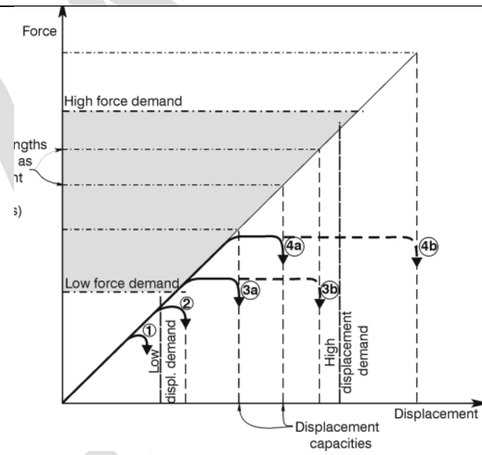
Dipartimento di Ingegneria Strutturale e Geotecnica
Sapienza Università di Roma

Riabilitazione Strutturale di Edifici in Cemento Armato

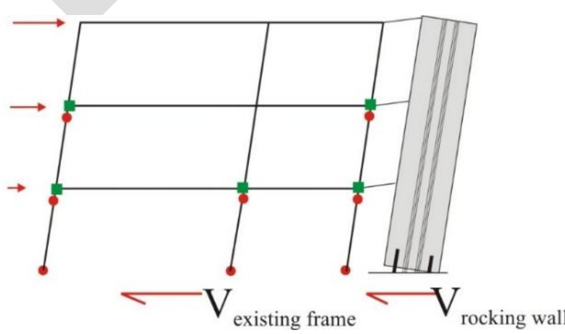
(Seismic Assessment and Retrofit of RC Buildings)

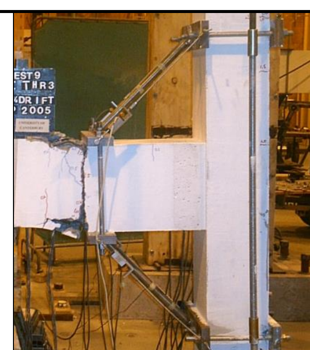
(Version 0 @27 September 2021)

Prof. Ing. Stefano Pampanin



Percentage of New Building Standard (%NBS)	Letter grade	Relative risk (approx)
>100	A+	< 1 time
80–100	A	1–2 times
67–80	B	2–5 times
33–67	C	5–10 times
20–33	D	10–25 times
<20	E	> 25 times





Background and Motivations

The crucial need for strengthening or retrofitting existing structures designed with substandard details, in order to withstand seismic loads without collapsing and possibly with repairable damage, has been further emphasized in the last decade by the catastrophic effects of earthquake events (e.g. Turkey, Colombia and Taiwan, 1999; India 2001; China 2008; Italy 2009, 2012; Chile 2010, New Zealand 2010-2011).

The impact of the Canterbury earthquakes sequence in 2010-2011 has dramatically emphasized, if at all needed, 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.

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 "non-structural" 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) defining a desired or acceptable level of damage that the retrofit structure should 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 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 the course 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.

Design Classes Introduction to the course project. Case- study buildings. Rapid assessment based on structural drawings to be continued independently as part of the project with more detailed assessment

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.

*Design Classe*s – Moment-curvature of structural elements. Flexure, shear, flexural-shear interaction and strength degradation. Hierarchy of strengths and sequence of events for a beam-column joint. Modelling of columns, beam-column joints and frame systems using lumped plasticity approach.

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

Design Classes Design example and application of FRP strengthening of a structural element for flexure, shear and confinement and of a beam-column joint subassembly to improve the sequence of events.

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

<u>*Design Class*</u> Design Class. Haunch retrofit evaluation and modelling using macromodels (e.g. SAP2000, Ruaumoko)

Design Project/Assignments:

As part of the assignment/project requirements, students, either individually or paired in groups, will be assigned a case-study **project**.
The project work will cover aspects of simplified or detailed assessment, analytical and numerical modelling of the structural response, conceptual design and performance evaluation of alternative retrofit solutions for a case study building.

Details on the case-study prototype building, type of analysis to carry, level of design vs. assessment (and possibly retrofit) will be discussed and agreed with each group.

The main findings will be presented via a **written report,** divided in two parts, assessment and retrofit, respectively, and, possibly, an oral presentation.

Options for Mid-term examinations ("Esoneri") will be available (optional) in discussion with the Professor in charge.

Assessment/Evaluation

The assessment of the exam consist of a **project written report** and **oral presentation** (worth 50%) and a **final written exam** (worth 50%).

Final Written Exam (tbc)	**50%**	(Appelli) **End of January 2021 (tbc)** (XXam-XXpm) **Mid- February 2021 (tbc)** (XXam-1pm)
Project Presentation and Report (tbc)	**50%**	Project Presentations (Appelli) Period: End of January 2022 (tbc) Period: End of February 2022 (tbc) *Optional ("Esoneri")* *Project Part I – Assessment –Mid December 2021* *Project Part 2 – Retrofit - Mid-End- January 2022*

tbc= to-be-confirmed (following discussion with the class)

L'ECTURES SCHEDULE

(tbc, version 27 September 2021)

Week	Date	Mon	Tuesday	Wednesday	Thu	Fri
1	Sept 27		**SP** 17.00-19:00 (Aula 48)		**SP** 13.00-16:00 (Aula 48)	
2	Oct 4		**SP** 17.00-19:00 (Aula 48)		**SP** 13.00-16:00 (Aula 48)	-
3 -	11		**SP** 17.00-19:00 (Aula 48)		**SP** 13.00-16:00 (Aula 48)	
4	18		**SP** 17.00-19:00 (Aula 48)		**SP** 13.00-16:00 (Aula 48)	
5	25		**SP** 17.00-19:00 (Aula 48)		**SP** 13.00-16:00 (Aula 48)	
6	Nov 1		**SP** 17.00-19:00 (Aula 48)		**SP** 13.00-16:00 (Aula 48)	
7	8		**SP** 17.00-19:00 (Aula 48)		**SP** 13.00-16:00 (Aula 48)	
8	15		**SP** 17.00-19:00 (Aula 48)		**SP** 13.00-16:00 (Aula 48)	
9	22		**SP** 17.00-19:00 (Aula 48)		**SP** 13.00-16:00 (Aula 48)	
10	29		**SP** 17.00-19:00 (Aula 48)		**SP** 13.00-16:00 (Aula 48)	
11	Dec 6		**SP** 17.00-19:00 (Aula 48)		**SP** 13.00-16:00 (Aula 48)	
12	13		**SP** 17.00-19:00 (Aula 48)		**SP** 13.00-16:00 (Aula 48)	

tbc=to-be-confirmed

Course weight: CFU 6 (1CFU= 10hrs)

Total Hours: approx. 60 hrs Lectures and Design Classes

Lecture timetable and venues

Modalità "blended" (presenza con prenotazione + distanza)

Link per lezioni a distanza:

https://uniroma1.zoom.us/j/82901334527?pwd=dHVuV3NmdHdiWGRid3NJSFo4SFNVdz09

(Meeting ID: 829 0133 4527; Passcode: 346935)

Tuesday 17:00-19:00- Aula 48

Thursday 13:00-16:00 - Aula 48

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, Google Classroom).

Course Coordinator & Lecturer

Prof. Ing. Stefano Pampanin	email: 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. He was a Fulbright Visiting Scholar at the University of California, San Diego from 1998-1999.

In 2002 he joined the Department of Civil ad Natural Resources Engineering at the University of Canterbury, Christchurch in New Zealand and 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) and was nominated Fellow of NZSEE in 2017.

In the past 20 years 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 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 and standards including: *fib*, international federation of concrete: WG 7.4, WG7.5 (Co-Chair), WG7.6, WG6.10, WG6.6 (Co-Chair) ACI440-F, NZS3101:2006 (appendix B), Department of Building and Housing (DBH) guidelines for the design, assessment and retrofit of hollowcore floors; current revision of NZS3101 (concrete), NZS3603 (timber), NZSEE2006 guidelines on "Assessment and Improvement of the Performance of Existing Buildings" (Task Leader), Minister of Business Innovation and Employment (MBIE) special technical committees to produce "White Paper on Residual Capacity of Reinforced Concrete Structures"; "Base Isolation Guidelines"; "Guide for Good Practice on Low-damage Design".

He has been Principal Investigator (PI) or Co-PI of externally funded and competitively granted research project for over NZ$15Million since 2002 with strong focus on development and implementation of new technological solutions for seismic resisting structures, either newly designed or existing ones.

He is author of more than 400 peer-reviewed scientific publications in the field of earthquake engineering, including 100 journal papers and book chapters, 2 edited books, 3 patents and has received several awards for his research and professional activities including:

- PCI (precast Concrete Institute) Martin P. Korn Award 2000
- fib Diploma 2003 for Younger Engineers (under 40-years old)
- 2005 EQC/NZSEE Ivan Skinner Award "for the advancement of Earthquake Engineering in NZ" (inaugural recipient).
- NZSEE (NZ Society for Earthquake Engineering) Best Research Paper Awards 2005,2007,2008, 2010
- Otto Glogau Award 2005, 2013
- NZ Concrete Society, Sandy Cormack Award 2004, 2010
- Supreme Concrete Award 2008
- IstructE Henry Adams Award, 2012
- UC Innovation Medal, 2013
- ACI Design Award 2015
- Fellow, IPENZ (FIPENZ), NZ Institute of Professional Engineers, 2015
- Fellow, NZSEE (New Zealand Society for Earthquake Engineering, 2017

He has delivered numerous invited/keynote lectures at conferences, universities, research institutions and groups of practicing engineers worldwide.

Following the 22 February 2011 earthquake in Christchurch, Prof. Pampanin has played an active and key role in the recovery and post-earthquake investigation activities: a) Leader of the Recovery Project "Seismic Performance of RC Buildings" under the Natural Hazard Research Platform; b) Expert Panel of the Department of Building and Housing, investigating the collapse of critical buildings, namely CTV, PGC, Forsyth Barr and Grand Chancellor Hotel reporting to the Canterbury Earthquake Royal Commission of Enquiry; c) Main author of a technical report commissioned by the Royal Commission on low-damage design philosophy and technology; d) Engineering Reference Group advising the Ministry of Business Innovation and Employment on policy making related to the civil design and construction industry sector.

In 2015 he was elected **Fellow of IPENZ** "*for his application of engineering technology in the community and innovation in creating technological products. As an internationally-regarded researcher, educator and innovator, he progressed the theory and practice of earthquake engineering. His work alongside others on developing earthquake-resistant buildings and materials aims to reduce seismic risk…*"
As a Charter Professional Engineer in Italy and in New Zealand he has assisted with the design and/or acted as peer reviewer on a number of special projects implementing: a) advanced design methodology, such as Displacement-Based-Design; b) numerical modelling for non-linear time history analyses; c) innovative/advanced technology, such as rocking-dissipative solutions for concrete, timber steel base isolation and supplemental damping; d) Seismic Assessment and Retrofit solutions.