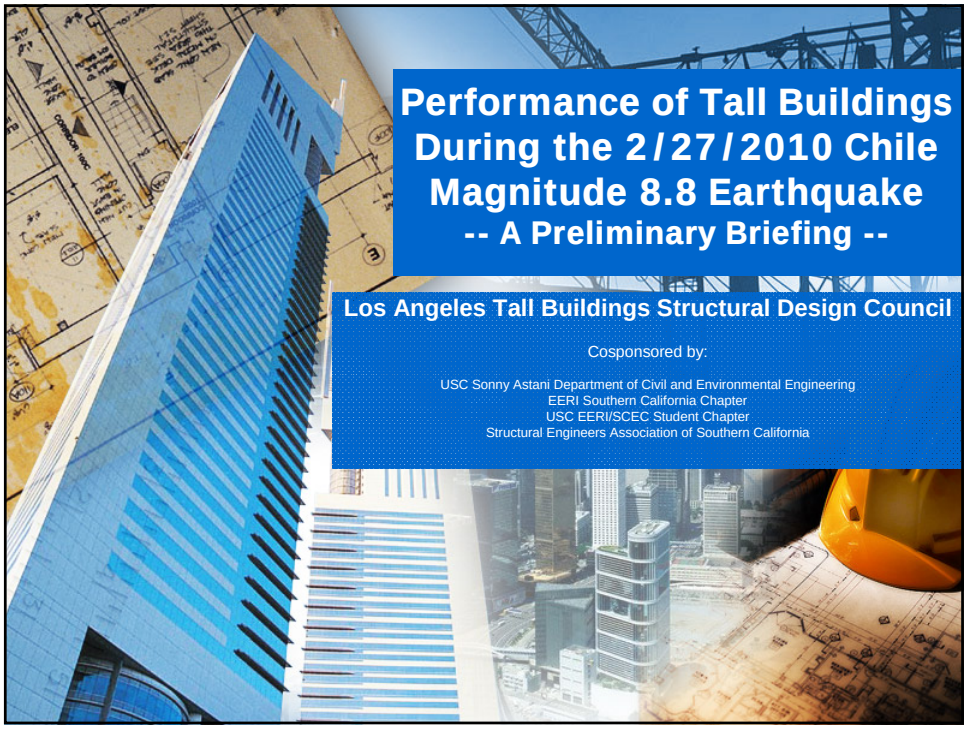


Performance of Tall Buildings During the 2/27/2010 Chile Magnitude 8.8 Earthquake

-- A Preliminary Briefing --

Los Angeles Tall Buildings Structural Design Council

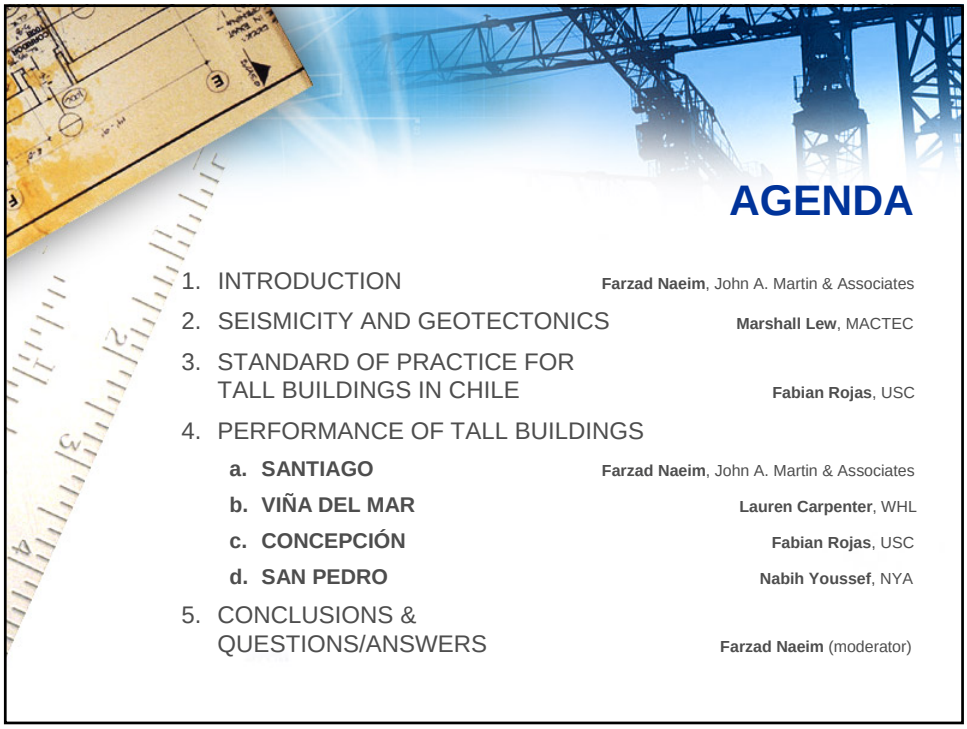
Cosponsored by:

USC Sonny Astani Department of Civil and Environmental Engineering
EERI Southern California Chapter
USC EERI/SCEC Student Chapter
Structural Engineers Association of Southern California

Reconnaissance Team Members

- Dr. Farzad Naeim
- Dr. Marshall Lew
- Dr. Lauren Carpenter
- Mr. Nabih Youssef
- Mr. Fabian Rojas
- Dr. Macarena Schachter Adaros

With special thanks to Prof. Saragoni of University of Chile

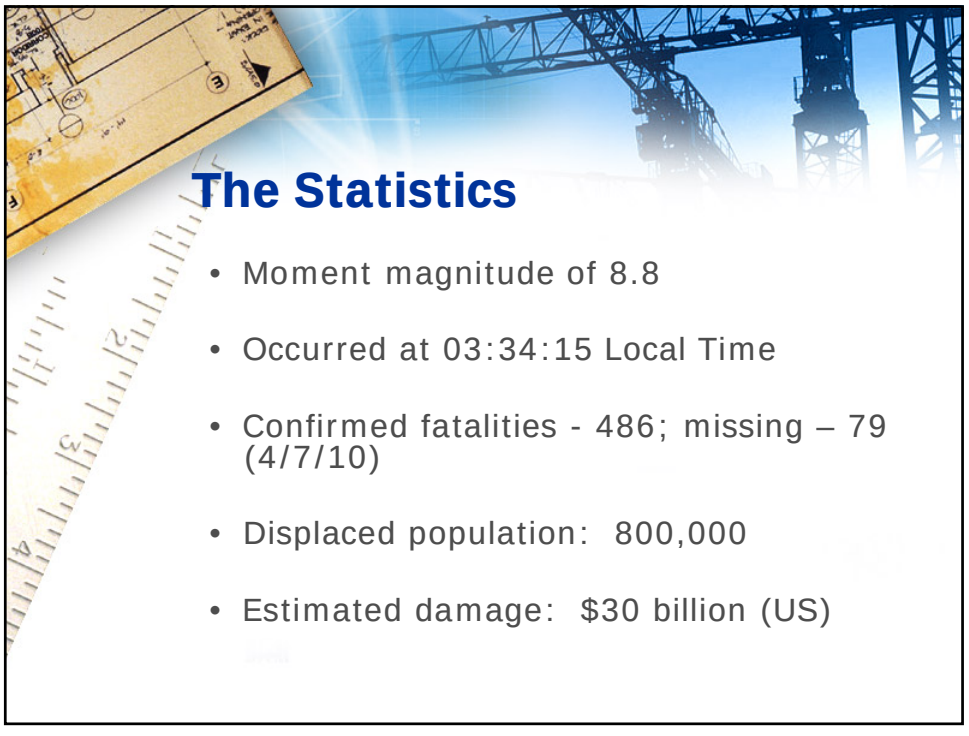


AGENDA

1. INTRODUCTION — **Farzad Naeim**, John A. Martin & Associates
2. SEISMICITY AND GEOTECTONICS — **Marshall Lew**, MACTEC
3. STANDARD OF PRACTICE FOR TALL BUILDINGS IN CHILE — **Fabian Rojas**, USC
4. PERFORMANCE OF TALL BUILDINGS
   a. **SANTIAGO** — **Farzad Naeim**, John A. Martin & Associates
   b. **VIÑA DEL MAR** — **Lauren Carpenter**, WHL
   c. **CONCEPCIÓN** — **Fabian Rojas**, USC
   d. **SAN PEDRO** — **Nabih Youssef**, NYA
5. CONCLUSIONS & QUESTIONS/ANSWERS — **Farzad Naeim** (moderator)

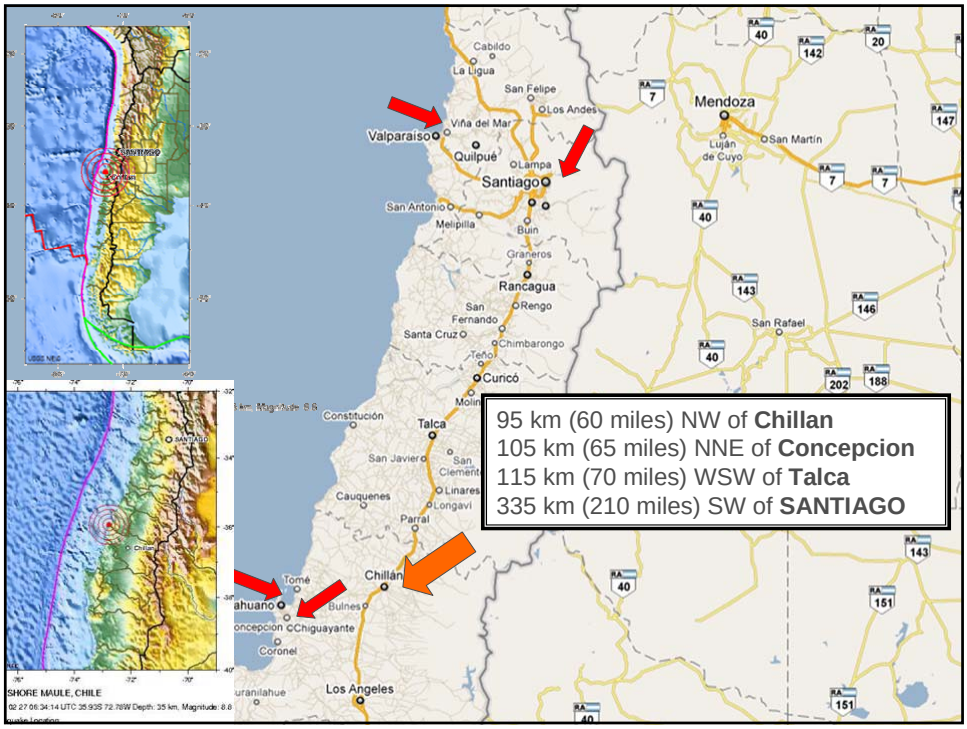
Seismicity and Geotectonics
February 27, 2010 Chile Magnitude 8.8 Earthquake

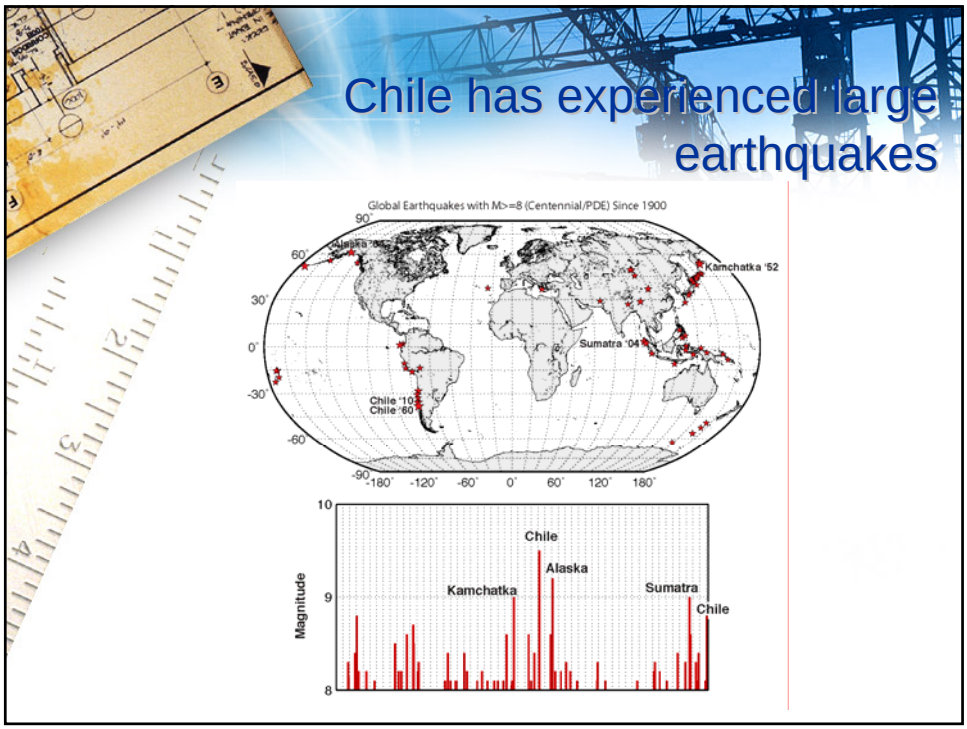
Marshall Lew, Ph.D., G.E.
MACTEC Engineering and Consulting, Inc.
Member, LATBSDC Chile Reconnaissance Team



The Statistics

- Moment magnitude of 8.8
- Occurred at 03:34:15 Local Time
- Confirmed fatalities - 486; missing – 79 (4/7/10)
- Displaced population: 800,000
- Estimated damage: $30 billion (US)

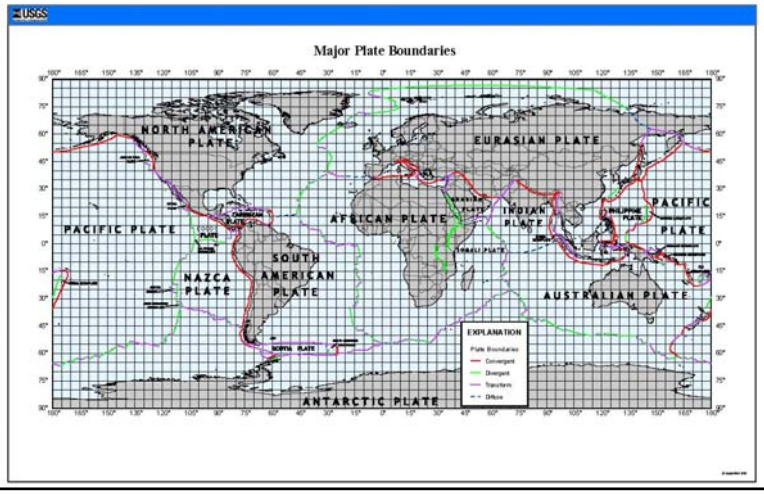

Cabildo
La Ligua
San Felipe
Los Andes
Valparaiso
Viña del Mar
Quilpué
Lampa
Santiago
San Antonio
Melipilla
Buin
Graneros
Rancagua
San Fernando
Rengo
Santa Cruz
Chimbarongo
Teño
Curicó
Constitución
Talca
San Javier
Cauquenes
Linares
Longavi
Parral
Chillán
Tomé
Bulnes
Chiguayante
Coronel
Los Angeles
Mendoza
San Martin
Luján de Cuyo
San Rafael
95 km (60 miles) NW of **Chillan**
105 km (65 miles) NNE of **Concepcion**
115 km (70 miles) WSW of **Talca**
335 km (210 miles) SW of **SANTIAGO**
SHORE MAULE, CHILE


Chile has experienced large earthquakes
Global Earthquakes with M>=8 (Centennial/PDE) Since 1900
Kamchatka '52
Sumatra '04
Chile '10
Chile '60
Magnitude
Chile
Alaska
Kamchatka
Sumatra
Chile

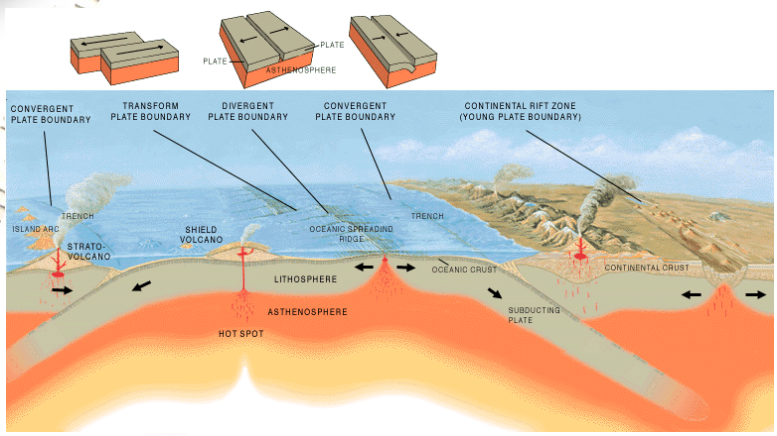
Earthquakes in Chile

1730 07 08 - Valparasio, Chile - M 8.7
1835 02 20 - Concepcion, Chile - M 8.2
1868 08 13 - Arica, Peru (now Chile) - M 9.0
1877 05 10 - Offshore Tarapaca, Chile - M 8.3
1906 08 17 - Valparaiso, Chile - M 8.2
1922 11 11 - Chile-Argentina Border - M 8.5
1928 12 01 - Talca, Chile - M 7.6
1939 01 25 - Chillan, Chile - M 7.8
1943 04 06 - Illapel - Salamanca, Chile - M 8.2
1960 05 21 - Arauco Peninsula, Chile - M 7.9
1960 05 22 - Chile - M 9.5
1965 02 23 - Taltal, Chile - M 7.0
1965 03 28 - La Ligua, Chile - M 7.4
1971 07 09 - Valparaiso region, Chile - M 7.5
1985 03 03 - offshore Valparaiso, Chile - M 7.8
1998 01 30 - Near Coast of Northern Chile - M 7.1
2002 06 18 - Chile-Argentina Border Region - M 6.6
2003 06 20 - Near the Coast of Central Chile - M 6.8
2004 05 03 - Bio-Bio, Chile - M 6.6
2005 06 13 - Tarapaca, Chile - M 7.8
2007 11 14 - Antofagasta, Chile - M 7.7
2007 12 16 - Antofagasta, Chile - M 6.7
2008 02 04 - Tarapaca, Chile - M 6.3
2009 11 13 - Offshore Tarapaca, Chile - M 6.5
2010 02 27 - Offshore Maule, Chile - M 8.8

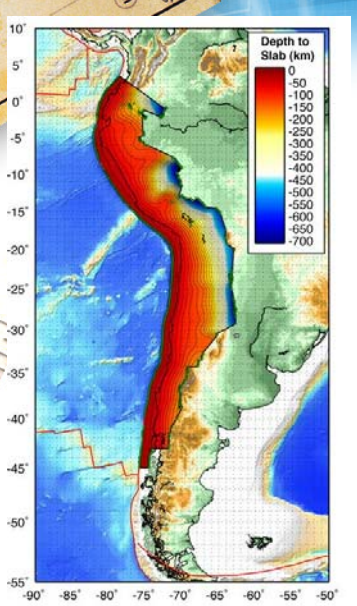
Chile is on a tectonic plate boundary

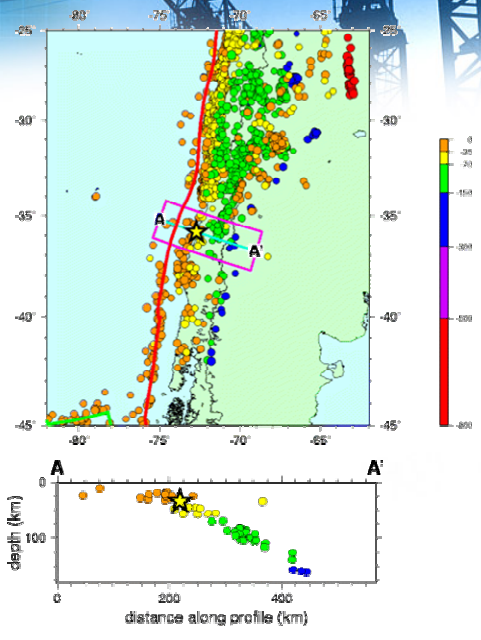


Chile is on a tectonic plate boundary

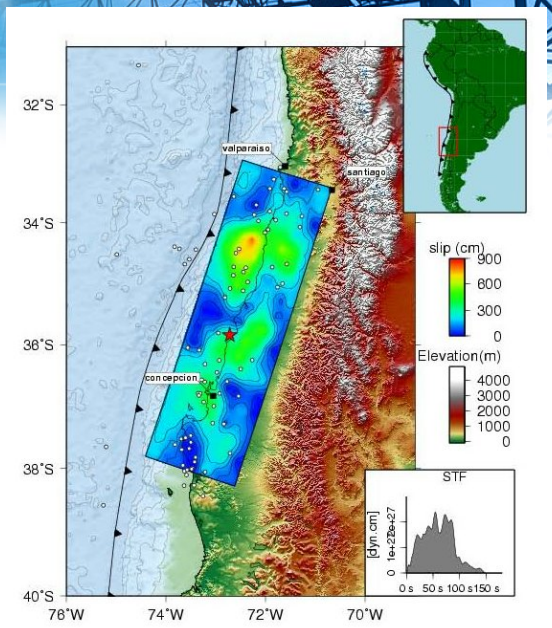


So American Subduction Zone





Slip on the fault



GPS Data for South America

Concepción moved ~10 feet west

Ground motions in Santiago at Universidad de Chile

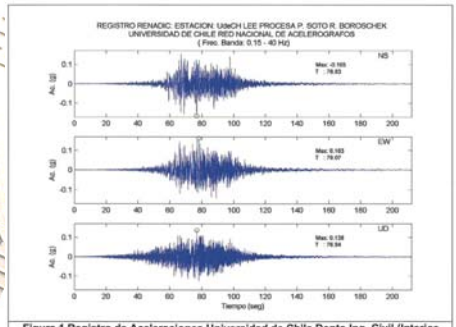


Figura 1 Registro de Aceleraciones Universidad de Chile Depto Ing. Civil (Interior Edificio) Santiago. Presenta posible alteración respuesta de Edificio

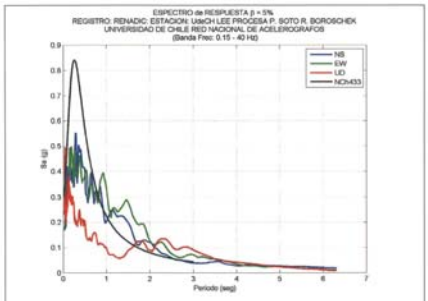


Figura 3 Comparación Espectro de Diseño Norma Chilena NCh433 – Universidad de Chile Depto Ing. Civil (Interior Edificio) Santiago. Presenta posible alteración respuesta de Edificio

Ground motions in Santiago at Maipu

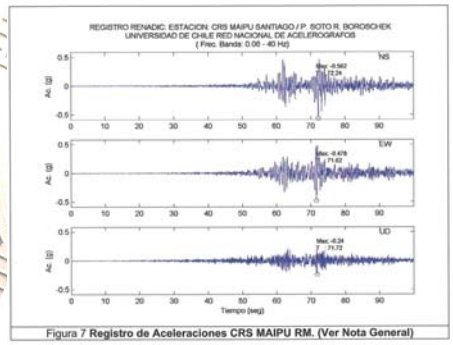


Figura 7 **Registro de Aceleraciones CRS MAIPU RM. (Ver Nota General)**

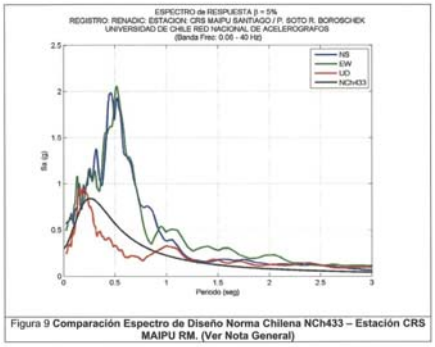


Figura 9 **Comparación Espectro de Diseño Norma Chilena NCh433 – Estación CRS MAIPU RM. (Ver Nota General)**

Ground motions in Santiago at Marga-Marga, Viña del Mar

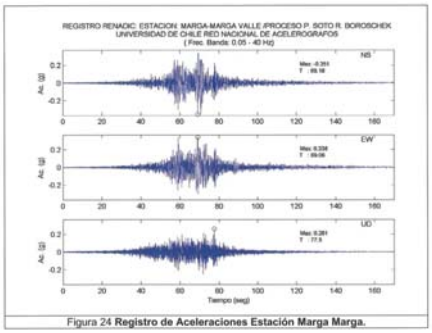


Figura 24 **Registro de Aceleraciones Estación Marga Marga.**

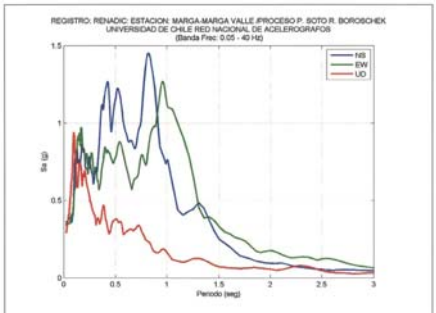
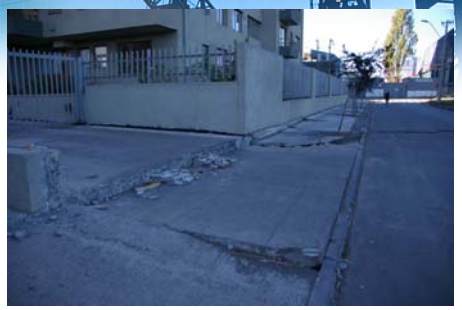


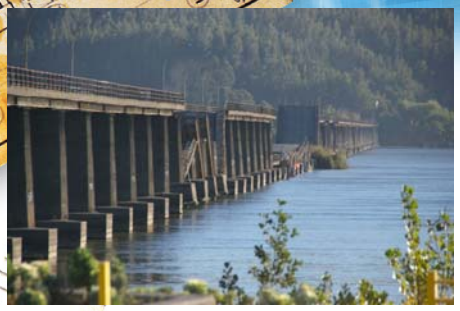
Figura 25 **Espectro Respuesta de Aceleración. Estación Marga Marga.**

Tsunami effects at Talcahuano

Liquefaction effects in Concepción

Liquefaction effects along Río Bío Bío




Thank you!

Standard of Practice for Tall Buildings in Chile

-- Preliminary LATBSDC Reconnaissance Briefing --

Performance of Tall Buildings During the 2/27/2010 Chile Magnitude 8.8 Earthquake

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

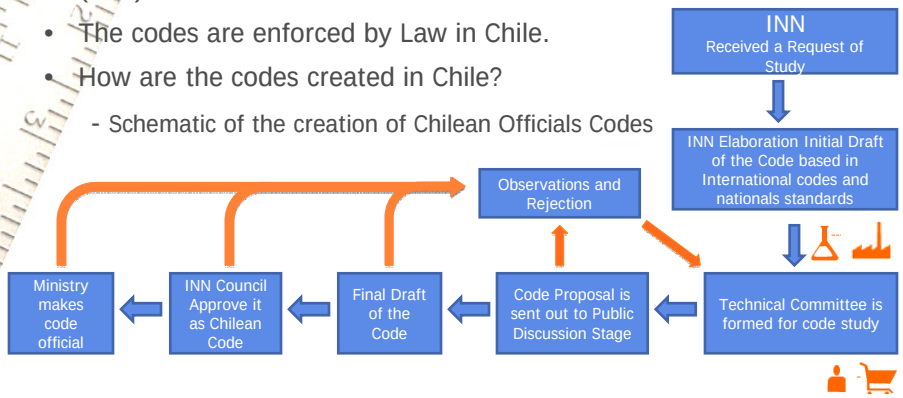
Agenda

- Codes and Standards
  - INN and NCH : Chilean Codes
  - Chilean Official Codes approval procedure
  - Overview of the Nch433 of 96 (Chilean Seismic Code)
- Peer Review (Seismic Design Review)
- Building Permit Procedures
- Main Characteristics of Chilean's Buildings
- A general view of the performance of the buildings during the 02/27/2010 Chilean Magnitude M8.8 Earthquake

Codes and Standards

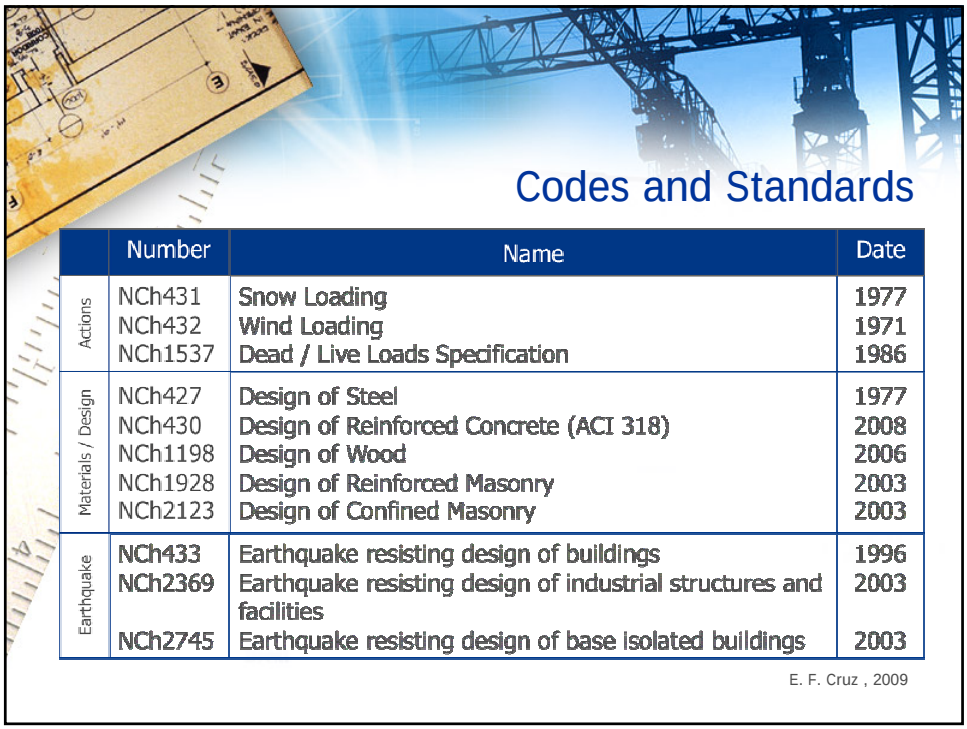
Codes and Standards

- Codes in Chile are issued by the National Institute of Normalization (INN)
- The codes are enforced by Law in Chile.
- How are the codes created in Chile?
  - Schematic of the creation of Chilean Officials Codes



Codes and Standards

- For Structural Design the different Chilean Codes can be grouped into 3 areas:
  - Definition of Loads and Actions
  - Materials behavior, strength, and detailing requirements
  - Codes for Seismic Loads



Codes and Standards

	Number	Name	Date
Actions	NCh431	Snow Loading	1977
	NCh432	Wind Loading	1971
	NCh1537	Dead / Live Loads Specification	1986
Materials / Design	NCh427	Design of Steel	1977
	NCh430	Design of Reinforced Concrete (ACI 318)	2008
	NCh1198	Design of Wood	2006
	NCh1928	Design of Reinforced Masonry	2003
	NCh2123	Design of Confined Masonry	2003
Earthquake	NCh433	Earthquake resisting design of buildings	1996
	NCh2369	Earthquake resisting design of industrial structures and facilities	2003
	NCh2745	Earthquake resisting design of base isolated buildings	2003

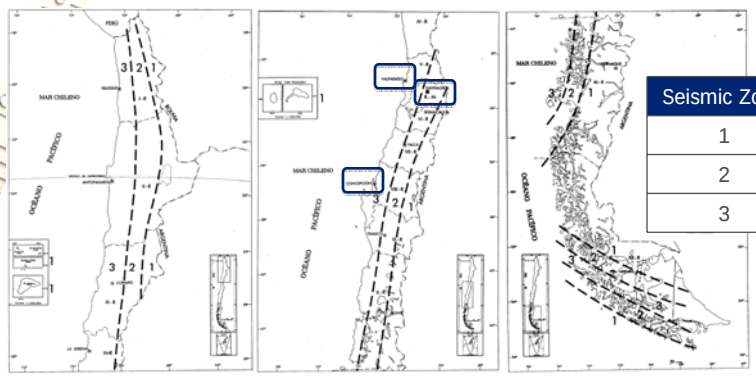
Earthquake Resistant Design of Buildings - Nch 433 of 96

- Basic Principles and Philosophy of the code:
  - Establishment of the minimal requirements for the seismic design of buildings.
  - Seismic Safety: (Provision 5.1)
    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 of 72 code" (Provision 5.1.1)

Overview - Nch 433 of 96

- Seismic Zoning: (Provision 4.1)
  - Three seismic zones in the national territory can be distinguished



Seismic Zone	Ao
1	0.2 g
2	0.3 g
3	0.4 g

Overview - Nch 433 of 96

- Soil Type (Provision 4.2)
  - Four type of soil can be distinguished:

Soil type Classification is made by a soil study of the top 10 meters of the soil prior to the foundation level.

Soil type	Description
I	**Rock**: Natural material, with in-situ shear wave propagation velocity equal to or greater than 900 m/s, or uniaxial compressive strength of intact specimens (without fissures) equal to or greater than 10 MPa and RQD equal to or greater than 50%.
II	a) Soil with v_s equal to or greater than 400 m/s in the upper 10 m, and increasing depth, or, b) Dense gravel with a dry unit weight γ_d equal to or greater than 20 kN/m^3, or greater than 95% of the maximum determined in the Modified Proctor Compaction Test, or a relative density (RD) equal to or greater than 75%, or, c) Dense sand with a (RD) greater than 75%, or a Penetration Resistance Index N greater than 40 (standardized at the effective overburden pressure of 0.10 MPa), or a compaction degree greater than 95% of the maximum Modified Proctor value; or, d) Stiff cohesive soil, with an undrained shear strength s_u equal to or greater than 0.10 MPa (compressive strength q_u equal to or greater than 0.20 MPa) in specimens without fissures. In all cases, the requirements specified must be met, regardless of the position of the ground water level, and the minimum stratum thickness must be 20 m. If the thickness above the rock is lower than 20 m, the soil may be classified as type I.
III	a) Permanently unsaturated sand with (RD) in the range of 55 and 75%, or N greater than 20 (without standardizing at the effective overburden pressure of 0.10 MPa); or, b) Unsaturated gravel or sand, with a compaction degree less than 95% of the maximum Modified Proctor value or, c) Cohesive soil with s_u in the range of 0.025 y 0.10 MPa (q_u between 0.05 and 0.20 MPa) , regardless of the ground water level; or, d) Saturated sand with N in the range of 20 and 40 (standardized at the effective overburden pressure of 0.10 MPa). Minimum stratum thickness: 10 m. If the stratum thickness above the rock or soil type II is less than 10 m, the soil may be classified as type II.
IV	Saturated cohesive soil with s_u equal to or greater than 0.025 MPa (q_u equal to or less than 0.050 MPa). Minimum stratum thickness: 10 m. If the stratum thickness above soil types I, II or III is less than 10 m, the soil may be classified as type III.

Overview - Nch 433 of 96

- Building Classification
  - Four categories of buildings are distinguished depending of the level of importance.

Building Category	I
A	1.2
B	1.2
C	1.0
D	0.6

- Combination of Seismic Loadings with other loadings (Provision 5.2)

a. When design with the allowable stress method
   Permanent Loads + Live Loads ± Earthquake
   Permanent Loads ± Earthquake

a. When design with the method of load and resisting Factors:
   1.4*(Permanent Loads + Live Loads ± Earthquake)
   0.9*Permanent Loads ± 1.4*Earthquake

Overview - Nch 433 of 96

- Method of Analysis allowed by the code: (Provision 6.1)

Two types of analysis are allowed by the code:

- Static method
- Spectral Modal Analysis

In any case should be considered a structural model with a minimum of three degrees of freedom per floor, two horizontal displacements and the floor rotation with respect to a vertical axis.

Overview - Nch 433 of 96

- Static method:

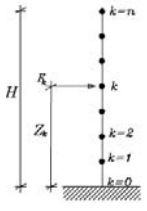
An equivalent lateral forces procedure where torsion is considered through an amplification of the static torsion in the building.

$$Q_o = CIP$$

$$C = \frac{2.75 A_o}{gR}\left(T'/T^*\right)^n$$

$$A_k = \sqrt{\left(1-\frac{Z_{k-1}}{H}\right)} - \sqrt{\left(1-\frac{Z_k}{H}\right)}$$

$$F_k = \frac{A_k P_k}{\sum_{j=1,n} A_j P_j} Q_o$$



Limited usually to structures less or equal to 5 stories

In no case the value of C will be less than Ao/6g

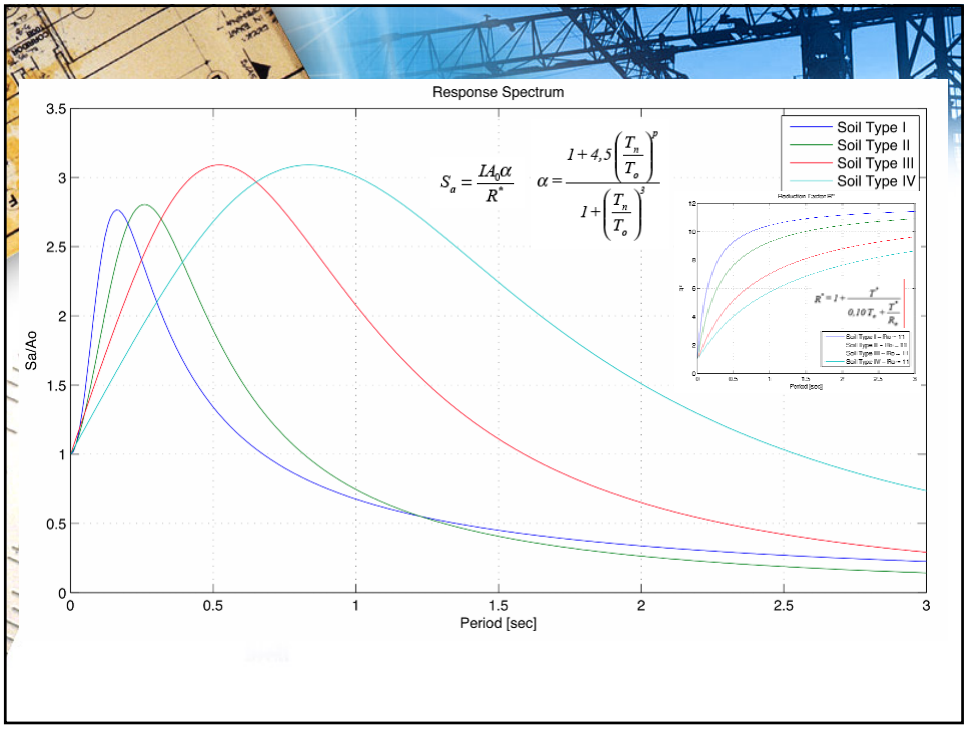
Overview - Nch 433 of 96

- Spectral Modal Analysis :

It is a standard response spectrum analysis method, with at least 3 degree of freedom per floor and the maximum response of the building is calculated through a combination of the modes using CQC combination rule.

Note: It is allowed the use of 5% of critical damping per mode and it is necessary to consider accidental torsion in the model and the force reduction factor R varies with period of the 1st mode of the building.

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	-



Overview - Nch 433 of 96

- Minimum Base Shear (Provision 6.3.7.1)

  The base shear in each direction of seismic analysis must not be consider less than: I Ao P / 6g

- Maximum Base Shear (Provision 6.3.7.2)

  The base shear component in each direction of seismic analysis should not be greater than: I Cmax P

R	C_{max}
2	0,90 SA_o/g
3	0,60 SA_o/g
4	0,55 SA_o/g
5,5	0,40 SA_o/g
6	0,35 SA_o/g
7	0,35 SA_o/g

Overview - Nch 433 of 96

- Deformation Control

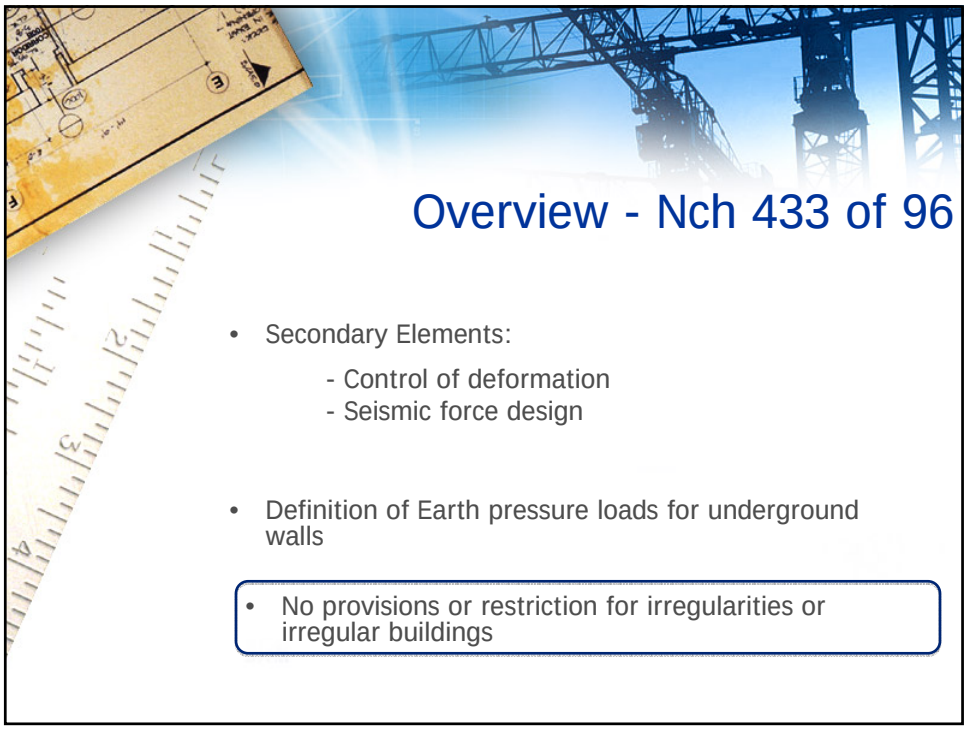
  The maximum relative displacement between two consecutive floors measured :

  - At their center of masses : 0.002*(Story Height)
  - At the extreme points : 0.003*(Story Height)

- Separation between buildings

  The minimum distance of the building to the dividing plane at any level shall not be less

  - 0.002*Height of the Level
  - 1.5 cm (3.8 in)



Overview - Nch 433 of 96

- Secondary Elements:
  - Control of deformation
  - Seismic force design
- Definition of Earth pressure loads for underground walls
- No provisions or restriction for irregularities or irregular buildings

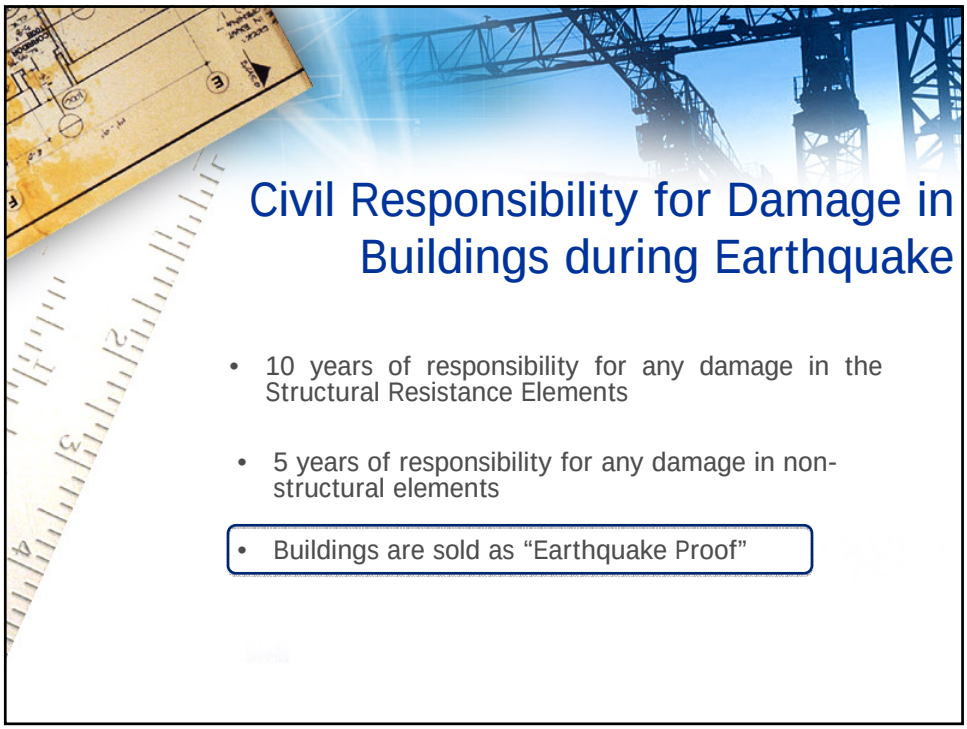
Overview - Nch 433 of 96

Important dispositions of the Code

Provision 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."*

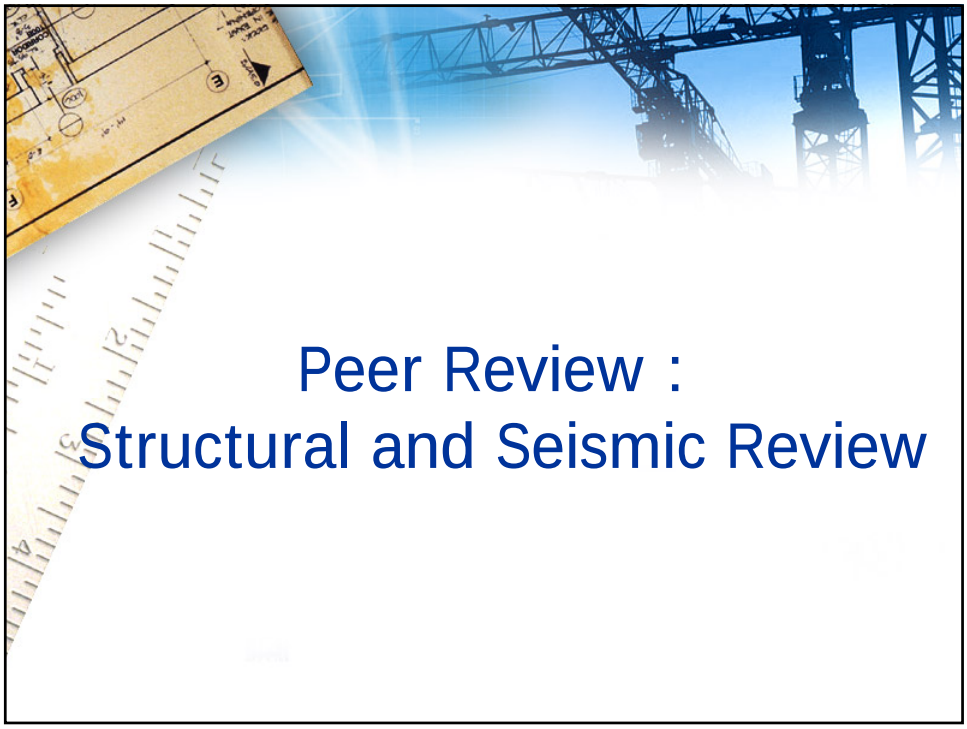
Provision B.2.2: *"When designing reinforced concrete wall it is not necessary to meet the provisions of paragraphs 21.6.6.1 through 21.6.6.4 of the ACI318-95."*

"*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 of 72 code*" (Provision 5.1.1)

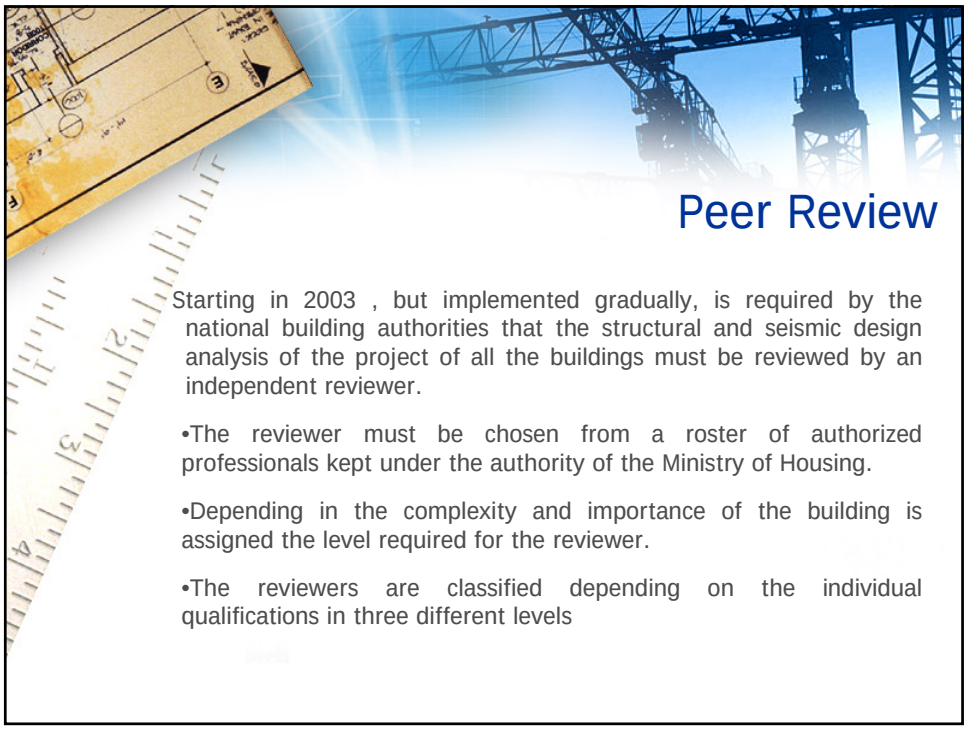


Civil Responsibility for Damage in Buildings during Earthquake

- 10 years of responsibility for any damage in the Structural Resistance Elements
- 5 years of responsibility for any damage in non-structural elements
- Buildings are sold as "Earthquake Proof"



Peer Review : Structural and Seismic Review



Peer Review

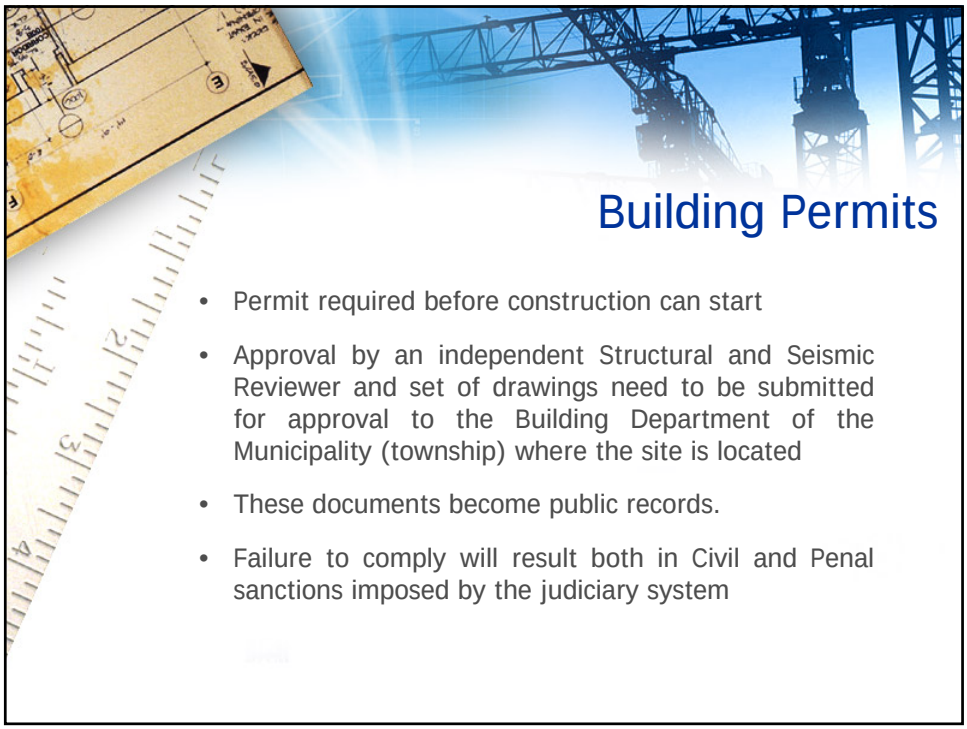
Starting in 2003 , but implemented gradually, is required by the national building authorities that the structural and seismic design analysis of the project of all the buildings must be reviewed by an independent reviewer.

•The reviewer must be chosen from a roster of authorized professionals kept under the authority of the Ministry of Housing.

•Depending in the complexity and importance of the building is assigned the level required for the reviewer.

•The reviewers are classified depending on the individual qualifications in three different levels

Building Permit Procedure



Building Permits

- Permit required before construction can start
- Approval by an independent Structural and Seismic Reviewer and set of drawings need to be submitted for approval to the Building Department of the Municipality (township) where the site is located
- These documents become public records.
- Failure to comply will result both in Civil and Penal sanctions imposed by the judiciary system

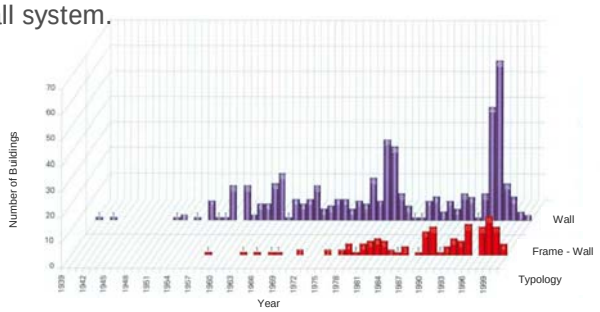
Characteristics of Chilean's Buildings

Characteristics of Chilean's Buildings

The principal system used in the design of mid to high rise buildings for Residential is shear walls construction, although for office buildings the approach has been changing in the last years from shear wall to dual system, Frame – Wall system.

Gomez in 2001 after study 640 Chilean's Building with more than 10 stories and built after 1950 concluded:

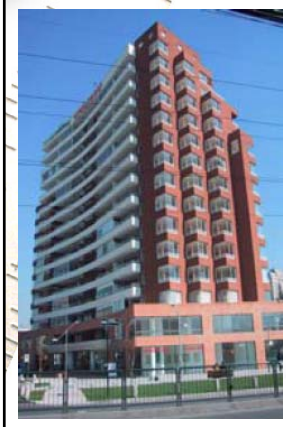
76.7 % used Wall
21.6 % used Wall- Frame

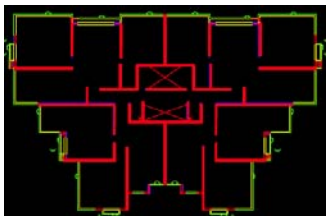


"Edificios Chilenos de Hormigon Armado", ICH 2002

Characteristics of Chilean's Buildings

19 Stories + 3 Basement



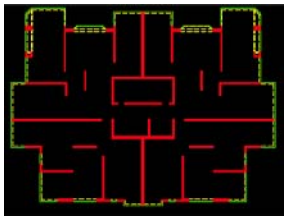


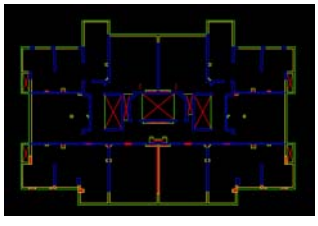
19 Stories + 3 Basement.

renelagos

Characteristics of Chilean's Buildings

25 Stories + 5 Basement



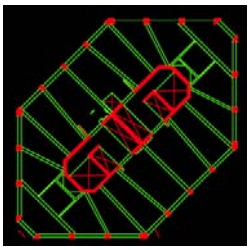


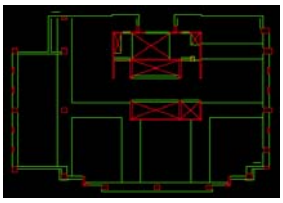
19 Stories + 3 Basement.

renelagos

Characteristics of Chilean's Buildings

19 Stories + 7 Basement.



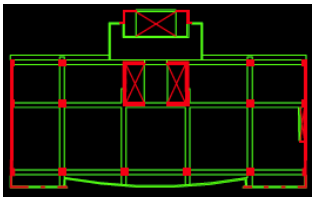


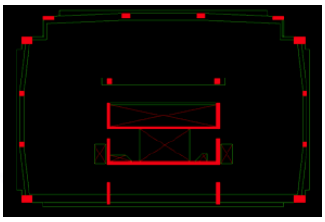
31 Stories + 5 Basement.

renelagos

Characteristics of Chilean's Buildings

25 Stories + 9 Basement.





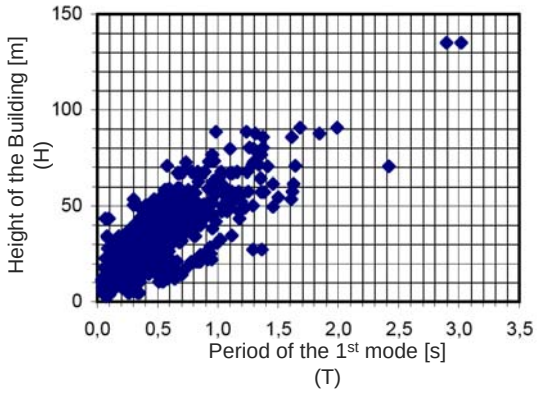
15 Stories + 3 Basement.

renelagos

Characteristics of Chilean's Buildings

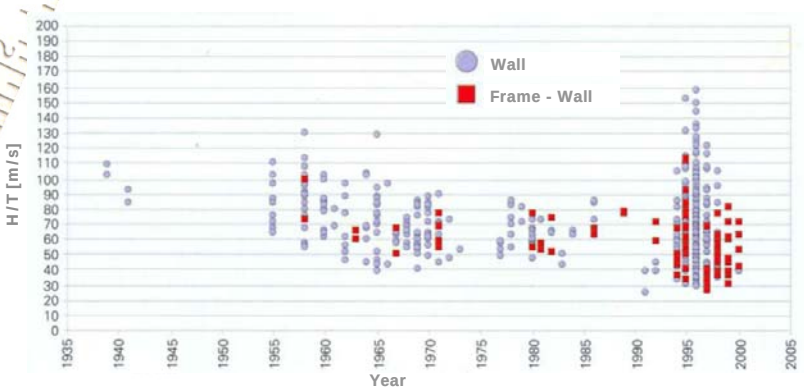
Parameter H/T for Chilean's Buildings (Guendelman et al. 2000)

	H/T < 20	[m/s]	Too Flexible
20	< H/T < 40	[m/s]	Flexible
40	< H/T < 70	[m/s]	Normal
70	< H/T < 150	[m/s]	Stiff
150	< H/T		Too Stiff



Characteristics of Chilean's Buildings

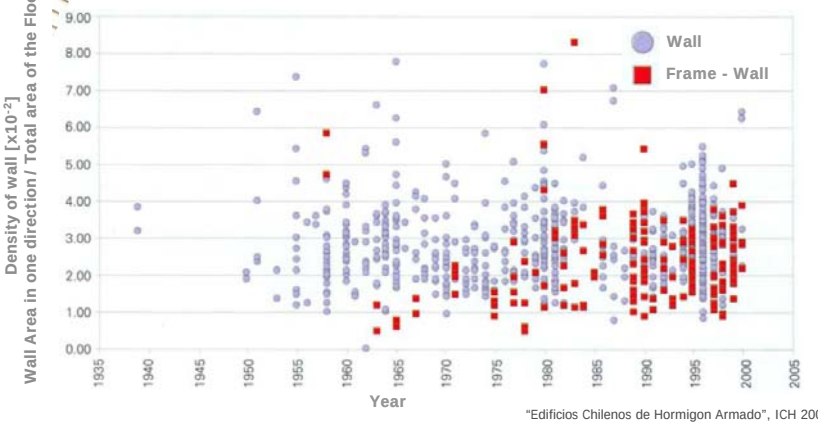
Variation of the Parameter H/T for Chilean's Buildings (ICH 2002)



"Edificios Chilenos de Hormigon Armado", ICH 2002

Characteristics of Chilean's Buildings

Variation of density of wall at one Floor during the years (ICH 2002)



"Edificios Chilenos de Hormigon Armado", ICH 2002

Performance of Buildings during the 02/27/2010 Chile Magnitude M8.8 Earthquake

Performance of Chilean's Buildings

From a study made by Rene Lagos on basis of building permit statistics from the National Institute of Statistics of Chile

NUMBER OF RESIDENTIAL BUILDINGS: 3 STORY +
CONSTRUCTION PERMITS FROM 1985 TO 2009

Building Height	Regions affected by the earthquake						Total
	V	Metro	VI	VII	VIII	IX	
3 story	598	3.412	390	202	673	75	5.350
4 story	213	517	87	28	98	82	915
5 story	143	548	20	17	63	37	828
6 story	53	75	3	3	22	15	171
7 story	22	290	2	13	20	7	354
8 story	63	330	5	2	12	5	417
9 story +	413	1.310	10	27	102	77	1.939
TOTAL	1.505	6.482	467	287	985	248	9.974

Source: Statistics from INE

renelagos

How did Buildings Perform?

Considering only buildings between 1985 to 2009

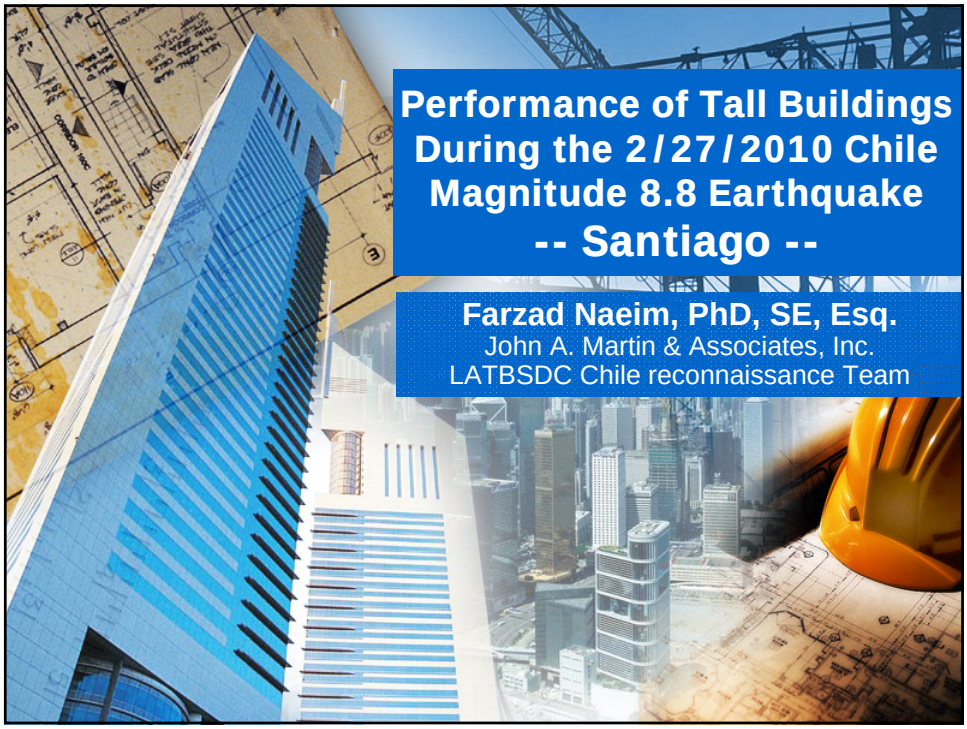
- Buildings that collapsed: 4 (app.)
- Buildings to be demolished: 50 (estimate)
- Number of buildings 3 + story 9.974
- Number of buildings 9 + story 1.939

- Failures 3 + story buildings: 0.5%
- Failures 9 + story buildings: 2.8%

Estimation made by Rene Lagos

renelagos

Thank you!



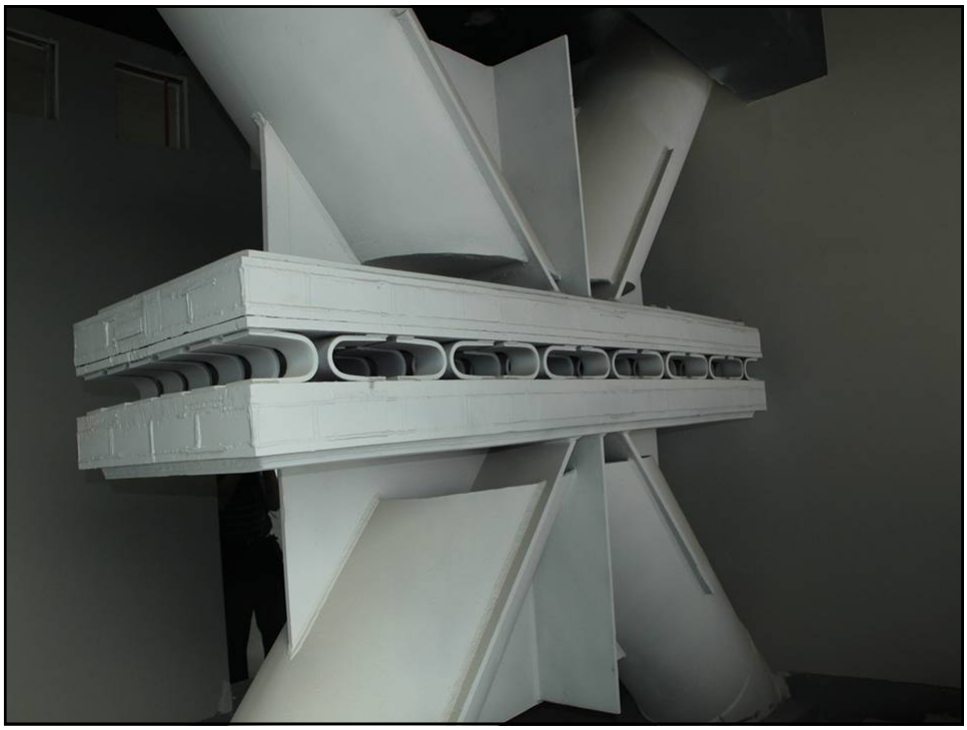
Performance of Tall Buildings During the 2/27/2010 Chile Magnitude 8.8 Earthquake -- Santiago --

Farzad Naeim, PhD, SE, Esq.
John A. Martin & Associates, Inc.
LATBSDC Chile reconnaissance Team

General observations on performance of tall buildings

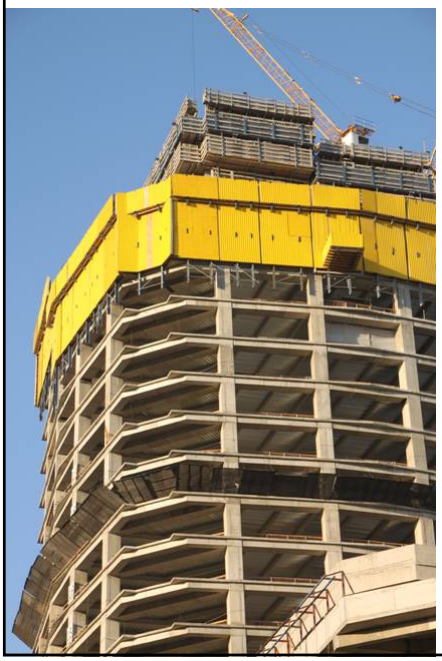
- Chile is not a developing country
- Building codes in Chile are substantially the same as U.S. codes (ACI 318) with some exceptions
- Santiago skyline is filled with smart buildings and technologies equal to if not surpassing those in major cities of U.S.
- Less than 2.5% of engineered structures in Chile suffered damage
- Out of ≈400 casualties, less than 20 died in engineered structures

Titanium Tower

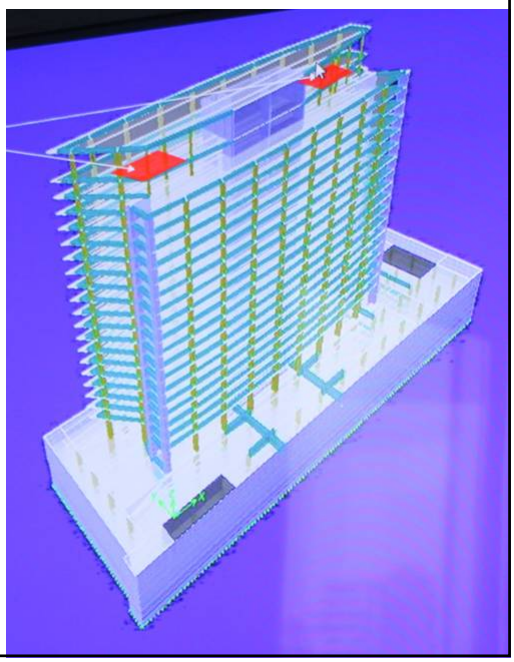


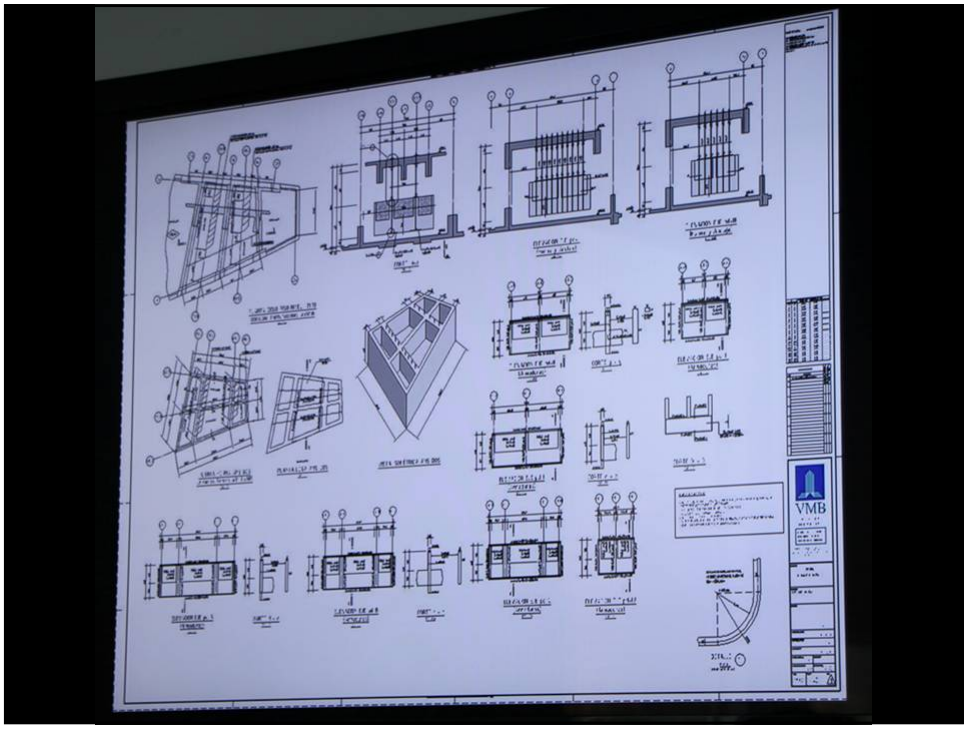

Piso
-7

Costanera Complex



Parque Araucano

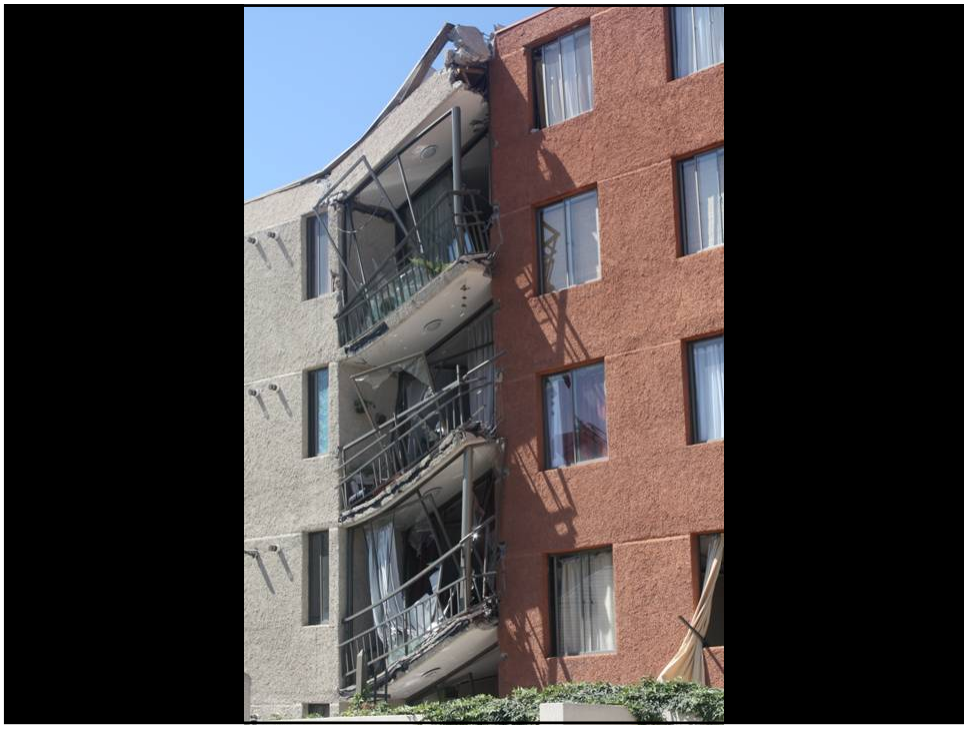


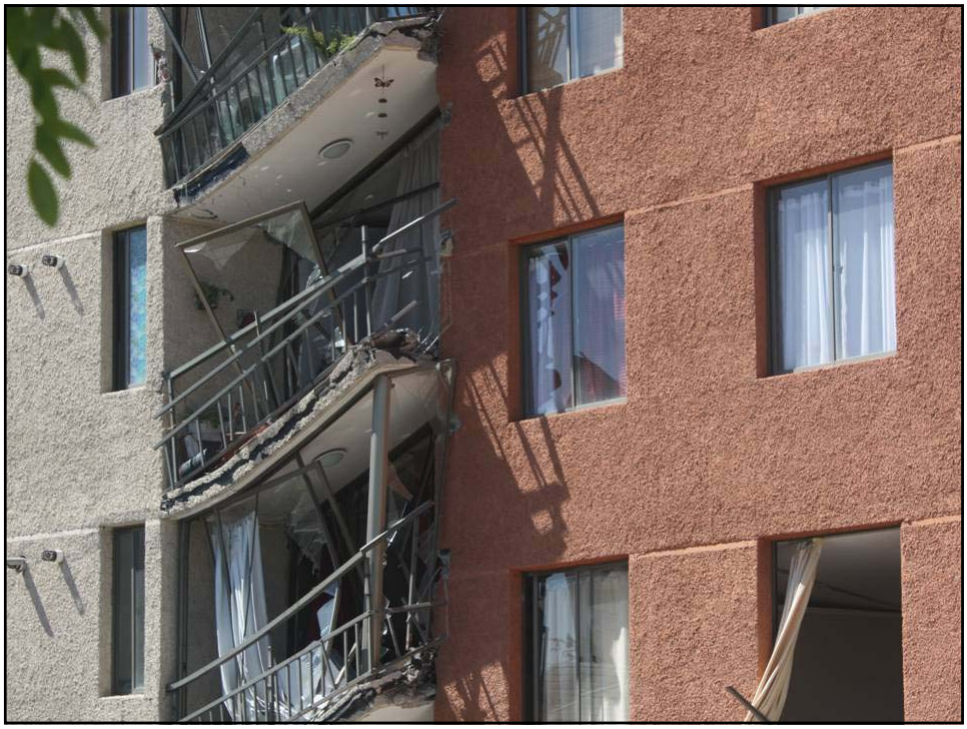

VMB


-8
RESPIRADOR
USO OBLIGADO

Echeverria Izquierdo

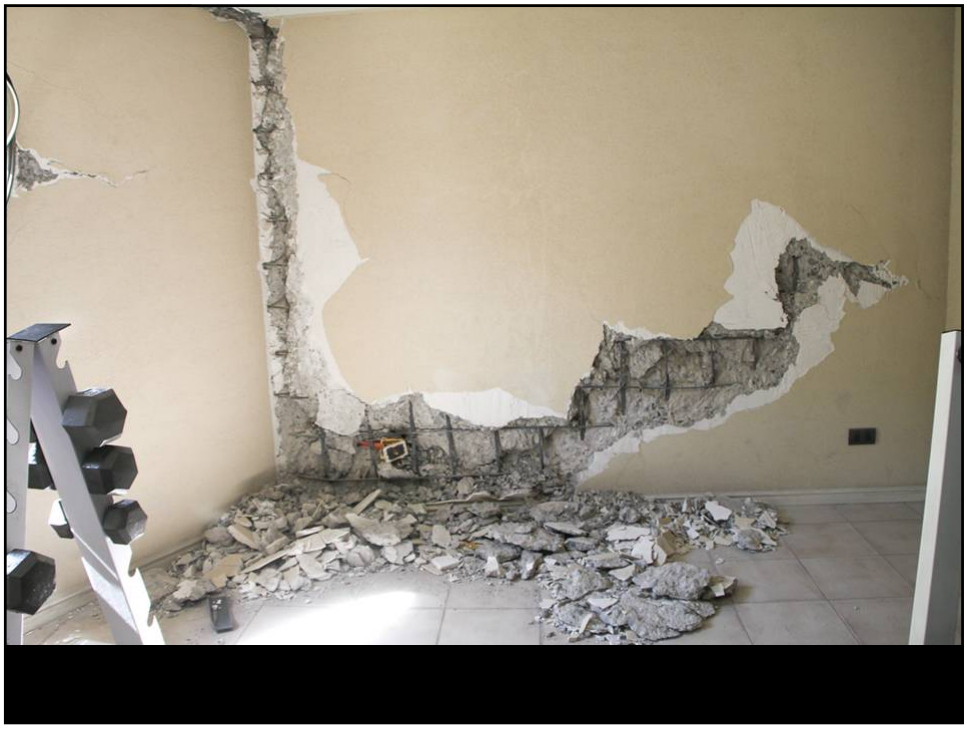
Don Tristan





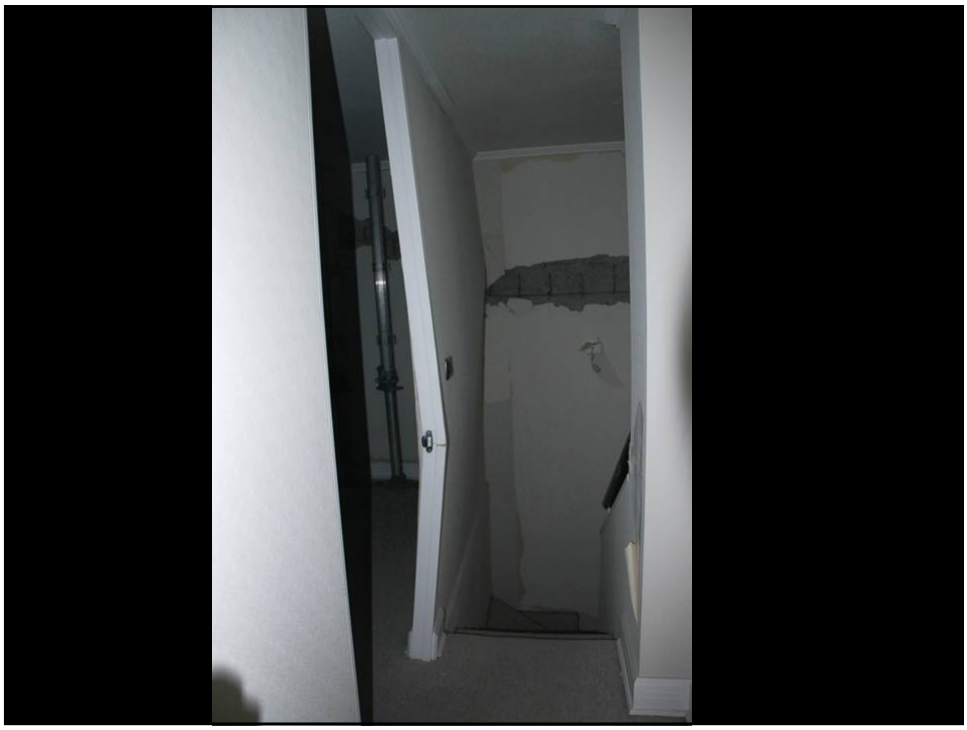

PELIGRO
PELIGRO
PELIGRO
PELIGRO
PELIGRO

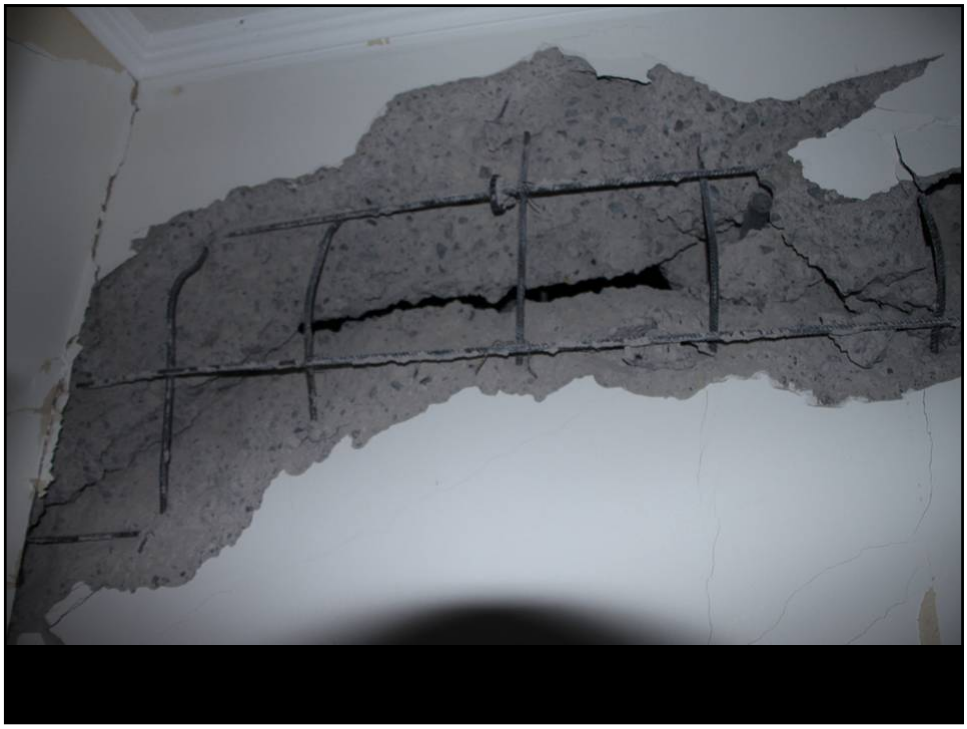
Central Park




49

Emerald



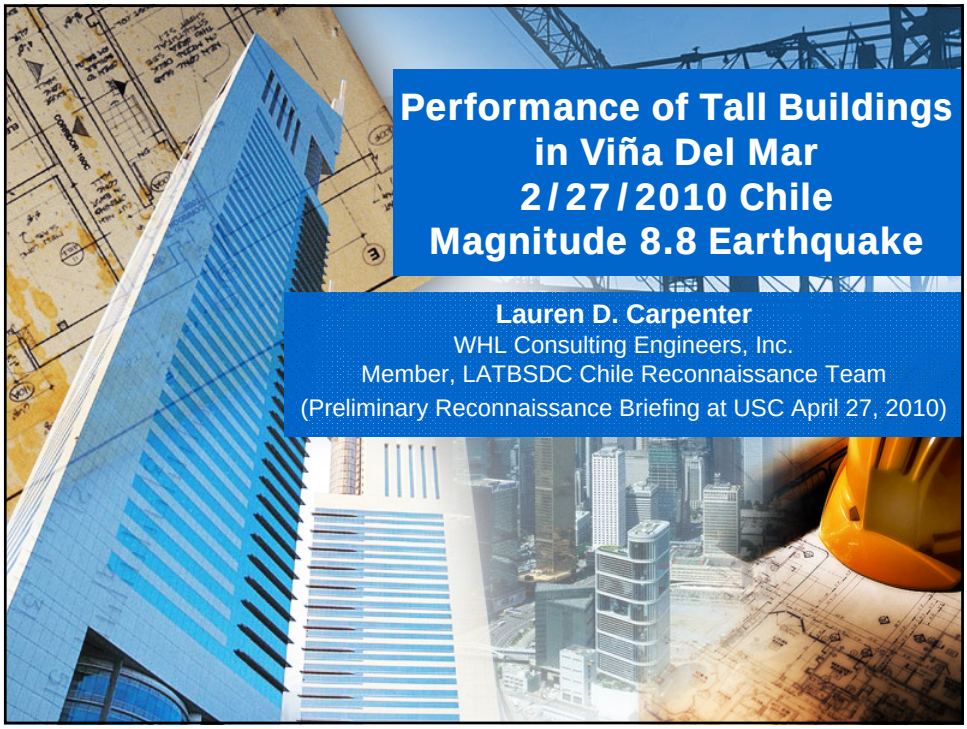



52
54
27 2 2010


1950K2
K27950


K2

Thank you!



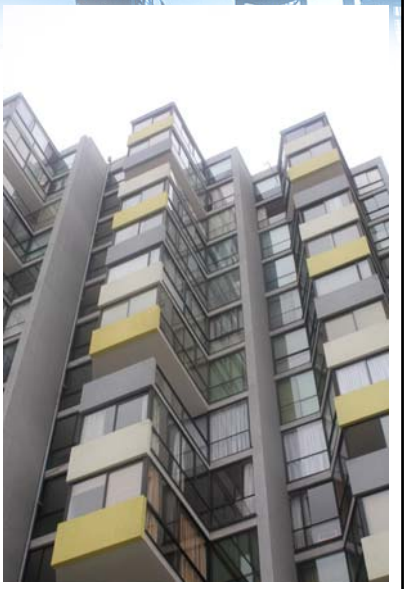
Performance of Tall Buildings in Viña Del Mar 2/27/2010 Chile Magnitude 8.8 Earthquake

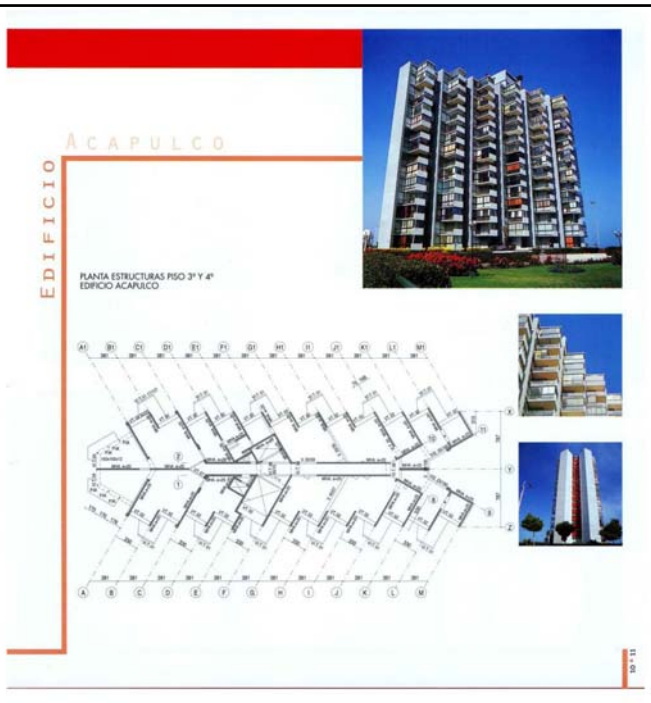
Lauren D. Carpenter
WHL Consulting Engineers, Inc.
Member, LATBSDC Chile Reconnaissance Team

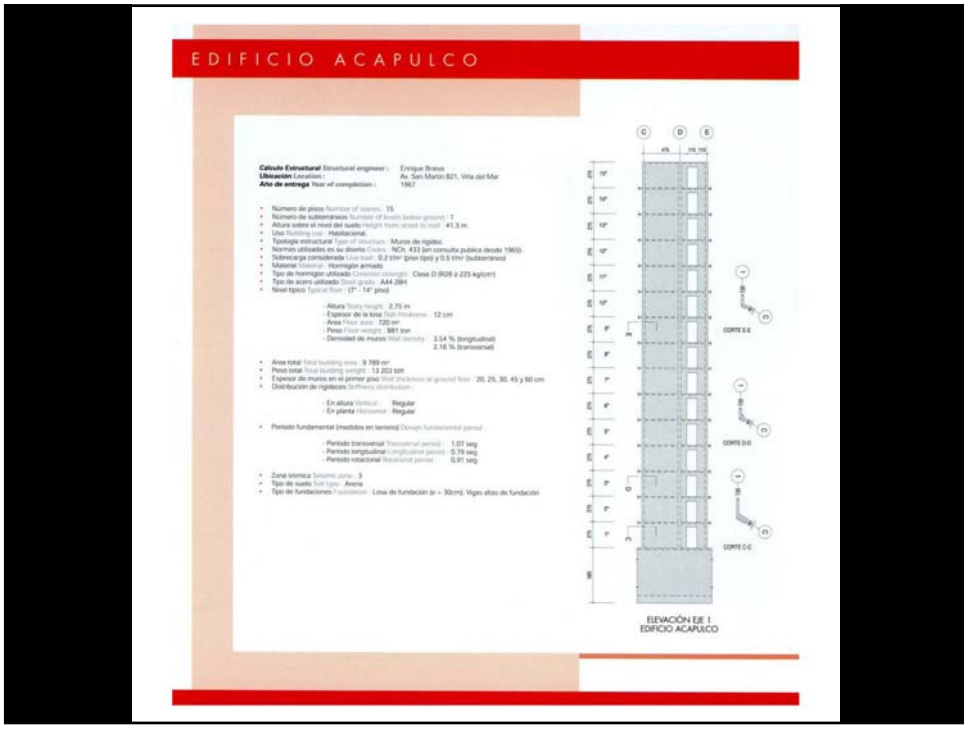
(Preliminary Reconnaissance Briefing at USC April 27, 2010)

Acapulco 33

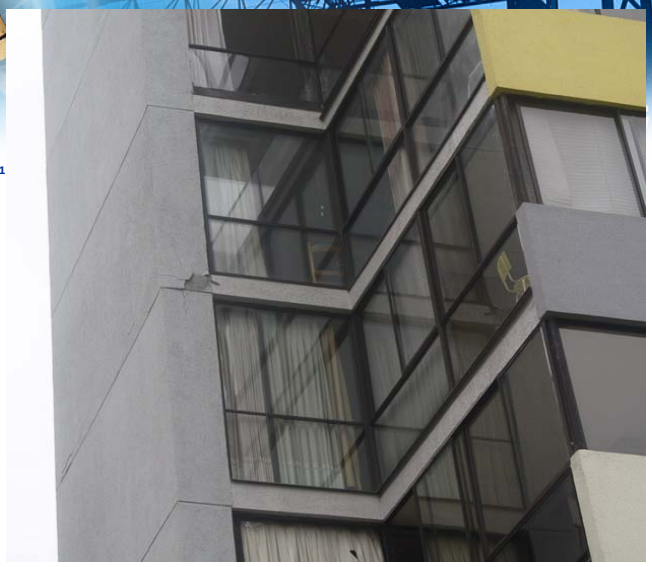
- Ave San Martin 821
- 15 storys 1 Basement
- Built 1967 to 1965 Code
- Wall thicknesses at GF
- 20, 25, 30, 45, 60
- Book pgs 11 and 12
- With floor plan







Acapulco [1]



- Minor apparent distress above

Acapulco 31

- Diagonal shear reinforcing

Acapulco 13

- Diagonal shear reinforcing
  outside of “end of wall” zone
  vertical reinforcing
- End of wall reinforcing
  not enclosed in ties

Acapulco 9

- Cross ties not apparent
- Wall has vertical load along full length
- Aggregate moderately large and rounded

Antigona 267

- 5 Oriente 260
- 16 storys 2 Basements
- Thin “brick” cladding mortar set

Antigona 252

- East face with spandrel distress
- Lower right base of shear wall

Antigona 251

- Horizontal reinforcing is OUTSIDE of vertical reinforcing at the end of the wall
- Horizontal reinforcing is INSIDE of vertical reinforcing in the center portions of the shear wall

Antigona 255

- Shear wall crushing failure
- Horizontal reinforcing 90 Hooks
- End of wall zone ties not apparent

Antigona 223

- Vertical wall panel between windows
- Single curtain of reinforcing

Antigona 144

- Basement shear wall with severe crushing at end of wall

Antigona 137

- Basement wall at end
- Some end of wall enclosing ties are apparent
- Horizontal reinforcing not anchored inside end of wall zone

Antigona 143

- End of wall with top of dowels
- Horizontal reinforcing with 90 hooks
- End of wall enclosing reinforcing with
- 90 hooks

Antigona 67

- Prevalent slab distress at “coupling”
- Over doorway openings
- Also slab flexural bending along wall edge

Festival 115

- 9 Norte 450/459
- 14 storys 2 basements
- I shaped foot print
- Longitudinal shear walls
  10 cm added each side of 30 cm original thickness as remedial/repair after March 1985 earthquake

Festival 100

- End of wall failure at GF
- Horizontal reinforcing 90 hooks
- End of wall ties not apparent

Festival 63

- End of shear wall reinforcing
- Wide spacing of ties
- Ties are horizontal shear reinforcing
- With 90 hooks

Festival 60

- End of shear wall
- Without ties at end of wall
- Horizotal shear reinforcing
- With 90 hooks

Festival 75

- Longitudinal shear wall
- With opening

Festival 56

- Longitudinal shear wall
- Without significant openings

Festival 33

- Longitudinal shear wall crushing
- Slab flexure across walls

Festival 1

- Exterior wall shear panel

Rio Petrohue 54

- 7 Norte 585
- 16 storys 2 basements
- Thin “brick” façade set in mortar

Rio Petrohue 185

- Corner at L shaped “column”

Rio Petrohue 184

- Shear cracks in interior coupling beams over doors

Rio Petrohue 17

- Prevalent behavior of coupling beams
- Close spaced stirrups
- Complete closed stirrups
- Side bars on beams

Rio Petrohue 44

- T ends of walls at GF

Rio Petrohue 48

- End T on shear wall
- End of shear wall ties not apparent
- Cross ties not apparent
- Wall ties longer than 3 to 1

Rio Petrohue 96

- End of shear wall crushing
- Some end of wall ties at wide spacing
- Horizontal shear reinforcing 90 hooks

Rio Petrohue 179

- Column ties wider spacing
- Cross ties not apparent

Rio Petrohue 158

- Basement shear wall end with “gravity” beam

Rio Petrohue 161

- End of basement shear wall
- Fractured vertical reinforcing

Rio Petrohue 68

- Opposite face of basement shear wall with fractured vertical reinforcing

Rio Petrohue 79

- Basement shear wall with T at end
- Crushing at opposite end at “gravity” beam

Rio Petrohue 65

- End of basement shear wall at narrow end (opposite end with T)

Rio Petrohue 63

- Short shear wall in basement
- Crushing at both edges
- Beam reinforcing outside of wall “cage”
- Cross ties not apparent over the depth of the beam

Antilco 62

- 5 Norte 161/169
- 9 stories
- 1960's vintage
- Damaged previously

Antilco 63

- End shear wall on street side
- Some damage at base of wall

Antilco 11

- End shear wall at opposite end
- With some damage at corner column
- And damage at beam to shear wall location

Antilco 12

- Damage at beam to shear wall location
- Ties at vertical reinforcing not apparent

Antilco 14

- Interior longitudinal shear wall shear cracking
- And shear cracking at wall opening

Antilco 34

- Prevalent coupling beam behavior
- At transverse shear walls
- And at door openings between segments of longitudinal shear walls
- Wide spacing of stirrups
- Side bars outside of stirrups

Antilco [48]

- Moderately large aggregate with rounded shapes

Torre Del Mar [3]

- 8 Norte at 3 Poniente
- 15 storys basements

Torre Del Mar 7

- Damage at transfer of short upper wall transfer to wider lower wall
- Column damage also present at some locations

Torre Del Mar 8

- Wall vertical reinforcing outside of horizontal reinforcing
- Vertical reinforcing not tied
- And cross ties are not apparent

Torre Del Mar 30

- Column reinforcing is tied with 90 hooks
- Cross ties are not apparent

Torre Del Mar 43

- Shear wall damage at offset of window openings at stair landings

Torre Del Mar [10]

- Shear wall damage at offset in windows at stair landings

  Horizontal reinforcing outside vertical reinforcing in center and ends of shear wall

Toledo [130]

- 3 Norte 487
- 10 storys 2 basements

Toledo 63

- 3 Norte 487
- 10 storys 2 basements

Toledo 120

- Crushing damage at shear wall across the full length of the wall of about 30 cm

Toledo

103

- Shear wall overall crushing damage

Toledo

80

- Crushing and shortening of shear wall
- Horizontal wall reinforcing 90 hooks
- End of wall ties around end of wall vertical reinforcing are not apparent

Toledo 76

- Opposite end of crushed and shortened shear wall

Toledo 81

- Opposite end of crushed and shortened shear wall

Toledo 105

- Directly below in the basement is not significantly damaged

Toledo 48

- Tension cracking on street side ends of transverse shear walls

Toledo

97

- Cantilevered portions beyond the ends of the transverse shear walls

Toledo

91

- Crushng at end of transverse shear wall
- At both top and bottom of the wall

Toledo

96

- Crushing at the base of the transverse shear wall at the GF

Toledo

92

- Top of wall
- Horizontal reinforcing 90 hooks
- End of wall zones ties not apparent

Toledo

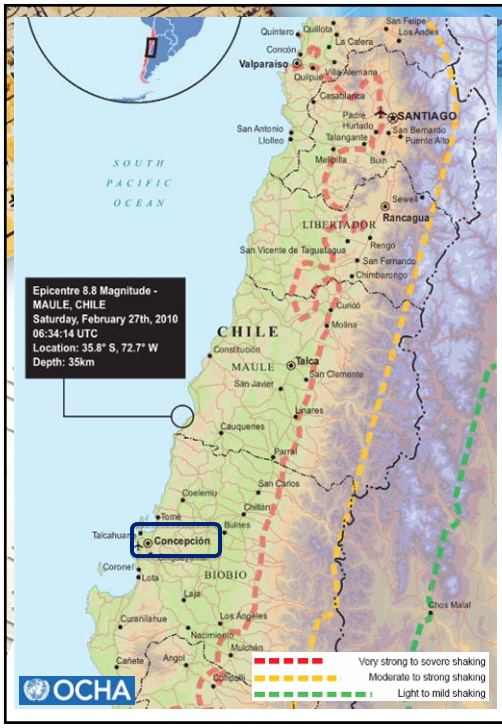
- Cantilevered back portion of floors
- Set back of upper shear wall at the Ground Floor story effectively shortened the length of the shear wall
- This shear wall crushed and shortened about 30 cm at the base of the wall at the GF
- Other shear walls along the complete backside of the building had severe crushing
- But the building did not collapse !!!

Thank you!

Performance of Tall Buildings in Concepción

-- Preliminary LATBSDC Reconnaissance Briefing --
Performance of Tall Buildings During the 2/27/2010 Chile Magnitude 8.8 Earthquake

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



Concepción

- Distance from the Epicenter: 105 km (65 miles) NNE
- Population Affected ≈ 225000
- Total number of Deaths: 32
- People Disappeared: 13
- Number of Deaths in Structures Design by Engineers: 8
- Estimated PGA ~0.6g

Image showing coastal inundation and floating debris

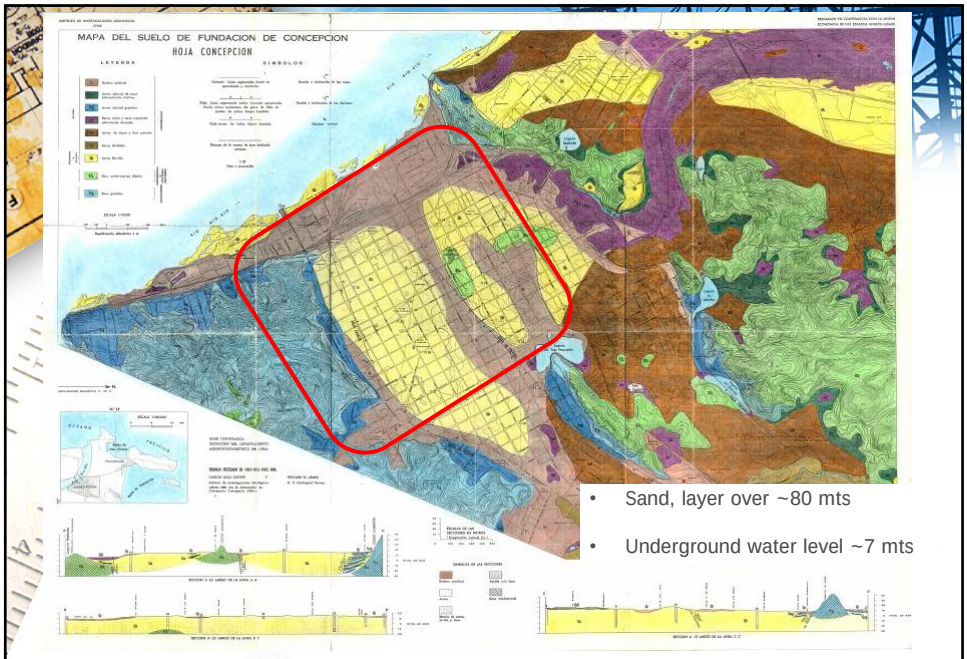
Concepción

Pre- Event Imaginary

USAID
FROM THE AMERICAN PEOPLE

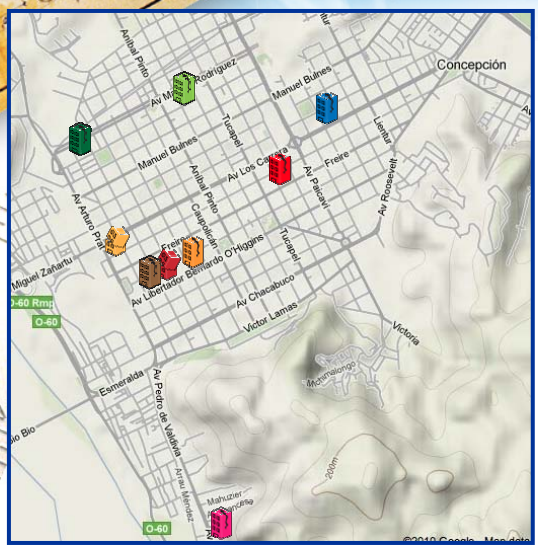
How did Buildings Perform in Concepcion?

- Collapsed Buildings: 1 Complete + 1 Partial
- Buildings to be Demolished:
  - Taller than 9 Stories = 8 (I. Mun. Concepción – April, 7)
- Number of Buildings 9 + stories: ~48 (Estimated)
- Severe Damage to 9 + Stories : 18.8 %
- Buildings with Moderate Damage:
  - Taller than 3+ Stories ≈ 64 (I. Mun. Concepción – April, 7)



- Sand, layer over ~80 mts
- Underground water level ~7 mts

Type Soil in Downtown Concepción



Buildings Visited

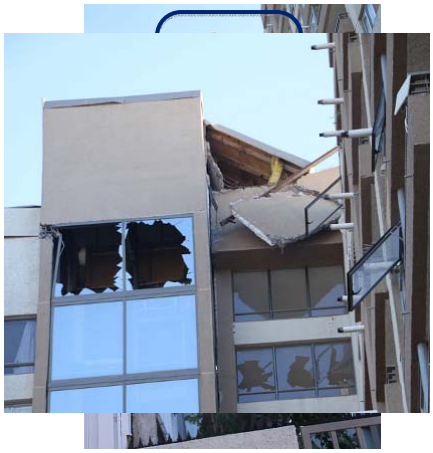
- Plaza del Rio
- Plaza Mayor Complex
- Alto Arauco II
- Centro Mayor
- Torre Libertad
- Obispo Salas
- Pedro de Valdivia
- Torre O'Higgins
- Alto Rio

Plaza del Rio

Salas 1345

- 2 Buildings connected with a seismic joint, Housing
- 13 Stories, RC, Built in 2007
- Underground Parking is not beneath the Towers

Plaza del Rio

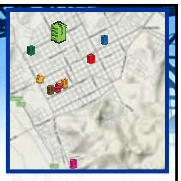



Plaza del Rio


Plaza del Rio

Plaza del Rio

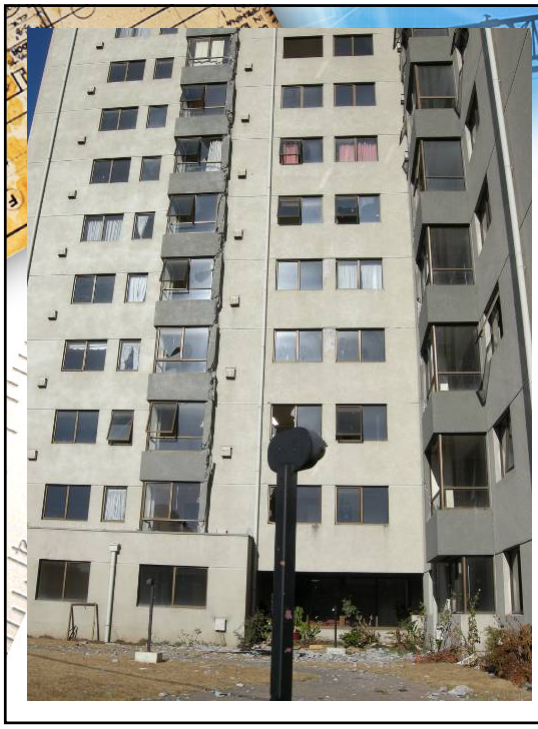
(Photo: El Sur)



Plaza Mayor Complex

Castellon 1367

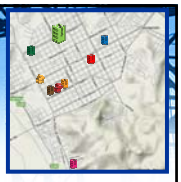
- Complex of 6 Buildings
- Plaza Mayor I :
  - 1 Building : 14 Stories



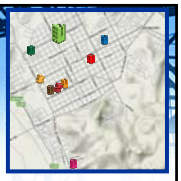
Plaza Mayor Complex

Plaza Mayor Complex

- Complex of 6 Buildings
- Plaza Mayor II :
  - 2 Building : 14 Stories

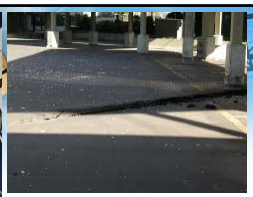


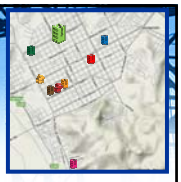
Plaza Mayor Complex



Plaza Mayor Complex

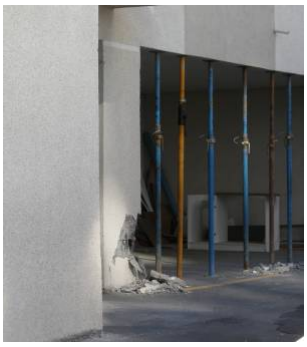
- Complex of 6 Buildings
- Plaza Mayor III :
  - 1 Building : 15 Stories

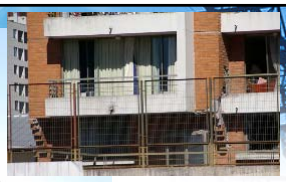


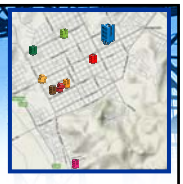


Plaza Mayor Complex

- Complex of 6 Buildings
- Plaza Mayor IV :
  - 2 Building : 16 Stories



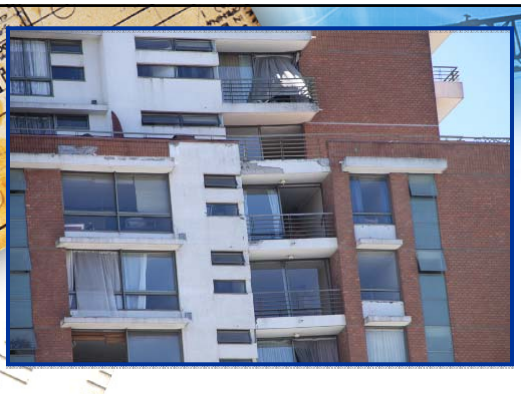




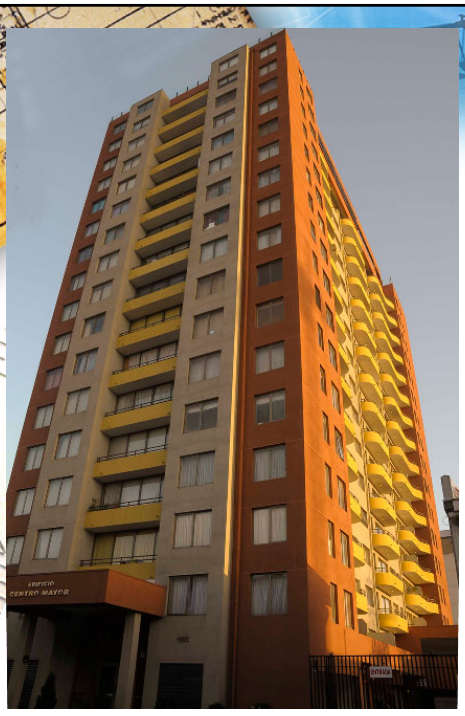
Alto Arauco II

Los Carreras 1535

- 18 Stories , RC, , Housing
- No underground level



Alto Arauco II

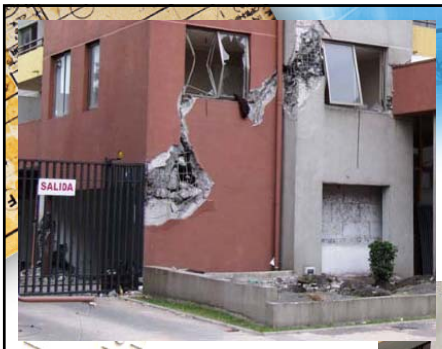


Centro Mayor

Freire 1065

- 17 Stories, RC, Housing
- No Underground Level

(Photo: La Tercera)



Centro Mayor

(Photos: J. Moehle)

Torre Libertad

Lincoyan 440

- 13 Stories, RC, Housing and Retails
- Built in 1985

Torre Libertad

Obispo Salas

Salas 445

- 24 Stories + 2 Underground Levels, Housing
- Built in 2009

Obispo Salas

Pedro de Valdivia

Pedro de Valdivia 1653

- 13 Stories , RC, Housing
- No Underground Level


Pedro de Valdivia


Pedro de Valdivia

Pedro de Valdivia

Torre O'Higgins

Av. Bernando O'Higgins 241

- 21 Stories , RC, Office
- 2 Underground Level
- Built in 2008

After Earthquake

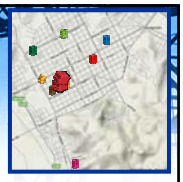
Before Earthquake


Torre O'Higgins

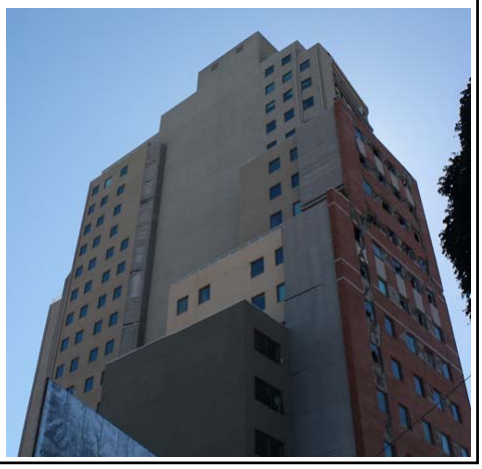

Torre O'Higgins

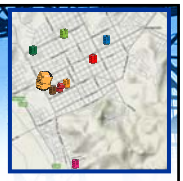

Torre O'Higgins


Torre O'Higgins



Torre O'Higgins





Alto Rio

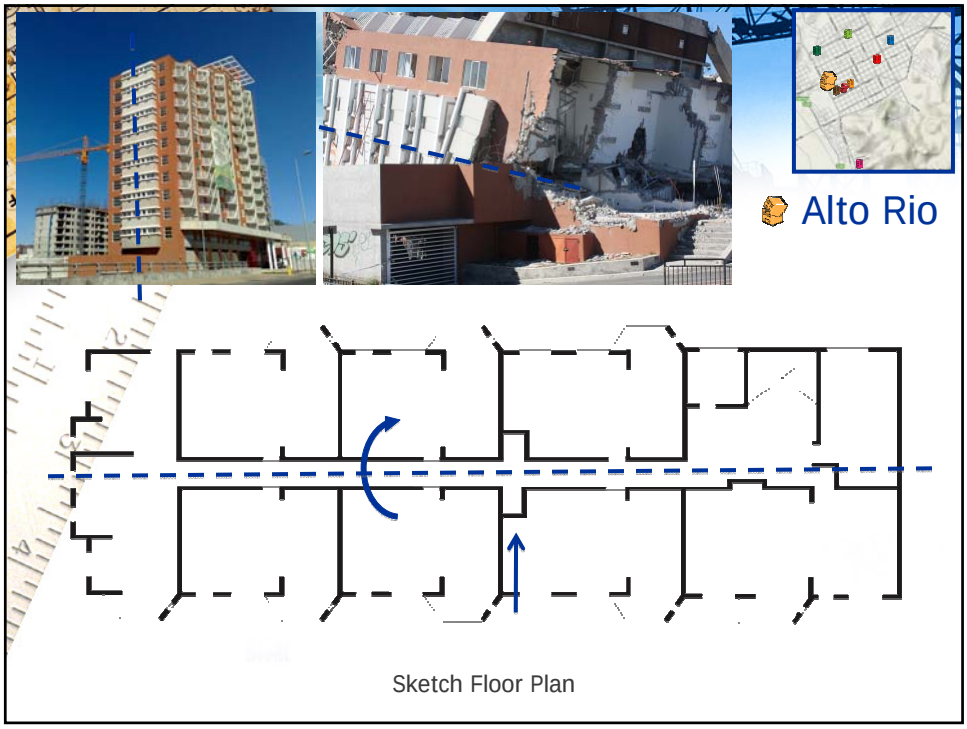
Arturo Prat

Before Earthquake

After Earthquake (Photo: www.elperiodistaonline.cl)

- 15 Stories, RC, Housing
- 2 Underground Levels
- Built in 2008
- At the moment of the earthquake in the building only 87 people were in there:
  - 8 Died
  - 79 survive : 52 got out of the building by their own, 27 were rescued for the debris

(Photos: web page Concepcion under Construction)

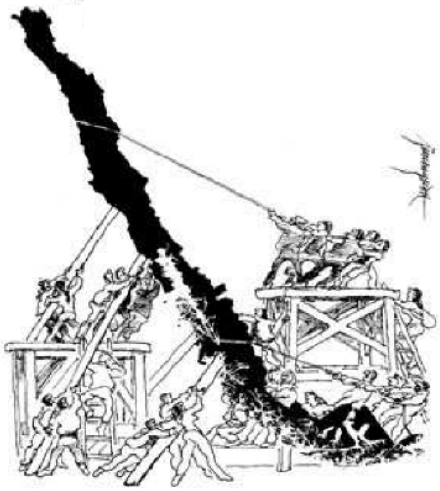

Alto Rio
Sketch Floor Plan

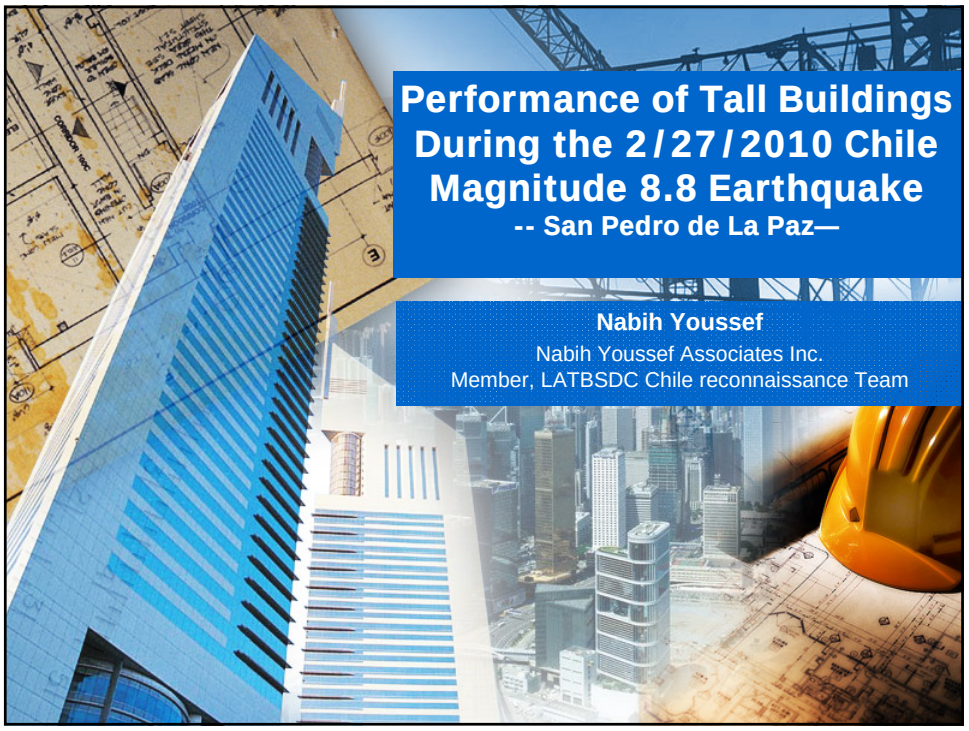

Alto Rio


Alto Rio


Alto Rio

Thank you!





Performance of Tall Buildings During the 2/27/2010 Chile Magnitude 8.8 Earthquake

-- San Pedro de La Paz—

Nabih Youssef
Nabih Youssef Associates Inc.
Member, LATBSDC Chile reconnaissance Team

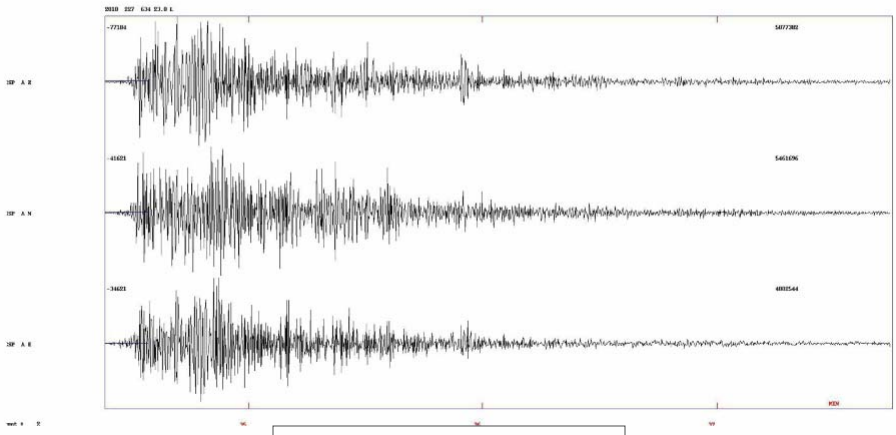
Agenda

- San Pedro de La Paz – Site Information
- Bosquemar - Damage Observations – Case Study
- Insights into the integration and deformation compatibility of primary and secondary concrete elements – Pedro de Valdivia

San Pedro de La Paz
Site Information

Ground Motions

Estación Colegio San Pedro, Concepción.

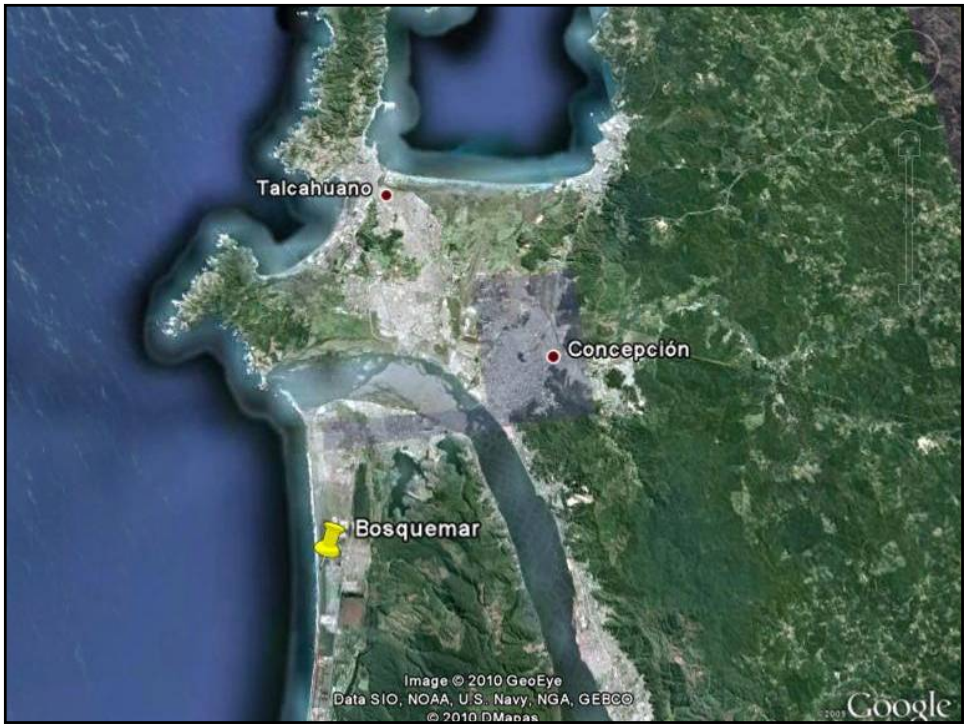


Max E-W Acceleration: 0.65g
Max N-S Acceleration: 0.58g
Max Vert. Acceleration: 0.6g

Universidad de Chile, Servicio Sismologico, "Terremoto Cauquenes 27 Febrero 2010"

Bosquemar – Damage Observations

- Located very close to beach shoreline.
- Soft soils; type III to IV = classification D.
- Two separate condominium towers with different configurations–
- One saw a great deal of damage, the other saw very little
- Shear Wall Crushing
- “Outrigger” Wall Effect at Lobby
- Slab Coupling

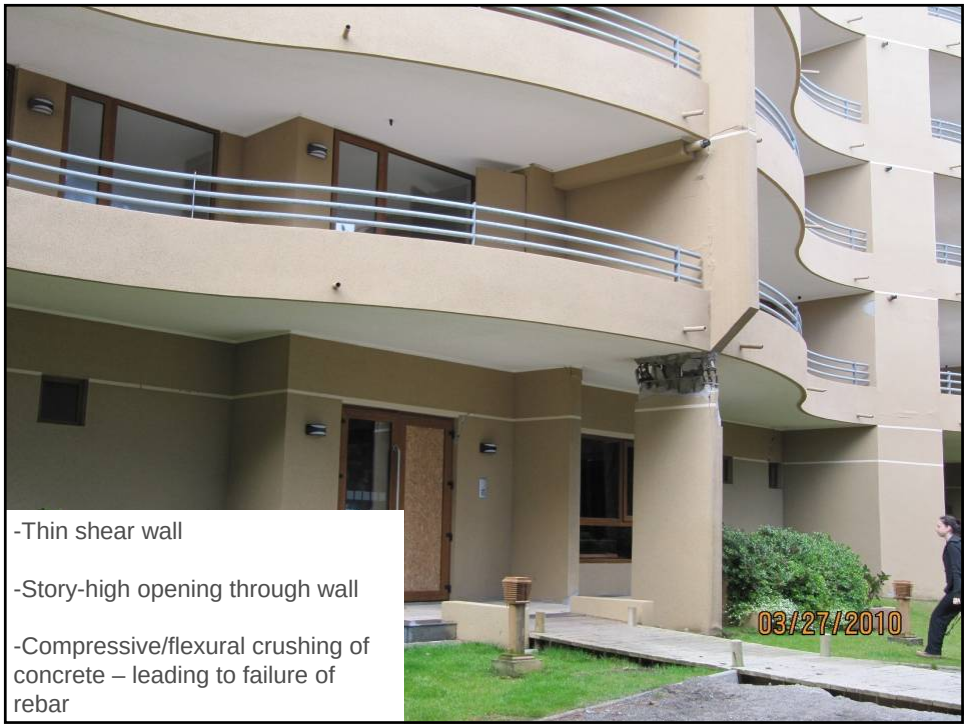



BOSQUEMAR
CONDOMINIO
Tienes que VIVIRLO para
03/27/2010
www.bosque


E-W Direction
Major Damage
to this building
Image © 2010 GeoEye
© 2010 Inav/Geosistemas SRL
© 2010 DMapas
Google
Imagery Date: Sep 16, 2009
36°53'07.59" S
73°09'03.30" W
elev 52 ft
Eye alt 1271 ft

Exterior Images

Exterior Damage



-Thin shear wall

-Story-high opening through wall

-Compressive/flexural crushing of concrete – leading to failure of rebar


03/27/2010


03/27/2010


03/27/2010


03/27/2010

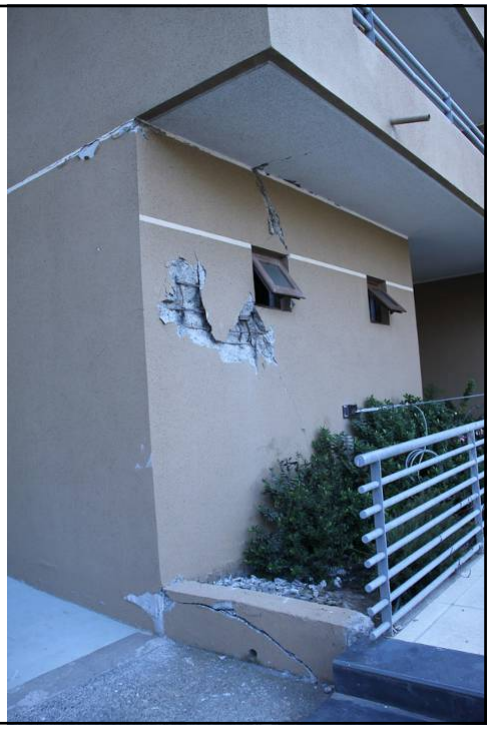

03/27/2010


03/27/2010

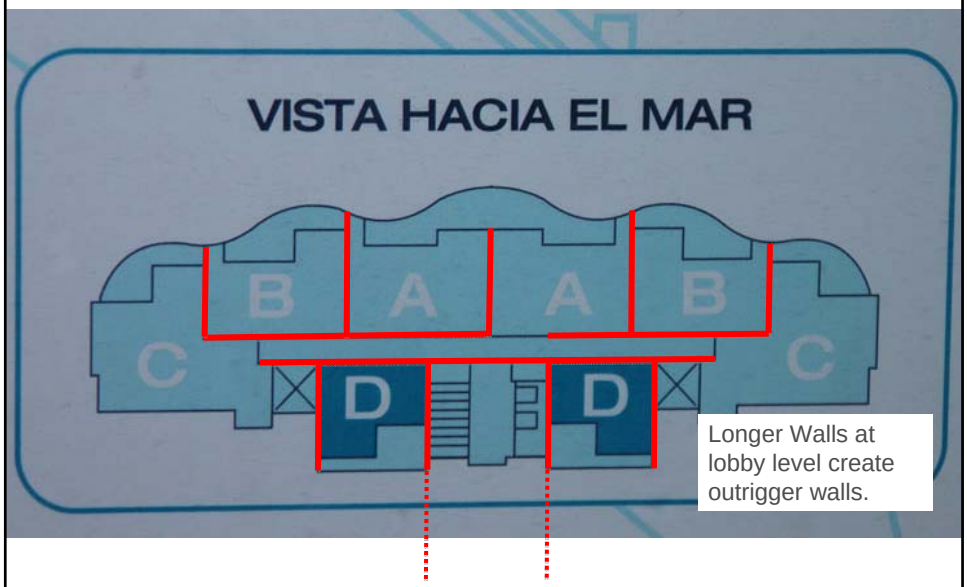

03/27/2010

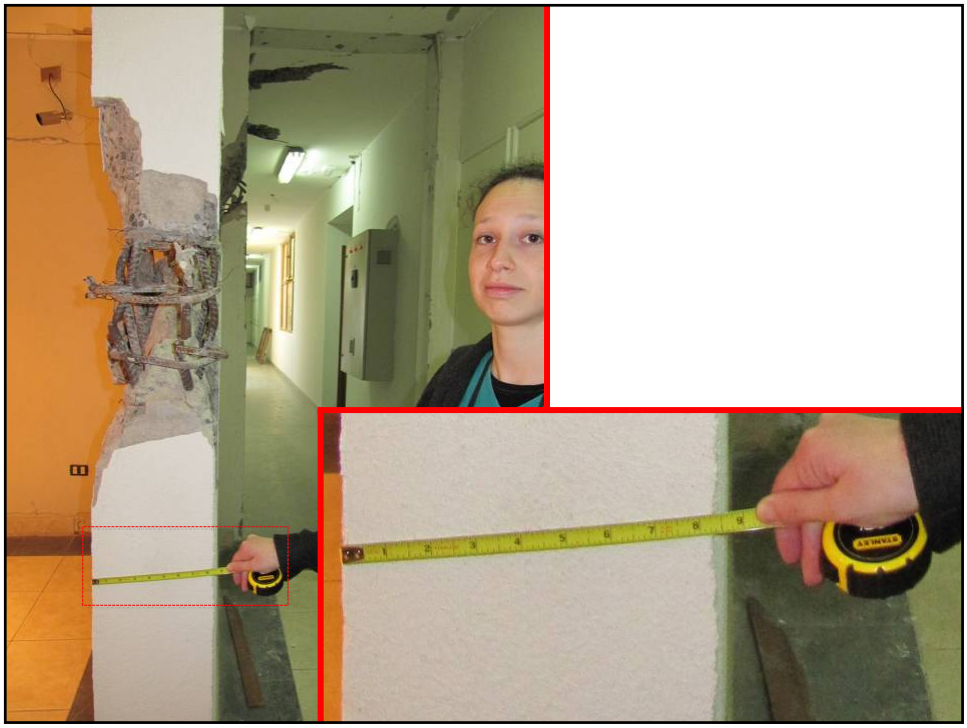

03/27/2010

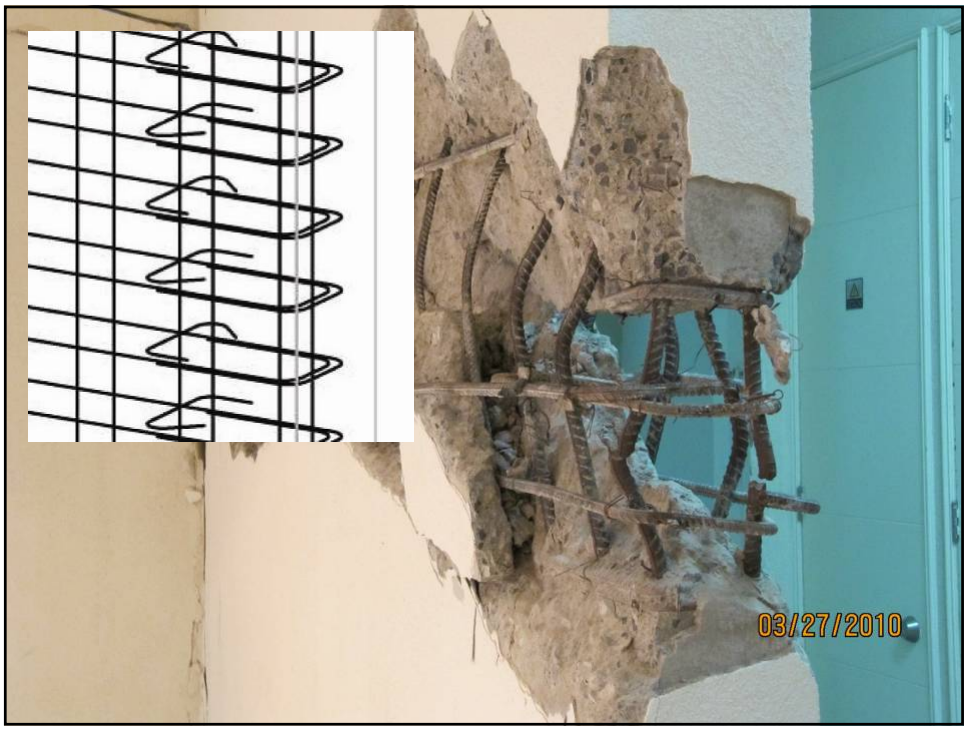

03/27/2010



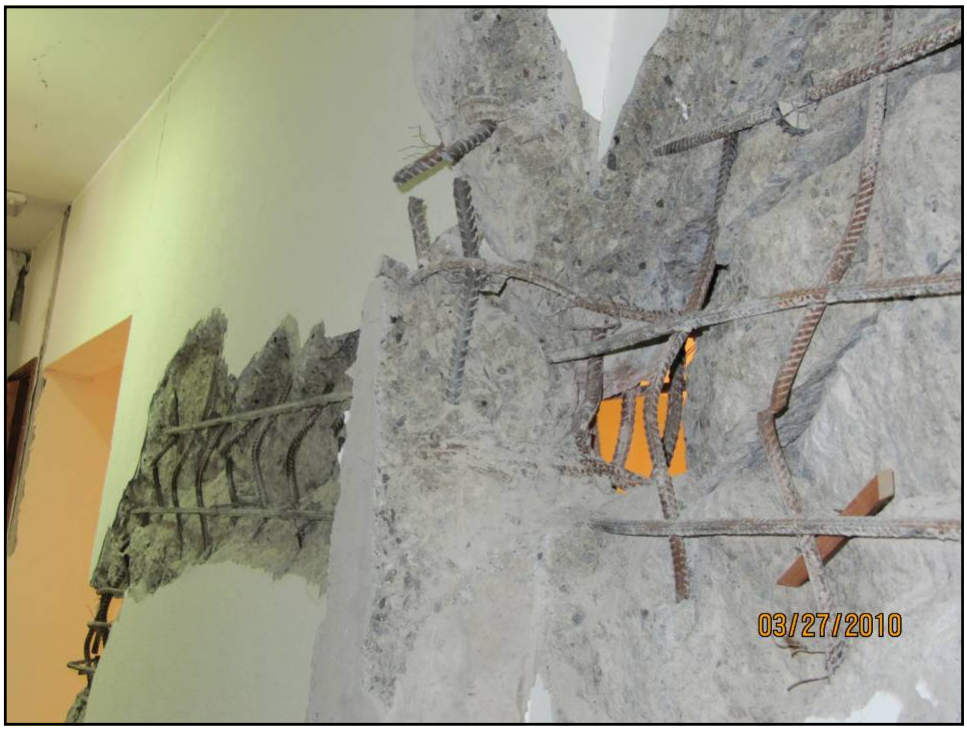
Condominium Layout

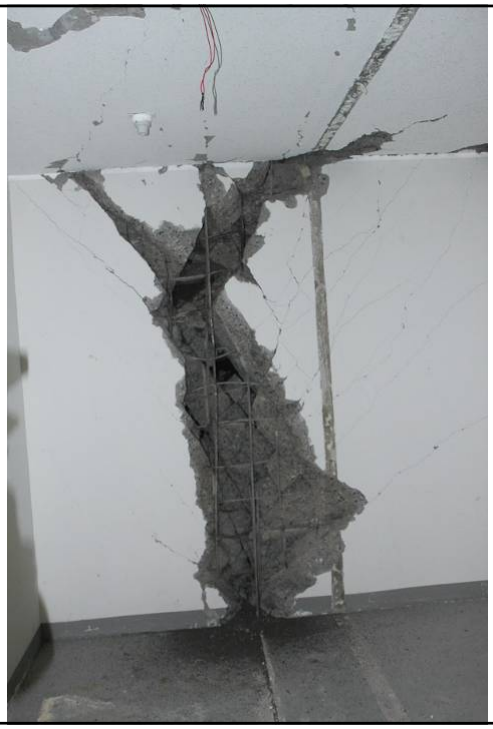

VISTA HACIA EL MAR
B
A
A
B
C
C
D
D
Longer Walls at lobby level create outrigger walls.



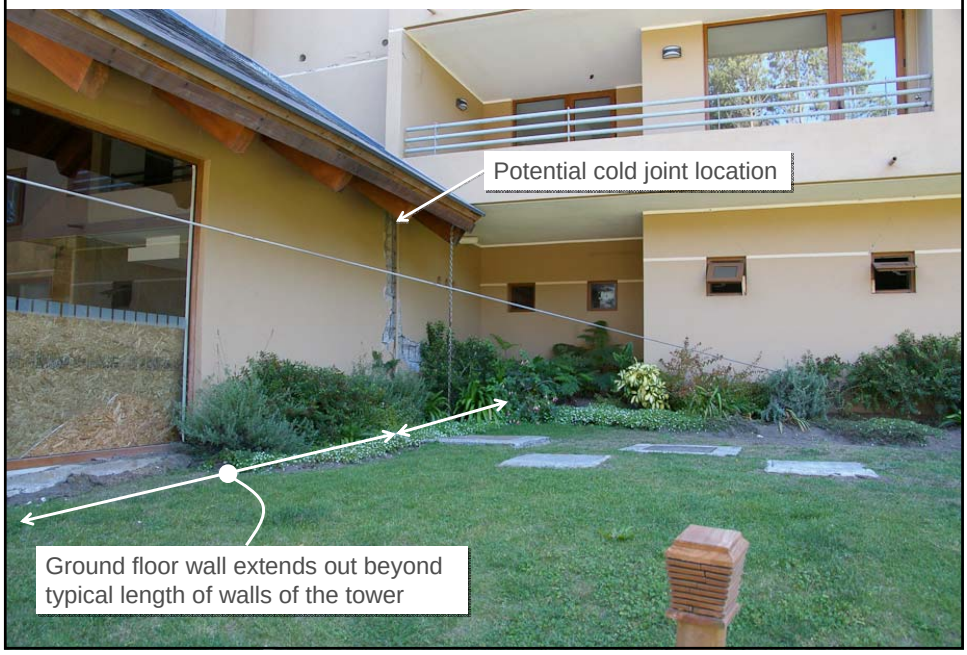

03/27/2010


03/27/2010


03/27/2010



“Outrigger” Walls

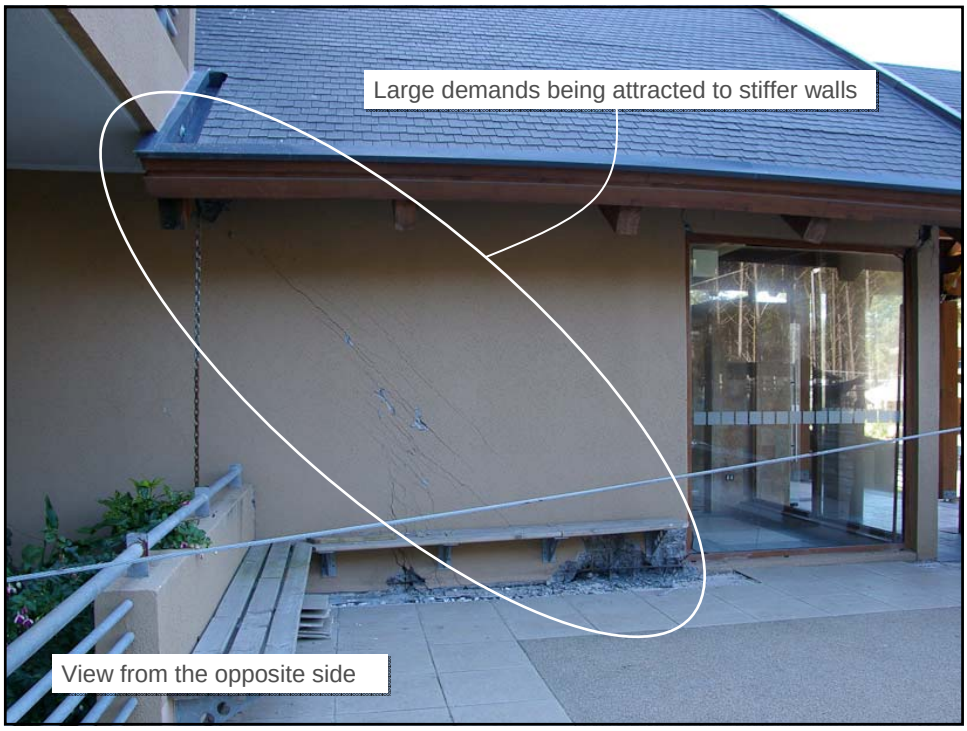



View from inside


03/27/2010


03/27/2010

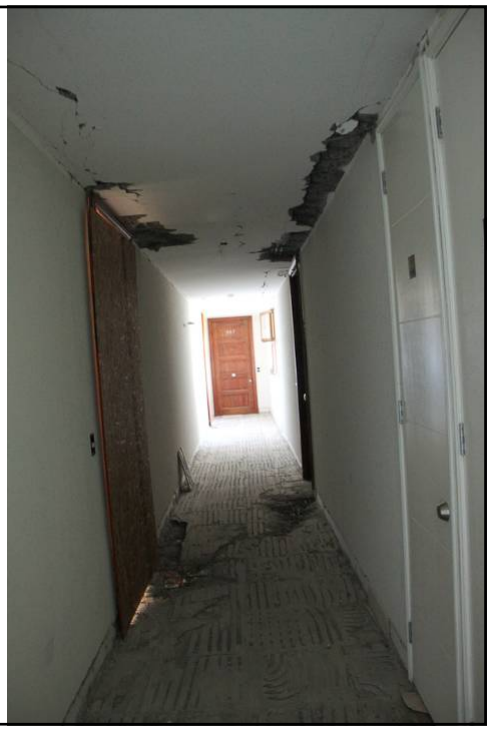

03/27/2010


Large demands being attracted to stiffer walls
View from the opposite side

Slab Coupling in Upper Levels

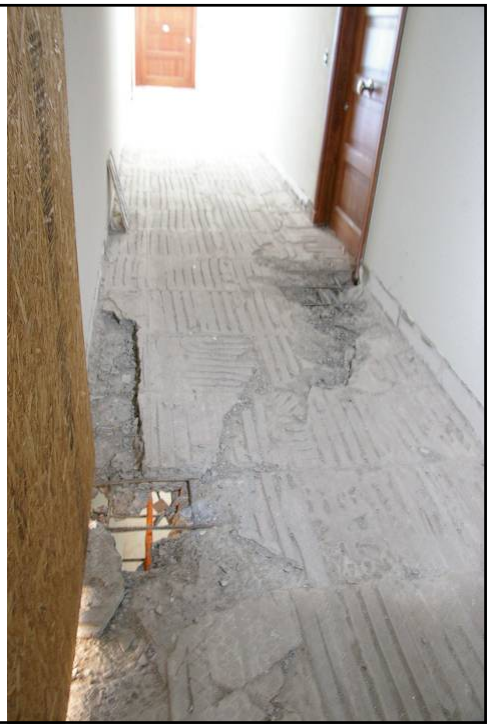

Flexural coupling in the slab between closely spaced longitudinal shear walls


Flexural coupling longitudinally over door openings

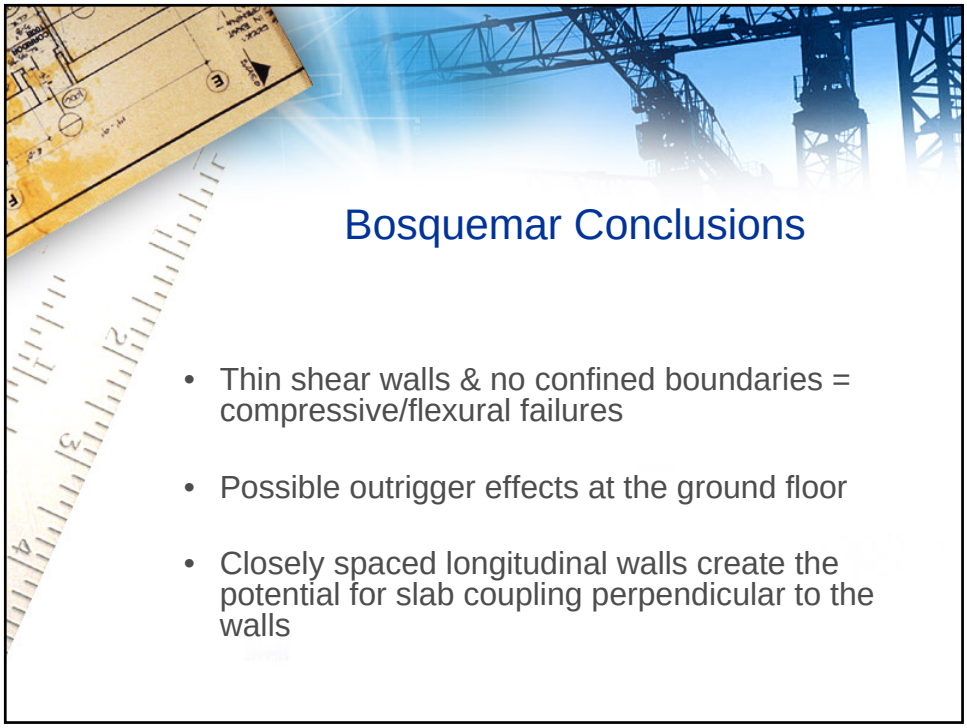



1305


1305



Top of the building
Pool mechanical penthouse



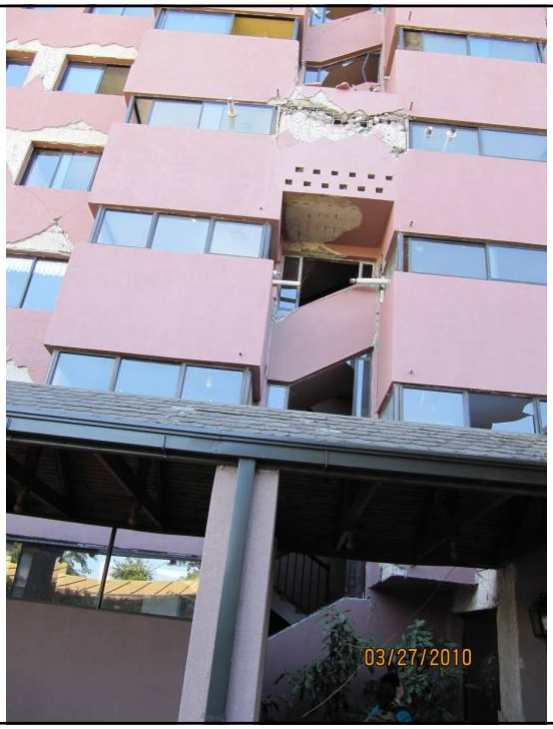
Bosquemar Conclusions

- Thin shear walls & no confined boundaries = compressive/flexural failures
- Possible outrigger effects at the ground floor
- Closely spaced longitudinal walls create the potential for slab coupling perpendicular to the walls

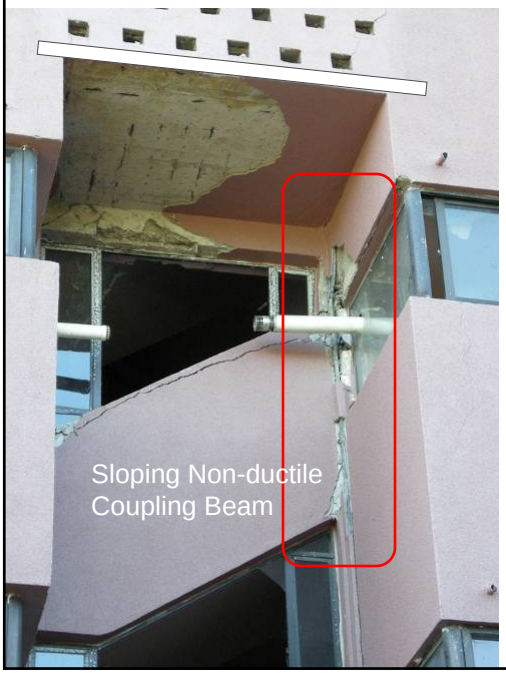
Insights into the integration and deformation compatibility of primary and secondary concrete elements

- Pedro de Valdivia in Concepcion
- Architectural stairway windows create unintended structural effects

Exterior View



Exterior View



-Evidence of damage caused by unintended coupling demands

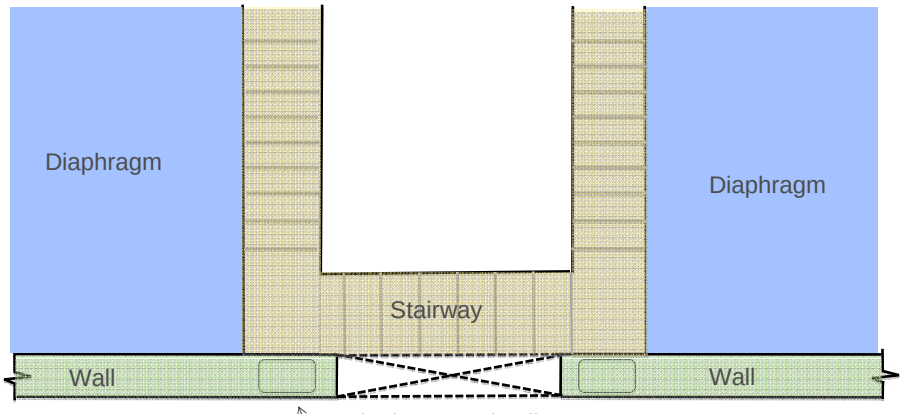
-Edges of stairways not detailed to accommodate these demands

-How does the coupling beam interact (or not) with the diaphragm?

Interior View

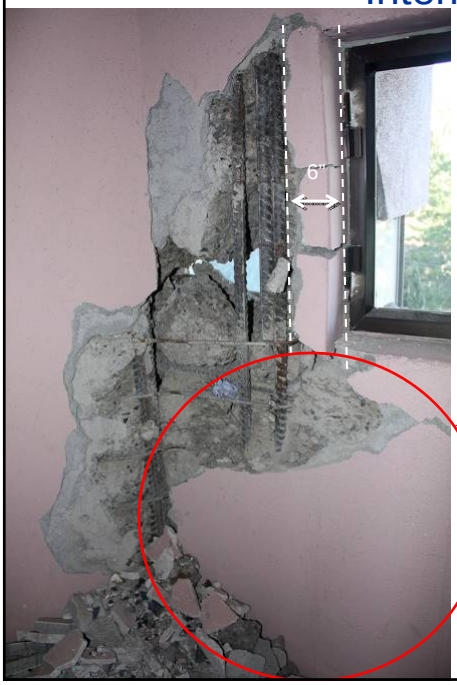
Interior View

Plan View



-Wall Boundaries outside of diaphragm limits.

Interior View



-Boundary reinforcement of wall offset from window opening by ~6”

-Area not reinforced to accommodate coupling demands

-Wall Boundaries outside of diaphragm limits.


Thank you!

The dilemma of being an structural engineer in Chile

- Of course there were damages and collapses as we saw
- However, the expectation of general public was totally unrealistic
- They thought they were sold lemons
- Structural engineers and contractors were blamed as cheaters and incompetents
- Let me give you an example in Concepcion.

Photos and comments from Mr. Francisco

Comments from Mr. Francisco

Hello Mr. Farzad,

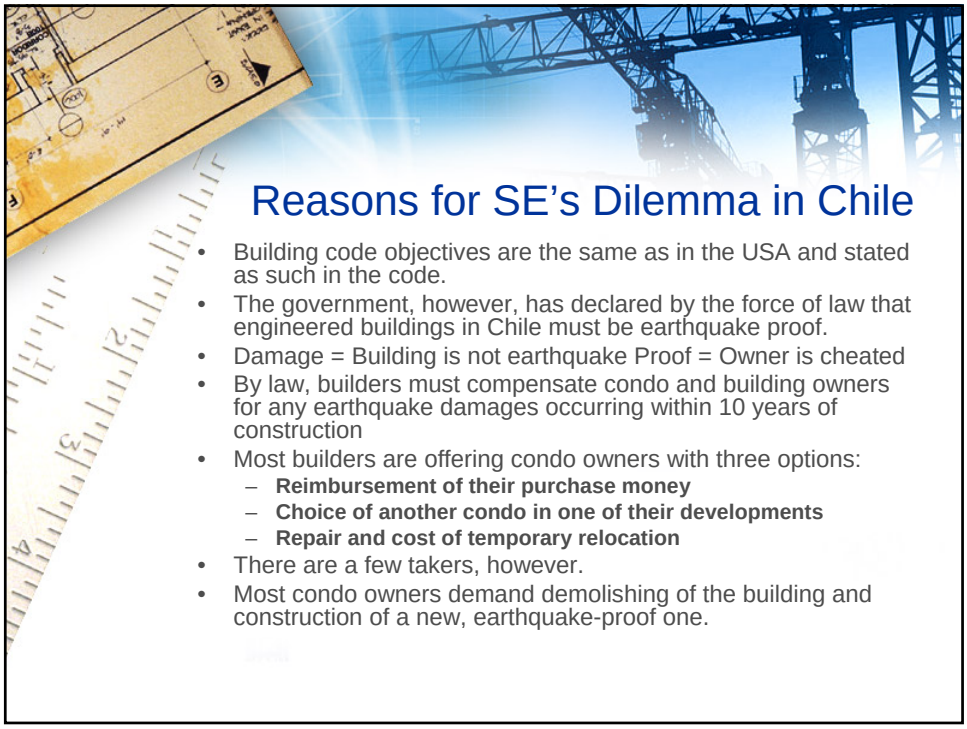
In attachment I am sending you pictures of some deteriorated buildings of Concepción.

The 303-304-305 y 594 pictures correspond to the building you were looking at called "obispo salas " and located on Salas street # 445, which you couldn´t take pictures due to the veil they put on to mask the situation and to be able to make up the building.

Wouldn´t you say it´s irresponsible to fix this building and not destroy it? What is your opinion?

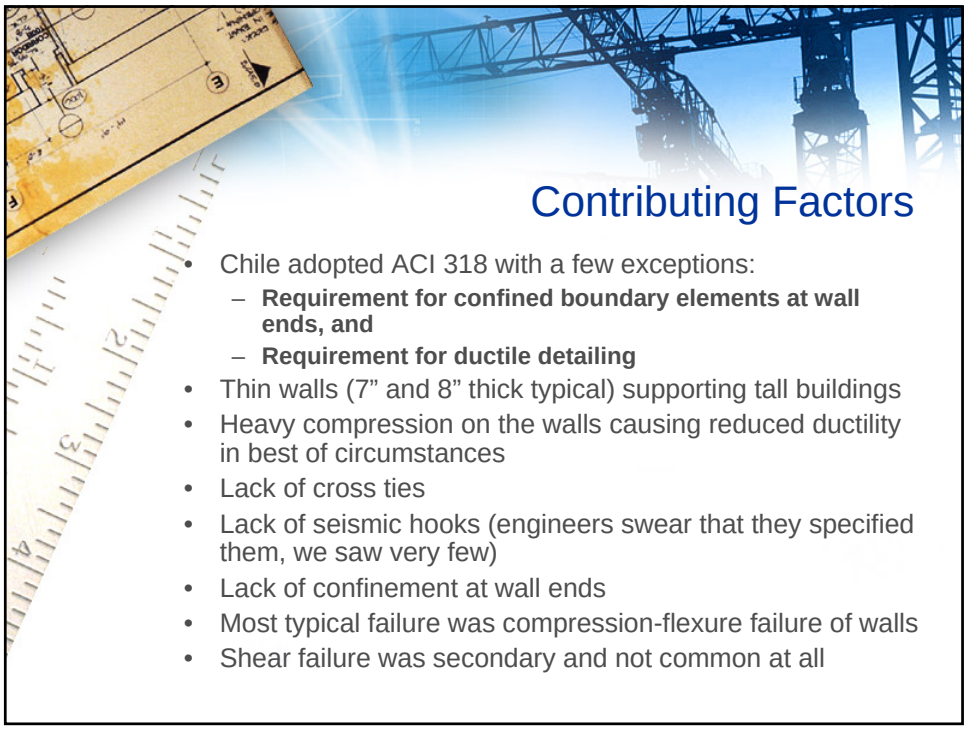
Thanks a lot, let´s keep in touch.

Francisco.
Tourism Business Manager.



Reasons for SE's Dilemma in Chile

- Building code objectives are the same as in the USA and stated as such in the code.
- The government, however, has declared by the force of law that engineered buildings in Chile must be earthquake proof.
- Damage = Building is not earthquake Proof = Owner is cheated
- By law, builders must compensate condo and building owners for any earthquake damages occurring within 10 years of construction
- Most builders are offering condo owners with three options:
  - **Reimbursement of their purchase money**
  - **Choice of another condo in one of their developments**
  - **Repair and cost of temporary relocation**
- There are a few takers, however.
- Most condo owners demand demolishing of the building and construction of a new, earthquake-proof one.



Contributing Factors

- Chile adopted ACI 318 with a few exceptions:
  - **Requirement for confined boundary elements at wall ends, and**
  - **Requirement for ductile detailing**
- Thin walls (7" and 8" thick typical) supporting tall buildings
- Heavy compression on the walls causing reduced ductility in best of circumstances
- Lack of cross ties
- Lack of seismic hooks (engineers swear that they specified them, we saw very few)
- Lack of confinement at wall ends
- Most typical failure was compression-flexure failure of walls
- Shear failure was secondary and not common at all

Thank you!

Time for Questions