

CHILE 2010 EARTHQUAKE

An overview and a lesson learned

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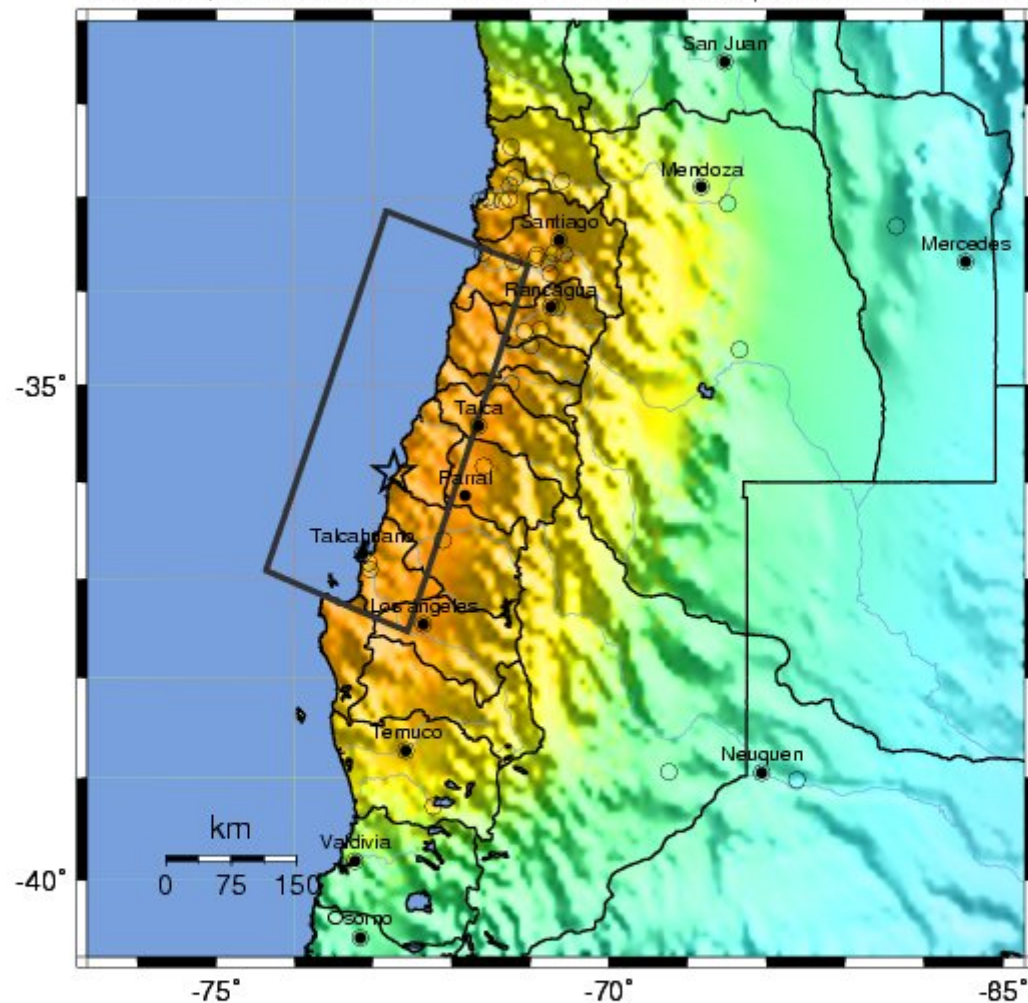
Basic data

- Date: 27.2.2010 at 3:34 (local time)
- $M_W = 8.8$
- Focal depth: 35 km
- Rupture length: about 500 km
- Epicentral distance
 - Santiago 335 km
 - Concepcion 105 km
- Intensity: MMI = IX and less



USGS ShakeMap : OFFSHORE MAULE, CHILE

Sat Feb 27, 2010 06:34:14 GMT M 8.8 S35.91 W72.73 Depth: 35.0km ID:2010tfan

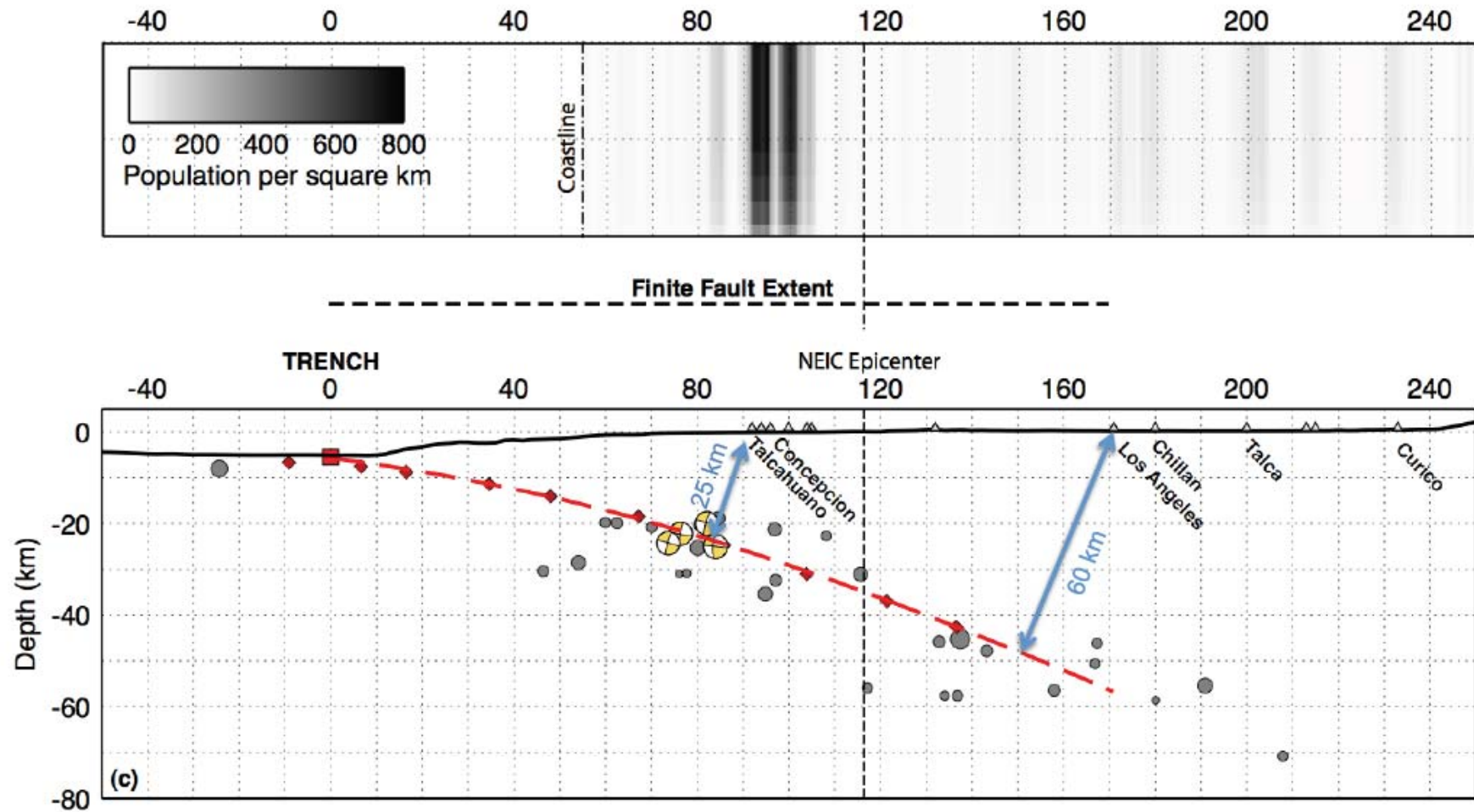


Map Version 7 Processed Fri Mar 5, 2010 03:00:13 AM MST -- NOT REVIEWED BY HUMAN

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Chile Earthquake: Depth extent of faulting

Closest cities to fault that slipped is about 25 km:







AP











Comparisons

Earthquake	Date	Magnitude M_W	Depth (km)	Max.intensity MMI	a_{gmax} (% g)	v_{gmax} (cm/s)
Chile	27/02/2010	8.8	35	IX	65	35?
Haiti	12/01/2010	7.0	13	X	30?	80?
L'Aquila	06/04/2009	6.3	9	IX-X	66	43

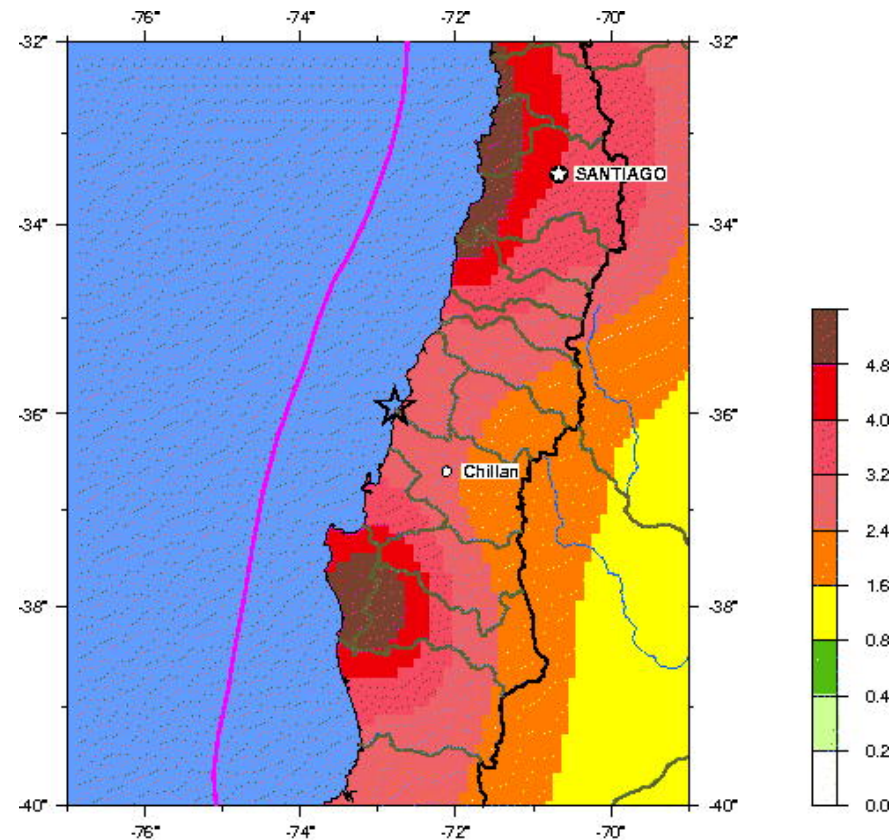
Data: USGS, Progettazione Sismica (L'Aquila)

Comparisons

Earthquake	Year	Killed	Wounded	Displaced	Destroyed Damaged Buildings	Damage (billion)
Chile	2010	521+56?	12.000	800.000	370.000	30 (USD)
Haiti	2010	222.570	300.000	1,300.000	285.000	8 (USD)
L'Aquila	2009	287	1.000	40.000	10.000	16 - 25 (Euro)

Data: mostly USGS

Design ground accelerations



OFFSHORE MAULE, CHILE

2010 02 27 06:34:14 UTC 35.93S 72.78W Depth: 35 km, Magnitude: 8.8

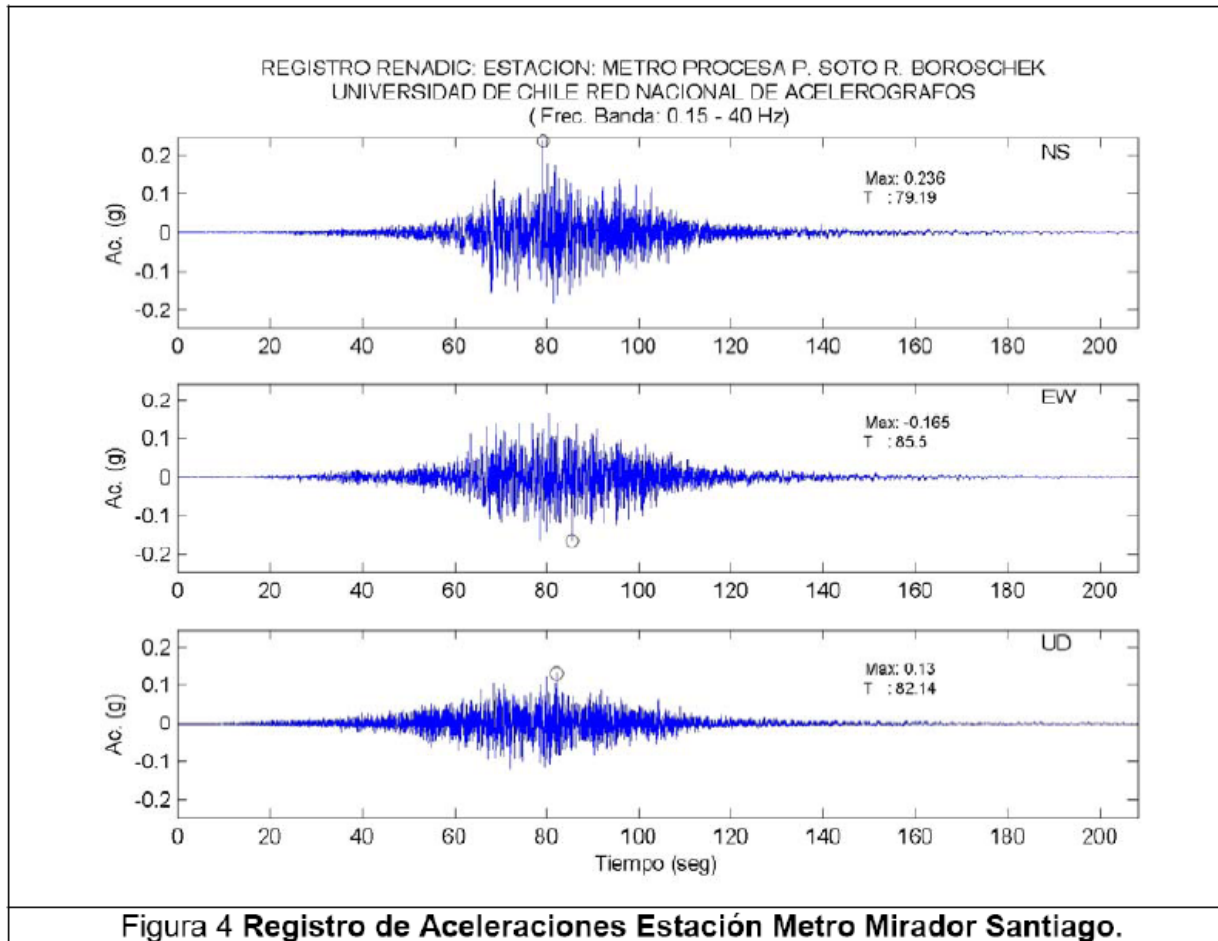
Peak Ground Acceleration (m/s²) with 10% Probability of Exceedance in 50 Years

Maximum accelerations

Station	Hor. PGA	Ver. PGA
Univ. de Chile, Depto Ing. Civil, Santiago	0.17	0.14
Metro Mirador Santiago	0.24	0.13
CRS MAIPU RM	0.56	0.24
Hosp. Tisne RM	0.30	0.28
Hosp. Sotero de Rio RM	0.27	0.13
Hosp. Curico	0.47	0.20
Hosp. Valdivia	0.14	0.05
Vina del Mar (Marga Marga)	0.35	0.26
Vina del Mar (Centro)	0.33	0.19
Colegio San Pedro, Concepción	0.65	

(Boroschek, 2010 and GEER, 2010)

Accelerograms Santiago

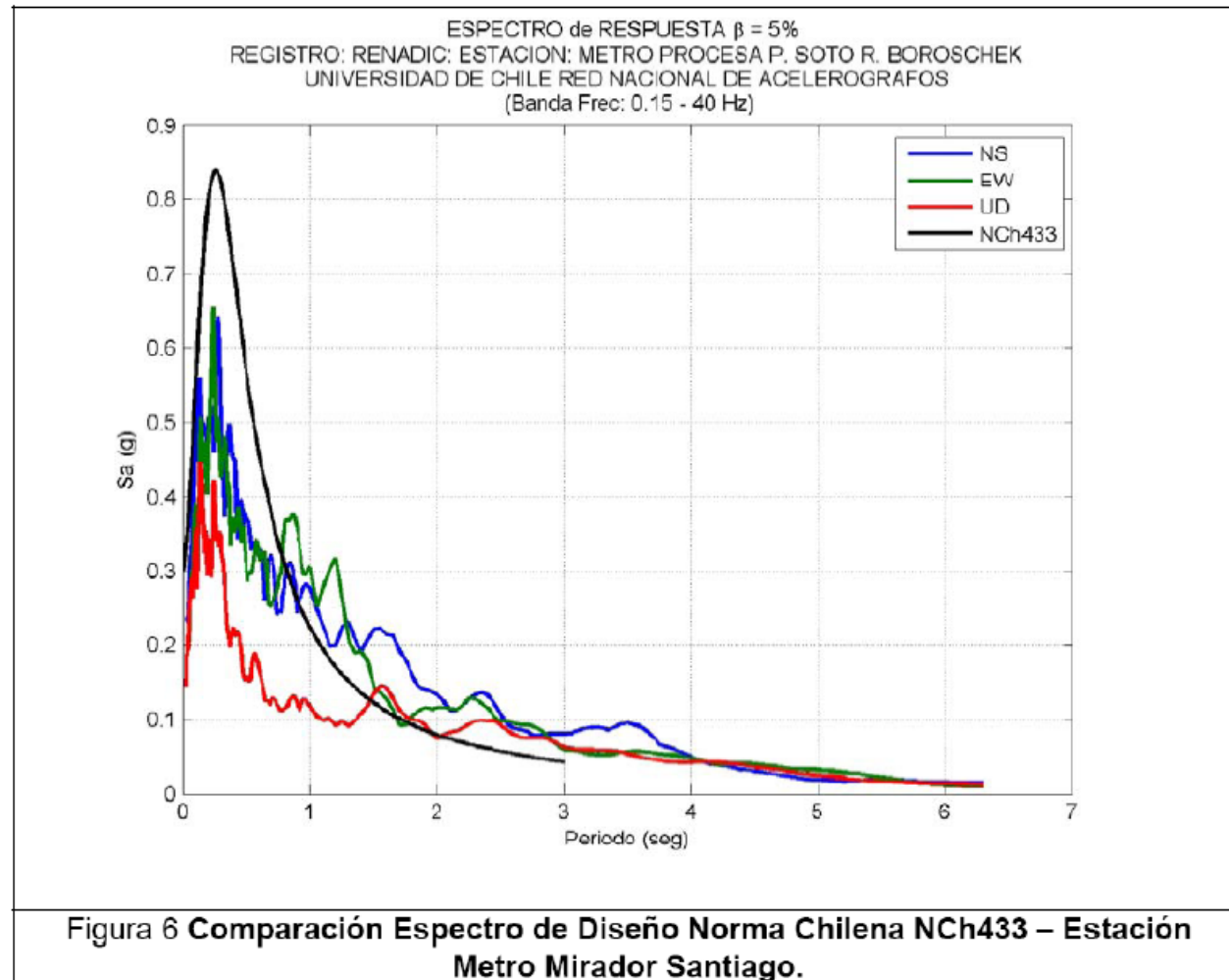


L'Aquila

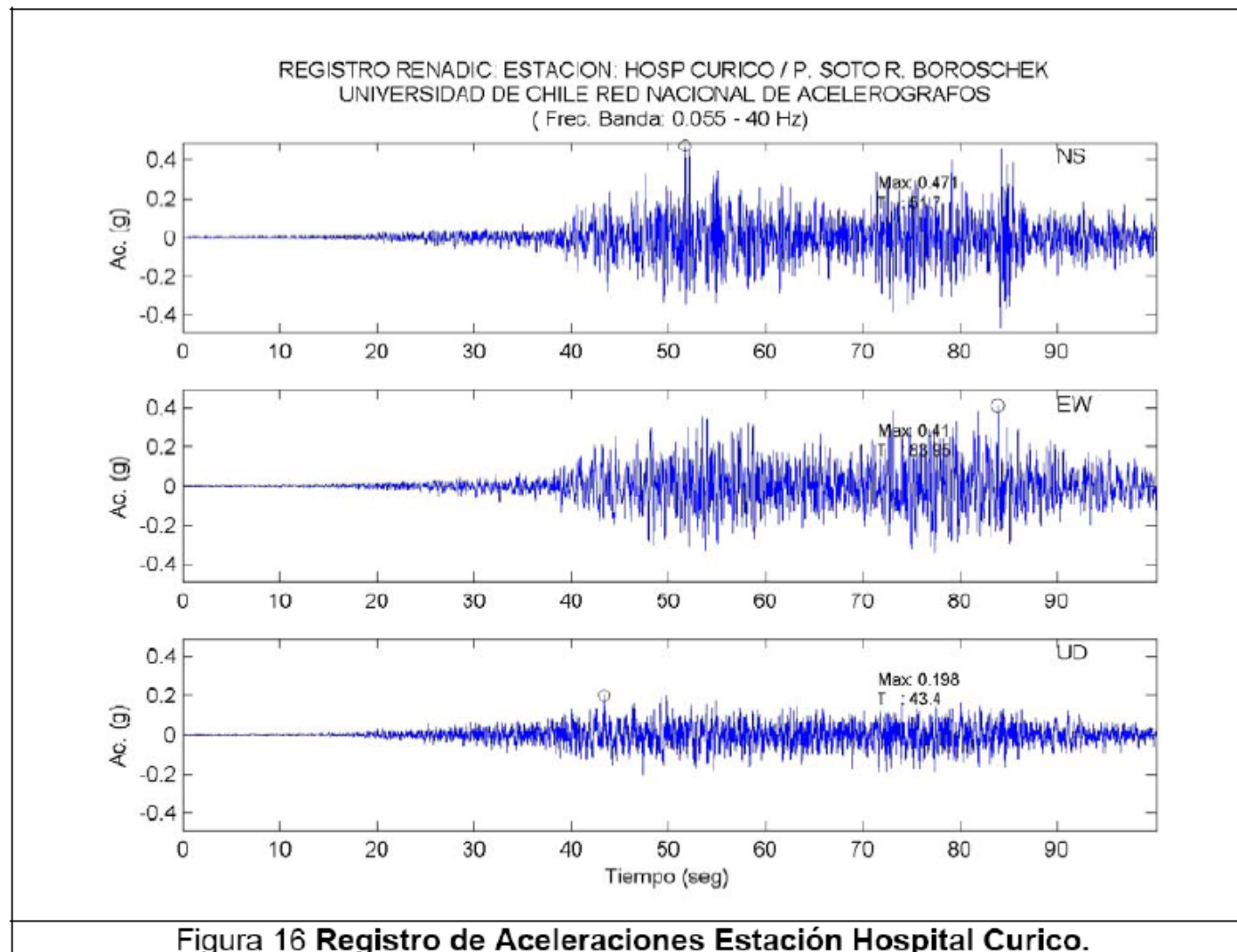


Soto, Boroschek

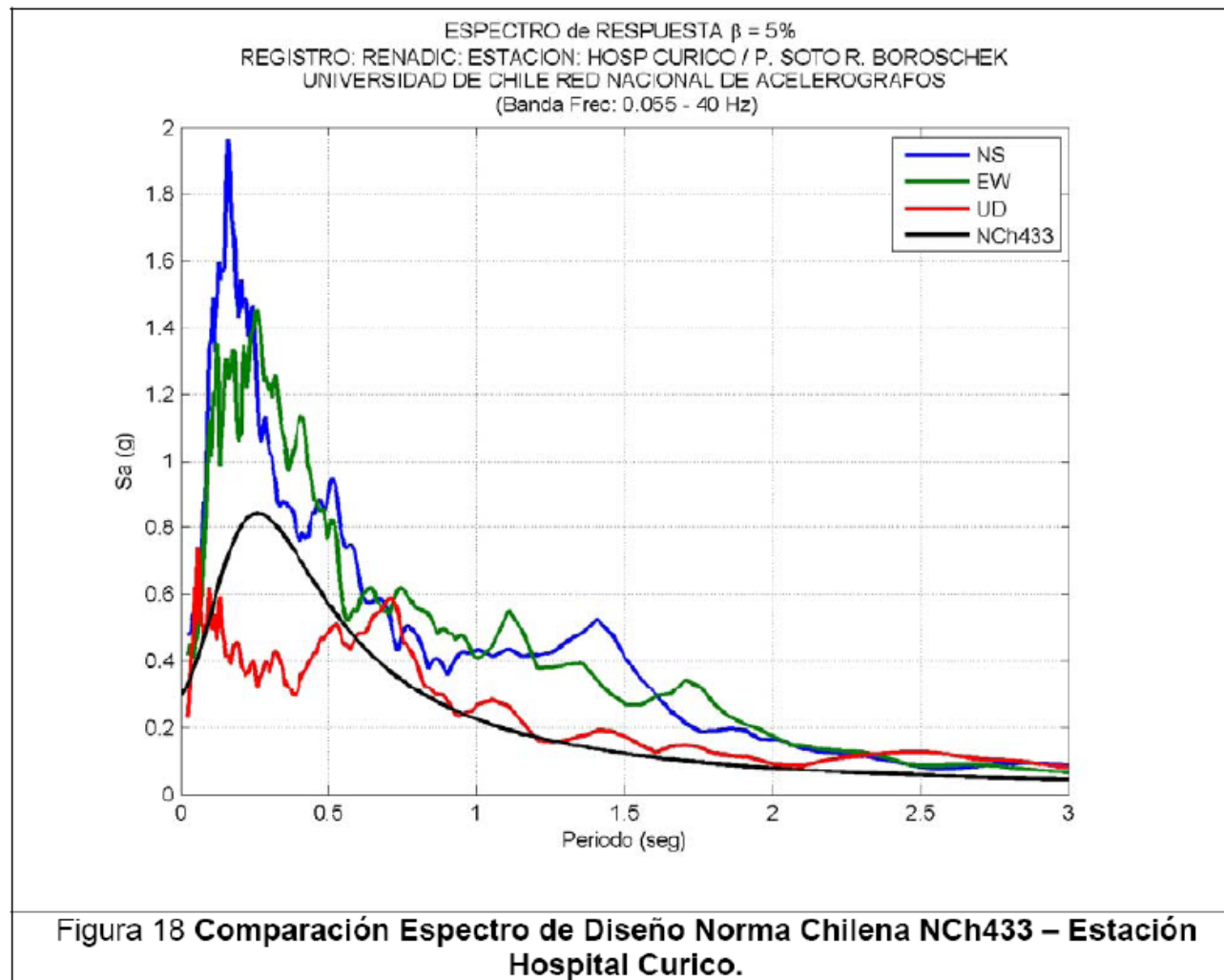
Acceleration spectra Santiago

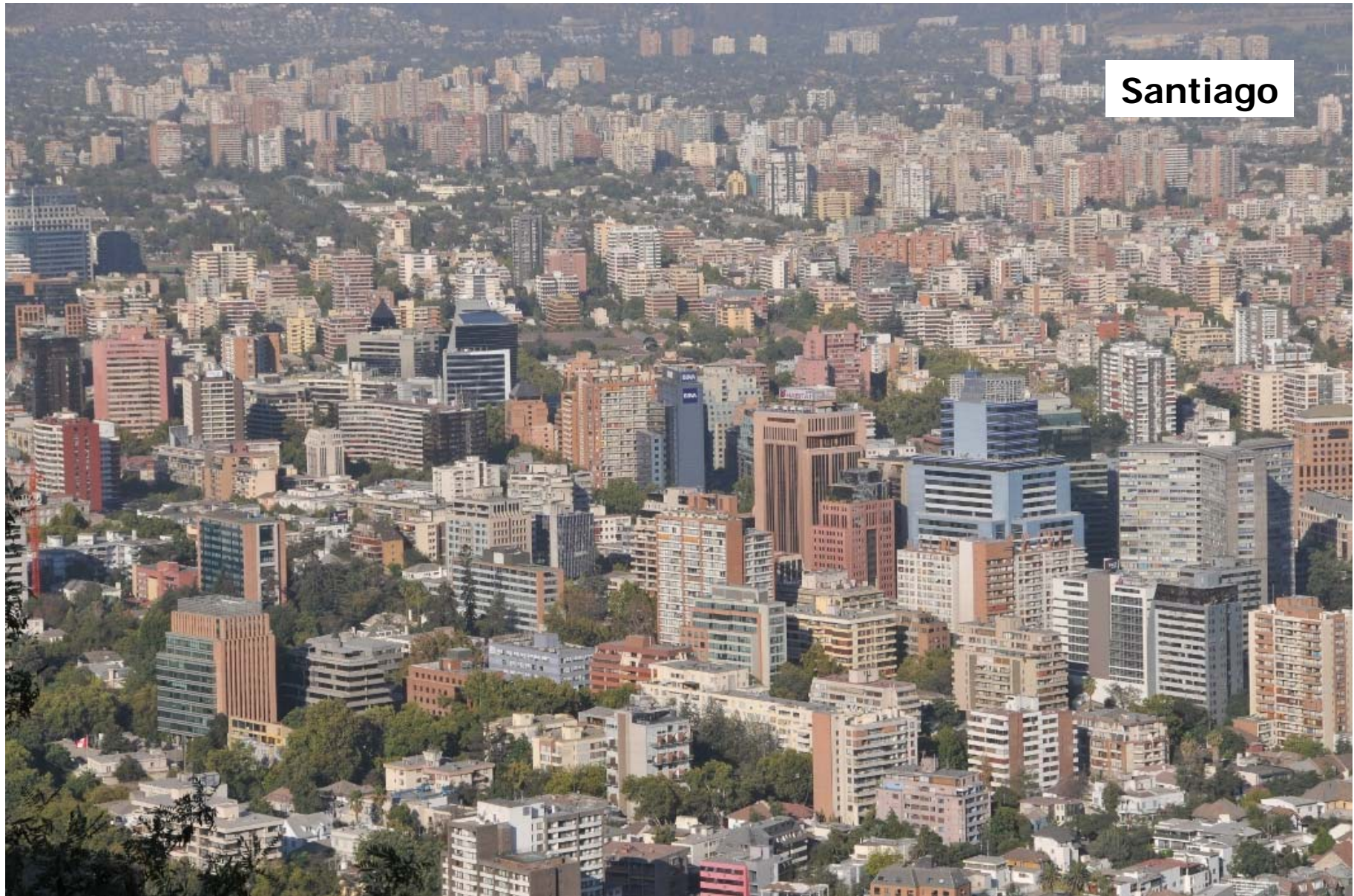


Accelerograms Curico



Acceleration spectra Curico



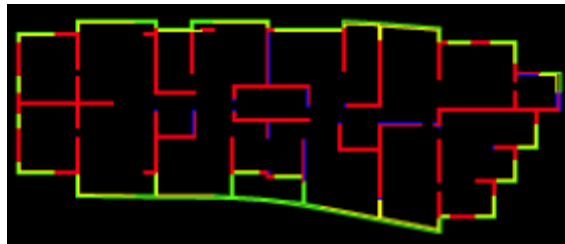


Santiago



Viña del Mar

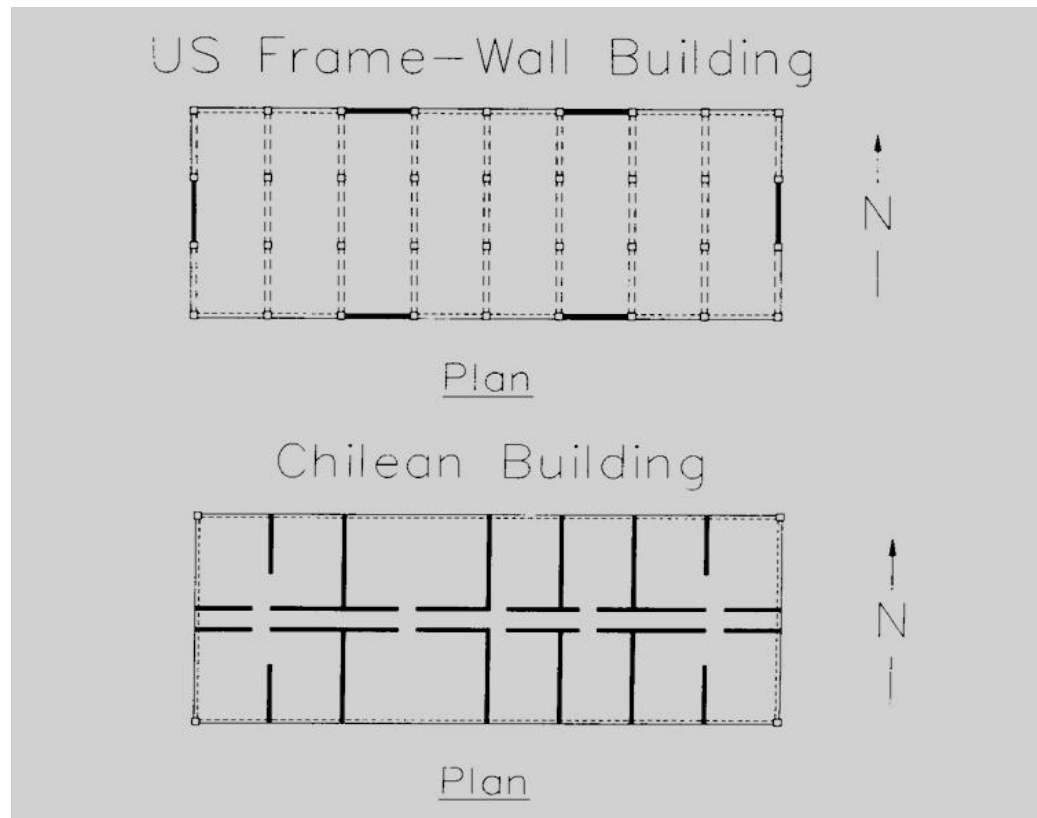
New buildings Chile



19 Stories + 3 Basement

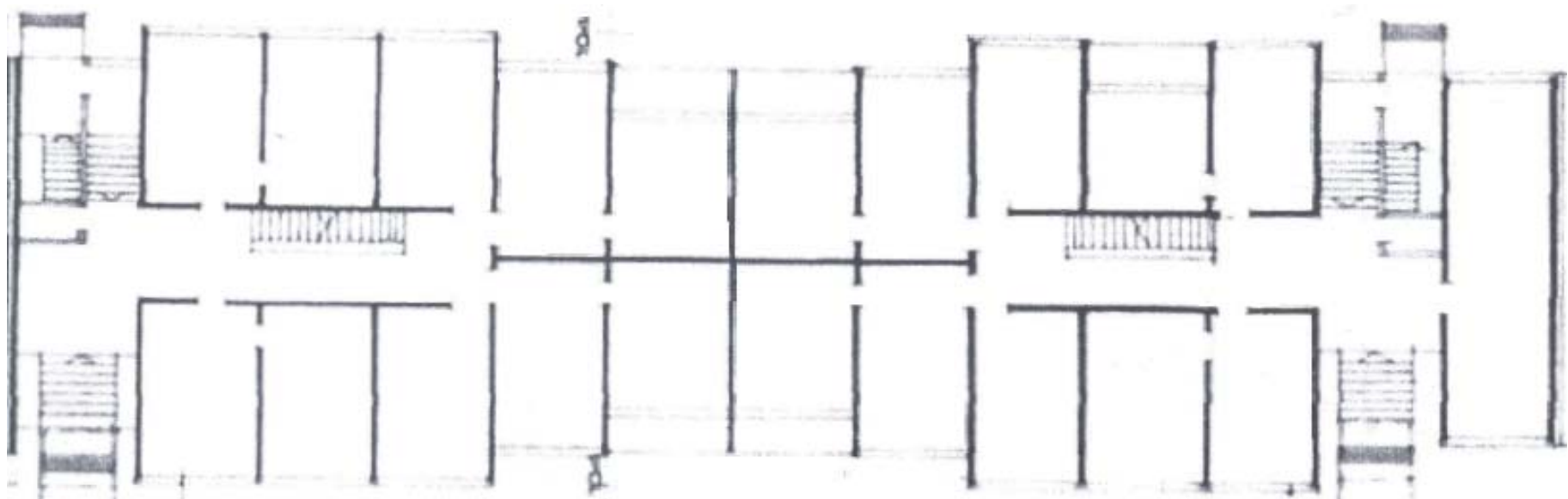


USA versus Chile



Wallace, Moehle, ASCE ST 1992

Typical building Slovenia



Chilean Code, NCh433 (1996)

5.1.1 This standard ... aims to achieve structures that:

- a) resist moderate intensity seismic actions without damages;
- b) limit damage to non-structural elements during earthquakes of regular intensity;
- c) prevent collapse during earthquakes of exceptionally severe intensity, even though they show some damage.

In particular, the **provisions for reinforced concrete wall buildings are based on their satisfactory behavior during the earthquake of March, 1985.** The design of those buildings was performed in accordance with the NCh433.Of72 code.

Chilean Code, NCh433 (1996)

Annex B Transitory references

B.2: The Provisions of the Building Code Requirements for Reinforced Concrete, ACI318-95, shall be used. In particular, the structural elements that form part of reinforced concrete frames intended to resist seismic loadings, must be dimensioned and detailed according to the provisions for zones of high seismic risk, located in chapter 21 of said code.

B.2.2 When designing reinforced concrete walls it is not necessary to meet the provisions of paragraphs 21.6.6.1 through 21.6.6.4 of the ACI 318-95 code.

Chilean Code, NCh433 (1996)

There are no specific provisions for vertical irregularities

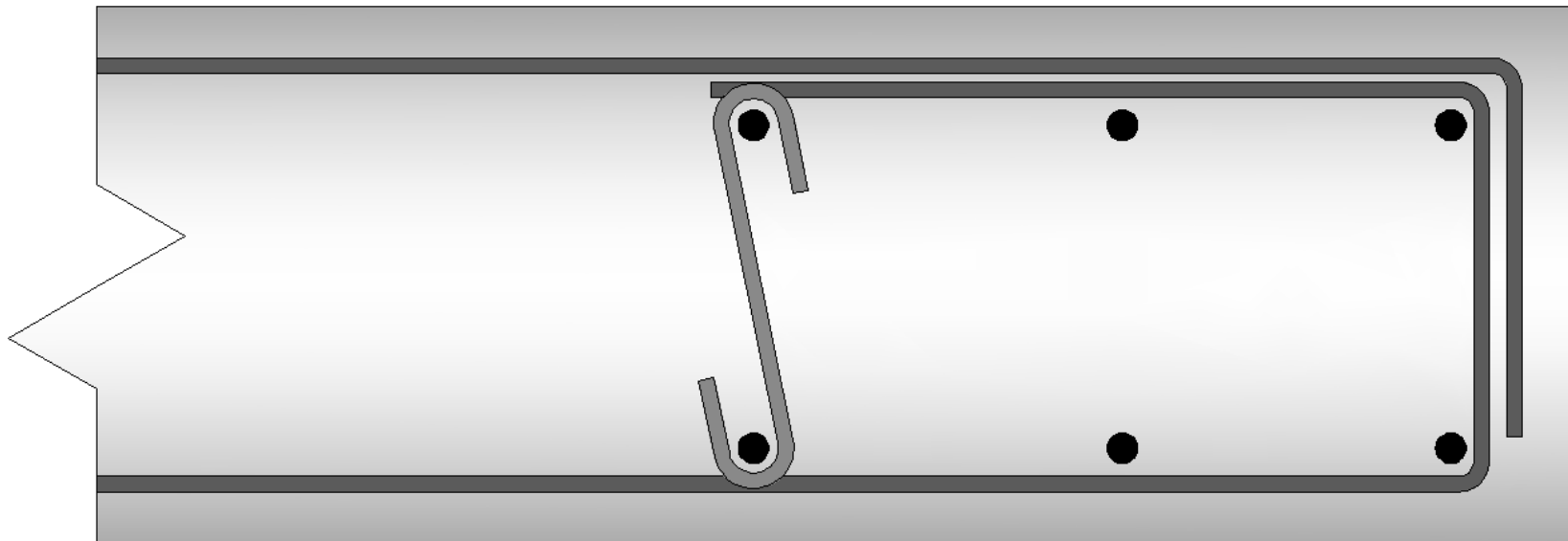
Chilean Code, NCh433 (1996)

Table 5.1 - Maximum values of the response modification factor ¹⁾

Structural system	Structural material	R	R_o
Space moment-resisting frames	Structural Steel	7	11
	Reinforced Concrete	7	11
Shear walls and braced systems	Structural steel	7	11
	Reinforced Concrete	7	11
	Reinforced Concrete and Confined Masonry		
	- If criterion $A^{2)}$ is met	6	9
	- If criterion $A^{2)}$ is not met	4	4
	Wood	5.5	7
	Confined Masonry	4	4
	Reinforced Masonry		
	- Of concrete blocks or units of similar geometry with full grouting and double-wythe masonry.	4	4
	- Of clay bricks with partial or full grouting and concrete blocks or units of similar geometry which have partial grouting.	3	3
Any type of structure or material that cannot be classified in one of the above categories. ³⁾		2	-

Design practice in Chile

Anchorage of the horizontal reinforcement in walls



Performance of buildings

Chile (buildings built between 1985 to 2009 in the earthquake affected areas, data from Rene Lagos)

- Number of buildings 3+ story 9.974
- Number of buildings 9+ story 1.939
- Buildings that collapsed 4 (app.)
- Buildings to be demolished 50 (estimate)

- Failure 3+ story buildings 0.5%
- Failure 9+ story buildings 2.8%

Concepcion (buildings taller than 9 stories, data from Fabian Rojas)

- Number of buildings 9+ story 48 (estimate)
- Buildings that collapsed 1 complete + 1 partial
- Buildings to be demolished 8

Problem

The area of walls as a fraction of the total floor area has remained about constant, but the number of stories has increased significantly, resulting in higher axial stresses in the walls.

Additional problem

Vertical irregularities, mostly vertical setbacks
(narrowing of walls near base – “flag wall”
configuration)

Long duration of earthquake – a large number of
loading cycles – and strong aftershocks



Alto Rio, Concepcion



Before Earthquake

- 15 Stories, RC, Housing
- 2 Underground Levels
- Built in 2008



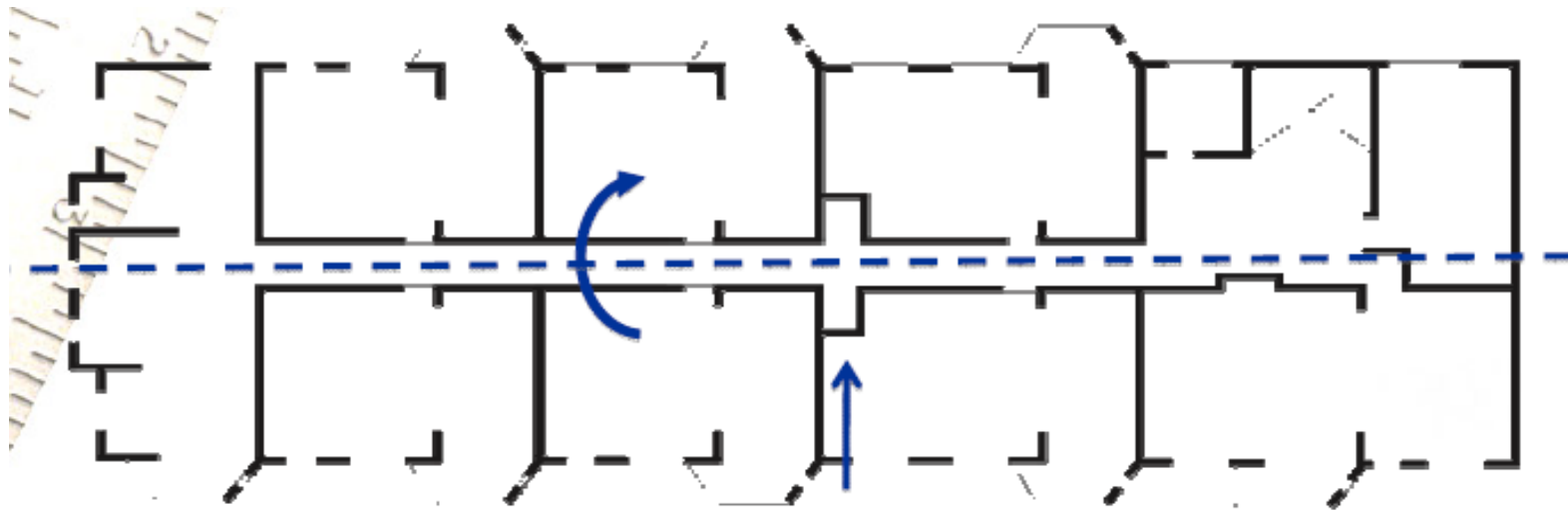
After Earthquake

(Photo: www.elperiodistaonline.cl)

- At the moment of the earthquake in the building only 87 people were in there:
 - 8 died
 - 79 survived: 52 got out of the building by their own, 27 were rescued from the debris

Fabian Rojas, USC

Alto Rio



Sketch Floor Plan

Fabian Rojas

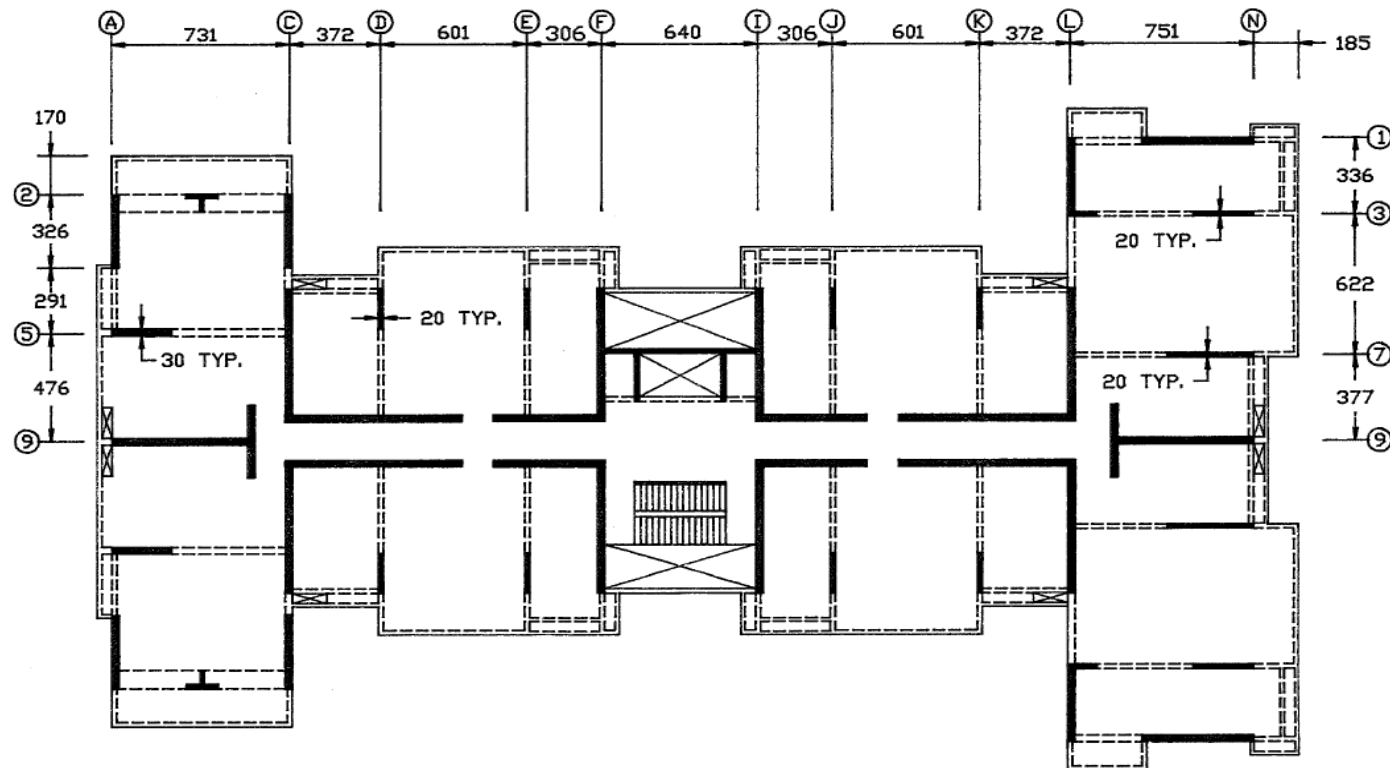
PhD Student, University of Southern California
Member, LATBSDC Chile reconnaissance Team

Fabian Rojas, USC





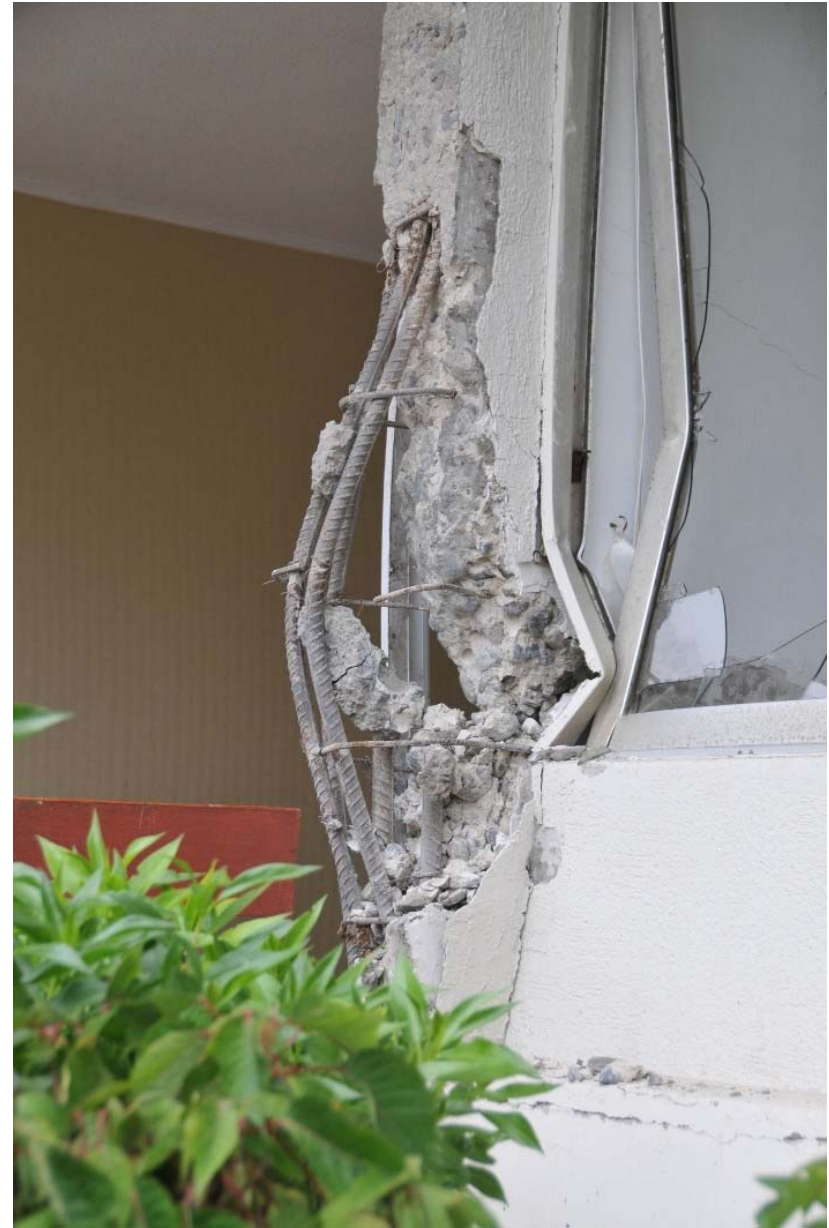
Festival, Viña del Mar



Wallace, Moehle, ASCE ST 1992

14 Stories, 1978





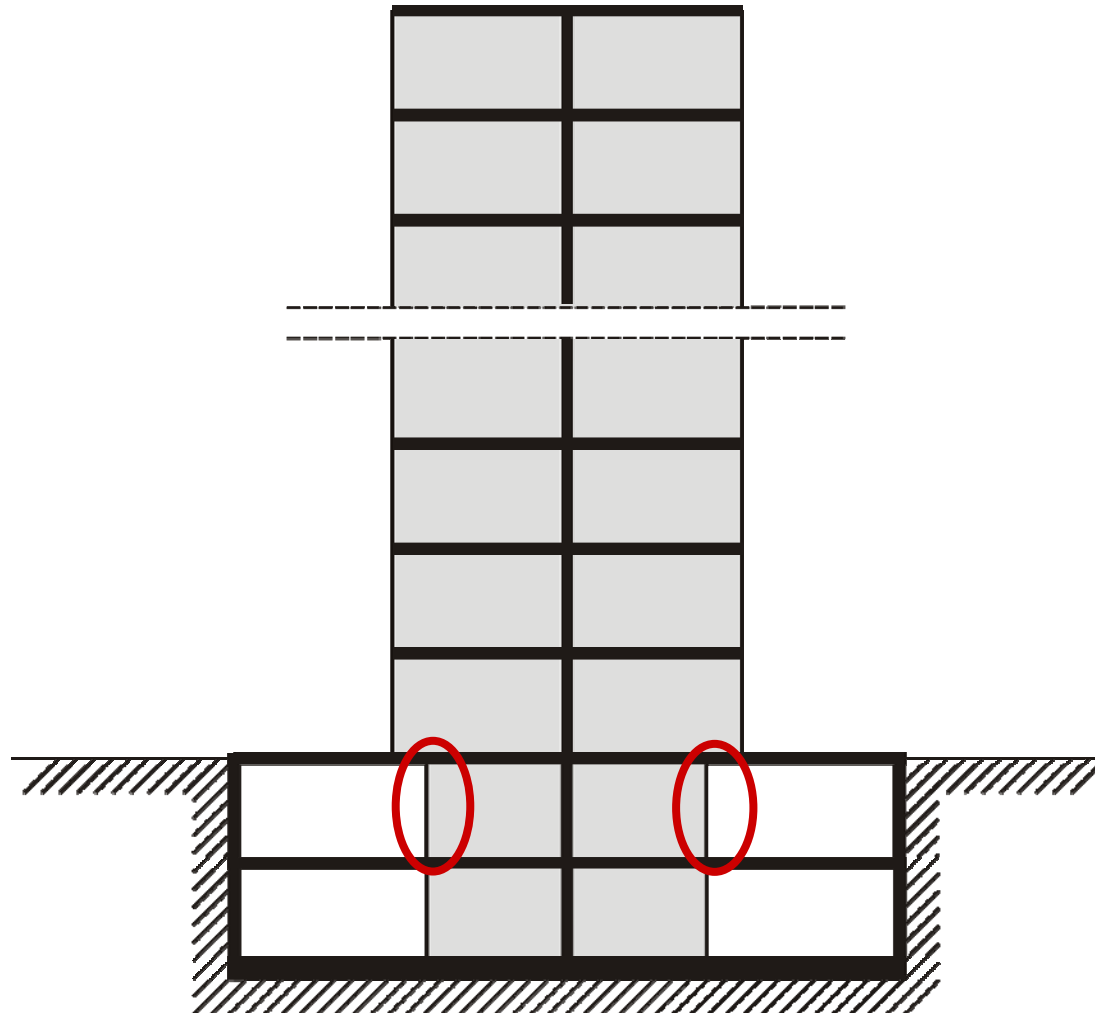








First basement





















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Secretaría de Salud 2010

DETERRACION



PLANTA CIELO 1º SUBTERRÁNEO

5-1

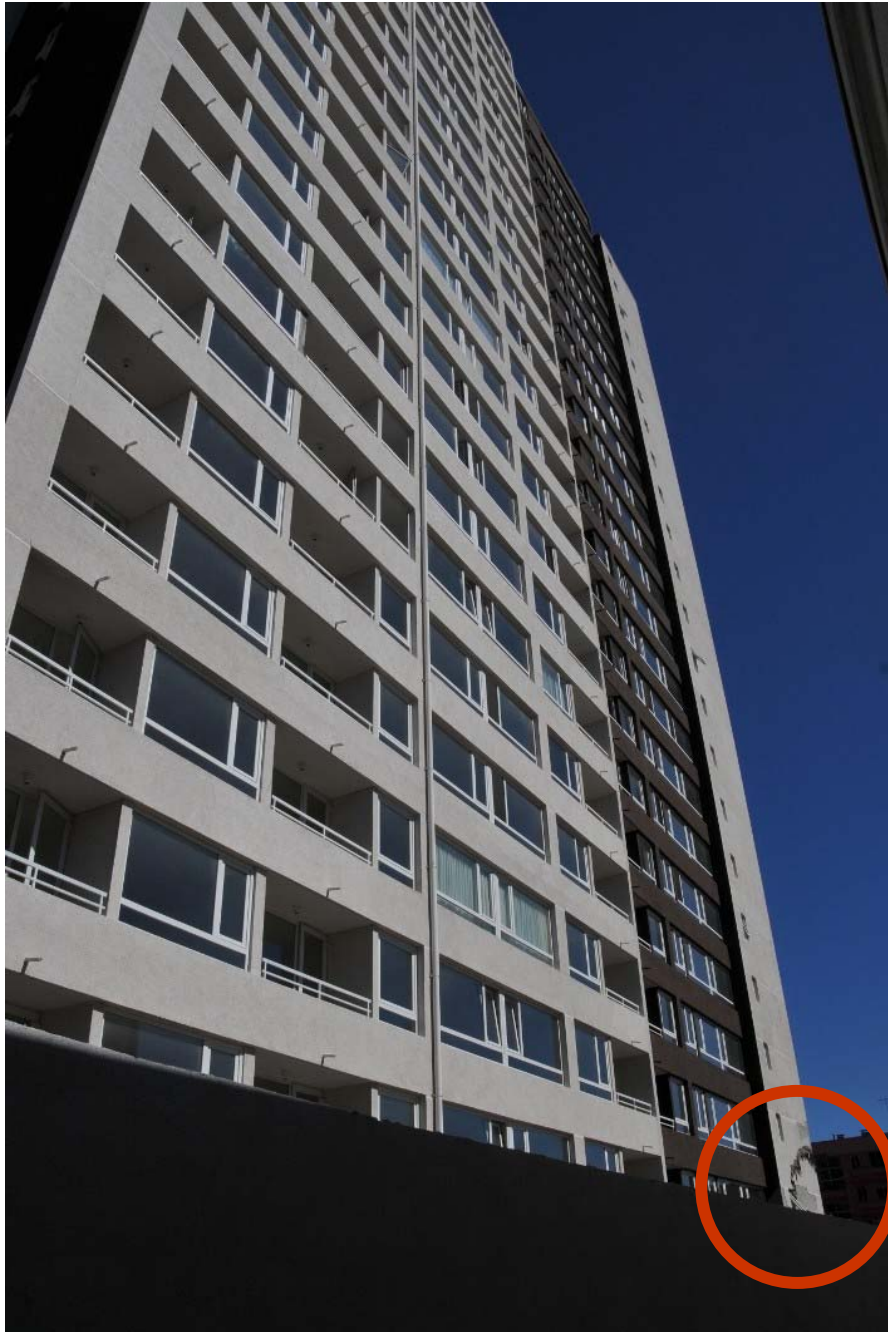
tota 5-1 = 43
 07/03/10 = 7
 08/03/10 = 12
 24

tota 5-1 = 43
 10/03/10 = 30 / 20
 10/03/10 = 20 / 19
 11/03/10 31 / 12
 16/03 42 / 1











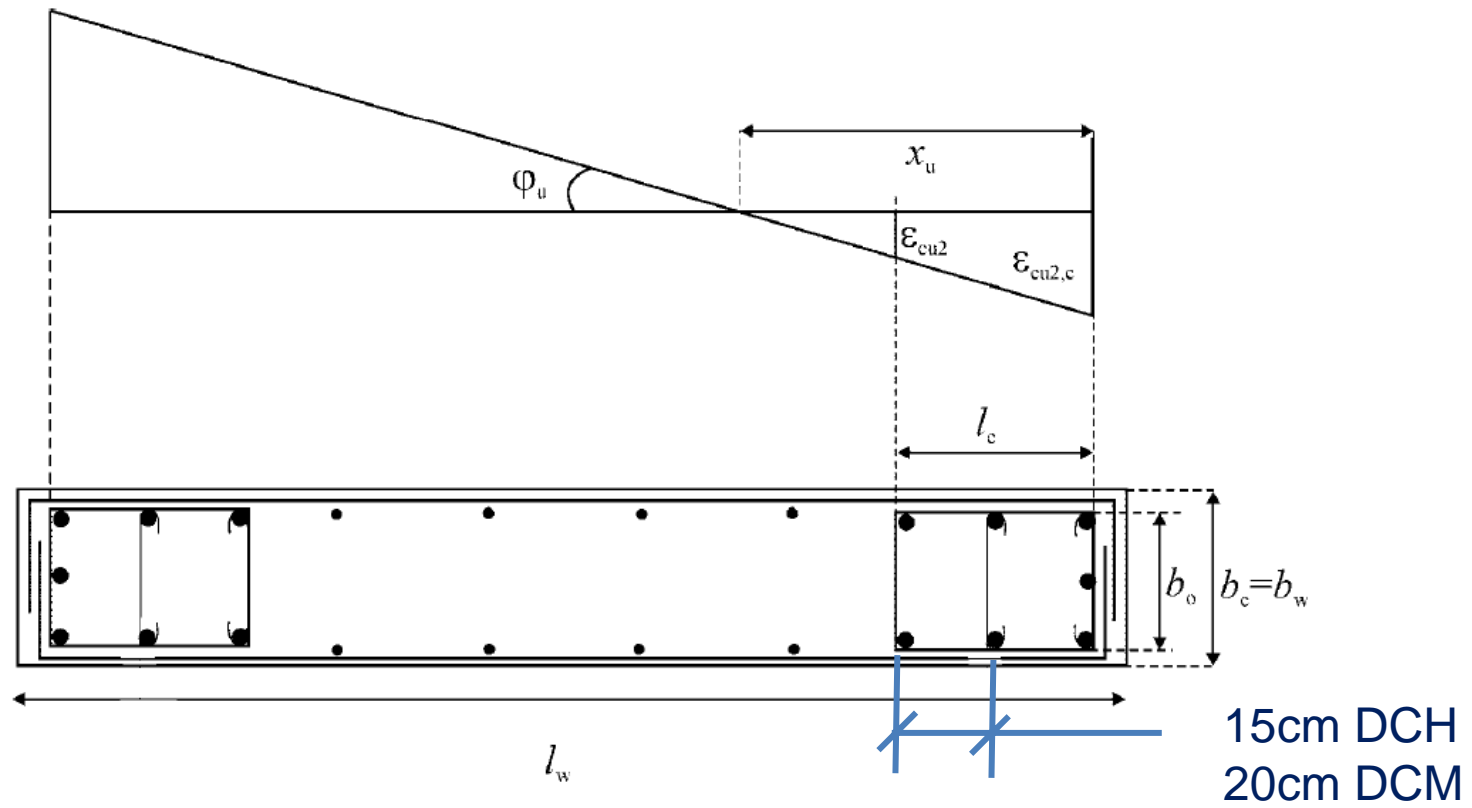
EC8 versus Chile experience

Axial stress limitations

Chile:	None		
EC8:	$\sigma \leq 0.40 \cdot f_{cd}$	DCM	
	$\sigma \leq 0.35 \cdot f_{cd}$	DCH	

EC8: No confinement required only if
 $\sigma \leq 0.15 \cdot f_{cd}$ DCM

EC8



Conclusions (1)

- Exceptional magnitude, long duration, moderate intensity
- Majority of engineered buildings survived the earthquake well
- Some buildings, also very new ones, were badly damaged

Conclusions (2)

- New observation: Systematic failures of slender walls with high compression in new buildings
- In particular in first basement
- Failure was local and brittle. Inadequate confinement (for high axial stress). Loading could not be transmitted to the peripheral basement walls

Conclusions related to EC8

- EC8 requirements could prevent such compressive failures.
- The wall-to-floor area limitation (related to the number of floors) is still missing
- Anchorage of the horizontal reinforcement into confined boundary areas is not specified

Acknowledgements

- Prof. Juan Carlos De la Llera
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- Prof. Rodolfo Saragoni
Univ. of Chile, Santiago
- Authors of the material provided on web



Thank you!

