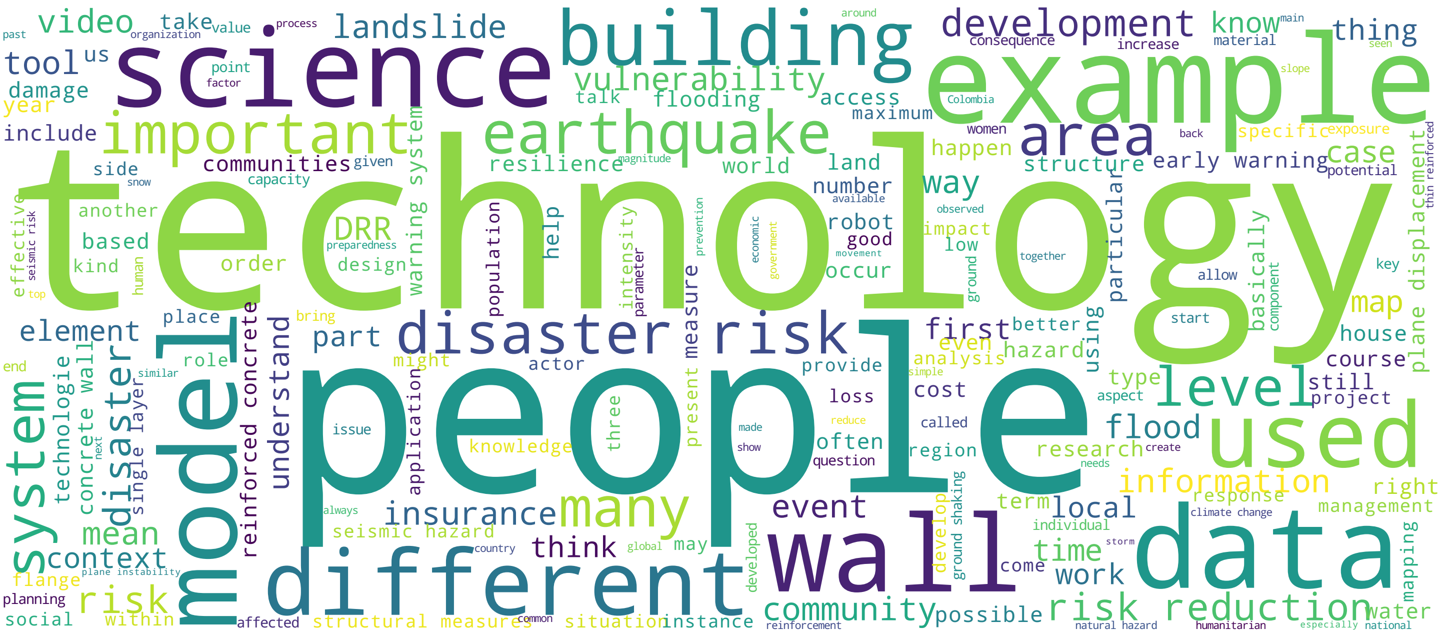
Integration of Tools, Technology, and Capacity: Application

A Resilient Future: Science and Technology for Disaster Risk Reduction

Dr. João Almeida
Former Postdoctoral Researcher
Earthquake Engineering and Structural Dynamics Laboratory

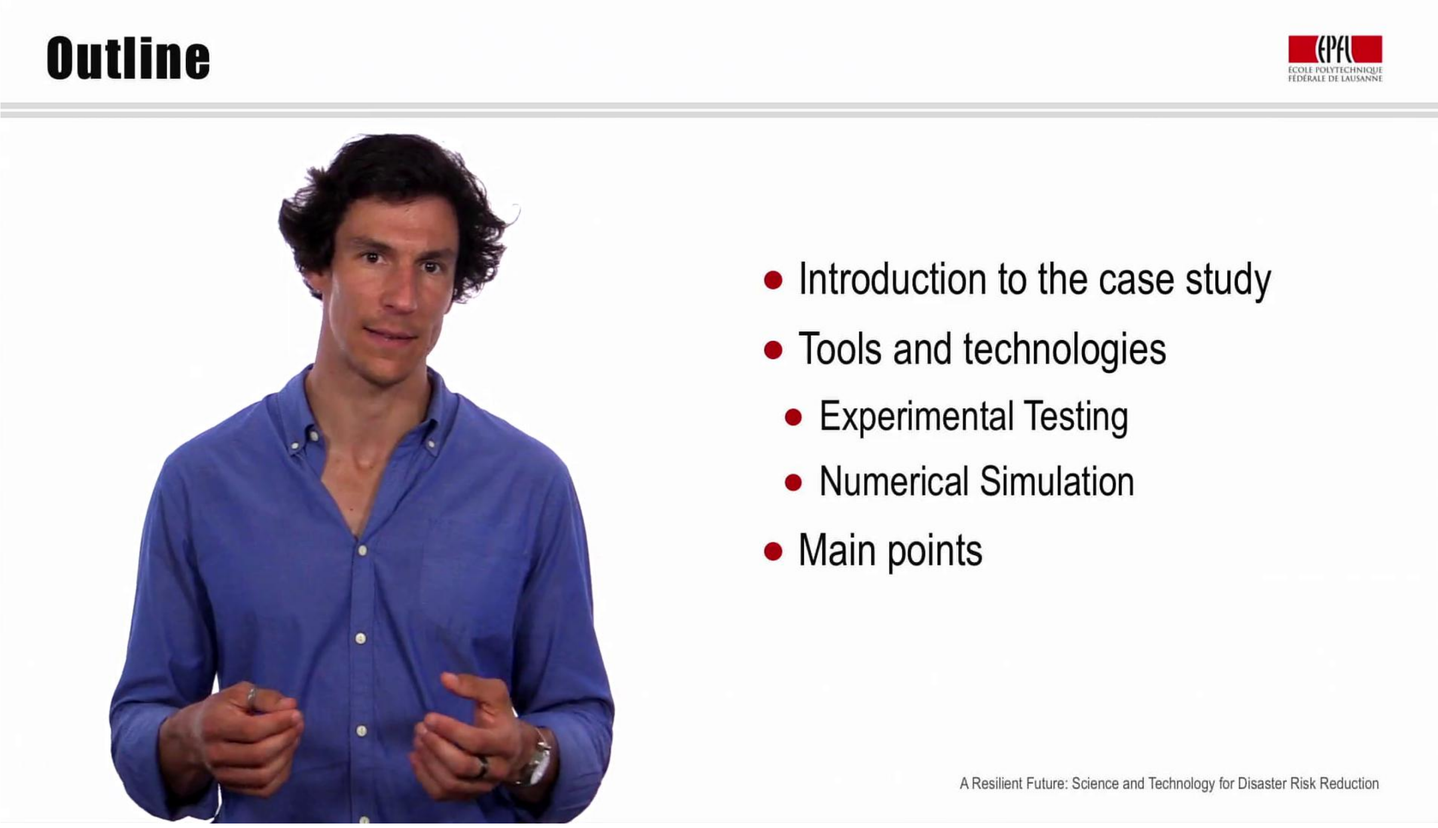
EESD



Search MOOC

Video

EPFL

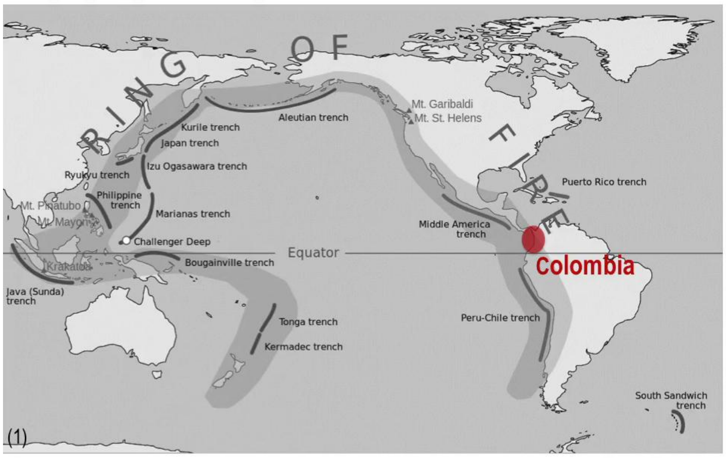


Hi again, science and technology can be used to increase disaster risk reduction knowledge which is a prior step to the development and implementation of structural and non-structural measures to mitigate risk. In this video I will give an example on the use of tools and technologies within the context of seismic risk. I will mainly focus on the application of experimental testing, which ideally should be combined with appropriate numerical simulation techniques.

Notes

Summary

0m 04s



1999 Armenia Earthquake, Colombia (~1900 deaths)

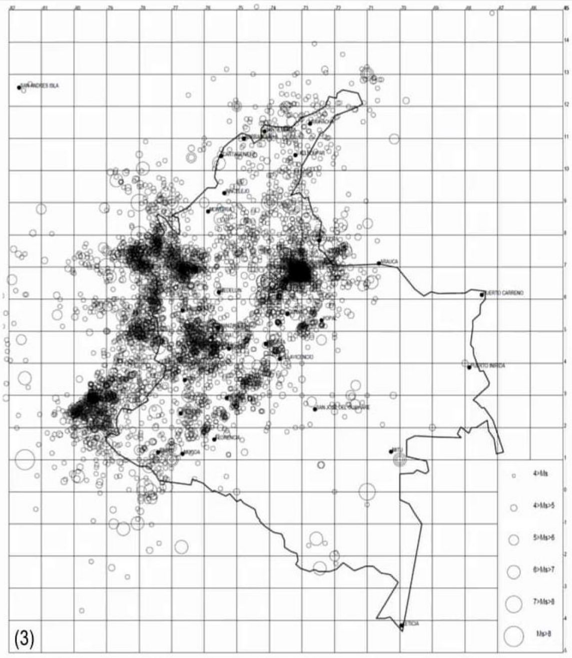
The pacific ring of fire is a long stretch of area along which most of the world's largest earthquakes and volcanic activities take place. Colombia is located in this region and it is therefore a seismically active country. In its long history of earthquakes, the first seismic event that we know of dates back to 1541. Since then, there have been many large magnitude earthquakes hitting the country, among which the one of 1906, with an estimated magnitude of around 8.8, ranks high within the list of strongest earthquakes ever. More recently, the Armenia earthquake of 1999 with a magnitude of 6.2 set a death toll of almost 2000 people.

Notes

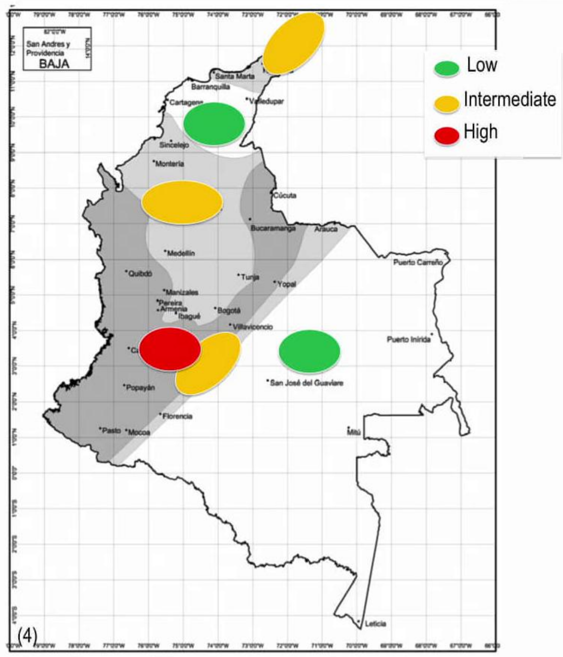
Summary

0m 34s

Introduction to the case study



Epicentral Location of Earthquakes with $M_s \geq 3$



Seismic Zonation Map for Colombia

This figure shows the epicentral location of earthquakes in Colombia taken from a catalog containing 9000 seismic events with magnitude above three. The seismic zonation map included in the Colombian construction code reflects this historical epicentral location of earthquakes. The country is divided into three main regions, with low, intermediate, and high level of seismic hazard.

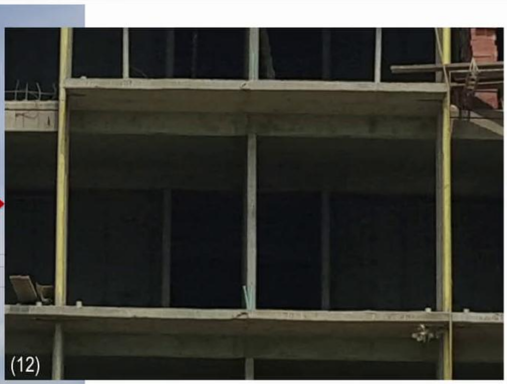
Notes

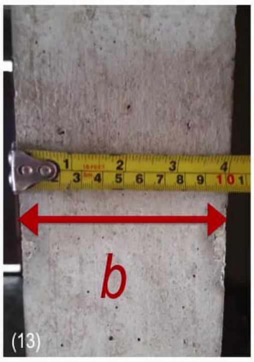
Summary

1m 20s

Introduction to the case study


(11)


(12)



(13)

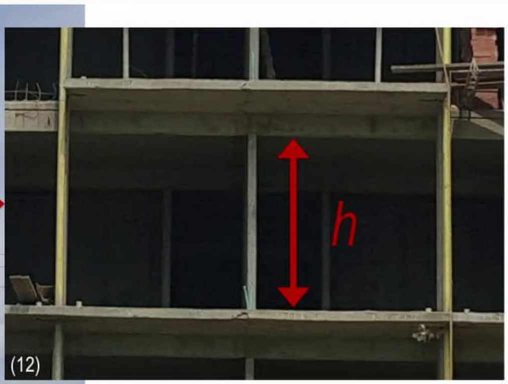
Although major cities are fortunately located in regions of low to medium seismic hazard, almost 40% of the population lives in areas of high seismicity. In these areas, the building code requires engineers to design the structures such that they can resist to horizontal forces equal to half of their own total weight. This is the case of the city of Cali, the third largest in Colombia, from where the next photos were taken. Over the last 10 to 15 years the increasing demand of housing for low income population in Colombia associated to the significant increase of cost of land has prompted construction companies to massively build medium to high rise reinforced concrete wall buildings. These structures are made of concrete and reinforcing steel and require a relatively non-specialized and cheap labor. Comparatively, the cost of materials is high and has pushed to the development and application of construction techniques that minimize its use. It is therefore not surprising that most of these new residential buildings have been constructed with walls that have thicknesses as low as 80 millimeters. Besides, there are typically only lightly reinforced often with just a single layer of steel rebars instead of the more common two rebar configuration.

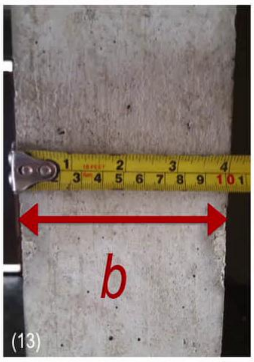
Notes

Summary

1m 46s

Introduction to the case study





- Residential buildings constructed with very thin walls and only one layer of reinforcement
- Very large ratios h / b $\Rightarrow$ Out-of-plane instability under seismic loading?

The end result are walls with very large ratios between their height and their thickness raising concerns regarding the possible development of instability when the earthquake strikes. That is, to say seismic loading.

Notes

Summary

3m 12s

Introduction to the case study


(14)


(15)


(16)

A Resilient Future: Science and Technology for Disaster Risk Reduction

It is a bit like holding a playing card in between your fingers and compressing it. Since the card is quite thin and very elongated, it will buckle or bend in direction perpendicular to it's own plane. Something similar can happen with thin reinforced concrete walls but we will see more about it soon. This failure mode was observed in the recent earthquakes of Chile in 2010 and of New Zealand in 2011, which caused significant damage to some modern reinforced concrete walls. These pictures show examples of buckled structural walls after the ground shaking suggesting stability problems.

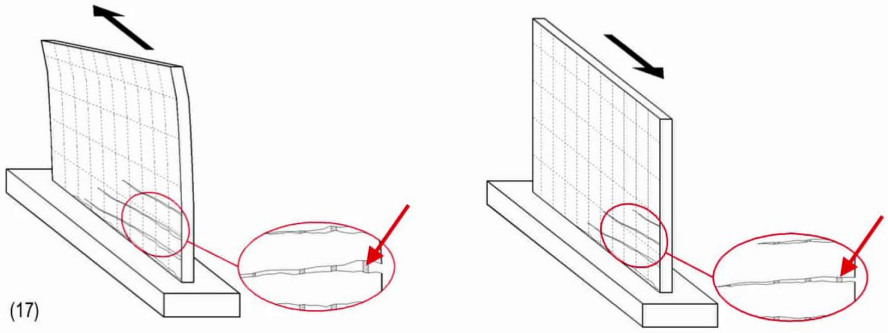
Notes

Summary

3m 27s

Introduction to the case study

How does out-of-plane instability occur?

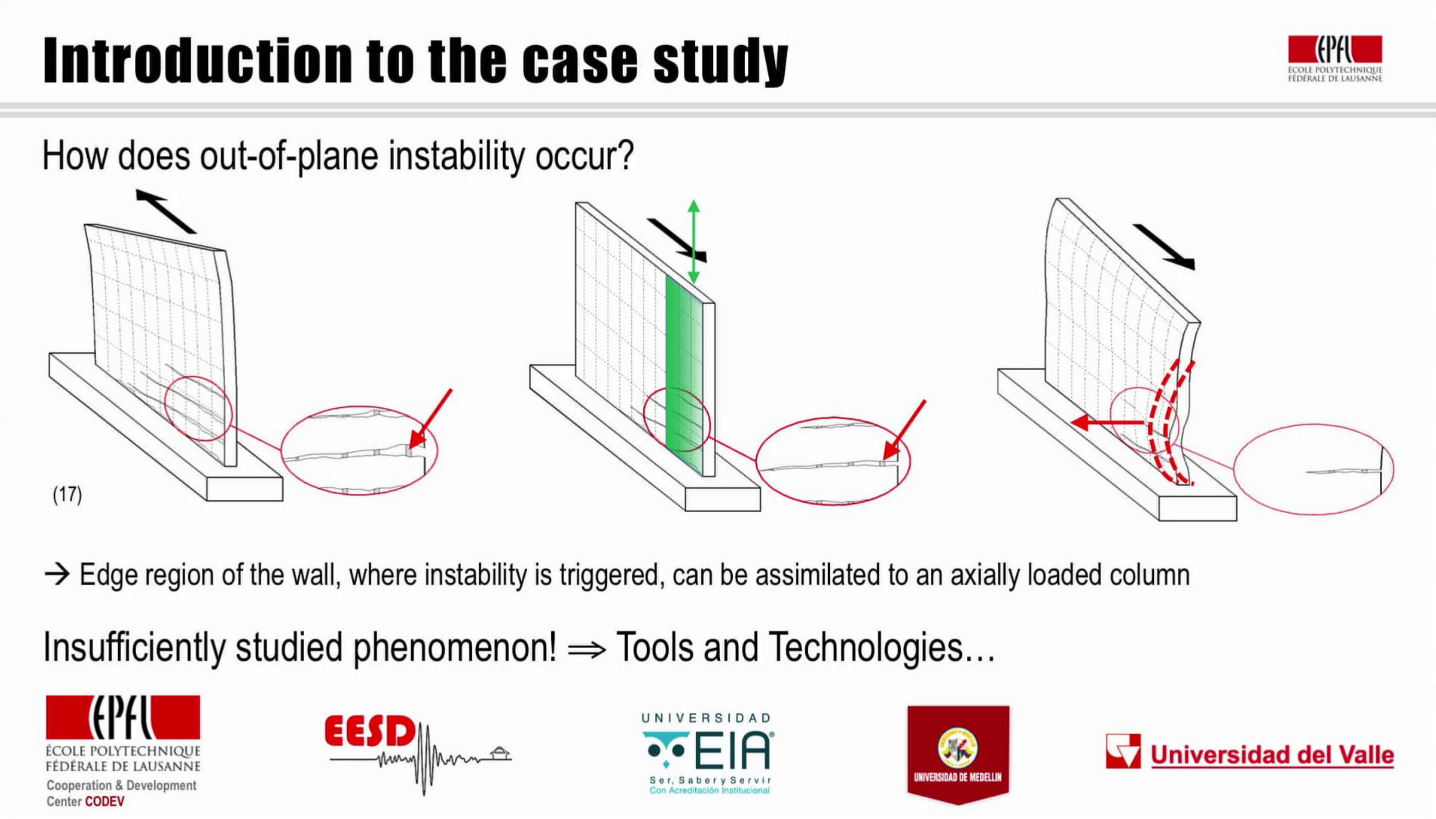


In Colombia, since the walls are significantly thinner than those used in Chile or in New Zealand, it is legitimate to fear that similar, out-of-plane deformations, and even failure could occur during a future earthquake. Additionally, the use of a single layer of reinforcement in some of these Colombian buildings may increase the vulnerability to out-of-plane instability. So, how does out-of-plane instability occur? When the earthquake pushes the wall in one direction, nearly horizontal cracks form in the bottom-edge region due to the large tensile strains that are imposed. As these cracks open, the vertical steel rebars inside the concrete yield in tension. When the ground shaking pulls back the wall, the plastic tensile strains accumulated in the rebars during the prior push phase prevent the cracks from closing. This means that the compression force in that part of the wall is resisted solely by the rebars and not by the concrete. As this compression force increases, the rebar may yield, leading to an abrupt reduction in out-of-plane stiffness and the consequent increase in the corresponding out-of-plane displacements, which can potentially lead to failure.

Notes

Summary

4m 08s



This was a very simplified explanation of the instability phenomenon, which unfortunately has been insufficiently studied in the past. Therefore, many aspects are still not clear, which we should strive to understand, but how? The most obvious answer, perhaps the best is, experimental testing. These tests can be carried out in walls or in a cheaper and simpler way, in actually loaded columns that are equivalent to the boundary element of the wall. This is where tools and technologies step in. The Earthquake Engineering and Structural Dynamics Laboratory of EPFL has teamed up with a few different Colombian universities to address this issue in two projects financed by the Cooperation & Development Centre of EPFL, CODEV.

Notes

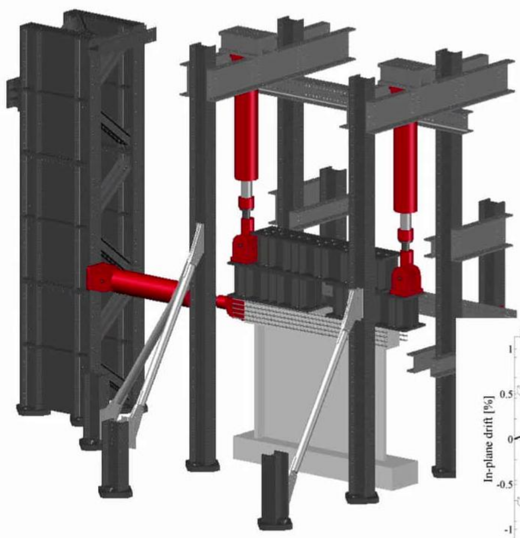
Summary

5m 29s

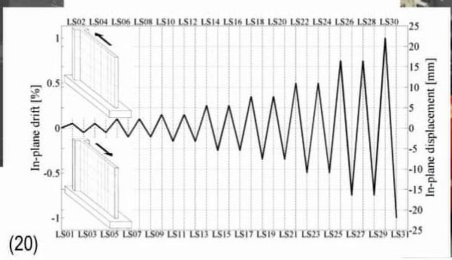
Tests on Thin Reinforced Concrete Walls

EESD

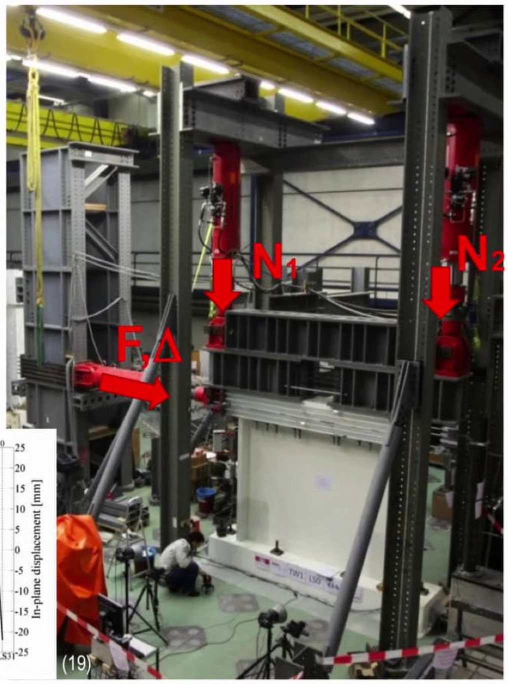
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
Cooperation & Development Center CODEV



(18)



(20)



(19)

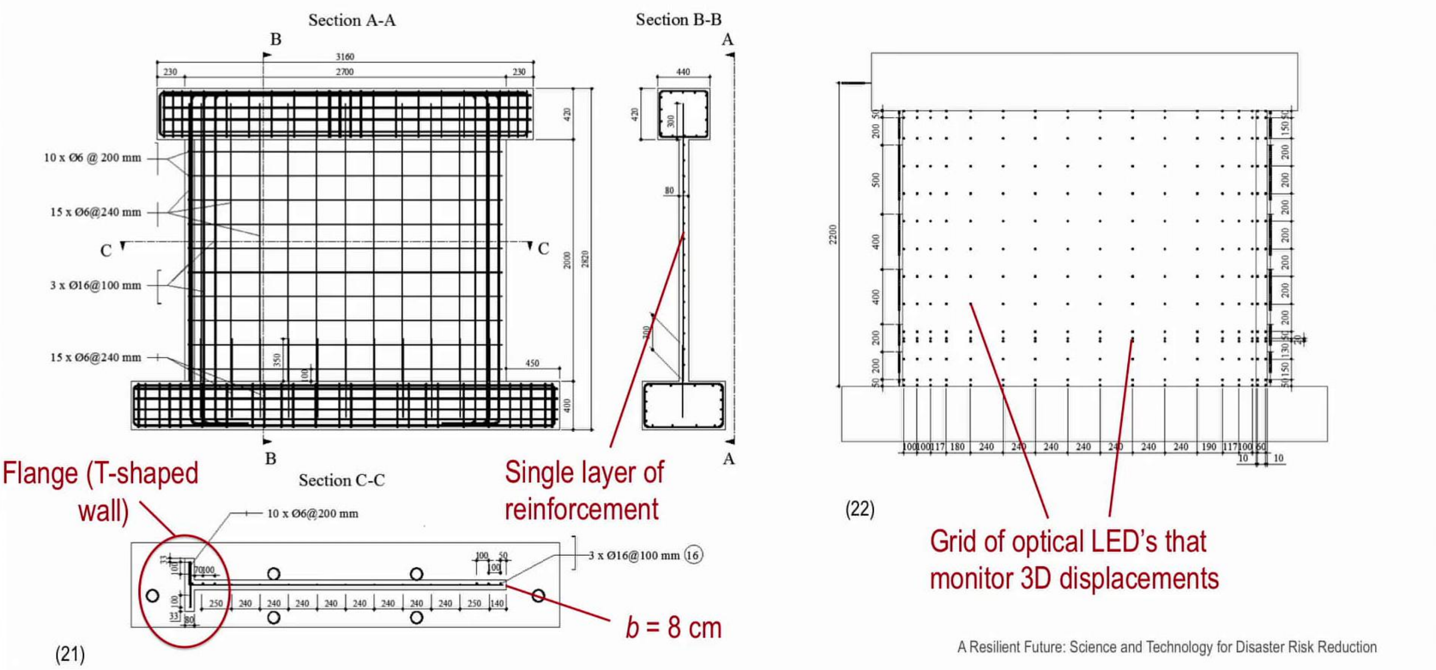
In the first project a thin reinforced concrete wall was tested using the test setup that one can see in this sketch and in the picture on the right. The test unit represents the portion of the wall on the ground story of a multi-story building, and therefore the applied boundary conditions and loading should reproduce those in the real building as much as possible. To do so, the test unit is loaded with three actuators. Two vertical ones, which simulate the weight of the stories above and, in a way, how they rotate during the ground shaking, and a horizontal one, which applies a cyclic displacement history of increasing amplitude that simulates the earthquake's loading effects.

Notes

Summary

6m 19s

Tools and technology > Experimental testing



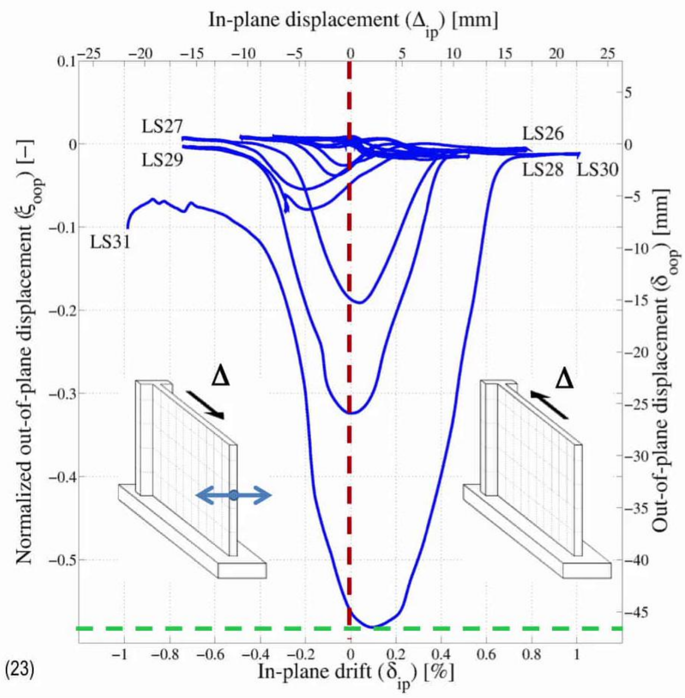
The wall was designed and built such that its geometrical dimensions, the material properties and the detailing of the reinforcement are similar to what we could find in a recent Colombian building. Note the low thickness of the wall, only eight centimeters, the use of a single layer of vertical and horizontal rebars and the presence of a flange in one of the extremities. In terms of measurements, these small dots in the figure represent a dense grid of optical light emitting diodes that monitor the evolution of the 3D displacement field throughout the loading.

Notes

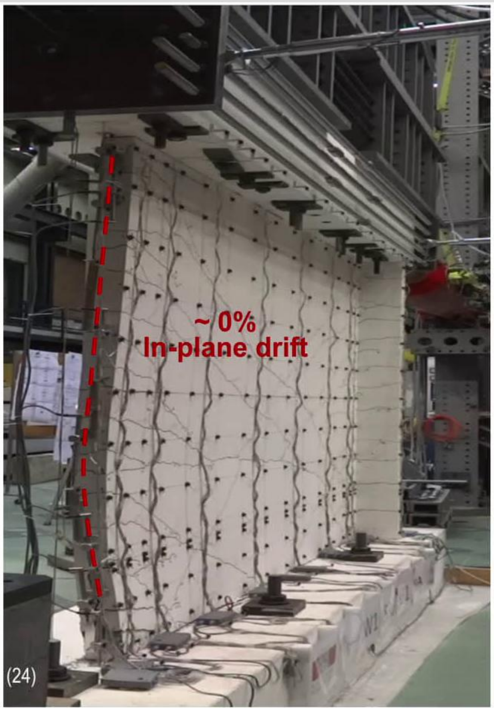
Summary

7m 06s

Tools and technology > Experimental testing



(23)



(24)

After the experiment has been conducted, we can post-process the data obtained with these LEDs and obtain plots such as this one. It shows, on the horizontal axis, the value of the imposed horizontal displacement at the top of the wall. To the left, when we're pulling towards the wall side that does not have the flange, which is when instability can occur, and to the right, when we are pushing towards the flange. The vertical axis displays the out-of-plane displacement at the height where maximum out-of-plane displacement was measured. It can be observed that the maximum out-of-plane displacement was higher than 45 millimeters, that is, more than half of the wall thickness. In addition, this plot shows that, for each cycle of increasing amplitude, the maximum out-of-plane displacement is attained approximately at 0% in-plane-drift, after which the wall straightens up again.

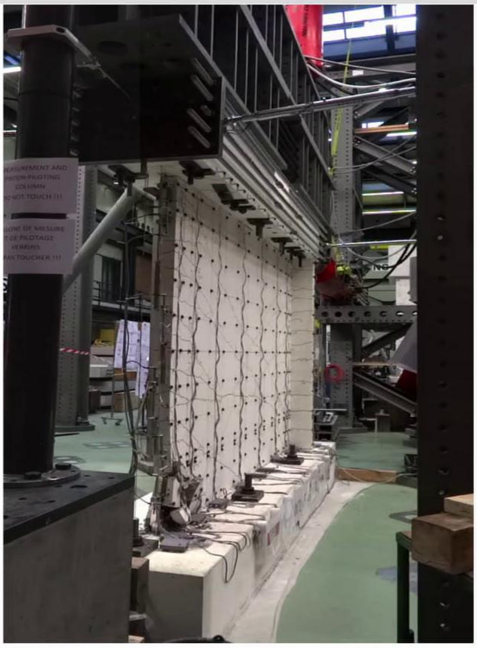
Notes

Summary

7m 44s

Tools and technology > Experimental testing

(25)



(26)

A Resilient Future: Science and Technology for Disaster Risk Reduction

The next time-lapse shows this structural behaviour during one half-cycle, over which, the wall is pulled towards the side that does not have the flange. The out-of-plane displacement progressively increases up to a maximum value reducing after. At the end of that half cycle, we can also see some concrete crushing and spalling at the base of the wall which was partially triggered by the large, out-of-plane deformations previously attained.

Notes

Summary

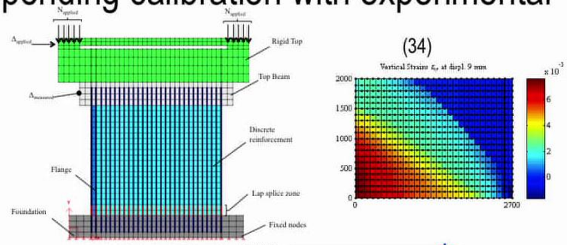
8m 45s

Development of finite element models and corresponding calibration with experimental results

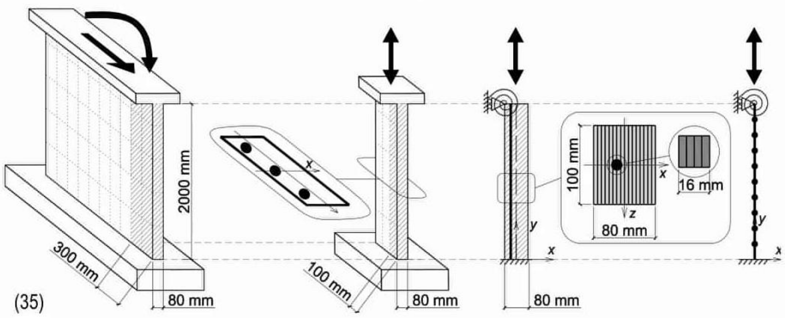
→ Shells with advanced nonlinear material models

(33)

(34)

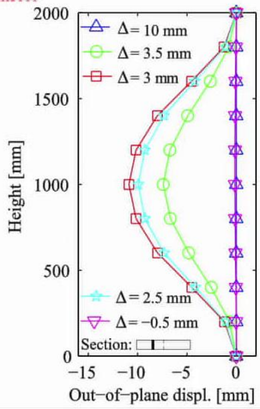


→ Beams with distributed plasticity and sectional fibre discretization



(35)

(36)



Finally, all these information and data that we manage to gather from experiments can be used to develop and calibrate numerical models. They range in their complexity from shell finite elements with advanced nonlinear material models to beams, where the cross section of the member is discretized into fibres among other even simpler approaches. Our studies have shown that many of these models do a pretty good job in simulating wall instability, which means that they can be used by practicing engineers to design and access the vulnerability of walls and buildings.

Notes

Summary

9m 15s

Main points

- New construction techniques may develop lesser known failure modes under earthquake loading
- Science and technology should be used to study and understand structural vulnerability
- The improvement of seismic risk reduction knowledge is fundamental to mitigation strategies

A Resilient Future: Science and Technology for Disaster Risk Reduction

To sum up, in this video we saw how thin reinforced concrete walls with a single layer of reinforcement are extensively used in modern construction in Colombia. They can be prone to out-of-plane instability with unknown and possibly serious consequences on the seismic vulnerability of buildings. Science and technology can and should be used to better understand the behavior of thin walls, combining experimental tests using new instrumentation techniques that provide detailed information on the local member response with advanced numerical simulation models. If needed, structural measures such as seismic retrofit or nonstructural measures including changes to the design codes or the development of new tools for design engineers, should be implemented. Overall, technologies can greatly improve seismic risk reduction knowledge which helps defining long-term strategies for the prevention or mitigation of the adverse effects of earthquakes.

Notes

Summary

9m 53s

References

- NIST (2014) Recommendations for seismic design of reinforced concrete wall buildings based on studies of the 2010 Maule, Chile Earthquake. National Institute of Standards and Technology, U.S. Department of Commerce, Gaithersburg
- NSR-10 (2010) Reglamento Colombiano de Construcción Sismo Resistente—Comisión Asesora Permanente para el Régimen de Construcciones Sismo Resistentes. Bogotá D.C, Colombia
- Rosso, A., Almeida, J.P. and Beyer, K. (2016) Stability of thin reinforced concrete walls under cyclic loads: state-of-the-art and new experimental findings. Bulletin of Earthquake Engineering, 14, 455–84.
- Rosso, A., Almeida, J.P., Jimenez, L., Beyer, K., Guerrero, Z.P., Blandon, C. et al. (2016) Experimental tests on the out-of-plane response of RC columns subjected to cyclic tensile-compressive loading. 16th World Conference on Earthquake Engineering, Santiago, Chile
- Sritharan, S., Beyer, K., Henry, R.S., Chai, Y.H., Kowalsky, H. and Bull, D. (2014) Understanding poor seismic performance of concrete walls and design implications. Earthquake Spectra, 30, 307–34

Thank you for watching this video.

Notes

Summary

10m 58s

Image credits

Image credits in order of appearance (please consult the annex to access the links)

Cover picture: "Jimbocho Theater-2" by Real Estate Japan is licensed under CC BY 2.0

(1) Modified from "Pacific Ring of Fire" by gringer licensed under public domain

(2) Void

(3) NSR-10 (2010) Reglamento Colombiano de Construcción Sismo Resistente—Comisión Asesora Permanente para el Régimen de Construcciones Sismo Resistentes. Bogotá D.C, Colombia.

(4) NSR-10 (2010) Reglamento Colombiano de Construcción Sismo Resistente—Comisión Asesora Permanente para el Régimen de Construcciones Sismo Resistentes. Bogotá D.C, Colombia.

(5) EPFL- UniValle SEED Money project - Lisandro Jimenez

(6) "Portugues Dam" by JaxStrong is licensed under CC BY 2.0

(7) EPFL- UniValle SEED Money project - Lisandro Jimenez

(8) "Five Floors Up" by Talbot Troy is licensed under CC BY 2.0

(9) "Coin Graph" by Petr Kratochvil is licensed under CC0 1.0

(10) Modified from "Coin Graph" by Petr Kratochvil licensed under CC0 1.0

(11) EPFL- UniValle SEED Money project - Lisandro Jimenez

(12) EPFL- UniValle SEED Money project - Lisandro Jimenez

(13) EPFL- UniValle SEED Money project - Lisandro Jimenez

(14) Sritharan, S., Beyer, K., Henry, R.S., Chai, Y.H., Kowalsky, H. and D. Bull (2014) Understanding poor seismic performance of concrete walls and design implications. Earthquake Spectra, 30, 307–34.

Notes

Summary

11m 02s

Image credits

Image credits in order of appearance (please consult the annex to access the links)

(15) NIST (2014) Recommendations for seismic design of reinforced concrete wall buildings based on studies of the 2010 Maule, Chile Earthquake. National Institute of Standards and Technology, U.S. Department of Commerce, Gaithersburg.

(16) NIST (2014) Recommendations for seismic design of reinforced concrete wall buildings based on studies of the 2010 Maule, Chile Earthquake. National Institute of Standards and Technology, U.S. Department of Commerce, Gaithersburg.

(17) - (26) EPFL – EESD

(27) - (32) Void

(33) EPFL – CODEV

(34) - (36) EPFL – EESD

Notes

Summary

11m 04s