIDELINES
- Chapter 2 ASSESSMENT OF THE ORIGINAL BUILDING
- Chapter 3 REHABILITATION STRATEGIES

*Seismic protection of historical buildings: study cases (Volume VI)*

# 3 Activities carried out within the Workpackages

## WP 1 OVERVIEW OF EXISTING TECHNIQUES

WP1 belongs to Part R1 – Intervention strategies of the project, concerned with the basic framing of the research and aimed at providing the first Prohitech main deliverable D-I – Assessment of intervention strategies for the seismic protection of historical building heritage in the Mediterranean basin. The outcome of Part R1 represents a necessary input to the Part R2 – Selection of materials and technologies, dealing with the core of Prohitech project, namely the use of reversible mixed technologies in seismic upgrading operations. Complying with Prohitech Technical Annex (2004), WP1 aimed at assessing the main criteria and methodologies underlying the traditional practice of structural rehabilitation and seismic upgrading, as commonly followed in the Member Countries. In particular, WP1 was mainly devoted to establish a commonly shared background and terminology as a basis for the development of the WPs of Part R2, namely WP5 – Innovative materials and techniques and WP6 – Reversible mixed technologies. Main objectives of WP1 as given in the Technical Annex are here briefly recalled:

- Establishing a commonly agreed background and terminology to base studies on structural typologies, condition references and retrofit requirements;
- Comparing the current design approaches and past design practices and codes;
- Reviewing the current practice in retrofit methods.

Because of its general character, WP1 has been contributed by the majority of PROHITECH Contractors, on the basis of their own national experience. Countries involved in the WP1 activity were: Italy (Partners 1 and 14), Republic of Macedonia (Partner 3), Greece (Partner 4), Portugal (Partner 6), Romania (Partner 7), Slovenia (Partner 9), Turkey (Partner 10), Morocco (Partner 13) and Algeria (Partner 15). A large amount of data from both governmental and private institutions has been collected in order to outline both old and current design and retrofit practices, with a special emphasis to the use of traditional techniques. As expected, a great quantity of data has been collected in the view to feed the activity of WP4 – *Intervention strategies*, which is mostly concerned with the assessment of the main strategies liable to be followed in the seismic protection of existing historical constructions.

Contributions from Partners clearly pointed out that both constructional techniques and systems adopted in each of the involved Countries can be considered very similar to each other. This may be assumed as a first important conclusion of WP1 activity, as they confirm that a common knowledge and awareness do exist among Partners at this stage of development of the state-of-art on structural rehabilitation. This shared know-how can be considered as a suitable common base and, hence, as a proper starting point for the study of innovative and reversible techniques to be framed within the next steps of PROHITECH (WP5 and WP6).

## WP 2 DAMAGE ASSESSMENT

The aim of this part of the research was to prepare an overview of damage assessment methodologies followed in various Mediterranean countries in the PROHITECH project. The focus was mainly on the Mediterranean region, a part of the world which unfortunately is no stranger to earthquakes. Therefore, in the performed study, reference has been made to building typologies and construction practices with some emphasis on the development of seismic design provisions, quick and detailed damage assessment methods, damage patterns that were observed in previous earthquakes in the region for various types of buildings, results of post-earthquake damage surveys for some of the most significant seismic events in the Mediterranean countries, and the history and earthquake performance of some buildings that are representative of the cultural heritage of this historically rich region.

## WP 3 RISK ANALYSIS

The PROHITECH WP3 is an important Workpackage that had two main objectives. The first objective consisted in reviewing the current approaches to damage assessment and definition of vulnerabilities of structural types, based upon observed damages due to recent earthquakes that occurred in some Euro-Mediterranean countries. The second objective was to help to define problems that require an approach based on innovative technologies.

Thus, and knowing that the Euro-Mediterranean region is one of the most seismically active regions in the world, the main activity of WP3 consisted of the analysis of seismic risk related to the historical buildings heritage of the Mediterranean area. It is, however, important to note that in this WP, we were primarily interested in assessing the extent of damage to which historical buildings are exposed without trying to evaluate human losses nor the costs involved.

This Workpackage activities were carried out with the contribution of all PROHITECH participating countries, on the basis of their national experiences. First, the information on seismic hazard in the PROHITECH Euro-Mediterranean countries were synthesised, including seismicity maps, main historical events, macroseismic intensity maps seismic zonation maps, and response spectra. The second chapter gives an overview on the methodologies used for seismic vulnerability assessment and a synthesis of the results on vulnerability studies performed in the different contributing Countries.

In terms of vulnerability, some of the PROHITECH countries, such as Italy, Macedonia, and Turkey have developed full vulnerability studies for their types of buildings, using both the LM1 and LM2 methods. Meanwhile, seemingly other countries have not yet developed their own vulnerability studies, while for others such studies were performed just recently using one or the other method. Such studies provide fragility curves, which are essential for the estimation of damages for the different expected levels of ground shaking and for the different scenarios.

In summary, the results show that for some of the PROHITECH participating countries, seismic accelerations and thus, seismic risk are quite high. While for other countries, although seismic hazard is considered low to moderate, seismic risk is relatively high, due to the fragility of the building stock and to the high seismic accelerations that are reached every now and then.

## WP 4 INTERVENTION STRATEGIES

The contents and objectives of WP4 were been established as follows:

1. Terminology in the field of intervention work on historical buildings;
2. Intervention solutions and criteria for seismic upgrading and rehabilitation of constructions;
3. Options for intervention strategy;
4. Country seismic legislation and actions for seismic intervention on constructions;
5. Reversible intervention for cultural heritage constructions

The work about ”Intervention strategies” focused on the main issues for seismic rehabilitation and strengthening of historical buildings and listed important preservation principles. The necessity and importance of using a correct terminology for interventions on historical buildings was emphasised.

The main principles and methods for the seismic rehabilitation and strengthening of historical buildings were provided and important preservation principles were considered. General criteria for selecting a correct intervention strategy were provided, based on preliminary cost-benefit analysis. The main intervention policies, including the financing issues, were duly considered, in relation to what has been done in PROHITECH partners countries.

## WP5 INNOVATIVE MATERIALS AND TECHNIQUES FOR SEISMIC PROTECTION

The main scope of WP5 was the individuation of innovative materials and devices on the basis of their mechanical features, in order to select suitable materials for creating both strengthening systems and special devices aimed at the optimization of the structural behaviour.

Each material or system has its own properties and was evaluated for the particular project for which it has been intended. In special way, reversibility requirements were addressed. At the same time, its performance will depend on whether the application is being used for the reduction of wind or seismic effects. In particular, experimental results obtained everywhere in the world demonstrate that a significant improvement of the energy dissipation capability of the structures involved by suitable dampers resulted in substantial drift reductions and, under certain conditions, in a reduction of inertia forces. For this reason the activity developed focused the identification and characterization of the most suitable materials and devices for the achievement of adequate structural performances compared with conventional solutions.

Reversible mixed technologies are intended to join the valuable performance characteristics of different materials and devices, together with the possibility of replacing them in case of development and availability of more effective protection systems. The natural approach for the utilization of this kind of technologies covers three interrelated topics: (1) innovative materials; (2) innovative devices and techniques; (3) seismic protection systems, as an application of the previous ones.

Both materials and techniques may be classified considering several issues. In this WP, the subjects which are taken into account are structural modification, reversibility and type of structural control. In this WP general materials and techniques are described, which despite of being innovative are commonly used.

The considered materials were: Mild Steel (MS), Stainless Steel (SS), Pure Aluminium(PA), Aluminium Alloys (AA), Titanium (TI), Shape Memory Alloys (SMA), Fiber Reinforced Polymers (FRP) and Elastomers (EL). Piezoelectric materials and Magnetorheological Fluids (MF) are briefly mentioned in this WP and they are directly described with reference to their application in the devices. Such an overview on the innovative materials for strengthening gives the possibility to define their advantages in comparison to traditional strengthening materials.

For each material a datasheet was prepared which includes: material principle, structural features, fields of application, experimental tests and numerical models, design criteria and codification issues, structural examples and economic aspects.

The considered devices were: Yielding Metal Devices (YMD), Pure Aluminium Shear Panels (PASP), Friction Devices (FD), Fluid Viscous Dampers (FVD), Magnetorheological Dampers (MRD), Fluid Springs (FSD), Tuned Mass Dampers (TMD), Base Isolation Systems (BI) and Visco-Elastic Devices (VED). According to the previously mentioned classification criteria, YMD, PASP and FD are Displacement – Dependent devices; FVD, MRD and FSD are Velocity – Dependent devices; TMD are Acceleration – Dependent devices; BI concerns the input modification; VED devices represent a combination. The relevant properties of the presented devices are carefully analysed and compared.

For each device a datasheet was also prepared which includes: device description, device properties, fields of application, experimental tests, design approach, structural examples and company / dealer.

The research involved all the partner of PROHITECH.

## WP6 SET-UP OF ADVANCED REVERSIBLE MIXED TECHNOLOGIES FOR SEISMIC PROTECTION

The aim of WP6 has been to complement and complete the work performed in WP4 and WP5 by providing the information necessary to the proper use of innovative materials and mixed technologies in strengthening interventions, as well as the definition of special systems for seismic protection to be applied to existing buildings. For this reason, the mechanical properties of materials and relevant features of innovative seismic protection systems have been studied in order to set-up adequate solutions for both intended purposes.

The innovative materials for strengthening identified in WP5 have been examined in order to define the possible advantages in comparison with the traditional strengthening materials. Particular emphasis has been given to metal materials, which prove to be the most suitable for reversible mixed applications. To this purpose, special attention has been paid to corrosion resistance, aesthetic appearance, increased ductility and low cycle fatigue resistance, and "smart" behaviour (in the case of shape memory alloys - SMA). Furthermore, some applications, namely confinement or coupling of masonry members with metal elements, taking advantage of special features of innovative materials, have been considered. Some of these applications for the strengthening of masonry members, have been already pointed out by in the technical literature, where their great effectiveness from the seismic point of view has been shown.

Moreover, the seismic protection systems based on passive energy dissipation and identified in WP4 and WP5 have been analysed. To this purpose, braces with axial plastic deformation capabilities, braces containing dissipative elements based on plastic deformation in bending, torsion or shear, as well as friction dampers, have been considered, focusing on their most important individual features, such as strength, ductility, dissipation capability, low-cycle fatigue resistance. Further on, the behaviour of innovative dissipative devices, namely viscous dampers, SMA dampers and similar devices, have been analysed, considering their possible application to the different structural systems.

The results of the research activity developed within the WP5 and WP6 workpackages have provided useful information and indications for the experimental-numerical activity developed in the part R3 of the project.

## WP7 EXPERIMENTAL ANALYSIS

The experimental analyses maybe represent the actual core of the PROHITECH research project. They have provided a very important contribution in the development of Reversible Mixed Technologies to be applied for the seismic protection of historical buildings.

The work has been carried out with the main aim of assessing and setting-up new mixed techniques for the repair and strengthening of historical buildings and monuments belonging to the Cultural Heritage of the Mediterranean basin.

The experimental activity has been developed at five different levels, namely materials and elements, devices, sub-systems, large scale models, full scale tests. The contributions by the project partners has consisted in a total of 49 datasheets, for a total number of about 1000 pages.

*1. Materials and elements*

The tests on materials and elements have represented the basis for all the experimental analyses carried out at different scales, as previously described. Simple elements and materials have been characterized from the mechanical point of view, so allowing the correct interpretation of the experimental results coming from the tests at larger scales. In the following, the titles of the collected datasheets dealing with the experimental activity on materials and elements are provided.

1.1 Adobe materials for the construction of earth traditional houses and stone houses
1.2 Brick & mortar
    1.2.1 Testing of Bricks and Lime Mortar for Mustafa Pasha Mosque Model
    1.2.2 Design process for defining the Equivalent Materials Bricks-Substitute for Stone for the Fossanova Cathedral Model
    1.2.3 Control Testing of Equivalent Materials Bricks-Substitute for Stone for the Fossanova Cathedral Model
    1.2.4 Characterization of mortar from the Fossanova Cathedral
1.3 Stone
    1.3.1 Sale Stone
    1.3.2 Stone material for construction of Mustafa Pasha Mosque Model
    1.3.3 Material characterization of Beylerbeyi Palace
    1.3.4 Characterization of the stone from the Fossanova Cathedral
1.4 Marble and limestone
    1.4.1 Characterization of marble and anchors
    1.4.2 Characterization of Unito limestone from Lipica
1.5 Iron
    1.5.1 Iron materials
    1.5.2 Iron plates
1.6 Characterization of pure aluminium
1.7 Timber
    1.7.1 Characterization of chestnut timber
    1.7.2 Characterization of ancient timber
1.8 Masonry
    1.8.1 Characterization of Adobe Masonry
    1.8.2 Characterization of Beylerbeyi Palace Masonry

*2. Devices*

The experimental investigation of the innovative devices has been aimed at characterizing the cyclic performances of the Reversible Mixed Technologies developed within the project, in order to optimize their use in the seismic protection of historical and monumental buildings. In the following, the titles of the collected datasheets dealing with the experimental activity on devices are provided.

2.1 Riveted connections
2.2 Architrave connection
2.3 Anchors in marble
2.4 Wood-to-concrete connectors
  2.4.1 Ancient Wood-to-Concrete-Steel Composite Slab System-Push-out Tests on connectors without slab
  2.4.2 Timber-Concrete-Steel Composite Slab System – Push-out Tests on connectors with Slab
  2.4.3 Timber-Concrete-Steel Composite Slab System – Push-out Tests on connectors without Slab
2.5 Dissipative torsional link for beam-to column connections of timber frames
2.6 Metal shear panels for retrofitting RC frames
2.7 Magnetorheological devices
2.8 DC90 energy absorber device

*3. Sub-systems*

A large number of experimental tests on sub-systems has been carried out within the PROHITECH project, which have been mainly related to the application of RMTs to masonry, timber, reinforced concrete and iron structures. In the following, the titles of the collected datasheets dealing with the experimental activity on sub-systems are provided.

3.1 Masonry walls
  3.1.1 Strengthening of masonry walls by innovative metal based technique
  3.1.2 Clay brick masonry walls retrofitted by FRP
  3.1.3 Masonry panels with and without FRP strengthening
3.2 Reinforced concrete
  3.2.1 Retrofitting solution for RC columns
  3.2.2 Large-scale model test on low-reinforced concrete walls
3.3 Timber-Concrete-Steel Composite Slab System-Beam Test
3.4 Chestnut timber frame reinforced by steel shear panel
3.5 R.C. frame strengthened by metal shear panels
3.6 Iron columns reinforced by FRP

*4. Large scale tests*

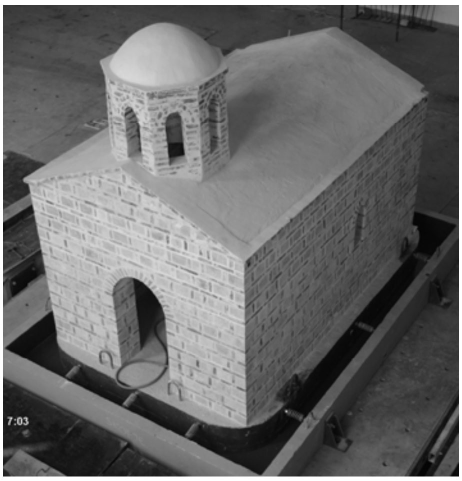
The programme of large scale tests has included experiments on the following models: Mustafa Pasha Mosque in Skopje; Fossanova Gothic Cathedral; Greek Temple; St. Nikola Byzantine Church in Psacha. In the following, the titles of the collected datasheets dealing with the experimental activity on large scale models are provided.

4.1 Mustafa Pasha Mosque Model
    4.1.1 Design, Construction and Strengthening
    4.1.2 Shaking table test
4.2 Fossanova Cathedral Model
    4.2.1 Design, Construction and Strengthening
    4.2.2 Shaking table test
4.3 Byzantine Basilica Model
    4.3.1 Construction and Shaking table test
4.4 Greek Temple Model

In Figure 3 the four above mentioned reduced scale models are shown.


(a)


(b)


(c)


(d)

Figure 3. Full scale models: (a) Mustafa Pasha Mosque; (b) Fossanova Gothic Cathedral; (c) Byzantine Basilica; (d) Greek Temple

*5. Full scale tests*

The full scale experimental tests have been referred to the following constructions: a reinforced concrete building located in the Bagnoli area in Naples (Italy); the Mustafa Pasha Mosque in Skopje (Macedonia); the Gothic Cathedral in Fossanova (Italy); the Byzantine St. Nikola Church in Psacha, Kriva Palanka (Macedonia); the Beylerbeyi Palace in Istanbul (Turkey). The experimental studies on the Bagnoli r.c. building have been extremely exhaustive and detailed, since this building is not an “ad hoc” built model but it is a “real” construction, actually representative of a large part of the building stock present in many Countries during the 20th Century, it representing a unique occasion of knowledge of wide interest. The full scale experimental work on the other above mentioned buildings, say the Mustafa Pasha mosque, the Gothic Cathedral in Fossanova, the St. Nikola Church in Psacha, Kriva Palanka, and the Beylerbeyi Palace in Istanbul, have been non-destructive tests, mainly focused on the characterization of the structural materials and on the dynamic identification of the constructions. In the following, the titles of the collected datasheets dealing with the experimental activity on full scale constructions are provided.

5.1 Reinforced Concrete Building in Bagnoli
5.2 Ambient vibration test on Mustapha Pasha Mosque
5.3 Ambient vibration measurement of Fossanova Gothic Cathedral, Italy
5.4 Ambient vibration test on St. Nikola Church, Psacha
5.5 Ambient vibration measurement of Beylerbeyi Palace in Istanbul

In Figure 4, the reinforced concrete building tested in Bagnoli is shown.


(a)


(b)


(c)

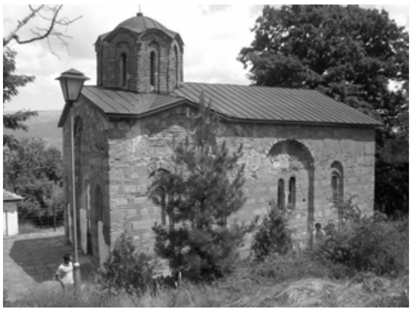

(d)

Figure 4. Bagnoli RC building: (a) original configuration; (b) reacting structure; (c) damage after first test; (d) consolidation by BRBs

The other buildings dealt with in chapter 5 are shown in Figure 5.

 (a)

 (b)

 (c)

 (d)

Figure 5. Full scale constructions: (a) Mustafa Pasha Mosque; (b) Fossanova Gothic Cathedral; (c) Byzantine Basilica; (d) Beylerbeyi Palace

**WP8 NUMERICAL ANALYSIS**

The numerical analyses developed within Workpackage 8 have represented the necessary counterpart of the experimental tests carried out within WP7. Most of the numerical analyses have been focused on models concerning the experimented test specimens.

The first part of the WP8 work has consisted in a benchmark study, namely a preliminary action before the beginning of the experimental investigations, with the main purpose to set-up and coordinate the activity of all the Partners involved in WP8. In particular, such a preliminary study has been aimed at the following issues: to obtain a background of the partner research units; to compare the analysis approaches and the software tools used by the Partners.

The second part of the WP8 work has concerned the calibration of the numerical models on the basis of the experimental studies carried out in WP7, with the ultimate goal of supporting WP9 in the development of analytical models to be used in design practice.

The number of pages is 325 for the benchmark study and about 400 for the numerical simulation.

Also the numerical analyses have been organized at different levels, from materials and elements to full scale building. In the following, the subjects deal with in the second part of WP8 are indicated, they being organized on the basis of the above mentioned levels.

*1. The benchmark study*

*2. Materials and elements*
2.1. Marble
2.2. Stone - Unito limestone
2.3. Stone plus brick Masonry walls
2.4. Adobe walls
2.5. Stone walls
2.6. Iron and FRP materials

*3. Devices*
3.1. Riveted Connections
3.2. Architrave connection
3.3. Anchors in marble
3.4. Wood-to-concrete connectors
3.5. Pure aluminium shear panels
3.6. Magnetorheological devices
3.7. DC90

*4. Sub-systems*
4.1. Masonry + panels
4.2. Timber composite floor
4.3. Timber frames + metal shear panels
4.4. RC frames + metal shear panels
4.5. Iron columns reinforced by FRP under axial compression

*5. Large scale models*
5.1. Mosque and Minaret
5.2. Ghotic Cathedral
5.3. Byzantine Basilica
5.4. Greek Temple Model

*6.Full scale buildings*
6.1. Bagnoli building
6.2. Beylerbeyi palace

Figure 6. shows the numerical models of the subjected to large scale tests.

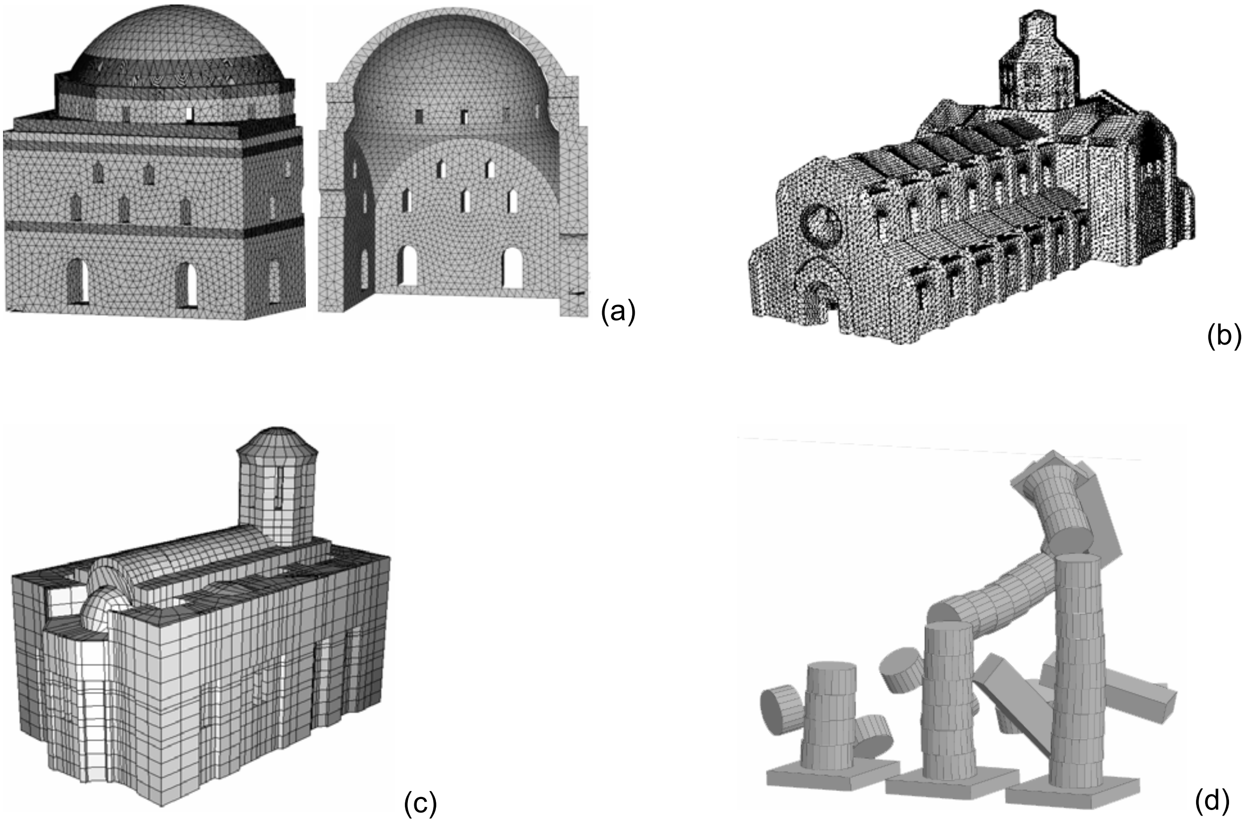



Figure 6. Numerical models of: (a) Mustafa Pasha Mosque; (b) Fossanova Gothic Cathedral; (c) Byzantine Basilica; (d) Greek Temple

## WP9 CALCULATION MODELS

Workpackage 9 has been aimed at setting-up suitable calculation models useful for supporting engineers in the design practice with regard to the application of Reversible Mixed Technologies for the seismic protection of historical buildings. The work has been carried out downstream the activities of both WP7 and WP8, focused on the experimental and numerical analyses.
The contributions of the PROHITECH partners have consisted in 24 datasheets, for a total number of 400 pages, in which all the main topics have been covered. The list of the received datasheet titles is shown herein.

The material collected within WP9 is organized at five levels, in the same way as WP7 and WP8, as indicated in the following.

## WP10 VALIDATION OF INNOVATIVE SOLUTIONS AND PROCEDURES

Workpackage 10 has been aimed at the validation of innovative solutions and procedures for the application of Reversible Mixed Technologies for the seismic protection of historical buildings. Its outputs has been arranged in two deliverables, namely "D12 - Validation criteria for structural restoration" and "D13 – Validation study cases".

D12 provides guidance on the conceptual planning, strategies, design, analysis and safety criteria of restoration / rehabilitation works for monumental and historical buildings. It also contains innovative information on validation criteria of such interventions that allow authorities to compare and validate alternative solutions. The work is organized as follows.

1. Principles for restoration interventions on monumental and historical buildings
2. Performance vs. Rehabilitation levels
3. Rehabilitation strategies: Design criteria for structural interventions
4. Analysis criteria
5. Safety verification
6. Validation criteria

In D13 study cases were collected for historical buildings in which restoration / rehabilitation works had been already carried out. The interventions were validated according to the criteria set-up in D12. A list of the study cases is given below. It may be seen that they include monuments and historical buildings ranging from the 5 century BC up to the end of the 20th century, various types of buildings in regard to their use and structural materials.

| Nr. | Monument / historical building | Year of construction | Material | Use | Partner |
|---|---|---|---|---|---|
| 1 | Acropolis Athens | 5 BC | Marble | Temple | NTUA |
| 2 | St. Sofia Church, Ohrid | 9-10 cent. | Masonry | Church | UKIM |
| 3 | El-Mardani Mosque, Cairo | 14$^{th}$ century | Stone | Mosque | U Cairo |
| 4 | Le Bastion, Algiers | 16$^{th}$ century | Masonry | Library | USTHB |
| 5 | Dimplomatic hall royal Palace, Naples | 17$^{th}$ century | Masonry, timber | Museum | UNINA |
| 6 | St Giovanni Battista Church, Carife | 18$^{th}$ century | Masonry | Church | UNINA |
| 7 | "Baroc" Palace, Timisoara | 18$^{th}$ century | Masonry, timber | Museum | ROPUT |

| | | | | | |
|---|---|---|---|---|---|
| 8 | Manor House, Banloc | 1750-93 | Masonry | | ROPUT |
| 9 | Palace of Justice, Bucharest | 1890-95 | Masonry, timber, concrete, steel | Office | ROBUT |
| 10 | Trajan Market Hall, Bucharest | 1894-96 | Masonry, steel | Market | ROBUT |
| 11 | Municipal Market Karditsa | 1925-30 | Concrete, steel | Market | NTUA |
| 12 | Bedouins children School, Beer-Ssheva | 1914 | Masonry, steel | Museum | Technion |
| 13 | Church of Holy Spirit, Javorka | 1916 | Timber | Church | U Ljubljana |
| 14 | Deutsche Bank, Naples | 1950 | Steel | Bank | UNINA |
| 15 | Jolly Hotel, Caserta | 1952 | Masonry, concrete | Hotel | UNINA |
| 16 | West University, Timişoara | 1970 | R. concrete | Univers. | ROPUT |

**WP11 STUDY CASES**

WP11 involved all the partners of the project.

The main task within WP11 was to select some outstanding cases of historical building falling within the heritage of each Mediterranean country, in order to perform analysis of feasibility of seismic protection interventions by means of RMT. These ones are called "study cases".

Design of relevant application solutions based on RMT was also foreseen, in order to highlight possible pilot interventions susceptible to be faced by partner countries.

30 study cases were proposed by the Partners and collected by WP11 coordinator. Two types of study cases were distinguished:

- **Type A**: interventions took already place in the past;
- **Type B**: no interventions aimed at strengthening the structure took place in the past.

Type A structures were systematically forwarded to WP10 where a judgement on the quality and the efficiency of the past interventions was proposed. Type B structures, on the contrary, were used in WP11 so as to suggest adequate interventions for possible future reinforcements.

Within WP11, it was not possible to investigate in detail all the proposed Type B study cases. Accordingly, during the Istanbul WP11 meeting on April 8th, 2006, a selection of the 9 most representative Type B study cases was achieved. In these 9 study cases, four correspond to structures tested at a large scale within WP7:

**Large scale tests:**

- Pasha Mosque in Skopje
- Saint Nikola Church in Psacha
- Parthenon in Athens
- Gothic Church in Fossanova

**Others:**

- Beylerbeyi Palace in Istanbul
- Gallery «Umberto I» in Naples
- Koletti building in Athens
- Royal Palace in Naples
- Medina in Salé

These ones correspond to various types of buildings (Mosque, Byzantine Church, Gothic Church, office building, palaces, commercial and tourist gallery, Medina and Greek temple) and various structural systems (masonry walls, reinforced concrete frames, timber floors and columns, masonry vaults and arches iron and marble structures + «mixed» structural systems).

The observed damages go from corrosion in iron elements to shear cracks in masonry walls, cracks in masonry vaults, degradation of timber structures due to moisture and insect attacks, … For the Koletti building in Athens, no damages are observed but a request for structural upgrading under seismic loading has been expressed.

Figure 7 shows some of the above selected study cases.


(a)


(b)


(c)

Figure 7. Some of the selected study cases: (a) Gallery "Umberto I"; (b) Koletti building; (c) Royal Palace of Naples

In the Istanbul WP11 meeting, nine corresponding working groups were set up on the basis of the following principle:

one study case → one working group

It was also agreed that the work to be achieved in each working group is to prepare a detailed report including:

- identification of the damages and evaluation of the structural response of the damaged structure;
- selection (in agreement of the activities within WP10) of the more appropriate interventions and devices;
- evaluation of the beneficial effect of the interventions on the structural response of the structure.

The responsible institution (called "coordinator") and the involved partners in the 9 working groups are listed in the table hereunder (a star "*" is attached to the name of the partners who are contributing to the study cases as reviewers of the produced documents, and not as drafters).

| Selected study cases | Coordinator | Involved Partners |
|---|---|---|
| Mustafa Pasha Mosque in Skopje | MK (Lazarov) | NA-ARC, ROPUT* |
| Saint Nikola Church in Psacha | MK (Kokalanov) | ISR*, ROPUT* |
| Beylerbeyi Palace in Istanbul | TR (Altay, Aras) | EG*, UNICH*, MK* |
| Gallery « Umberto I » in Naples | NA-ARC (Landolfo) | B, ROPUT* |
| Koletti building in Athens | GR (Papageorgiou) | AL, ISR, TR, SUN, UNICH, UNINA |
| Gothic Church in Fossanova | UNICH (De Matteis) | UNINA, MK |
| Royal Palace in Naples | UNINA (Mazzolani, Faggiano) | PT*, TR*, B* |
| Medina in Salé | M (Iben Brahim) | AL, ROPUT, UNINA |
| Parthenon in Athens | GR (Dasiou) | SL |

The whole foreseen tasks have been achieved. Obviously, the amount of work performed within WP11 is very huge and it is impossible to summarise within this report the main achievements.
All the details of the performed investigations are reported in Deliverable 14 of the project. In the main Deliverable DIV, only a summary of the performed investigations is reflected in Chapter 6.

## WP12 DEVELOPMENT OF DESIGN GUIDELINES

The activity developed within WP12 has concerned the design guidelines for the application of innovative techniques for the seismic protection of historical buildings. The work has mainly consisted in the collection of existing codes and guidelines relating to the seismic rehabilitation of buildings by means of innovative techniques. Emphasis has been placed on Reversible Technologies.
In addition, the editorial activity necessary for the set-up of the fourth Main Deliverable, whose detailed list of contents is provided in the following, has been carried out.
Based on the editorial work carried out, the Fourth Main Deliverable has been set up, according to the following list of contents.

**CHAPTER 3. REHABILITATION STRATEGIES**

3.1 GENERAL
3.2 CHOICE OF REHBILITATION STRATEGIES: DESIGN, ANALYSIS & EVALUATION CRITERIA
3.3 SAFETY VERIFICATION
3.4 VALIDATION CRITERIA

**CHAPTER 4. UPGRADING SYSTEMS**

4.1 DISCRETE BLOCK STRUCTURES
4.2 MANSONRY STRUCTURES
4.3 WOODEN STRUCTURES
4.4 REINFORCED CONCRETE STRUCTURES
4.5 IRON/STEEL STRUCTURES

**CHAPTER 5. PRACTICAL APPLICATION OF PROPOSED PROCEDURES**

5.1 INTRODUCTION
5.2 CRITICAL OVERVIEW OF TRADITIONAL TECHNIQUES
5.3 SELECTED ADVANCED SYSTEMS:

1 - Seismic upgrade of an existing 2-storey reinforced concrete structure by means of FRPs
2 - Seismic upgrade of an existing 2-storey reinforced concrete structure by means of base isolation - elastomeric bearing and lead rubber bearing
3 - Seismic upgrading of the Bagnoli 2-storey concrete frame building by means of base isolation - friction pendulum system
4 - Seismic upgrading of Byzantine church by reversible innovative base isolation ALSC floating-sliding system
5 - Seismic upgrading of an existing 2-storey reinforced concrete structure by metal shear panels
6 - Seismic upgrading of a real two-storey reinforced concrete structure by means of buckling restrained braces (BRBs)
7 - Seismic upgrade of an existing 2-storey reinforced concrete structure using a friction damper
8 - Seismic upgrading of a real two-story reinforced concrete structure by means of eccentric braces (EBS)
9 - Design of viscous dampers for seismic upgrade of an existing 2-storey reinforced concrete structure: two techniques: linear fluid viscous dampers, nonlinear viscous dampers
10 - Seismic upgrade of a 2-storey reinforced concrete structure using shape memory alloys
11 - Seismic upgrading of the Bagnoli 2-storey concrete frame building by means of different techniques: conventional, BRB and SMA bracing
12 - Study on seismic upgrade of 2 storey reinforced concrete building by tuned mass damper

**CHAPTER 6. SELECTED STUDY CASES**

6.1 VALIDATION STUDY CASES
6.2 DESIGN STUDY CASES

# 4 Plan for using and disseminating the knowledge

## 4.1 Exploitable knowledge and its Use

The knowledge acquired within the PROHITECH research project can be conveniently used for consolidating historical constructions belonging to the Euro-Mediterranean historical building stock, so achieving a satisfactory level of seismic protection of constructions very valuable from the cultural point of view. Important applications of the technological solutions developed within the PROHITECH project are represented by the consolidation of the Mustafa Pasha Mosque in Skopje, Macedonia (references 85, 86 in section 4.3), as well as the upgrading of the capacity of wooden floors in the Royal Palace of Naples, Italy (references 69, 70). In addition, they were developed several proposals finalized to the practical application of Reversible Mixed Technologies to specific categories of constructions, like, for example, the use of special titanium clamps for connecting the architraves of Greek Temples (references 31, 32).

## 4.2 Dissemination of knowledge

The following dissemination of knowledge has been processed during the project duration:

***Conferences/Workshops***

| *Date* | *Place* | *Contents and Information* |
|---|---|---|
| *28-30 August,2005* | *Ohrid, Macedonia* | *Paper presented at the international conference providing a general presentation of the PROHITECH Project results achieved in the first year (Mazzolani).* |
| *January 2005* | *Innsbruck* | *Mazzolani introduced at the international conference related to the COST C12 programme, the PROHITECH project to all the participants.* |
| *March 2005* | *Rome* | *Mazzolani presented the PROHITECH Project to the GLIS group (Italian Working-group on Seismic Isolation)* |
| *April 2005* | *Beijing, China* | *Mazzolani presented the PROHITECH Project to the Joinlab of the Archimede Bridge project* |
| *July 2005* | *Nagoya, Japan* | *Mazzolani presented the PROHITECH Project to the participants of the International Conference "Advances in Experimental Structural Engineering"* |
| *September 2005* | *Nizza* | *Mazzolani presented the PROHITECH Project to the ECCS Annual Meeting* |
| *28-30 September,2005* | *Skopje, Macedonia* | *Partner No.3 -MK, Faculty of Civil Engineering and IZIIS and Partner No.1-UNINA presented the PROHITECH project at the Symposium of Macedonian Association of Structural Engineers (MASE)* |
| *September 2005* | *Ischia, Italy* | *Italian National Conference on Metal constructions (CTA) – Several papers were presented by the Italian partners related to the activities developed in the project (Mazzolani, De Matteis, Landolfo, Mandara). In addition, Mazzolani gave a general presentation on the whole project.* |
| *13-15 October 2005* | *Timisoara, Romania* | *Mazzolani presented the paper "Innovation des batiments anciens"* |
| *10 May, 2006* | *Qiandao Lake City, China* | *General presentation of the PROHITECH project (Mazzolani)* |

| | | |
|---|---|---|
| *1 June, 2006* | *Prague, Czech Republic* | *Paper presented at the 7th European Commission Conference, "Safeguard Cultural Heritage. Understanding & Viability for the Enlarged Europe" (Mazzolani)* |
| *14-17 August, 2006* | *Yokohama, Japan* | *Keynote lecture on the PROHITECH project ongoing activity presented by Mazzolani at the Fifth International Conference on the Behaviour of Steel Structures in Seismic Areas (STESSA2006)* |
| *18 August, 2006* | *Yokohama, Japan* | *Italy-Japan Seminar on monumental constructions. PROHITECH participant Institutions: UNINA (Mazzolani), NA-ARC (Landolfo), SUN (Mandara), UNICH (De Matteis), ROPUT (Gioncu). During this Seminar the Japanese partners declared their strong interest in the PROHITECH activity.* |
| *14-17 October 2006* | *Dubrovnik, Croatia* | *Conference and brokerage event - the construction aspects of built heritage protection (Mandara)* |
| *18 January 2007* | *Napoli, Italy* | *Technical meeting with the delegation of the St. Thomas University, Minnesota – USA* |
| *12-13 February 2007* | *Salerno, Italy* | *Workshop of the national project RELUIS<br>"Innovative materials and approaches for the seismic design and mitigation of seismic<br>vulnerability" (Mazzolani)* |
| *30-31 March 2007* | *Prague, Czech Republic* | *Workshop of the COST C26 action (Mazzolani)* |
| *16-18 April 2007* | *Lecco, Italy* | *Meeting of the SIJLAB and REHICO Projects (Mazzolani)* |
| *22 June 2007* | *Napoli, Italy* | *Master School<br>"Materiali e tecniche per il recupero edilizio in area mediterranea" organized by CITTAM (Mazzolani)* |
| *05 July 2007* | *Catania, Italy* | *Workshop in honour of Antonio La Tegola<br>"Materiali e metodi innovativi nell'ingegneria strutturale" (Mazzolani)* |
| *20-23 August 2007* | *Whistler, Canada* | *PROTECT 2007 International Workshop on "Performance, protection and strengthening of structures under extreme loading" (Mazzolani)* |
| *11 December 2007* | *Rome, Italy* | *Italian Emergency Management Agency (Mazzolani)* |
| *4-5 February 2008* | *Zurich, Switzerland* | *COST TU 601 Meeting on Robustness (Mazzolani)* |
| *27 February 2008* | *London, UK* | *SECED – Invited lecture (Mazzolani)* |
| *6 May 2008* | *Irbid, Giordania* | *Invited lecture (Mazzolani)* |
| *23-24 May 2008* | *Thessalinoki, Greece* | *Course on Structural Restoration – Invited lecture (Mazzolani)* |
| *27 June 2008* | *Salerno, Italy* | *Invited lecture (Mazzolani)* |
| *1-3 July 2008* | *Bath, UK* | *SAHC 2008 Conference (Mazzolani)* |
| *6-7 October 2008** | *Dresda, Germany* | *COST C25 Seminar (Mazzolani)* |
| *22-25 October 2008** | *Malta* | *COST C26 Symposium (Mazzolani)* |
| *16 October 2008** | *Reggio Calabria, Italy* | *Course on the new Italian Standards (Mazzolani)* |
| *11-12 November 2008** | *Ljubljana, Slovenia* | *CHRESP Conference (Mazzolani)* |
| *20-21 November 2008** | *Malta* | *Invited Lecture (Mazzolani)* |
| *28-29 November 2008** | *Timisoara, Romania* | *TC13 meeting (Mazzolani, Landolfo)* |

**These events were held after the official end of the project, but during the following period in view of the final Conference.*

Besides the above reported "individual" dissemination activities, the following joint dissemination activities have been made by the PROHITECH partners.

***Joint Dissemination Activities by PROHITECH Partners (Milestones)***

| *Date* | *Place* | *Contents and Information* |
|---|---|---|
| *30 August 2005* | *Ohrid, Macedonia* | *International Seminar. Four papers related to the first four WPs were presented by the WP leaders, addressing the final output of the WP (Mazzolani, Mandara, Altay, Iben Brahim, Lungu).* |
| *8 April 2006* | *Istanbul, Turkey* | *International Seminar on Earthquake Protection of Historical Buildings by Reversible Mixed Technologies. Presentations provided by several Partners (Altay, Mazzolani, Calado, Proença,, Beg, Gramatikov, Tashkov, Dubina, Papantonopoulos, Landolfo, De Matteis, Kokalanov)* |
| *31 August 2008* | *Cairo, Egypt* | *International Seminar On Risk To Cultural Heritage. Presentations Provided By Several Partners (El Zahabi, Mazzolani, Mandara, Altay, Calado, Beg, Gramatikov, Landolfo, Dubina, Vayas, Jaspart, Iben Brahim, De Matteis)* |

The final and widest dissemination activity, representing the lat milestone, is the **First International Conference PROHITECH 2009 "Protection Of Historical Buildings"**, chaired by Professor Federico M. Mazzolani and organized by the University of Naples "Federico II", with the cooperation of all other partners Institutions, to be held in **Rome on 21-24 June 2009**.

In order to increase the dissemination of the activity of PROHITECH, a **brochure** and a **poster** have been created (they are available on the web site www.prohitech.com in the "dissemination material" area). The **brochure** has been distributed and the **poster** exhibited in many international conferences and seminars.

### 4.3 Publishable results

In this section, all the papers and presentations dealing with research activities framed in the PROHITECH project, presented by the partners, are summarized. The large number of reported publications testifies the huge amount of work carried out for disseminating the results of the activities carried out. The publications produced jointly by people belonging to different institutions testify the strict cooperation occurred. The Main Deliverables will be printed and distributed by an international publisher.

1. **Attari N., Amziane S., Chemrouk M.** (2008). Performance of Strengthened Beam-Column Joints by Hybrid FRP Laminates. *Proceedings of the International Congress 'Beton 2008'*, Istanbul, 19-22 June 2008.

2. **Attari N., Amziane S., Chemrouk M.** (2008). Strengthening Reinforced Concrete Beams using Hybrid FRP Laminates. *Proceeding of the Fourth International Conference on FRP Composites in Civil Engineering (CICE2008)*, 22 – 24 July 2008, Zurich, Switzerland.

3. **Birouk A., Toto E., Kasmi M., Hafid M., El Mouraouah A., Iben brahim A., Benammi M., Haida S., Zouine E., Kaabouben F., Talhaoui A., Khairi Z., Stitou Y.** (2005). Site effects assessment using H/V method: application to urban expansion of Al Hoceima city in northeast Morocco. *Proceedings EE-21C, Topic 3: Geotechnical Earthquake Engineering, Dynamic Properties and Response of Soil Deposit*, Macedonia Aug. 27 – Sep. 1, 2005, pp. 9.

4. **Birouk, A., El Hammoumi A., Iben brahim A., Toto E., El Mouraouah A., Kerroum M., Kasmi M., Messaoud A.** (2005). Buildings seismic vulnerability assessment in urban areas in Morocco, *Proceedings EE-21C, Topic 4: Structural Modeling, Analysis, Design and Seismic Safety*, Macedonia Aug. 27 – Sep. 1, 2005, pp. 8.

5. **Bordea S.** (2007). Strengthening of non-seismic RC frames located in seismic areas with combined Steel Buckling Restrained Bracing (BRB) systems and Fibre Reinforced Polymers (FRP) techniques. *Third International PhD Symposium in Engineering* 25-26 October, 2007 - University of Pecs, Pollack Mihaly Faculty of Engineering, Hungary.

6. **Bordea S.** (2008). Seismic upgrade of RC MR Frames with dissipative BR Steel Braces. *7'th International PhD Symposium in Civil Engineering* –Stuttgart – FIB, Germany (publish on conference CD) Part 13: Structural analysis, pg. 3-10, Ed. Eligehausen R., Gehlen C., Stuttgart, 2008.

7. **Bordea S.** (2008). Strengthening of non-seismic RC frames located in seismic areas with combined Steel Buckling Restrained Bracing (BRB) systems and Fibre Reinforced Polymers (FRP) techniques. *Pollack Periodica*, Hungary, Publisher Akadémiai Kiadó (in print)

8. **Bordea S., Dubina D.** (2006). Evaluarea performantei seismice a unui cadru de beton armat existent printr-o analiza de tip pushover (Performance based assesement of an existing RC frame). *Sesiunea Nationala de Comunicari Stiintifice Studentesti* May 2006 – Cluj Napoca, Romania.

9. **Bordea S., Stratan A., Dogariu A., Dubina D.** (2006). Performance of noseismic reinforced concrete frame retrofitted with bracing systems. August 2006 – *Summer School "Advanced studies in structural engineering and CAE"* Weimar, Germany.

10. **Bordea S., Stratan A., Dogariu A., Dubina D.** (2007). Seismic upgrade of non-seismic r.c. frames using steel dissipative braces. *COST 26 - Urban Habitat Construction Under Catastrophic Events -Proceedings of Workshop in Prague*, editors. Wald F., Mazzolani F.,

Byfield M., Dubina D., Faber M., Ed. Czech Technical University in Prague 30-31 March 2007, ISBN 978-80-01-03583-2;pg. 211-220.

11. **Calado L., Proença J.M., Panão A., Mazzolani F.M., Faggiano B., Marzo A.**, (2008). Experimental analysis of rectangular shaped sleeve connectors for composite timber-steel-concrete floors: bending tests: bending tests. *Proceedings of the 6th International Conference of Structural Analysis of Historical Construction*, Bath, United Kingdom, 2-4 Giugno 2008.

12. **Campitiello F., De Matteis G., Mazzolani F.M.** (2007). Risposta a taglio di pannelli murari tozzi rinforzati mediante elementi metallici: prove sperimentali ed analisi numeriche mediante un approccio smeared cracking. in *Workshop on Design for Rehabilitation of Masonry Structures (Wondermasonry 2),* Lacco Ameno, Ischia (NA), 11-12 ottobre 2007.

13. **Chemrouk M.** (2006). Ultimate Behaviour of Concrete Deep Beams with Particular Reference to Slender Deep Beams. *Proceedings of the 9th International Conference on Concrete Engineering & Technology 2006 (CONCET 2006) – 'Structural Concrete for the Millennium'*, 9 – 11 May 2006, Kula Lumpur, Malaysia.

14. **Chemrouk M.** (2007) The Casbah of Algiers - Damage Assessment of the Traditional Houses. *1rst Euro-Mediterranean Conference on 'Traditional Mediterranean Architecture : - Present and Future'* ; 12 – 15 July 2007, Barcelona.

15. **Chemrouk M.** (2008). Influence of Poor Workmanship and Construction Defects on the Durability and Strength of Concrete Constructions. *A Paper Published in a book edited by R.K. Dhir, T.Harrison, L.Zheng and S.Kandasami : ''Concrete Durability - achievement and enhancement''* and published by IHS BRE Press, Bracknell, UK, 2008; pp970.; ISBN: 978-1-84806-039-5; Paper pp. 153-164.

16. **Chemrouk M.** (2009). Learning from Earthquake Disasters:- the Case of Algeria. *International Symposium on Disaster Management*; 18-21 April 2009, Riyadh (SA) (Abstract accepted, paper sent).

17. **Chemrouk M., Attari A., Derradj Z., Bouzid F.** (2007). Concrete Constructions in Seismic Regions: - Intervention Strategies and Lessons Learned from past Earthquakes in Algeria. *Proceedings, 32nd Conference on Our World in Concrete and Structures* ; 27 – 29 August 2007, Singapore.

18. **Chemrouk M., Attari N., Si-Youcef Y.** (2005). Lessons from the Boumerdes-Algiers Earthquake. *A Paper Published in a book edited by R.K. Dhir, M.D. Newlands and A. Whyte : ''Application of Codes, Design and Regulations''* and published by Thomas Telford, London, 2005; pp.787; ISBN: 0 7277 3403 2.

19. **Chemrouk M., Derradj Z., Bouzid F.** (2009). Damage Assessment of the Historical Houses of the Old Medina of Algiers. *First International Conference for the Protection of Historical Buildings – PROHITECH09*, 21-24 June 2009, Roma (Italy) (Abstract accepted).

20. **Chemrouk, M.** (2009). The Design of Reinforced Concrete Deep Beams – Review of the Major Design Approaches''; *10th International Conference on Concrete Engineering and Technology: CONCET 2009;* 2 - 4 March 2009, Kuala Lumpur, Malaysia, (Abstract accepted and paper sent).

21. **Cherraj M., Guerraoui K., Bouabid H., Charif D'Ouazzane S., Bouabid R., Hammoumi A., Fassi-Fehri O.** (2008). Mechanical characterization of earth stabilized mortar, determination of the techno-economic optimum, *Phys. Chem. News*, 42, 64-70.

22. **Cherraj M., Guerraoui K., Bouabid H., Charif D'Ouazzane S., Bouabid R., Hammoumi A., Fassi-Fehri O., Kerroum M.** (2008), Coupled elasticity damage model to characterize the behaviour of cement stabilizer compressed earth-blocks; a simple for determination of ductility, *International Review of Mechanical Engineering* (accepted).

23. **Cherraj M., Guerraoui K., Bouabid H., Charif D'Ouazzane S., Bouabid R., Hammoumi A., Fassi-Fehri O., Kerroum M.** (2008). Project of protocol for the determination of technico-Economic optimum (TEO) for compressed earth blocks construction, cement and concrete composites (submitted).

24. **D'Aniello M., Della Corte G., Mazzolani F.M.** (2007). A special type of buckling-restrained brace for seismic retrofitting of RC buildings: design and testing. *Atti del XXI Congresso CTA (Collegio dei Tecnici dell'Acciaio)*, Catania, 1-3 ottobre.

25. **D'Aniello M., Della Corte G., Mazzolani F.M.** (2007). Steel buckling restrained braces for seismic upgrading of RC buildings. *Atti del Workshop "Materiali ed approcci innovativi per il progetto in zona sismica e la mitigazione della vulnerabilità delle strutture"*, Fisciano (Salerno), 12-13 febbraio, pp. 423-430.

26. **D'Aniello M., Della Corte G., Mazzolani F.M.** (2008). "Only-steel" buckling restrained braces: an experimental study. *Proceedings of the 5th European Conference on Steel and Composite Structures (Eurosteel)*, Graz, Austria, 3-5 September.

27. **D'Aniello M., Della Corte G., Mazzolani F.M.** (2008). Experimental tests of a real building seismically retrofitted by special buckling restrained braces. *Proceedings of the 1908 Messina and Reggio Calabria Earthquake commemorating Conference*, 8-11 July, Santa Trada di Cannitello, Italy.

28. **D'Aniello M., Fiorino L., Landolfo R.** (2008). Structural performance of riveted connections in historical metal structures. In *Proc. of Sixth Int. Conf. on Structural Analysis of Historical Constructions, Preserving Safety and Significance (SAHC08)*, 2-4 July, Bath,

UK. (Vol. 1 pp. 431-439). Ed. D. D'Ayala & E. Fodde. CRC Press, Balkema, The Netherlands.

29. **D'Aniello M., Fiorino L., Portioli F., Landolfo R.** (2008). Riveted connections in historic metal structures: An experimental study. In *Proc. of 5th European Conf. on Steel and Composite Structures (EUROSTEEL 2008)*, Graz, Austria, 3-5 Sept 2008. Vol A. (pp.69-74). ISBN: 92-0147-000-90. Ed. R. Ofner et. al. ECCS Brussels, Belgium.

30. **Dasiou M.-E., Mouzakis H., Psycharis I., Papantonopoulos K., Vayas I.** (2008). Experimental investigation of columns and sub assemblages of ancient temples. *National Conference on Anti-Seismic Engineering Technology*, Athens , Greece, 5-7 November, An.No 1833.

31. **Dasiou M.-E., Mouzakis H., Psycharis I.N., Vayas I.** (2008). Seismic behaviour of ancient Greek Temples- Experimental investigation - Numerical simulation. *SPRECOMACH 2008 (Seminars on PREventive COnservation and Monitoring of the Architectural Heritage)*, Saumur, 26-31/5/2008.

32. **Dasiou M.-E., Mouzakis H., Psycharis I., Vayas I.** (2008). Study on the influence of metal clamps on the dynamic behaviour of ancient Greek temples. *6th national conference on steel structures*, Ioannina, Greece, (Proceedings edited by J. Ermopoulos, I. Vayas, Ch. Gantes, G. Ioannidis, pages:419-426).

33. **Dasiou M.-E., Psycharis I., Vayas I.** (2008). Numerical analysis of the seismic behavior of columns and sub assemblages of ancient temples. *National Conference on Anti-Seismic Engineering Technology*, Athens , Greece, 5-7 November, An.No 1832.

34. **Dasiou M.-E., Vayas I., Papageorgiou M., Dakanali I.** (2008). Seismic action on telecommunication towers on buildings and on buildings with towers. *6th national conference on steel structures*, Ioannina, Greece, (Proceedings edited by J. Ermopoulos, I. Vayas, Ch. Gantes, G. Ioannidis, pages:387-394).

35. **De Matteis G., Colanzi F., Eboli A., Mazzolani F.M.** (2008). Seismic vulnerability evaluation of the Fossanova Gothic church. In *Structural Analysis of Historic Constructions, Proceedings of the 6st International Conference SAHC2008* (Eds. D. D'Ayala and E. Fodde), Bath (UK), July 2–4, 2008, CRC Press Taylor & Francis Group, ISBN 978-0-415-46872-5, Vol. 2, pp. 1225-1235.

36. **De Matteis G., Colanzi F., Mazzolani F.M.** (2007). La chiesa abbaziale di Fossanova: indagini sperimentali per la valutazione della vulnerabilità sismica. in *Workshop on Design for Rehabilitation of Masonry Structures (Wondermasonry 2)*, Lacco Ameno, Ischia (NA), 11-12 ottobre 2007.

37. **De Matteis G., Colanzi F., Viskovic A., Mazzolani F.M.** (2007). Structural behaviour of Gothic style churches in the earthquake prone Mediterranean area. *Proceedings of International Symposium "Studies on Historical heritage" (SHH07)*, Yildiz Technical University, Istanbul, Turkey, 13-15 September 2007.

38. **De Matteis G., Formisano A., Mazzolani F.M.** (2007). Steel shear panels as seismic retrofitting devices for existing RC buildings. in *Atti del XXI Congresso CTA "Costruire con l'Acciaio"*, Catania 1-3 ottobre 2007, Dario Flaccovio Editore, ISBN 978-88-7758-787-9, 233-242.

39. **De Matteis G., Formisano A., Mazzolani F.M.** (2008). Full scale tests of a RC frame building with metal shear panels. *Proceeding of the 14th World Conference on Earthquake Engineering (14th WCEE)*, Beijing, China, 12-17 October, 2008. Paper ID: 12-03-0085 (Published on DVD).

40. **De Matteis G., Formisano A., Mazzolani F.M.** (2008). RC structures strengthened by metal shear panels: experimental and numerical analysis. In *2008 Seismic Engineering Conference commemorating 1908 Messina and Reggio Calabria Earthquake, Proc. of the Int. Conf. MERCEA'08* (Eds. A. Santini, N. Moraci), Reggio Calabria 8-11 July 2008, American Institute of Physics publisher, New York, ISBN 978-0-7354-0542-4, ISSN 0094-243X, Vol. 1 pp. 27-34.

41. **De Matteis G., Formisano A., Mazzolani F.M.** (2009). Seismic retrofitting methodology of existing R.C. buildings based on metal shear panels. in *Earthquake Engineering and Structural Dynamics*, ISSN: 1096:9845, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, England, Wiley InterScience, Volume 38, Issue 1, January 2009, Pages: 61-78, DOI: 10.1002/eqe.841.

42. **De Matteis G., Langone I., Colanzi F., Eboli A., Mazzolani F.M.** (2007). Numerical evaluation of the seismic response of the Fossanova cathedral based on experimental dynamic identification. In *Recent developments in Structural Engineering, Mechanics and Computation - Proc. of the Third International Conference SEMC 2007*, 10-12 September 2007, Cape Town, South Africa, A. Zingoni Editor, Millpress Science Pub., Rotterdam, The Netherlands, ISBN: 978 90 5966 054 0,135-136.

43. **De Matteis G., Langone I., Colanzi F., Mazzolani F.M.** (2007). Experimental and numerical modal identification of the Fossanova Gothic Cathedral. in *Key Engineering Materials*, ISSN: 1013-9826, Trans Tech Publications Inc. Laubisrutistr. 24, CH-8712 Stafa-Zurich. Switzerland, Vol. 347, 351-358, 2007.

44. **De Matteis G., Langone I., Colanzi F., Mazzolani F.M.** (2007). Experimental and Numerical Modal Identification of the Fossanova Gothic Cathedral. in *Proc. of 7th International Conference on Damage Assessment of Structures (DAMAS 2007)*, Torino, 25-27 June 2007, Trans Tech Publication Ltd, Stafa-Zurich, Switzerland, ISSN 1013-9826 .

45. **De Matteis G., Mazzolani F.M., Krstevska L., Tashkov Lj.** (2008). Seismic analysis and Strengthening intervention of the Fossanova Gothic church: numerical and experimental activity. In *Urban Habitat Construction Under Catastrophic Events* (Eds. F.M. Mazzolani, E. Mistakidis, R.P. Borg, M. Byfield, G. De Matteis, D. Dubina, M. Indirli, A. Mandara, J.P. Muzeau, F. Wald, Y. Wang), Malta University Publishing, Malta, 2008, ISBN 978-99909-44-42-6, pp. 247-254.

46. **Della Corte G., Fiorino L., Mazzolani F.M.** (2008). Experimental results from lateral-loading tests of a real masonry-infilled RC building. *Atti del Convegno RELUIS "Valutazione e riduzione della vulnerabilità sismica di edifici esistenti in c.a."*, Roma, 29-30 Maggio.

47. **Della Corte G., Fiorino L., Mazzolani F.M.** (2008). Lateral loading tests on a real RC building including masonry infill panels with and without FRP strengthening. *Journal of Materials in Civil Engineering, ASCE*, Vol. 20, No. 6.

48. **Della Corte G., Fiorino L., Mazzolani F.M.** (2008). Push-pull tests on a real masonry-infilled RC building. *Proceedings of the 14th World Conference on Earthquake Engineering*, Beijing, China, 12-17 October.

49. **Della Corte G., Mazzolani F.M.** (2006). Full-scale lateral-loading tests of a real masonry-infilled RC building. *Proceedings of the Second fib Congress*, Naples, Italy, 5-8 June 2006, paper No. 0433.

50. **Dogariu A, Bordea S**. (2005). Seismic Retrofit of RC and/or Masonry Buildings using Reversible Steel Based Dissipative Bracing Systems. *First international PhD Symposium*, 20-21 September 2005, Pecs, Hungary.

51. **Dogariu A.** (2006). Models for calculation and analysis of masonry shear walls. *Buletinul Ştiinţific al Universităţii "Politehnica" Timisoara, România* - Seria Construcţii si Arhitectura - Vol54(68), Fascicola 2, Ed. Politehnica, Romania, 2006, ISSN 1224-6026; pg 95-106.

52. **Dogariu A.** (2007). Experimental test on innovative retrofitting techniques for masonry walls. *Third International PhD Symposium in Engineering* 25-26 October, 2007 - University of Pecs, Pollack Mihaly Faculty of Engineering, Hungary.

53. **Dogariu A.** (2008). Masonry walls strengthened with metal sheathing: FEM modelling. *Buletinul Stiintific al UPT - seria Constructii-Arhitectura*, Tomul 53 (67), Fascicola I, 2008, Ed. Politenhica, Timisoara, Romania, 2008, ISSN-1224-6026, pg 5-14.

54. **Dogariu A.** (2009). Study on seismic retrofiting techniques based on metalic materials of RC and/or masonry buildings - *PhD Thesis, The "Politehnica" University Timisoara*, 2009, Ed. "Politehnica", Romania.

55. **Dogariu A., Dubina D.** (2008). Performance of masonry shear walls strengthened with steel and aluminium sheeting - datasheet no. 2.20 - *Urban Habitat Construction under*

*Catastrophic Events - COST 26* - Editors: Mazzolani, Mistakidis, Borg, Byfield, De Matteis, Dubina, Indirili, Mandara, Muzeau, Wald & Wang, Ed. Malta University Publishing, Malta, Octomber 2008- ISBN 978-99909-44-40-2 (paperback); ISBN 978-99909-44-42-6 (Hardback) - pg. 229-234.

56. **Dogariu A., Dubina D., Campitiello F., De Matteis G.** (2008). FEM Modeling Masonry Shear Walls strenghtened with metal sheating - datasheet no. 2-21 *Urban Habitat Construction under Catastrophic Events - COST 26* - Editors: Mazzolani, Mistakidis, Borg, Byfield, De Matteis, Dubina, Indirili, Mandara, Muzeau, Wald & Wang, Ed. Malta University Publishing, Malta, Octomber 2008, - ISBN 978-99909-44-40-2 (paperback); ISBN 978-99909-44-42-6 (Hardback) - pg. 235-240.

57. **Dogariu A., Muntean N., Bordea S., Daescu C., Diaconu D., Demeter I., Florut C.** (2007). Studiu experimental a unei soluții de consolidare a zidăriei (Experimental studies on masonry retrofitted with SWM) – Sesiunea Naționala de Comunicări Ştiințifice Studențeşti May 2007, Cluj-Napoca, România.

58. **Dogariu A., Stratan A., Dubina D.** (2005). Earthquake protection of historical buildings by reversible mixed technologies (EU FP VI Project). *Conservation and rehabilitation of historical buildings and monuments by using light gauge metal structural elements*, 18 April 2005, Thessalonica, Greece.

59. **Dogariu A., Stratan A., Dubina D., Gyorgy-Nagy T., Daescu C., Stoian V.** (2007). Strengthening of masonry walls by innovative metal based techniques. *COST 26 - Urban Habitat Construction Under Catastrophic Events -Proceedings of Workshop in Prague*, editors. Wald F., Mazzolani F., Byfield M., Dubina D., Faber M., Ed. Czech Technical University in Prague 30-31 March 2007, ISBN 978-80-01-03583-2; pg. 201-210.

60. **Dogariu, A**. (2007). Experimental research on innovative retrofitting techniques for masonry shear walls - *Strengthening and rehabilitation of historical buildings by reversible technologies* – 22 February 2007, Thessalonica, Greece.

61. **Dubina D., Bordea S., Stratan A.** (2007). Seismic retrofit of r.c. frames with hysteretic bracing systems. *International Conference on Steel and Composite Structures ICSCS07*, Manchester, UK , Steel and composite structures, editors Y.C. Wang & C.K. Choi, Taylor & Francis / Balkema, Netherlands, 2007, ISBN 978-0-415-45141-3; pg. 833-839.

62. **Dubina D., Bordea S., Stratan A.** (2008). Seismic Upgrade of Reinforced Concrete Moment Resisting Frame with Dissipative Buckling Restrained Steel Braces. *Conferința „Construcții 2008" May 2008, ACTA TECHNICA NAPOCENSIS*, Section Civil Engineering-Architecture, 51, vol I, 2008, editors Ioani A., Mircea C., Publish Napoca Star, 2008, ISSN 1221-5848, pg. 353-360.

63. **Dubina D., Dogariu A., Stratan A., Stoian V., Nagy-Gyorgy T., Dan D., Daescu C.** (2007). Masonry wall strengthening with innovative metal based techniques. *International Conference on Steel and Composite Structures ICSCS07*, Manchester, UK , Steel and composite structures, editors Y.C. Wang & C.K. Choi, Taylor & Francis / Balkema, Netherlands, 2007, ISBN 978-0-415-45141-3; pg. 1071-1077.

64. **Dubina D., Grecea D., Dogariu A.** (2007). Consolidarea antiseismica a cladirilor istorice: Proiectul FP6 "PROHITECH" (Seismic consolidation of historical building: FP6 PROHITECH) *Zilele academice timisene – Ediția a X-a Structuri metalice amplasate in zone seismice preocupari actuale*, 25 May 2007, Timişoara, România.

65. **El Hammoumi A., Iben brahim A.** (2006). Aléa sismique et vulnérabilité des constructions au Maroc, *Conference given et the School of Architecture*, May 11 2006, Rabat, Morocco.

66. **El Hammoumi A., Iben brahim A., Birouk A., Toto A., El Mouraouah A., Kerroum M., Guerraoui K., Kasmi M.** (2008), Assessment of seismic vulnerability of urban Buildings in Morocco, *International Review of Mechanical Engineering* (submitted).

67. **El Hammoumi A., Iben brahim A., Toto A. E., El Mouraouah A., Kerroum M., Kasmi M., Birouk A., Omira R.** (2006). Matériaux locaux dans la construction des logements traditionnels en terre, *Rabat PROHITECH Seminar on the study and techniques for the rehabilitation of Medinas*, Jul. 10 2006, Rabat, Morocco.

68. **El Hammoumi, A., Iben brahim A., Birouk A., Toto A., El Mouraouah M., Kerroum M., Kasmi M., Hafid M., El Harrouni K.** (2008). Seismic vulnerability and protection of ancient Medinas ; case study of foundouk bouâlam, *Presentation at the "Risk To Cultural Heritage (RICH)" PROHITECH Egypt Seminar held at the Faculty of Engineering* - Cairo University, August 31, 2008, CAIRO - Egypt.

69. **Faggiano B., Marzo A., Formisano A., Mazzolani F.M.** (2008). Innovative steel connections for a composite wood – steel – concrete floor: a numerical investigation, *Computer & Structures* (Elsevier – K. J. Bathe and B.H.V. Topping editors, ISSN 0045-7949), November 2008.

70. **Faggiano B., Marzo A., Mazzolani F.M., Calado L.** (2007). Experimental analysis of rectangular shaped sleeve connectors for composite wood-steel-concrete floors: push-out tests. *Proceedings of the 9th International Conference of Modern Building Materials, Structures and Techniques*, Vilnius, Lituania, 16-18 Maggio 2007.

71. **Formisano A., De Matteis G., Mazzolani F.M.** (2008). Seismic retrofitting of existing r.c. buildings by means of steel shear panels: the Koletti building in Athens in *Atti Convegno RELUIS "Valutazione e riduzione della vulnerabilità sismica di edifici esistenti in c.a."*, Roma, 29-30 maggio 2008.

72. **Formisano A., De Matteis G., Panico G., Mazzolani F.M.** (2007). Metal shear panels as innovative system for seismic upgrading of existing RC buildings: from numerical analyses to full-scale experimental tests. *Association of Computational Mechanics in Engineering - UK (ACME meeting)*, Glasgow, 2-3 April, 2007.

73. **Formisano A., De Matteis G., Panico S., Calderoni B., Mazzolani F.M.** (2006). Full-scale test on existing RC frame reinforced with slender shear steel plates. in *Behaviour of Steel Structures in Seismic Areas (STESSA 2006)*, F. M. Mazzolani and A. Wada editors, Taylor and Francis/Balkema publisher, London, ISBN 0-415-40824-5, 827-834.

74. **Formisano A., De Matteis G., Panico S., Calderoni B., Mazzolani F.M.** (2006). Full-scale experimental study on the seismic upgrading of an existing R.C. frame by means of slender steel shear panels. in *Steel: A new and traditional material for building*, D. Dubina and V. Ungureanu editors, Balkema Publisher, London, ISBN 0-415-40817-2, 2006, pp 609-617.

75. **Formisano A., De Matteis G., Panico S., Calderoni B., Mazzolani F.M.** (2006). Full-scale experimental study on the seismic upgrading of an existing R.C. frame by means of slender steel shear panels. *International conference on metal structures 2006: steel - a new and traditional material for building* , Poiana Braşov (Romania), September 20-22, 2006.

76. **Formisano A., De Matteis G., Panico S., Mazzolani F.M.** (2006). Full scale test of an existing rc frame reinforced with pure aluminium shear panels. *Proceedings of the International Colloquium on Stability and Ductility of Steel Structures (SDSS '06)*, Lisbon, 6-8 September 2006, D. Camotim et al. (eds.), IST Press, Lisbon, 2006 (publisher), ISBN 972-8469-61-6, pp. 903-910.

77. **Formisano A., De Matteis G., Panico S., Mazzolani F.M.** (2007). Full-scale tests on a RC building retrofitted by means of metal shear panels: comparison among proposed solutions. In *Recent developments in Structural Engineering, Mechanics and Computation - Proc. of the Third International Conference SEMC 2007*, 10-12 September 2007, Cape Town, South Africa, A. Zingoni Editor, Millpress Science Pub., Rotterdam, The Netherlands, ISBN: 978 90 5966 054 0, 745-746.

78. **Formisano A., De Matteis G., Panico S., Mazzolani F.M.** (2008). Seismic upgrading of existing RC buildings by slender steel shear panels: a full-scale experimental investigation. in *International Journal of Advanced Steel Construction (IJASC)*, S.L. Chan, W.F. Chen and R. Zandonini (editors-in-chief), ISSN 1816-112X, Hunghom, Kowloon, Hong Kong, China, The Hong Kong Institute of Steel Construction, Vol. 4, No. 1, March 2008, 26-45.

79. **Grecea D., Bordea S., Stratan A., Dogariu A., Dubina D.** (2008). Solutii moderne pentru consolidarea si reabilitarea cladirilor amplasate in zone seismice (Modern solution for rettrofitting buildings situated in seismic areas)- *Structuri metalice amplasate in zone seismice - Preocupari actuale* - Ed. Orizonturi Universitare, Romania, 2008, ISBN 978-973-638-377-9; pg.141-155.

80. **Grecea D., Bordea S., Stratan A., Dogariu A., Dubina D.** (2008). Solutii moderne pentru consolidarea si reabilitarea cladirilor amplasate in zone seismice - *2/2007 Buletinul AICPS*, Ed. AICPS, Bucuresti, 2008, ISSN 1454-928X; pg. 2 – 14.

81. **Iben brahim A., El Hammoumi A., Toto E.A., El Mouraouah A., Birouk A., Kerroum M., Kasmi M.** (2005). Assessment of seismic Risk maps and evaluation of seismic vulnerability of historical building heritage in the Mediterranean area: 2004-2005 activity report of PROHITECH WP3, EE-21C, *Special Theme Session STS-2: 6EC FP Project "Earthquake Protection of Historical Buildings by Reversible Mixed Technologies - PROHITECH"*, Macedonia Aug. 27 – Sep. 1, 2005.

82. **Iben brahim, A., El Mouraouah A., El Hammoumi A., Birouk A., Kasmi M., Toto A., El Harrouni K.** (2006). The Foundouq Boualam study case, Part I: Seismic Hazard, *Rabat PROHITECH Seminar on the study and techniques f or the rehabilitation of Medinas*, Jul. 10 2006, Rabat, Morocco.

83. **Kourkoulis S.K., Papanicolopulos S.-A., Marinelli A., Vayas I.** (2008). Restaurierung antiker Tempel: Experimentelle Untersuchungen zum Ausziehverhalten von Verankerungen im Marmor. *Bautechnik*, Volume 85 Issue 2, Pages: 109-119.

84. **Kourkoulis S.K., Vayas I., Marinelli A., Papanicolopulos S-A.** (2007). Restoring marble fragments: The pull-out problem. *13th International Conference on Experimental Mechanics (ICEM13)*, Alexandroupolis Greece 1-6/7/2007 (Proceedings edited by E.E.Gdoutos – Springer, pg.949).

85. **Krstevska L., Tashkov Lj., Gramatikov K., Landolfo R., Mammana O., Portioli F., Mazzolani F.M.** (2007). Experimental and numerical investigations on the Mustafa Pasha Mosque large scale model. In *Proc. of COST C26 Workshop "Urban Habitat Constructions Under Catastrophic Events*, Prague, 30-31 March 2007. (pp. 158-169). Ed. F. Wald, F.M. Mazzolani, M. Byfield, D. Dubina, M. Faber. COST Bruxelles.

86. **Krstevska L., Tashkov Lj., Gramatikov K., Landolfo R., Mammana O., Portioli F., Mazzolani F.M.** (2008). Shaking table tests on the large scale model of Mustafa Pasha Mosque without and with FRP. In *Proc. of Sixth Int. Conf. on Structural Analysis of Historical Constructions, Preserving Safety and Significance (SAHC08)*, 2-4 July, Bath, UK. (Vol. 1 pp. 383-391). Ed. D. D'Ayala & E. Fodde. CRC Press, Balkema, The Netherlands.

87. **Landolfo R., Di Lorenzo G., Guerrieri M.R., Mammana O., Portioli F.** (2007). The Umberto I Gallery in Naples: influence of corrosion damage on the seismic performance of the iron roofing structure. *(DAMAS' 07). KEY ENGINEERING MATERIALS*. vol. 347, pp. 345-350 ISSN: 1013-9826. doi:10.4028/0-87849-444-8.345. Trans Tech Publications, Switzerland

88. **Landolfo R., Mammana O., Portioli F.** (2005). Assessment of the seismic performance of the iron roofing structure of the Umberto I Gallery in Naples. In *Proc. of XX Congress C.T.A. “Avanzamenti nelle costruzioni in acciaio”*, Ischia, 26-28 Settembre 2005. (pp.531-538) Ed. ACS ACAI SERVIZI srl, Milano.

89. **Landolfo R., Mammana O., Portioli F., Mazzolani F.M.** (2007). Analisi numerica della prestazione sismica del modello in grande scala della moschea di mustafa pasha in skopje. In *Proc. of WonderMasonry 2007 Workshop*, Ischia, Lacco Ameno, Italy, 11-12 Oct. 2007. Ed. A. De Luca and P. Spinelli. Ed. Polistampa.

90. **Landolfo R., Portioli F., Mammana O., Mazzolani F.M.** (2007). Finite element and limit analysis of the large scale model of Mustafa Pasha Mosque in Skopje strengthened with FRP. In *Proc. of the First Asia-Pacific Conference on FRP in Structures APFIS 2007*, Hong Kong, 12-14 December 2007. (Vol 1 pp. 283-288). Ed. by S.T. Smith. University of Hong Kong, China

91. **Lavan O., Levy R.** (2005). Optimal Design of Supplemental Viscous Dampers for Irregular Shear-Frames in the Presence of Yielding, *Earthquake Engineering and Structural Dynamics*, Vol. 34, No. 8, pp. 889-907.

92. **Lavan O., Levy R.** (2005). Optimal Seismic Retrofit of Irregular 3D Framed Structures using Supplemental Viscous Dampers, *Proceedings of the 4th European Workshop on the Seismic Behaviour of Irregular and Complex Structures*, Thessaloniki, 26-27 August, (A. J. Kappos, Editor), Aristotle University Thessaloniki, Department of Civil Engineering, paper no. 52.

93. **Lavan O., Levy R.** (2006). Optimal Design of Supplemental Viscous Dampers for Linear Framed Structures, *Earthquake Engineering and Structural Dynamics*, Vol. 35, No. 3, pp. 337-356.

94. **Lavan O., Levy R.** (2006). Optimal Peripheral Drift Control of 3D Irregular Framed Structures using Supplemental Viscous Dampers, *Journal of Earthquake Engineering*, Vol. 10, no. 6, pp. 903–923.

95. **Lavan O., Levy R.** (2006). Simple Iterative use of Lyapunov's Solution for the Optimal Seismic Design of Passive Devices in Framed Buildings, *Proceedings of the 4th World Conference on Structural Control and Monitoring (4WCSCM)*, 11-13 July, San Diego, California.

96. **Lavan O., Levy R.** (2006). Simple Iterative use of Lyapunov's Solution for the Optimal Seismic Design of Passive Devices in Framed Buildings, *Proceedings of the 4th World Conference on Structural Control and Monitoring (4WCSCM)*, 11-13 July, San Diego, California.

97. **Lavan O., Levy R.** (2008). Simple Iterative use of Lyapunov's Solution for the Linear Optimal Design of Passive Devices in Framed Structures, *Engineering Structures*. (accepted, December 2008).

98. **Levy R.** (2007). Optimal Seismic Retrofitting of Structures Using Added Viscous Damping, *Proceedings of the Third Structural Engineers World Congress [SEWC-Nov.-2007]*, Bangalore, India, November 2-7, (Invited Speaker).

99. **Levy R., Lavan O.** (2006). Fully Stressed Design of Passive Controllers in Framed Structures for Seismic Loadings, *Journal of Structural and Multidisciplinary Optimization*, Vol. 32, no. 6, pp. 485-489.

100. **Levy R., Lavan O.** (2006). Fully stressed seismic design of dampers in framed structures, *Proceedings of an International Conference on Advances in Engineering Structures, Mechanics and Construction*, M. Pandey, W. C. Xie, and L. Xu (Eds.), Waterloo, Ontario, Canada, 14-17 May, Springer, the Netherlands, pp. 303-315.

101. **Levy R., Lavan O.** (2006). Gradient based optimization of added viscous damping for seismic applications, *Proceedings of an International Conference on Advances in Engineering Structures, Mechanics and Construction*, M. Pandey, W. C. Xie, and L. Xu (Eds.), Waterloo, Ontario, Canada, 14-17 May, Springer, the Netherlands, pp. 663-671.

102. **Levy R., Lavan O.** (2006). Performance Based Optimal Seismic Retrofitting of Yielding Plane Frames Using Added Viscous Damping, *Proceedings of the First European Conference on Earthquake Engineering and Seismology (1st ECEES)*, Centre International des Conférences de Genève, Geneve, September 3-8, paper No. 1300.

103. **Levy R., Lavan O.** (2006). Riccati solution versus truly optimal design of supplemental damping in earthquake engineering practice, *Proceedings of the 8th U.S. National Conference on Earthquake Engineering*, San-Francisco, California, 18-22 April, Mira Digital Publishing Inc., Paper no. 617.

104. **Levy R., Lavan O.** (2009). Quantitative Comparison of Optimal Solutions for the Design of Supplemental Damping in Earthquake Engineering Practice, *ASCE J. of Structural Engineering*. (in press; to appear March 2009).

105. **Levy R., Lavan O., Rutenberg A.** (2005). Seismic Design of Friction Damped Braced Frames Based on Historical Records, *Earthquake Spectra*, Vol. 21, No. 3, pp. 761-778.

106. **Lungu D, Arion C.** (2008). Seismic Protection and Protection Against Demolition of Bucharest Heritage Building. *Symposium on NATO Project – Harmonization of Seismic Hazard and Risk Reduction in Countries Influenced by Vrancea Earthquakes*. Kishinev,

Republic of Moldavia, May, in Proceedings of the Symposium, Springer Verlag (to be published in 2008).

107. **Lungu D.** (2005). Seismic risk mitigation in Romania. Synergy from national and international projects. *United Nations, World Conference on Disaster Reduction*, Jan 18-22, Kobe, Hyogo, Japan, Cluster Session 4.6., Policies for Safer Buildings, Housing, 21 p.

108. **Lungu D., Aldea A., Arion C.** (2008). Major Historical Earthquakes, *Transylvania Nostra*, Built Heritage, Year 11, ISSUE 5-6, No. 1-2, Cluj, p. 6-31.

109. **Lungu D., Aldea A., Arion C., Vacareanu R.** (2007). Cutremure istorice majore în România, Revista Monumentelor Istorice, Nr. LXXVI, *Institutul Național al Monumentelor Istorice*, Bucureşti, 2007, p.92-116.

110. **Lungu D., Aldea A., Arion C., Vacareanu R.** (2007). Seismic Hazard, Vulnerability and Risk for Vrancea Earthquakes. *Proceedings of International Symposium on Strong Vrancea Earthquakes and Risk Mitigation*, Oct. 4 – 6, Bucharest, Romania, p. 291 – 307.

111. **Lungu D., Aldea A., Arion C., Vacareanu R.** (2008). Major Historical Earthquakes in Romania, *International Conference Constructions 2008*, Technical University of Cluj, 8p.

112. **Lungu D., Aldea Al., Demetriu S.** (2005). City of Bucharest: Seismic Hazard and Microzonation of Site Effects. *Proceeding of the Conference 250th Anniversary of the 1755 Lisbon Earthquake, Lisabona*, Portugalia, 1-4 Nov, p. 288 – 295.

113. **Lungu D., Arion C., Aldea A.** (2005). Seismic protection of cultural heritage in Bucharest. *The Second International Conference Science and Technology for Safe Development of Lifeline Systems Natural Risks: Earthquakes and Co-seismic Associated Risks, Neotectonics and Seismic Hazard Assessment in the CEI Area* October 24-25, 2005, Bratislava, Slovak Republic, 8p.

114. **Lungu D., Arion C., Vacareanu R.** (2006). National and International Efforts for Seismic Risk Mitigation in Bucharest, Romania. *Proceedings of the First European Conference on Earthquake Engineering and Seismology*, Geneva, Sept 3-8, Paper No. 995.

115. **Lungu D., Arion C.,Vacareanu R.** (2005). City of Bucharest: Buildings Vulnerability and Seismic Risk Reduction Actions. *Proceeding of the Conference 250th Anniversary of the 1755 Lisbon Earthquake*, Lisabona, Portugalia, 1-4 Nov, p. 653- 659

116. **Ly L., Demonceau J.F., Jaspart J.P., Landolfo R.** (2008). Experimental and numerical investigations on iron columns reinforced by FRP under axial compression. *Seismic risk conference - Earthquakes in North-Western Europe*, 11-12 September 2008, Liège, Belgium.

117. **Ly L., Rondal J., Jaspart J.P.** (2007). Numerical and analytical investigations on iron columns reinforced by FRP under axial compression. *APFIS07 conference* 12-2007, Hong Kong, China.

118. **Marinelli A., Kourkoulis S.K., Vayas I.** (2006). Crack Opening Displacement: could it serve as fracture criterion in case of marble?. *16th European Conference of Fracture*, Alexandroupolis Greece 3-7/7/2006.

119. **Marinelli A., Papanicolopulos S.-A., Kourkoulis S.K., Vayas I.** (2008). The Pull-out Problem in restoring marble fragments: a design criterion based on experimental results. *Strain*, 2008 (accepted for publication).

120. **Marzo A., Formisano A., Faggiano B., Mazzolani F.M.** (2006) Numerical analysis of innovative steel connections for a composite wood-steel-concrete floor. *Proceedings of the 8th International Conference on Computational Structures Technology (CST '06)*, Las Palmas, 14-16 September 2006, B.H.V. Topping et al. (eds.), Civil-Comp Press, Stirling, United Kingdom.

121. **Mazzolani F.M.** (2005) Earthquake protection of historical buildings by reversible mixed technologies: the PROHITECH project (oral presentation), *Symposium on Seismic protection of the cultural heritage by innovative techniques*, Rome, Italy.

122. **Mazzolani F.M.** (2005) Earthquake protection of historical buildings by reversible mixed technologies: the PROHITECH project, *Proceedings of the Symposium on Damage and repair of historical and monumental buildings*, Venice, Italy.

123. **Mazzolani F.M.** (2005) Earthquake protection of historical buildings by reversible mixed technologies: the PROHITECH project, *2nd H & mH International Conference on "Vulnerability of 20th Century Cultural Heritage to Hazards and Prevention Measures"*, KOS, Greece.

124. **Mazzolani F.M.** (2006) Earthquake protection of historical buildings by reversible mixed technologies, *Proceedings of STESSA 2006 Conference*, Yokohama, Japan.

125. **Mazzolani F.M.** (2006) The research project PROHITECH: state of advancement, *In The Construction Aspect of Built Heritage Protection*, Dubrovnik, Croatia.

126. **Mazzolani F.M.** (2007) Earthquake protection of historical buildings, *Invited lecture, Reluis workshop*, Salerno, Italy.

127. **Mazzolani F.M.** (2007) Earthquake protection of historical buildings, *COST C26 Workshop*, Prague, Czech Republic.

128. **Mazzolani F.M.** (2008) Advanced techniques for seismic protection of historical buildings: experimental and numerical approach, *Proceedings of MERCEA '08 Conference*, Reggio Calabria, Italy.

129. **Mazzolani F.M.** (2008) Advanced techniques for seismic protection of historical buildings, *Proceedings of CHRESP 2008 Conference*, Ljubljana, Slovenia.

130. **Mazzolani F.M.** (2008) The PROHITECH research project, *Proceedings of SAHC 2008 Conference*, Bath, UK.

131. **Mazzolani F.M., D'Aniello M., Della Corte G.** (2005). Modal testing and dynamic identification of a two-story RC building. *Proceedings of the EE-21C International Conference (Earthquake Engineering in the 21st Century)*, August 28 – September 1, Skopje-Ohrid, Macedonia.

132. **Mazzolani F.M., De Matteis G., Panico S., Formisano A., Brando G.** (2007). Shear panels for seismic upgrading of new and existing structures. *Proceedings of Workshop of COST Action C26 "Urban Habitat Constructions under Catastrophic Events"*, Prague, March 30-31, 2007, print by Prazska technika, Czech Technical University in Prague, ISBN 978-80-01-03583-2, pp 237-244.

133. **Mazzolani F.M., Della Corte G., Fiorino L., Barecchia E.** (2007). Full-scale cyclic tests on a real masonry-infilled RC building for seismic upgrading. *Proceedings of the Workshop COST-Action C26 "Urban habitat constructions under catastrophic events"*, Prague, Czech Republic, March 30-31.

134. **Mazzolani F.M., Faggiano B., Marzo A., Guglielmo E., Mascilli Migliorini P.** (2008). Seismic vulnerability of historical buildings: the Royal Palace of Naples. *Proceedings of the First International Symposium on Life-Cycle Civil Engineering (IALCEE '08)*, Varenna, Lago di Como, Italia, 11-14 Giugno, 2008.

135. **Mazzolani F.M., Fiorino L., D'Ambrosio S., Della Corte G.** (2005). Seismic performance assessment of an existing building based on experimental pushover test results. *Proceedings of the EE-21C International Conference (Earthquake Engineering in the 21st Century)*, August 28 – September 1, Skopje-Ohrid, Macedonia.

136. **Mazzolani F.M., Gramatikov K., Dumova-Jovanoska E., Milutinovic Z., Taskov L.** (2005). Earthquake protection of historical buildings by reversible mixed technologies: the PROHITECH project, *MASE Macedonian Association of Structural Engineers*, 2005.

137. **Mazzolani F.M., Mandara A., De Matteis G.** (2006). The PROHITECH project: a summary of the ongoing activity. *Proc. of the 7th European Conference "SAUVEUR" Safeguarded Cultural Heritage, Understanding & Viability for the Enlarged Europe*, Prague, Czech Republic, 31st May-3rd June 2006, ISBN 987-80-86246-29-1, vol. 2, pp. 987-989.

138. **Mazzolani, F.M.** (2006) Earthquake protection of historical buildings by reversible mixed technologies: the PROHITECH project, *Proceedings of the 7th European Commission Conference, "Safeguard Cultural Heritage. Understanding & Viability for the Enlarged Europe"*, Prague, Czech Republic.

139. **Omira R., El Hammoumi A., Iben brahim A., Toto A. E., El Mouraouah A., Kerroum M., Kasmi M., Birouk A.** (2006). The Foundouq Boualam study case, Part III: Structural Analysis & characterization of construction materials, *Rabat PROHITECH Seminar on the study and techniques f or the rehabilitation of Medinas*, Jul. 10 2006, Rabat, Morocco.

140. **Panico S., De Matteis S., Mazzolani F.M.** (2007). Dissipative torsional device for seismic protection of timber frames. In *Recent developments in Structural Engineering, Mechanics and Computation - Proc. of the Third International Conference SEMC 2007*, 10-12 September 2007, Cape Town, South Africa, A. Zingoni Editor, Millpress Science Pub., Rotterdam, The Netherlands, ISBN: 978 90 5966 054 0, 140-150.

141. **Si Youcef Y., Amziane S., Chemrouk M.** (2008). The Influence of CFRP on the Behaviour of Reinforced Concrete Columns Subjected to Buckling. *Proceedings of the Fourth International Conference on FRP Composites in Civil Engineering (CICE2008)*, 22 – 24 July 2008, Zurich, Switzerland.

142. **Toto E.A., Haida S., Benammi M., Hafid M., Birouk A., Iben brahim A., El Mouraouah A., Kasmi M., El Hammoumi A.** (2006). The Foundouq Boualam study case, Part II: Seismic Site Effects, *Rabat PROHITECH Seminar on the study and techniques f or the rehabilitation of Medinas*, Jul. 10 2006, Rabat, Morocco.

143. **Vayas I., Dasiou M.-E., Dakanali I., Papageorgiou M.** (2008). Seismic analysis of buildings with mast. *Bauingenieur*, Volume 83, Issue 10, Pages: 432-439.

144. **Vayas I., Dasiou M.-E., Marinelli A.** (2007). Seismic behaviour of columns of Greek Temples. *Bautechnik*, Volume 84, Issue 6, Pages: 388-396.

145. **Vayas I., Dasiou M.-E., Marinelli A.** (2007). Seismic behaviour of ancient columns. *ECCOMAS Thematic Conference on Computational Methods* in Structural Dynamics and Earthquake Engineering, Rethymno, Crete, Greece, 13–16 June 2007, (Proceedings edited by M.Papadrakakis, D.C.Charmpis, N.D.Lagaros and Y. Tsompanakis, pg.50).

146. **Vayas I., Dasiou M.-E., Papageorgiou M.** (2008). Strengthening of buildings with telecommunication mast using steel elements. *National Conference on Anti-Seismic Engineering Technology*, Athens, Greece, 5-7 November, An.No 1798.

147. **Vayas I., Papageorgiou M., Hatzinikolis I., Avloniti K.** (2008). Pre-seismic assessment of buildings with telecommunication towers. *5th European Conference on Steel*

*and Composite Structures* 3rd to 5th September 2008,Graz, Austria, Volume B (Proceedings edited by R. Ofner, D. Beg, J. Fink, R. Greiner, H. Unterweger, p.1311).

148. **Vilnay M.** (2008). Using Shape Memory Alloys for Seismic Upgrading of Structures, M.S., Technion.

# 5 Meetings

During the research project development, the following meetings have been held:

<u>First year</u>

- 1st General plenary (kick-off) meeting in Anacapri, Naples (Italy) in November 2004
- 2nd General plenary meeting which was held in Azores (Purtugal) in June 2005
- WP1-WP4 Joint Meeting, held in Naples (Italy) on 14-15th July 2005
- 1st Editorial Board (EB-I) MEETING held in Ohrid (Macedonia) on 29th August 2005

<u>Second year</u>

- 3rd General Plenary Meeting in Heraklion (Crete – Greece), on 24th and 25th November 2005
- 1st WP8 special meeting in Naples (Italy), on 23rd and 24th February 2006
- 1st WP6 meeting in Ljubljana (Slovenia), on 9th to 11th March 2006
- 4th General Plenary Meeting in Istanbul (Turkey) on 6th to 8th April 2006
- 1st WP11 meeting in Istanbul (Turkey), on 8th April 2006
- WP11 "Iron" meeting in Naples (Italy), on 8th June 2006
- WP7 meeting in Prague (Czech Republic), on 3rd June 2006
- WP11 "Rabat PROHITECH meeting on rehabilitation techniques for Medinas " in Rabat (Morocco), on 9th to 11th July 2006
- 5th General Plenary Meeting in Poiana Brasov (Romania), on 18th and 19th September 2006

<u>Third year</u>

- WP7 Group meeting, held in Skopje (Macedonia), on 13th and 14th November 2006
- WP9 meeting, held in Timisoara (Romania), on 7-8th December 2006
- WP10-WP11 Group meeting, held in Athens (Greece), on 8th and 9th March 2007
- 6th General plenary meeting in Liège (Belgium), on 26th and 27th April 2007
- WP10, WP1, WP12 Joint meeting, held in Haifa (Israel), on 5th and 6th September 2007

Fourth year

- WP7 to WP 12 joint meeting, held in Antalya (Turkey), on 11$^{th}$ and 12$^{th}$ January 2008
- Meeting for the first test on the Fossanova cathedral model, held in Skopije (Macedonia), on 19$^{th}$ and 20$^{th}$ March 2008
- Meeting for the second test on the Fossanova cathedral model, held in Skopije (Macedonia), from 2$^{nd}$ to 4$^{th}$ April 2008
- Medina meeting, held in Naples (Italy), on 13$^{th}$ March 2008
- Meeting for the test of the model of Byzantine Church and D-III & D-IV editorial group meeting, held in Skopje (Macedonia), from 14$^{th}$ to 16th July 2008
- Final General meeting, held in Sharm El Sheikh (Egypt), on 28$^{th}$ and 29$^{th}$ August 2008