University of Pavia IUSS School of Advanced Studies

Civil Engineering for Mitigation of Risk from Natural Hazards

SEISMIC DESIGN OF NONSTRUCTURAL BUILDING COMPONENTS

FIRST SEMESTER 2019-2020

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Course Dropbox: TBD
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CLASS SCHEDULE

Lectures: Tuesdays, Wednesdays and Thursdays; 9:00 am to 1:00 pm.
Tutorials: Tuesdays, Wednesdays and Thursdays; 2:30 pm to 5:30 pm.

OFFICE HOURS

Mondays and Fridays; 1:00 pm to 4:00 pm: Roberto Merino in CAR College.
By e-mail appointment with Roberto Merino only – 24-hour notice required.

BACKGROUND

With the development and implementation of performance-based earthquake engineering, harmonization of performance levels between structural and nonstructural building components becomes vital. Even if the structural components of a building achieve a continuous or immediate occupancy performance level after a seismic event, failure of architectural, mechanical or electrical components can lower the performance level of the entire building system. This reduction in performance caused by the vulnerability of nonstructural building components has been observed during recent earthquakes worldwide. Moreover, nonstructural damage has limited the functionality of critical facilities, such as hospitals following major seismic events. The investment in nonstructural building components and building contents is far greater than that of structural components and framing. Therefore, it is not surprising that in many past earthquakes, losses from damage to nonstructural building components have exceeded losses from structural damage. Furthermore, the failure of nonstructural building components can become a safety hazard or can hamper the safe movement of occupants evacuating or of rescue workers entering buildings. In comparison to structural components and systems, there is relatively limited information on the seismic design of nonstructural building components. Basic research work in this area has been sparse, and the available codes and guidelines are mostly based on experiences, engineering judgment and intuition, rather than on objective experimental and analytical results. Often, design engineers are forced to start almost from square one after each earthquake event: to observe what went wrong and to try to prevent repetitions. This is a consequence of the empirical nature of current seismic regulations and guidelines for nonstructural building components.

GENERAL OBJECTIVES

The main objective of the course is to familiarize Structural Engineers with current knowledge on the seismic design and analysis of nonstructural building components. At the end of the course, Structural Engineers should be able to:

- classify the various types of nonstructural building components and understand their performance during recent earthquakes;
- conduct seismic analysis of nonstructural building components by the direct and cascading methods;
- understand and apply correctly current regulations and guidelines for the seismic design and specifications of nonstructural building components in North America and Europe including the seismic qualification requirements for important nonstructural building components that have been introduced recently in building codes;
- conduct seismic qualification of nonstructural building components by testing, analysis or experience database according to recent building code requirements; and
- be familiar with the seismic performance and fragility of specific nonstructural building components and systems through the review of research case studies.

TOPICS COVERED

CHAPTER1: INTRODUCTION

Definition of nonstructural building components; Classification of nonstructural building components; Importance of considering nonstructural building components in seismic design; Challenges associated with the seismic design of nonstructural building components; Causes of seismic damage to nonstructural building components; Performance of nonstructural building components in recent earthquakes.

CHAPTER 2: PRACTICAL SEISMIC ASSESSMENT AND MITIGATION OF NONSTRUCTURAL BUILDING COMPONENTS

FEMA E-74 Methodology; FEMA 74 Field manual; Performance levels for retrofit; Non-engineered design method; Prescriptive design method; Engineering design method; Checklist of nonstructural hazard; Assessment of architectural components; Assessment of building utility systems; Assessment of building contents.

CHAPTER 3: SEISMIC ANALYSIS OF NONSTRUCTURAL BUILDING COMPONENTS

Direct analysis method; Cascading analysis method; Challenges with direct analysis method; Examples of direct analysis method; Floor Response Spectrum (FRS) method; Generation of floor response spectrum; Examples of FRS Analysis.

CHAPTER 4: SEISMIC DESIGN OF NONSTRUCTURAL BUILDING COMPONENTS

Objectives of seismic design for nonstructural building components; Steps in seismic design of nonstructural building components; Definition of rigid and flexible nonstructural building components; Seismic design requirements for nonstructural building components in the United States, Canada and Europe; Seismic qualification of nonstructural building components by analysis, testing and experience data; California's hospital seismic upgrade program (SB 1953); Impediments to incorporating nonstructural design into practice.

CHAPTER 5: SEISMIC PERFORMANCE OF LIGHT AND HEAVY PARTITION WALLS

Seismic performance of cold-formed steel framed gypsum partition walls; Seismic performance of masonry infill partition walls in reinforced concrete frames; Eurocode 8 seismic provisions for masonry infilled reinforced concrete frames.

CHAPTER 6: SEISMIC PERFORMANCE OF PRESSURIZED FIRE SUPPRESSION SPRINKLER PIPING SYSTEMS

Description of sprinkler piping systems; Components of fire sprinkler systems; Vertical hangers; Sway bracing systems; Performance of sprinkler piping systems in past earthquakes; Code provisions for seismic design of fire sprinkler systems; NFPA-13 design by rule and design by analysis requirements; Cyclic response of sprinkler piping joints; Dynamic response of full-scale sprinkler piping systems; Numerical modelling of sprinkler piping systems.

CHAPTER 7: SEISMIC PERFORMANCE OF STEEL STORAGE RACKS

Lateral load-resisting systems of steel storage racks; Seismic performance objectives for storage racks (FEMA 460); Performance of steel storage racks in past earthquakes; Seismic provisions of Rack Manufacturers Institute (RMI) design standard (ANSI MH16.1-12); Stiffness of steel storage rack connectors; Displacement-based procedure for collapse prevention of steel storage racks; Seismic response of base isolated steel storage racks; Concept of inclined shelving for storage racks.

CHAPTER 8: SEISMIC PERFORMANCE OF VIBRATION-ISOLATED MECHANICAL EQUIPMENT

Differences between seismic protection and vibration isolation; Performance of vibration-isolated equipment in past earthquakes; Code seismic design requirements for vibration-isolated equipment; Shake table tests of vibration-isolated equipment; Concept of displacement-dependant energy dissipation restraint.

CHAPTER 9: SEISMIC PERFORMANCE OF SUSPENDED CEILING SYSTEMS

Performance of suspended ceiling systems in past earthquakes; Failure mechanisms in suspended ceiling systems; Influence of installation conditions effects/efficiency of various protective systems; ACM7 Seismic Clips; Recommendations for development of standards and for design methodologies; Numerical modelling of suspended ceiling systems.

CHAPTER 10: SEISMIC PERFORMANCE OF BOOKCASE-PARTITION WALL SYSTEMS

Objectives; Test specimens; Test series; Seismic restraints; Floor seismic input motions; Test results; Practical recommendations.

CLASS NOTES AND PROVIDED REFERENCES

- Slide sets posted on the course Dropbox:
- References posted on the course Dropbox:

- ASTM (2010). Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions. ASTM Standard E 580/E 580M – 09a. ASTM International, West Conshohocken, PA.
- Calvi, P.M., and Sullivan, T.J. 2014. "Estimating floor spectra in multiple degree of freedom systems," Earthquakes and Structures, An International Journal, Techno Press, 6(7), 17-38.
- Calvi, P. 2014. "Relative Displacement Floor Spectra for Seismic Design of Non Structural Elements," Journal of Earthquake Engineering, 18: 1037–1059.
- Christovasilis, I.P., Filiatrault, A. and Wanitkorkul, A. 2007. Seismic Testing of a Full-Scale Two-Story Light-Frame Wood Building: NEESWood Benchmark Test. NEESWood Report No. MCEER-09-0005, Multidisciplinary Center for Earthquake Engineering Research, University at Buffalo, State University of New York, Buffalo, NY, 216 p.
- Davies, R.D. 2010. Seismic Evaluation, Parameterization, and Effect of Light-Frame Steel Studded Gypsum Partition Walls, MS Thesis, University at Buffalo, State University of New York, Buffalo, NY, 621 p.
- Fathali, S., and Filiatrault, A., 2007. Experimental Seismic-Performance Evaluation of Isolation/ Restraint Systems for Mechanical Equipment, Part I: Heavy Equipment Study, Technical Report MCEER-07-0007, MCEER, University at Buffalo, State University of New York, Buffalo, NY.
- FEMA. 2005. Seismic Considerations for Pallet Type Steel Storage Racks and their Contents in Areas Accessible to the Public. FEMA 460, Federal Emergency Management Agency, National Institute of Building Sciences, Washington, DC, 160 p.
- FEMA. 2011. Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide. FEMA E-74, Federal Emergency Management Agency, Washington, DC, 755 p.
- FEMA 2007. Interim Protocols For Determining Seismic Performance Characteristics of Structural and Nonstructural Components Through Laboratory Testing. FEMA 461, Federal Emergency Management Agency, Washington, DC.
- FEMA 2009. NEHRP Recommended Seismic Provisions for New Buildings and Other Structures. 2009 Edition (FEMA P-750). Federal Emergency Management Agency, Washington, DC, 406 p.
- Filiatrault, A., Uang, C-M., Folz, B., Christopoulos, C. and Gatto, K. 2001. Reconnaissance Report of the February 28, 2001 Nisqually (Seattle-Olympia) Earthquake. Structural Systems Research Project Report No. SSRP-2001/02, Department of Structural Engineering, University of California, San Diego, La Jolla, CA, 67 p.
- FM Approvals 2010. Approval Standard for Seismic Sway Braces for Automatic Sprinkler Systems. FM Approvals LLC, Norwood, MA.
- FM Approvals 2013. Approval Standard for Seismic Sway Braces for Pipe, Tubing and Conduit. FM Approvals LLC, Norwood, MA.
- ICC-ES 2007. Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components and Systems. International Code Council Evaluation Service, International Code Council AC156. Whittier, CA, 10 p.

- NIST 2017. Seismic Analysis, Design, and Installation of Nonstructural Components and Systems – Background and Recommendations for Future Work. NIST GCR 17-917-44, National Institute of Standards and Technology, Gaithersburg, MD, 228p.
- Retamales, R., Mosqueda, G., Filiatrault, A., & Reinhorn, A. 2008. New Experimental Capabilities and Loading Protocols for Seismic Qualification and Fragility Assessment of Nonstructural Components. Buffalo: Technical Report MCEER-08-0026, MCEER, University at Buffalo, State University of New York.
- Retamales, R., Davies, R., Mosqueda, G. and Filiatrault, A. 2013. "Experimental Seismic Fragility of Cold-Formed Steel Framed Gypsum Partition Walls," ASCE Journal of Structural Engineering. 139(8), 1286-1293.
- Ryu, K.P., Reinhorn, A.M. and Filiatrault, A. 2012. "Full Scale Dynamic Testing of Large Area Suspended Ceiling System," 15th World Conference on Earthquake Engineering, Lisbon, Portugal, Paper No. 5474, 10 p.
- Ryu, K.P. and Reinhorn, A.M. 2017. "Experimental Study of Large-Area Suspended Ceilings," Journal of Earthquake Engineering, https://doi.org/10.1080/13632469.2017.1342294.
- Ryu, K.P. and Reinhorn, A.M. 2017. "Analytical Study of Large-Area Suspended Ceilings," Journal of Earthquake Engineering, https://doi.org/10.1080/13632469.2017.1326416.
- Soroushian, S., Zaghi, A. E., Maragakis, E. M., Echevarria, A., Tian, Y., Filiatrault, A. 2015. "Analytical Seismic Fragility of Fire Sprinkler Piping Systems with Threaded Joints," Earthquake Spectra, 31(2), 1125-1155.
- Soroushian, S., Zaghi, A. E., Maragakis, E. M., Echevarria, A., Tian, Y., Filiatrault, A. 2015. "Seismic Fragility Study of Fire Sprinkler Piping Systems with Grooved Fit Joints," ASCE Journal of Structural Engineering, 141(6), 1-15. DOI: 10.1061/ (ASCE) ST.1943-541X.0001122.
- Sullivan, T.J., Calvi, P.M., and Nascimbene, R. 2013. "Towards improved floor spectra estimates for seismic design," Earthquakes and Structures, An International Journal, Techno Press, 4(1), 109-132.
- Tian, Y., Filiatrault, A. and Mosqueda, G. 2015. "Seismic Response of Pressurized Fire Sprinkler Piping Systems I: Experimental Study," Journal of Earthquake Engineering, 19(4), 649-673.
- Tian, Y., Filiatrault, A. and Mosqueda, G. 2015. "Seismic Response of Pressurized Fire Sprinkler Piping Systems II: Numerical Study," Journal of Earthquake Engineering, 19(4), 674-699.
- Vukobratović, V., and Fajfar, P. 2016. "A method for the direct estimation of floor acceleration spectra for elastic and inelastic MDOF structures," Earthquake Engineering & Structural Dynamics, 45, 2495–2511.
- Vukobratović, V., and Fajfar, P. 2017 "Code-oriented floor acceleration spectra for building structures," Bulletin of Earthquake Engineering, 15, 3013-3026.
- Wanitkorkul, A. and Filiatrault, A. 2008. "Influence of Passive Supplemental Damping Systems on Structural and Nonstructural Seismic Fragilities of a Steel Building," Engineering Structures, Vol. 30, No. 3, 675-682.

OTHER SUGGESTED REFERENCES:

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), 2017. 2012-2015 ASHRAE Handbook: HVAC Applications (2015), Refrigeration (2014), Fundamentals (2017), HVAC Systems and Equipment (2016), Atlanta, GA, available online at http://www.techstreet.com/ashrae/lists/ashrae_handbook.html.

ANSI MH16.1-2012. Specification for the Design, Testing and Utilization of Industrial Steel Storage Racks, American National Standard Institute, Washington, DC. Available online at:
http://webstore.ansi.org/RecordDetail.aspx?sku=ANSI+MH16.1-2012.

Gatscher, J.A., McGavin, G.L. and Caldwell, P.J. 2012. Earthquake Protection of Building Equipment and Systems – Bridging the Implementation Gap, ASCE Press, American Society of Civil Engineers, Reston, VA, Available online at: https://ascelibrary.org/doi/book/10.1061/9780784411520.

National Fire Protection Association (NFPA), 2016. NFPA 16: Standard for the Installation of Sprinkler Systems, Quincy, MA, Free online read-only version available at:
https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=13,
Printed version:
https://catalog.nfpa.org/NFPA-13-Standard-for-the-Installation-of-Sprinkler-Systems-2016-Edition-P114.aspx?icid=D729.

GRADING

Evaluation	% of Final Mark	Documentation
Assignments	50%	Open
Final Examination 13/07/18	50%	1 sheet A4

ASSIGNMENTS

The assignments must be solved individually or by teams of two students. The same teams must be maintained during the entire course. Each assignment shall be neatly written and shall be handed in on time (no exception). The first page of each assignment shall include the course name (i.e. Seismic Design and Analysis of Nonstructural Building Components), the title of the assignment, the date, the student name(s) and signature(s). An assignment must be signed to be accepted. No late assignments will be accepted. Each assignment will be returned a maximum of one week after the due date and the assignment solution will be posted in the course Dropbox promptly afterwards.

COURSE SCHEDULE

Week	Date	Lecture hours From____ To____	Tutorial hours From____ To_____	Subject	Total hours
1	4/2/20	9:00 am to 1:00 pm IUSS Sala del Calmino	2:30 pm to 5:30 pm IUSS Sala del Calmino	Lecture 1: Course Presentation; Chapter 1 – Introduction. Tutorial No.1: Assignment No. 1, Introduction to Ruaumoko and Opensees Software, Q&A.	7
	5/2/20	9:00 am to 1:00 pm IUSS Sala del Calmino	2:30 pm to 5:30 pm IUSS Sala del Calmino	Lecture 2: Chapters 2 - Practical Seismic Assessment and Mitigation of Nonstructural Building Components, Chapter 3 - Seismic Analysis of Nonstructural Building Components. Tutorial No.2: Assignment No. 2, Record Scaling and Producing Response Spectra with SeismoSpect, Introduction to Dynamic Analyses in OpenSees, Q&A.	7
	6/2/20	9:00 am to 1:00 pm IUSS Sala del Calmino	2:30 pm to 5:30 pm IUSS Sala del Calmino	Lecture 3: Chapter 4 - Seismic Design of Nonstructural Building Components. Tutorial No. 3: Assignment No. 3, Running Ruaumoko and Dynaplot in Batch Mode and Linking with Computer Programming, MatLab and OpenSees, Q&A.	7
2	11/2/20	9:00 am to 1:00 pm IUSS Sala del Calmino	2:30 pm to 5:30 pm IUSS Sala del Calmino	Lecture 4: Chapter 4 - continued Tutorial No. 4: Assignment No. 4, Modeling Equivalent SDOF Systems and Implementing User Specified Damping in Ruaumoko and Opensees, Q&A, Assignment No. 1 due at 5:30 pm.	7
	12/2/20	9:00 am to 1:00 pm IUSS Sala Del Calmino	2:30 pm to 5:30 pm IUSS Sala del Calmino	Lecture 5: Chapter 5 - Seismic Performance of Partition Walls. Tutorial No. 5: Assignment No. 5, Q&A, Assignment No. 2 due at 5:30 pm.	7
	13/2/20	9:00 am to 1:00 pm IUSS Sala Del Calmino	2:30 pm to 5:30 pm IUSS Sala del Calmino	Lecture 6: Chapter 5 - continued Tutorial No. 6: Assignment No. 6, Wayne-Stewart Hysteresis Model in RUAUMOKO and Estimating Wallboard Partition Damage, Pinching4 Material model in OpenSees, Q&A, Assignment No. 3 due at 5:30 pm	7
3	18/2/20	9:00 am to 1:00 pm IUSS Sala del Calmino	2:30 pm to 5:30 pm IUSS Sala del Calmino	Lecture 7: Chapter 6 - Seismic Performance of Pressurized Fire Suppression Sprinkler Piping Systems. Tutorial No. 7: Assignment No. 7, Q&A, Assignment No. 4 due at 5:30 pm.	7
	19/2/20	9:00 am to 1:00 pm IUSS Sala del Calmino	2:30 pm to 5:30 pm IUSS Sala del Calmino	Lecture 8: Chapter 7 - Seismic Performance of Steel Storage Racks. Tutorial No. 8: Assignment No. 8, Q&A, Assignment No. 5 due at 5:30 pm.	7
	20/2/20	9:00 am to 1:00 pm IUSS Sala del Calmino	2:30 pm to 5:30 pm IUSS Sala del Calmino	Lecture 9: Chapter 8 - Seismic Performance of Vibration-Isolated Mechanical Equipment. Tutorial No. 9: Q&A, Assignment No. 6 due at 5:30 pm.	7
4	25/2/20	9:00 am to 1:00 pm IUSS Sala del Calmino	2:30 pm to 5:30 pm IUSS Sala del Calmino	Lecture 10: Chapter 9 - Seismic Performance of Suspended Ceiling Systems. Tutorial No. 10: Q&A. Assignment No. 7 due at 5:30 pm	7
	26/2/20	9:00 am to 1:00 pm IUSS Sala del Calmino	2:30 pm to 5:30 pm IUSS Sala del Calmino	Lecture 11: Chapter 10 - Seismic Performance of Bookcase-Partition Wall Systems. Tutorial No. 11: Q&A, Assignment No. 8 due at 5:30 pm.	7
	27/2/20	9:00 am to 1:00 pm IUSS Sala del Calmino	2:30 pm to 5:30 pm IUSS Sala del Calmino	Lecture 12: Contingency and review. Tutorial No. 12: Q&A, Review.	7
	28/2/20	9:00 am to 12:00 pm EUCENTRE 1 Classroom	---	AM: Final written examination	3
				Total hours	**87**