IUSS
Scuola Universitaria Superiore Pavia

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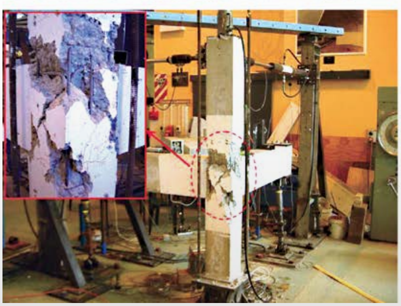
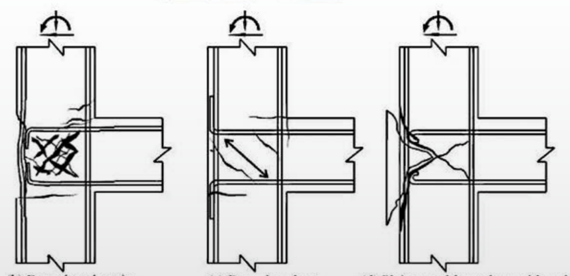
## Short Course on

# SEISMIC ASSESSMENT AND RETROFIT STRATEGIES FOR REINFORCED CONCRETE BUILDINGS

**Pavia, 5-9 June, 2017**
**IUSS - Classroom 1-14 / 1-17**

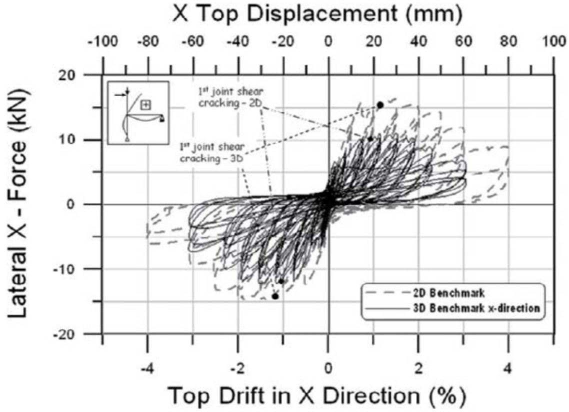




(b) Beam bars bent in - loss of joint integrity

(c) Beam bars bent away from the joint

(d) Plain round beam bars with end-hooks: "concrete wedge mechanism"




## • Background and Motivation

The urgent need to develop and implement simple and cost-effective (repair and) retrofit solutions for existing reinforced concrete buildings, designed according to older (though, in some cases, relatively recent) seismic code provisions has been further emphasized in the last decade by the catastrophic effects of earthquake events.
More so, the crucial need of a medium-long-term seismic retrofit and risk reduction strategy and implementation plan on a national scale is becoming increasingly evident.

Even prior to selecting the most appropriate retrofit strategy and technique, the assessment of the seismic vulnerability of the structure represents a crucial and very delicate step. Important knowledge in this complex area has been gained in the past recent years at both national and international level, with more reliable procedures and techniques to support both the assessment and the retrofit phases.

Based on recent lessons learned from past earthquakes and on extensive experimental and analytical-numerical investigations, it is becoming more and more evident that major and sometimes controversial issues can arise when, for example:

a) deciding whether the retrofit is actually needed and, if so, in what proportions and to what extent;
b) assessing and predicting the expected seismic response pre and post-intervention by relying upon alternative analytical/numerical tools and methods;
c) evaluating the effects of the presence of infills, partitions or in general "nonstructural" elements on the seismic response of the overall structure, typically and improperly evaluated considering only the "skeleton";
d) deciding, counter-intuitively, to "weaken" one of more structural components in order to "strengthen" the whole structure;
e) adopt a selective upgrading to independently modify strength, stiffness or ductility capacity;
f) relying upon the deformation capacity of an under-designed member to comply with the displacement compatibility issues imposed by the overall structure;

g) sustain after a given seismic event, i.e. targeting a specific performance level after the retrofit.

Finally, while, on one hand, issues related to the socio-economical consequences of excessive damage and/or downtime should be a major if not the first priority, on the other hand, considerations of costs, invasiveness, disruption of working activities as well as architectural aesthetics contributes to further complicate such a complex decision-making process.
Similarly to what pursued for the design of new structures, a performance-based approach should be adopted when assessing the vulnerability and defining the retrofit strategy for existing buildings.

## • Scope

The short course intends to provide the students/attendees with basic information and background on seismic assessment procedures, strengthening/retrofitting strategies and techniques for reinforced concrete buildings.
At the end of this short course, the students would be expected to have gained familiarity with:

a) the general concepts and principles underpinning seismic assessment and retrofit approaches, according to a performance-based philosophy;
b) the relevant existing literature at national and international level for either assessment and retrofit, based on experimental, numerical, analytical studies and observations/reports from post-earthquake recognisance missions;
c) the general potentiality, as well as limitations, of a range of strengthening retrofit solutions, either based on traditional or more recently developed techniques.

## • Content

The course will cover the following main aspects:

- Overview of key and most common structural weaknesses and associated anticipated behaviour/response of existing reinforced concrete buildings. Reference will be given to experimental tests, analytical/numerical studies and the recent lessons learnt from post-earthquake building inspections and investigations.
- Discussion on main features and approaches of alternative seismic assessment procedures, with reference to existing national and international literature.
- Fundamentals of analytical and numerical modeling techniques to represent the seismic response of as-built reinforced concrete buildings.
- Introduction to Performance-Based Retrofit Strategies and alternative solutions/techniques.
- Feasibility and efficiency of adopting and/or combining different solutions such as Fibre Reinforced Polymers, low-invasive low-cost metallic diagonal haunches, (post-tensioning or traditional) wall systems and selective weakening techniques.

- **Lectures**

## BLOCK 1 – SEISMIC ASSESSMENT

### Introduction to seismic assessment of RC buildings

Introduction. Statement of the Problem. Main structural deficiencies of existing reinforced concrete buildings. Seismic performance of existing buildings: observed behaviour in real earthquakes, lessons learned from the Canterbury Earthquake Sequence; experimental/ numerical studies and evidences.
Seismic assessment methodologies and procedures according to different codes. General principles and approaches. Performance objectives and compliance criteria.

### Evaluation of local and global response and mechanisms – Non-linear Modelling

Global vs. local mechanisms. Evaluation of hierarchy of strength and sequence of events in as-built structural subassemblies and systems. Vulnerability and behaviour of elements and connections, e.g. columns, beams, beam-column joints, walls, floor-to-lateral resisting systems Interaction of bare frame systems with "non-structural" masonry or concrete infills. Simplified Modelling techniques based on lumped plasticity (macro) models. Numerical investigations on the response of pre-1970 frames with and without infills.

## BLOCK 2 - RETROFIT STRATEGIES AND TECHNIQUES

### Introduction to Seismic Retrofit Strategies-Fiber Reinforced Polymers FRP

Overview of Alternative retrofit strategies and techniques. Performance-based and displacement based retrofit approach.
Introduction to Fibre Reinforced Polymers, FRP. Design and applications. Upgrading for flexural, shear and confinement. Seismic Strengthening of beam- column joints with FRP.

### Retrofit Solutions using external walls, diagonal haunch or selective weakening

Retrofit using mini-brace in the form of a diagonal metallic haunch. Concept, design and experimental validation.
Displacement-Based Retrofit approach using rocking-dissipative walls.
Principles and examples of selective weakening strategies and techniques.

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## • Lectures Schedule

**Monday 5 June - Block 1 - Seismic Assessment**
Introduction to seismic assessment of RC bulidings
9.00-12.30 – 14.30-17.30

**Tuesday 6 June - Block 1 Seismic Assessment**
Evaluation of local and global response and mechanisms –
Non-linear Modelling
9.00-12.30 – 14.30-17.30

**Wednesday 7 June - Block 2 - Seismic Retrofit**
Introduction to Seismic Retrofit Strategies-Fiber Reinforced Polymers
FRP
9.00-12.30 – 14.30-17.30

**Thursday 8 June - Block 2 - Seismic Retrofit**
Retrofit Solutions using external walls, diagonal haunch or selective weakening
9.00-12.30

**Friday 9 June**
Project Presentations
14.00-17.00

## • Handouts/Reading

Handouts of the lectures will be provided in .pdf form
A selection of suggested reading material on the topics covered in class will also be provided in electronic form and uploaded on a common repository (DropBox-type).
The NZSEE2016 Guidelines on "Seismic Assessment of Existing Buildings" can be downloaded at http://www.eq-assess.org.nz/

- **Course Coordinator & Lecturer**

**Prof. Ing. Stefano Pampanin** - stefano.pampanin@uniroma1.it

Stefano Pampanin is Full Professor (Professore Ordinario) of Structural Engineering at the Department of Structural and Geotechnical Engineering at La Sapienza University of Rome where he joined in 2015.
He has received a Laurea (cum laude) in Civil Structural Engineering at the University of Pavia, a Master in Structural Engineering at the University of California, San Diego and a PhD in Earthquake Engineering at the Technical University of Milan.
In 2002 he joined as a Senior Lecturer the Department of Civil ad Natural Resources Engineering at the University of Canterbury, Christchurch in New Zealand, where he became Professor of Structural Design and Earthquake Engineering and Chair of the Structural and Geotechnical Cluster.
He has been President of the New Zealand Society for Earthquake Engineering, NZSEE, (2012- 2014). He has been nominated Fellow of the IPENZ (Institution of Professional Engineers, New Zealand) in 2015 and of NZSEE in 2017.
In the past two decades, he has been dedicating a significant effort in the research and development, codification and practical implementation through design and peer review, as well as knowledge-dissemination of innovative solutions for the seismic design of low-damage structural systems in concrete and timber, as well as for the seismic assessment and retrofit of existing reinforced concrete structures.
He has been actively involved in a number of national and international code and technical committees for the preparation of design guidelines, state-of-art, guides for good practice guides and/or design standards on reinforced concrete, precast and prestressed concrete, assessment and retrofit, prestressed timber, e.g. fib WG7.4, &7.5, WG7.6, WG 6.10, WG 6.17, ACI440-F, NZS3101:2006 (appendix B), Department of Building and Housing guidelines for the design, assessment and retrofit of hollowcore floors.
As part of the current review of the NZSEE2006 guidelines on "Assessment and Improvement of the Performance of Existing Buildings" he is acting as Task Leader or the section on Reinforced Concrete structures.
He is author of more than 350 scientific publications in the field of earthquake engineering and received several awards for his research activities including the fib Diploma 2003 for Younger Engineers (under 40-years old) and the 2005 EQC/NZSEE Ivan Skinner Award "for the advancement of Earthquake Engineering in NZ" (inaugural recipient).
Following the 22 February 2011 earthquake in Christchurch, Prof. Pampanin has played an active role in the recovery and post-earthquake investigation activities. He led the Recovery Project "Seismic Performance of RC Buildings" under the Natural Hazard Research Platform and was part of the Expert Panel of the Department of Building and Housing, investigating the collapse of critical buildings and reporting to the Canterbury Earthquake Royal Commission of Enquiry. He has been an invited member of the Engineering Reference Group advising the Ministry of Business Innovation and Employment on policy making related to the civil design and construction industry sector.

Education and Culture

Erasmus Mundus

The European Commission has approved and financed within the Erasmus Mundus II the Masters onEarthquake Engineering and Engineering Seismology (MEEES), coordinated by the UME School as part of the ROSE programme and featuring also the participation of the University of Grenoble Joseph Fourier (France), the University of Patras (Greece) and the Middle East Technical University (Turkey), which aims to enhance quality in European higher education and to promote intercultural understanding through cooperation with third countries, a relatively large number of scholarships are available for both non-European as well as European students. Interested applicants are invited to visit the MEEES website (www.meees.org) for detailed information and instructions on financial conditions and application procedures.