Chile Earthquake – 2/27/2010
Implications for U.S. Building Codes and Standards

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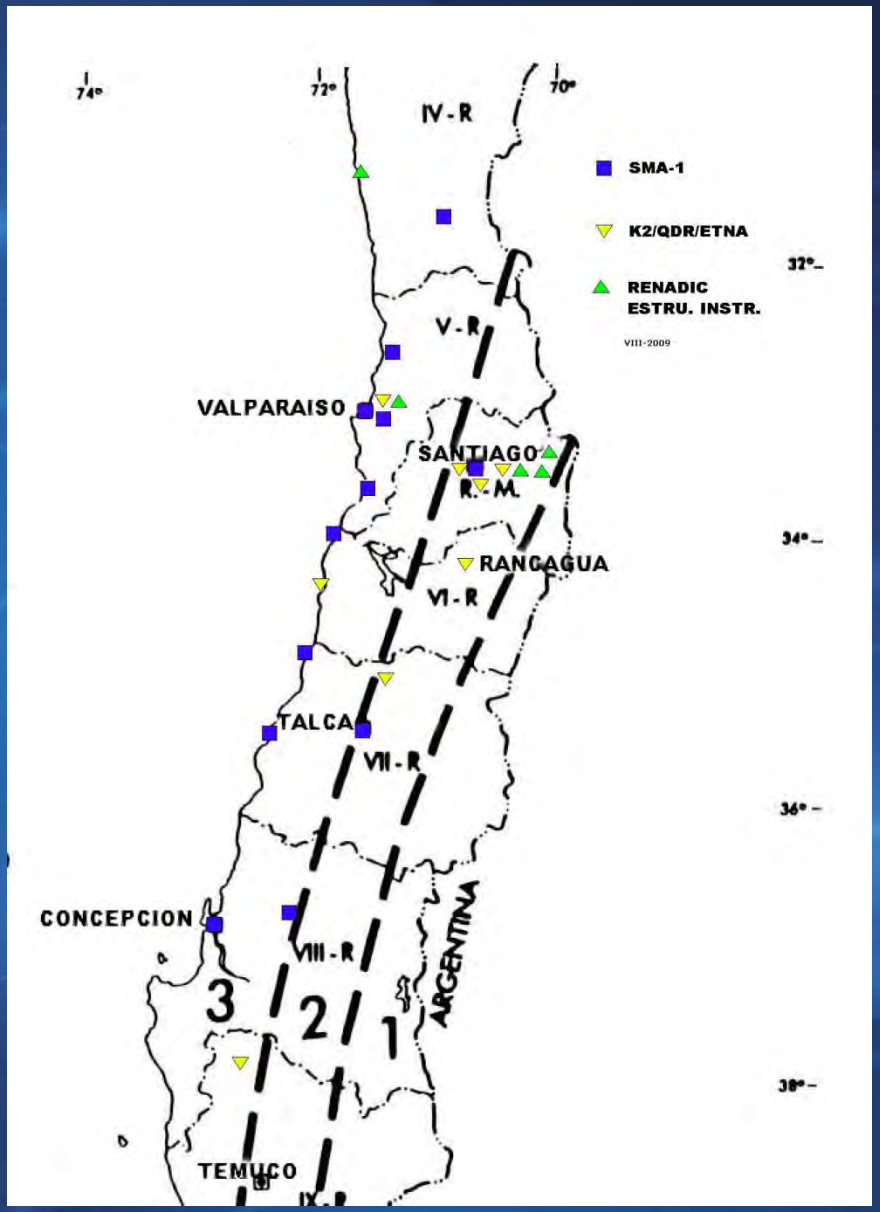
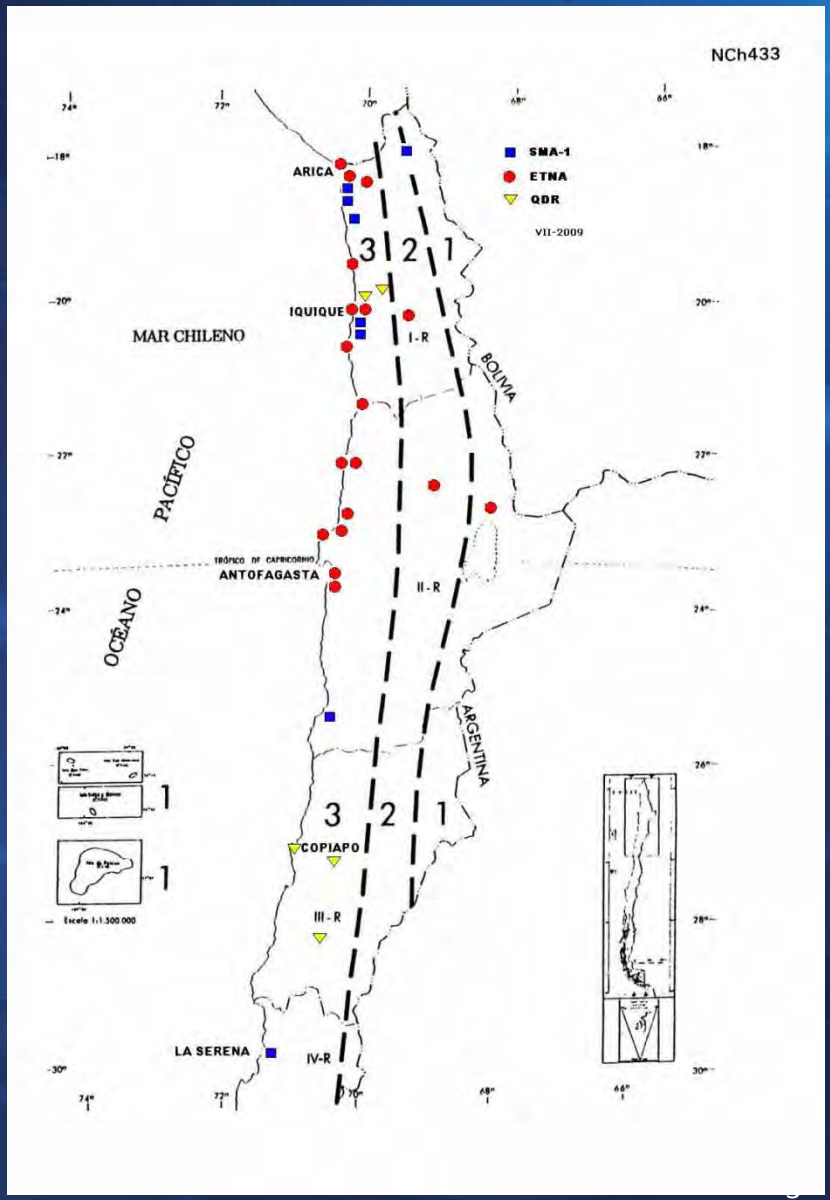
San Francisco – June 2, 2010

Overview

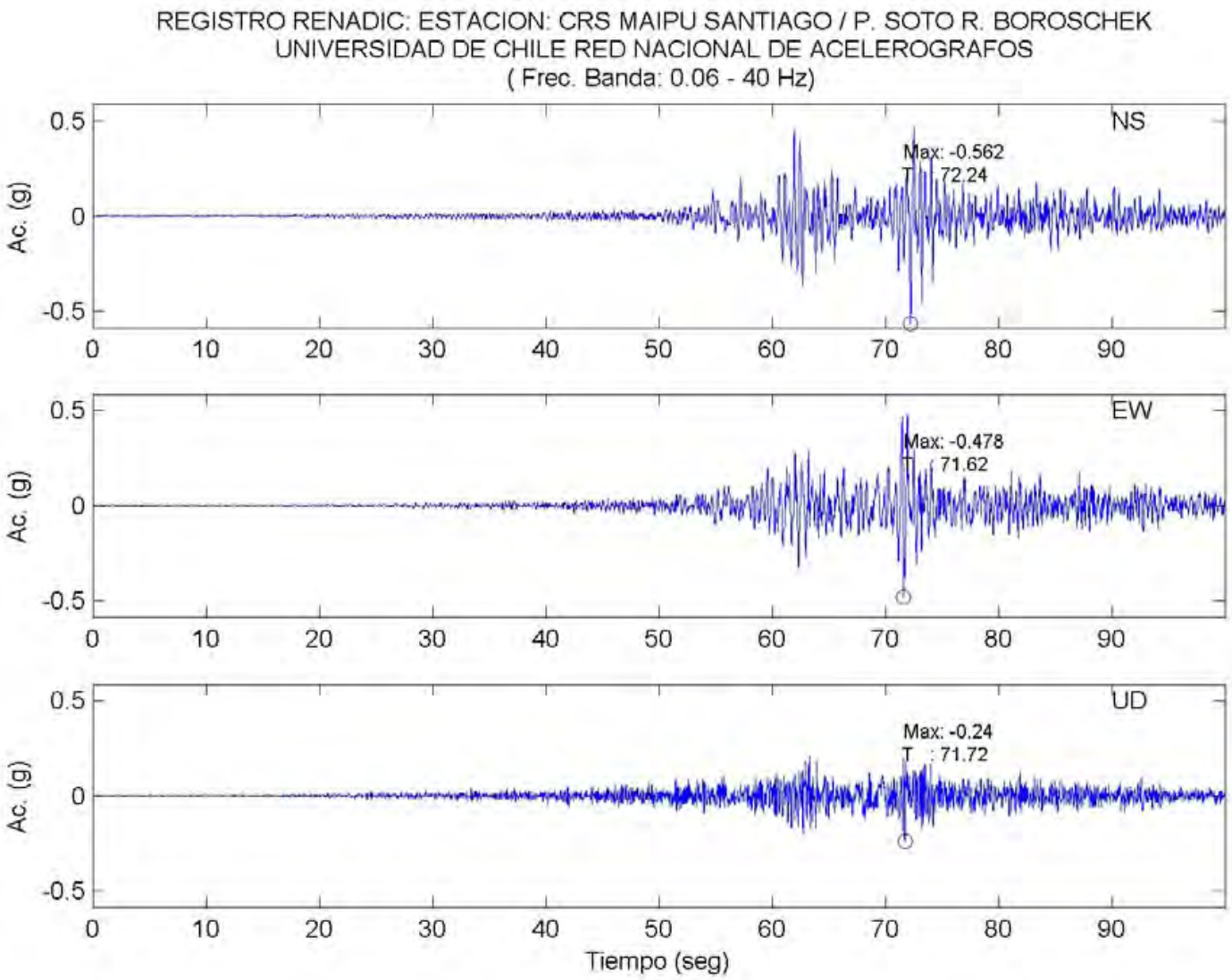
- Background
  - Ground Motions
  - Response Spectra
  - Code Spectra
- Places Visited
  - Concepción
  - Viña del Mar
  - Santiago
  - Talca
- US Code Implications

U de Chile: Ground Motion Array





Santiago: Ag,max =0.562g



Santiago Hospital: Ag,max =0.265g

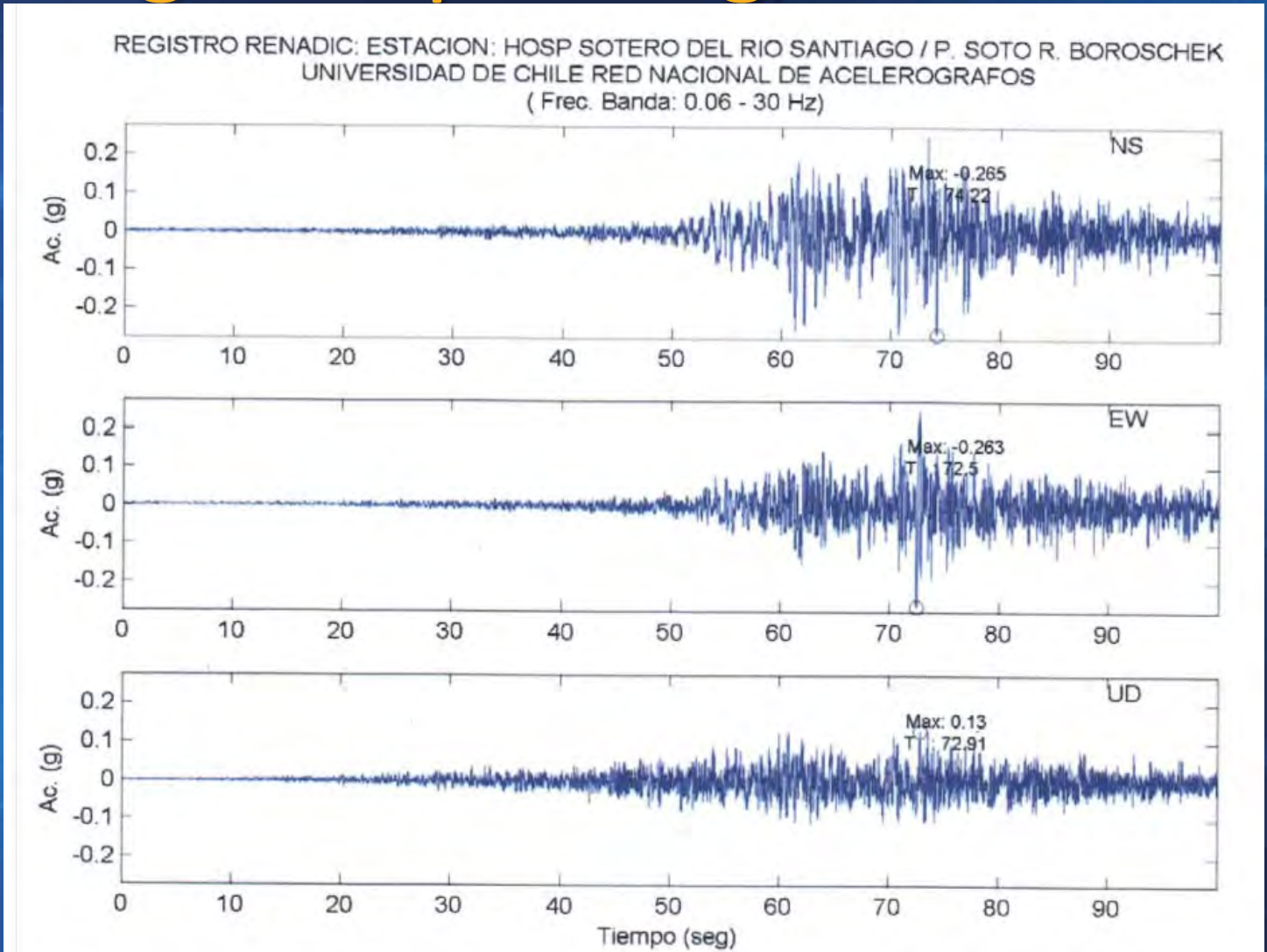


Figura 13 **Registro de Aceleraciones Estación Hospital Sotero del Río RM.**

R. Boroschek, Universidad de Chile

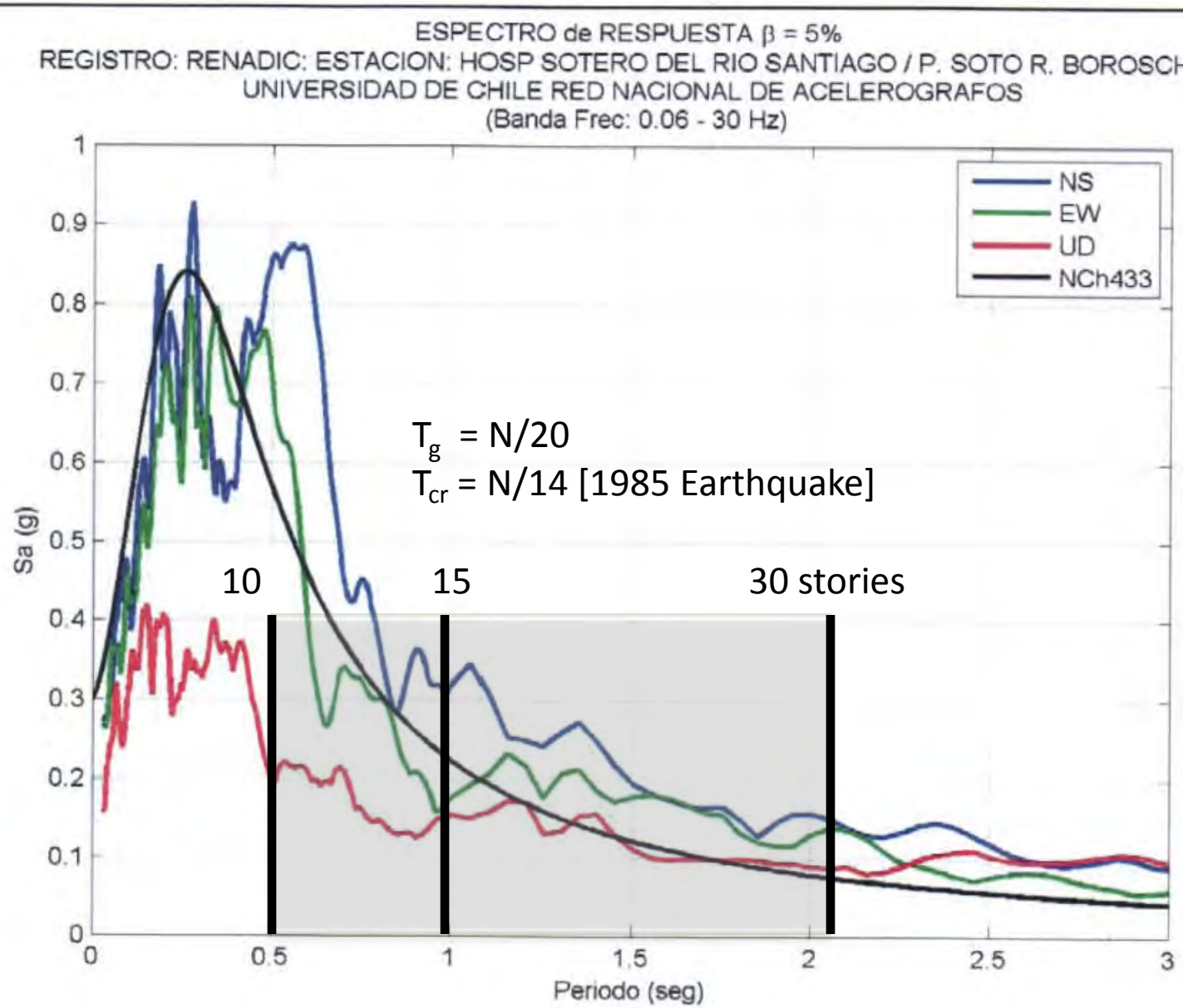


Figura 15 **Comparación Espectro de Diseño Norma Chilena NCh433 – Estación Hospital Sotero del Río RM.**

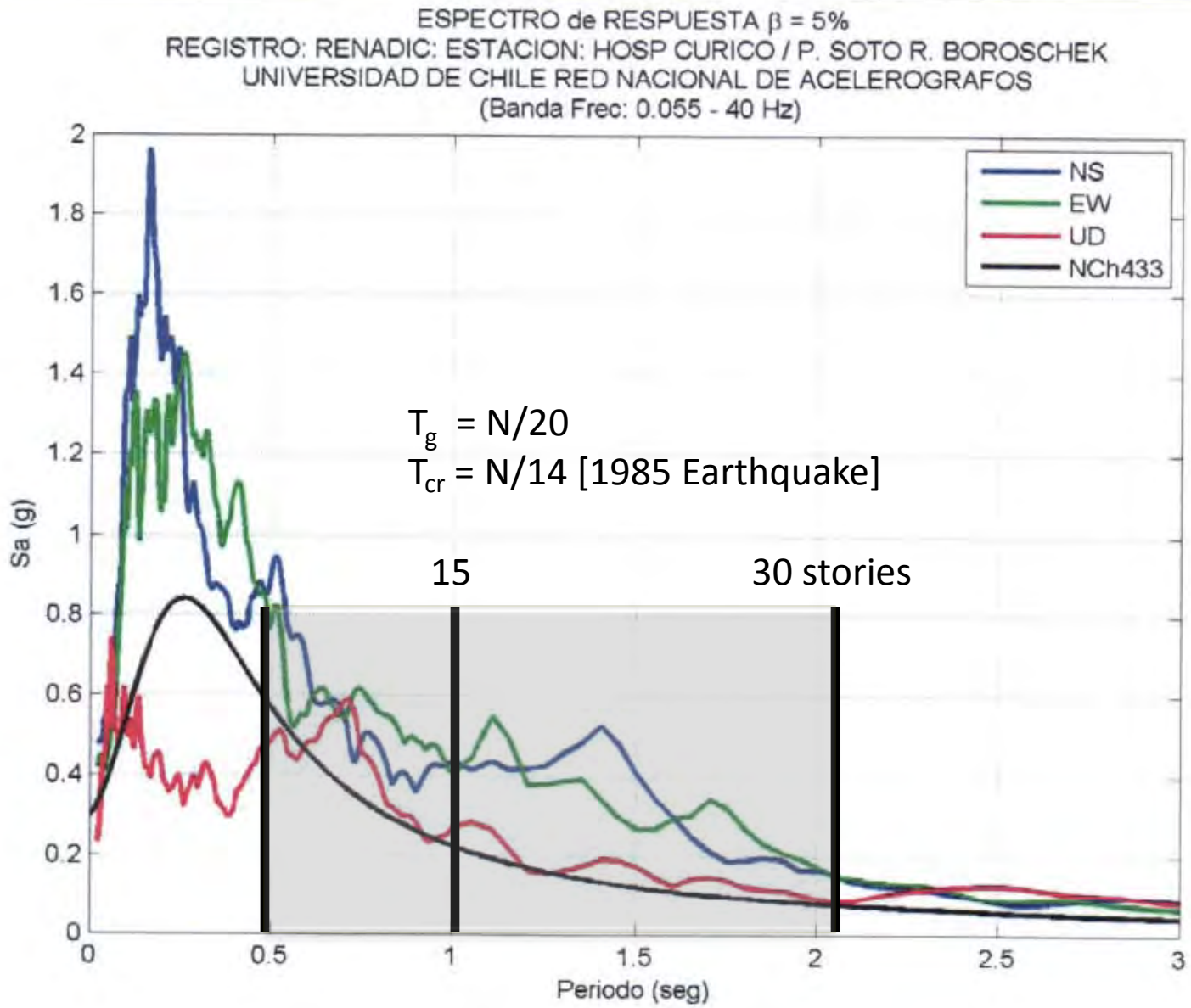


Figura 18 **Comparación Espectro de Diseño Norma Chilena NCh433 – Estación Hospital Curico.**

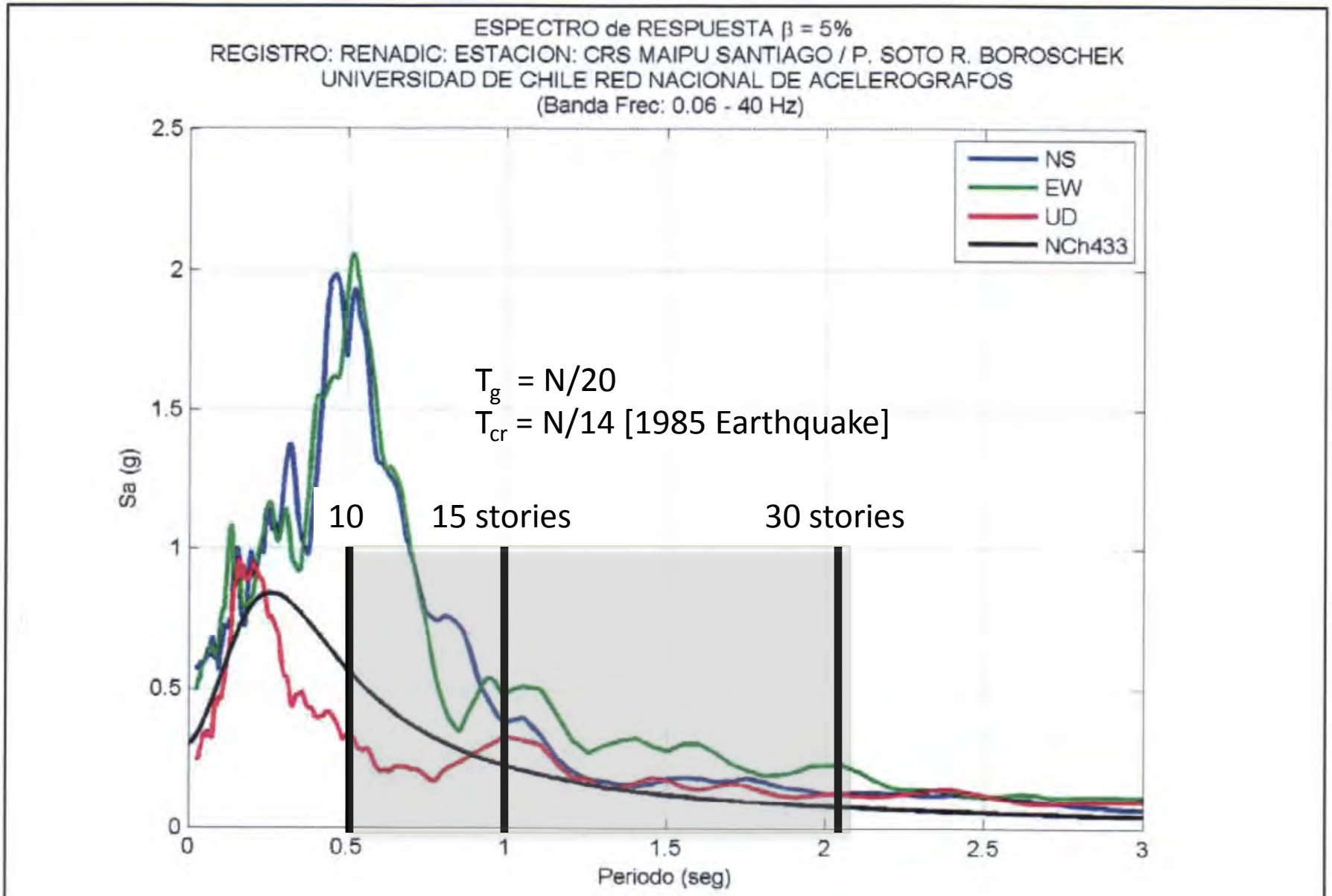
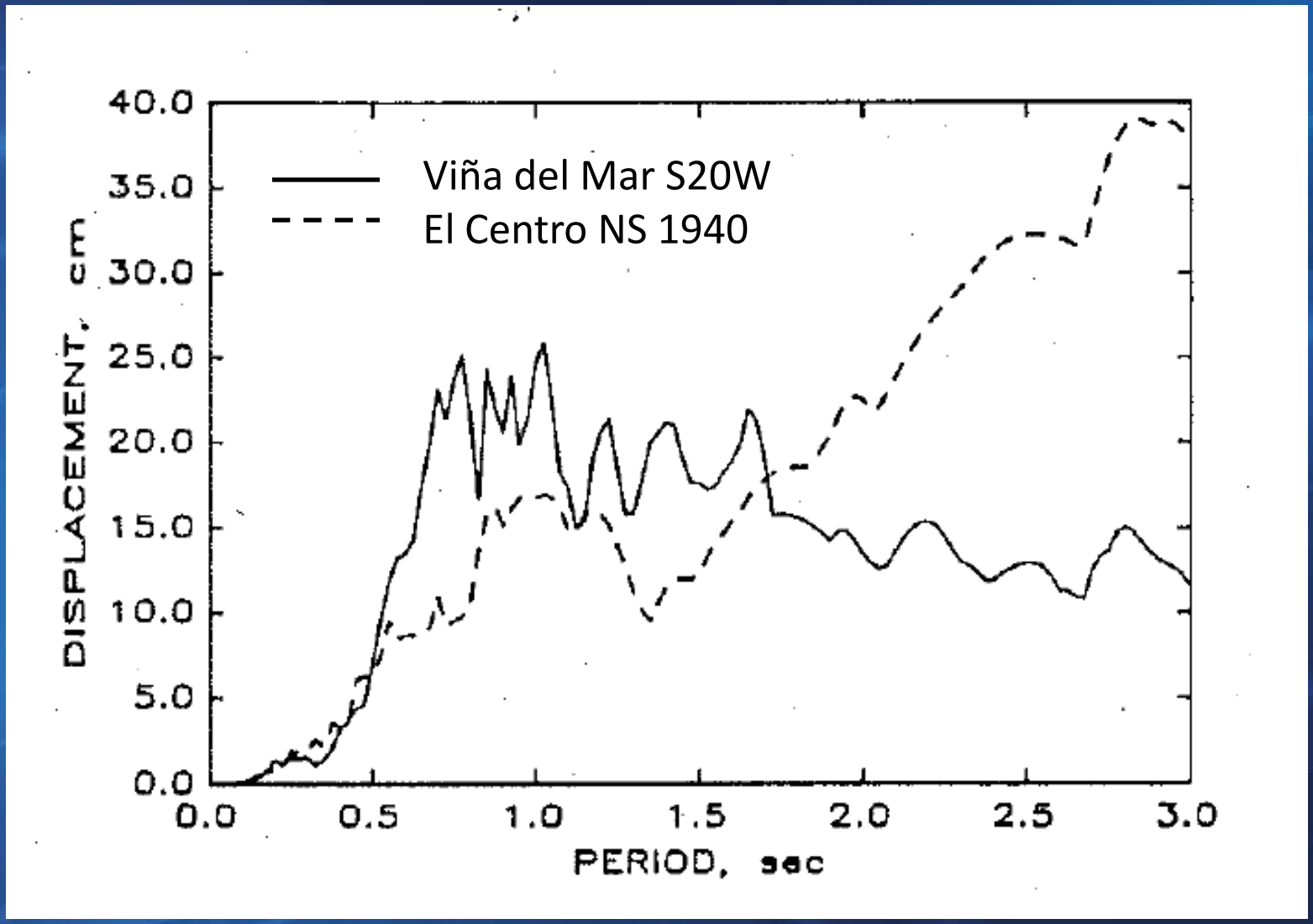
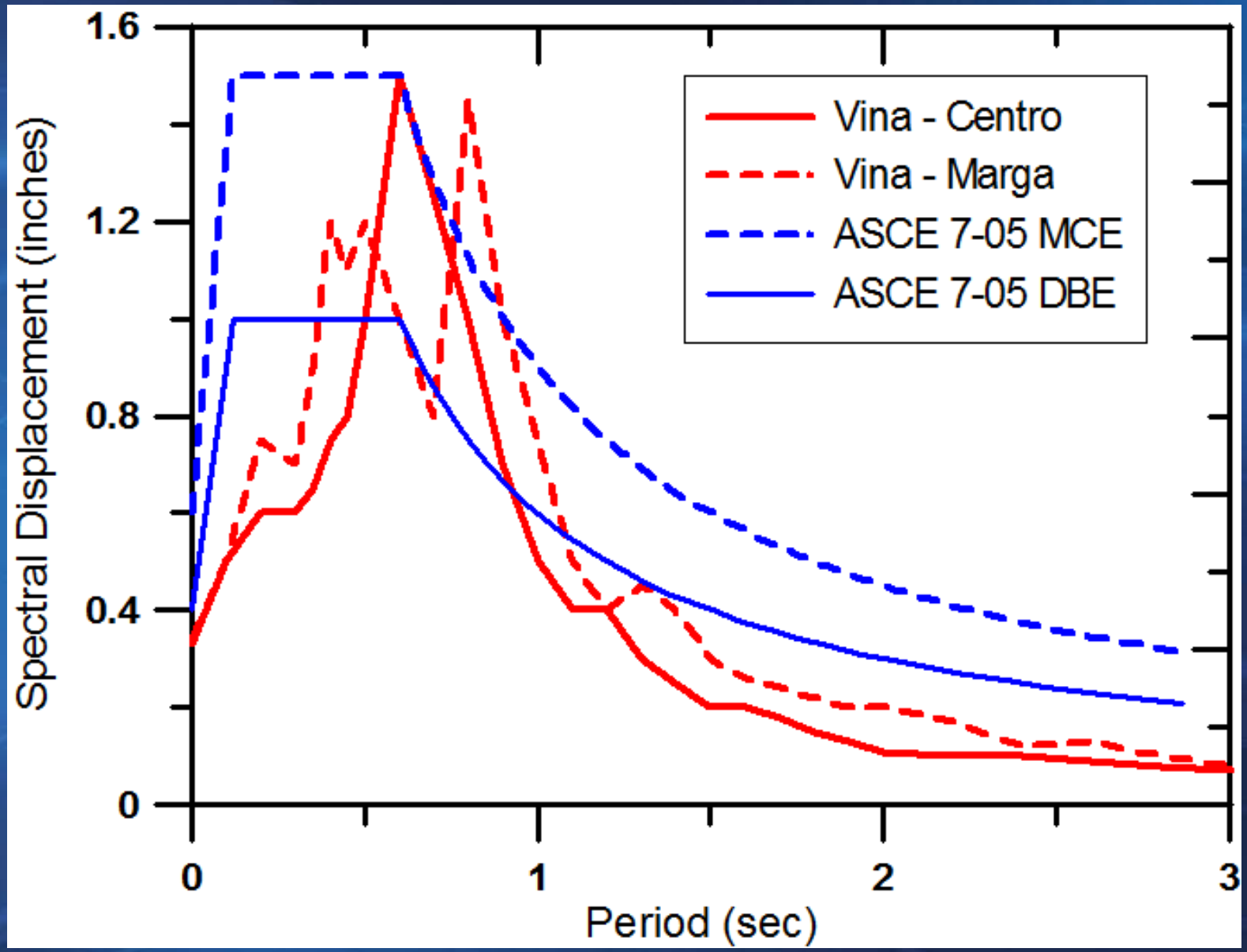


Figura 9 **Comparación Espectro de Diseño Norma Chilena NCh433 – Estación CRS MAIPU RM. (Ver Nota General)**

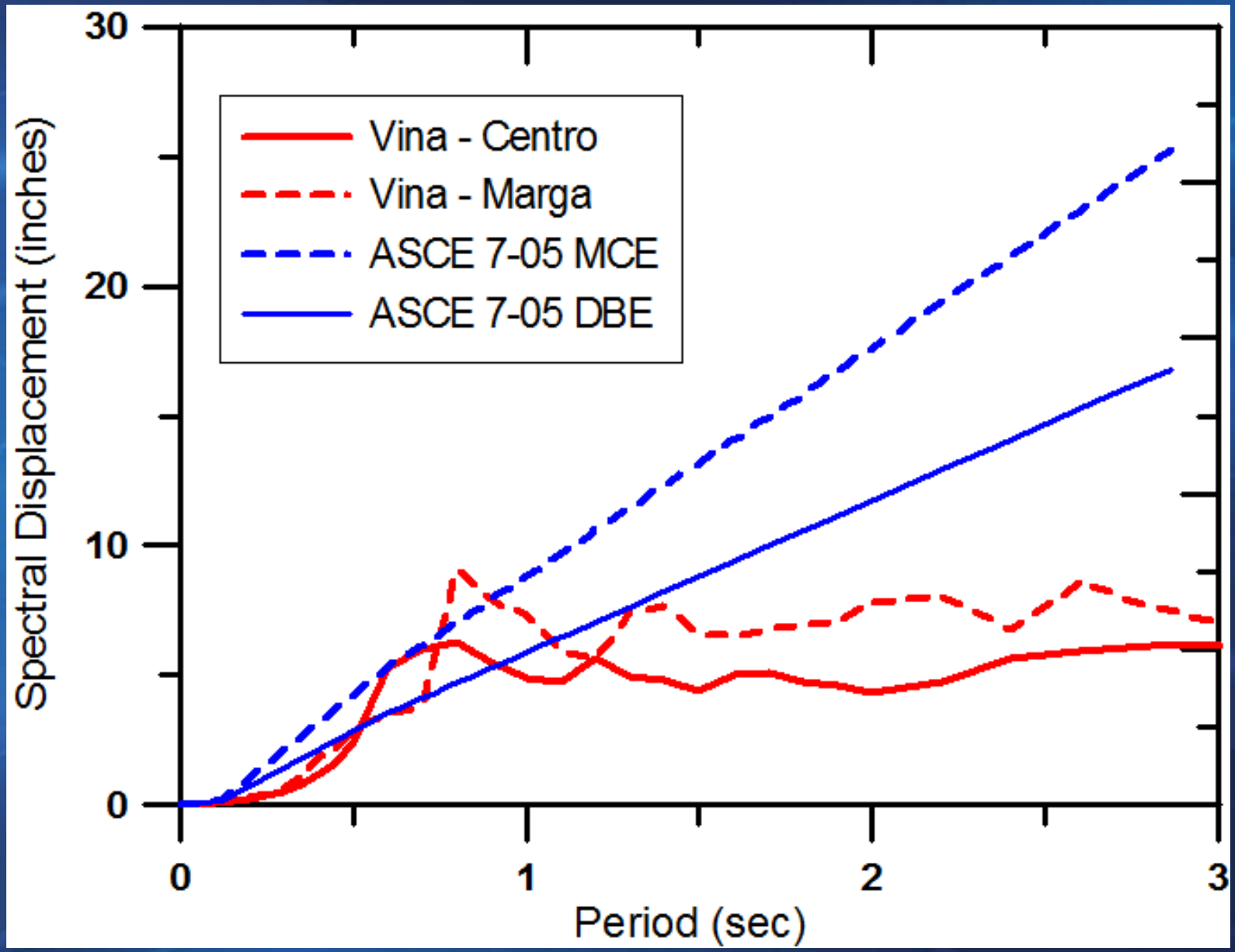
M7.8 1985 Earthquake; 2% Damped



Viña del Mar: Acceleration Spectra

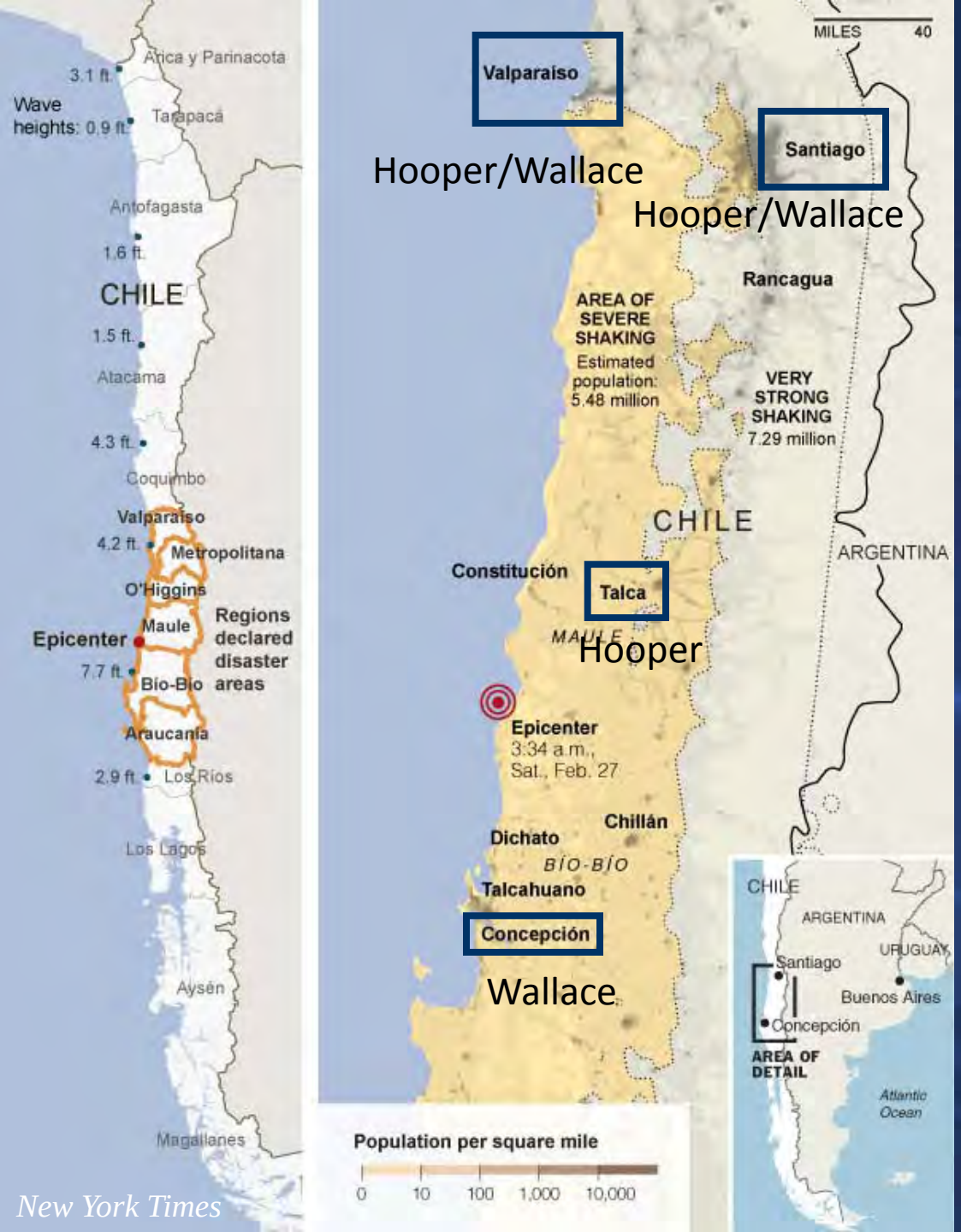


Viña del Mar: Displacement Spectra



RC Buildings

- Team effort
- Topics focused
  - Buildings as examples
  - ACI 318-08
  - ASCE 7-05
  - ASCE 41-06
  - Performance-based design



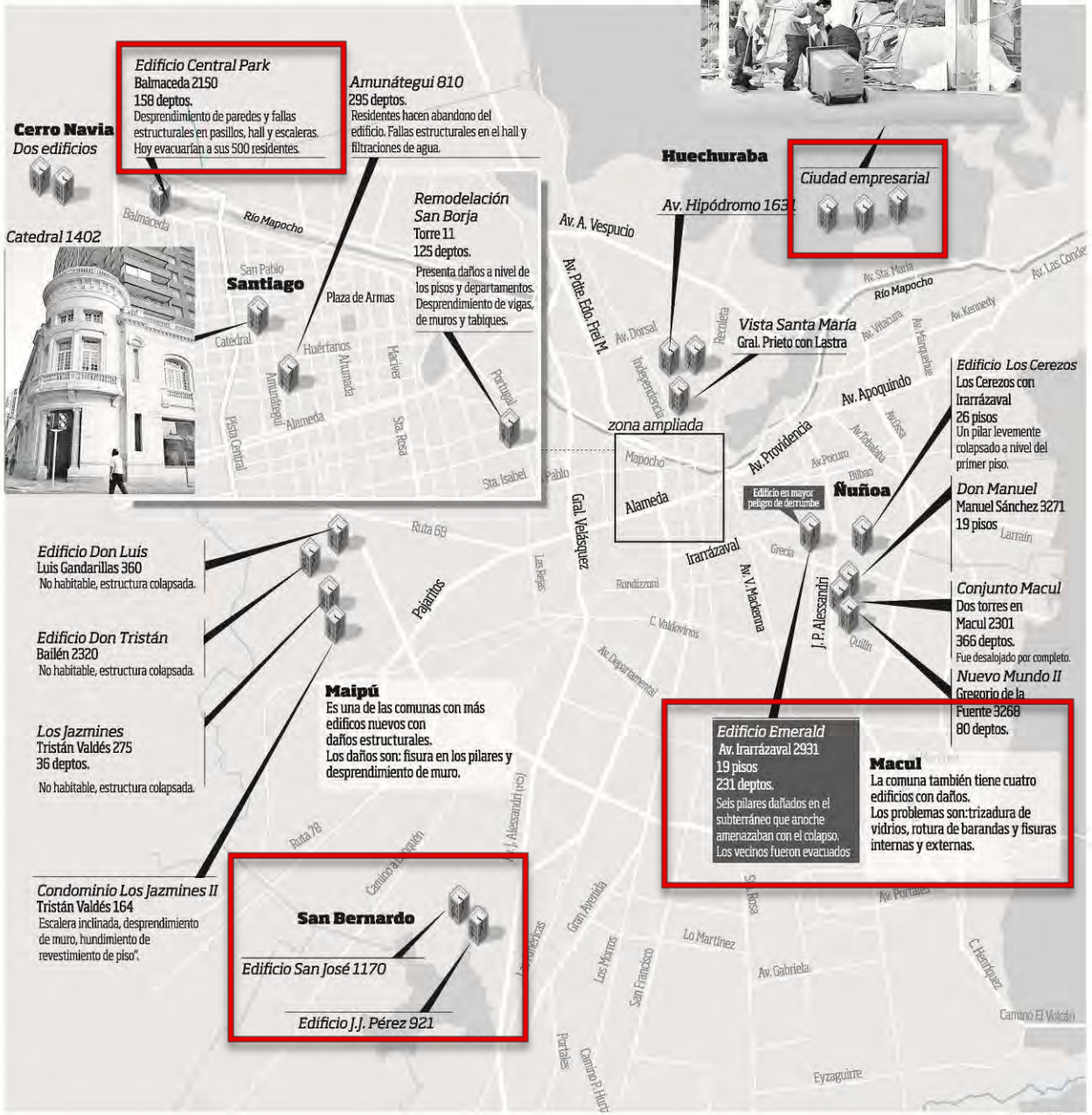
New York Times

Santiago

- Primary sources
  - Peers in Chile
  - J. Moehle
  - Others

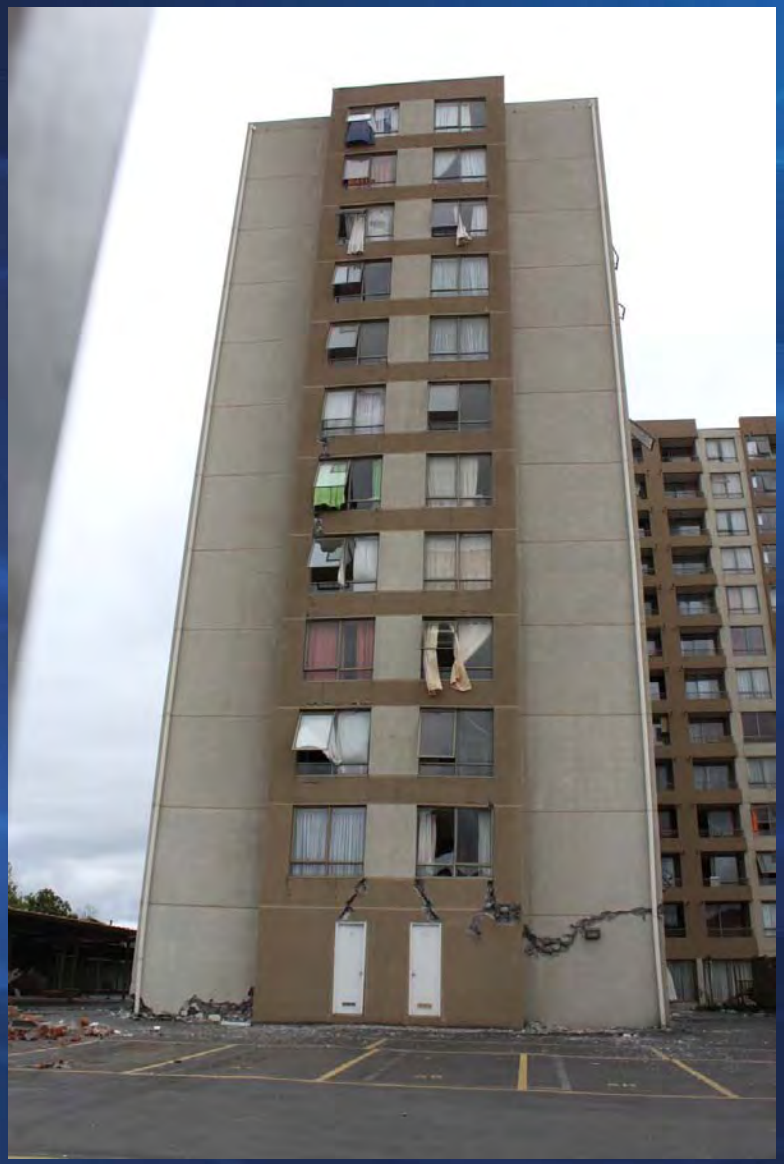
Catastro por comuna

Tras el fuerte sismo, las municipalidades de la Región Metropolitana han iniciado un catastro de sus construcciones para determinar los daños. Hasta el momento, más de 23 presentan daños severos.



Concepción: 11+ Modern Buildings

- Caupolican 518
- Los Carrera 1535
- Salas 1343, Torre A
- O'Higgins 241
- Lincoyan 440
- Freire 1165
- Rozas 1145
- Padre Hurtado 776
- Obispo Salas
- Bosquemar (San Pedro)
- Olas (San Pedro)



Concepción: 11+ Modern Buildings

Viña del Mar: 11 Red, 4+ others

Discussion Topics

In no particular order…

And not necessarily limited to a single research project per topic…

1. Wall Axial Stress

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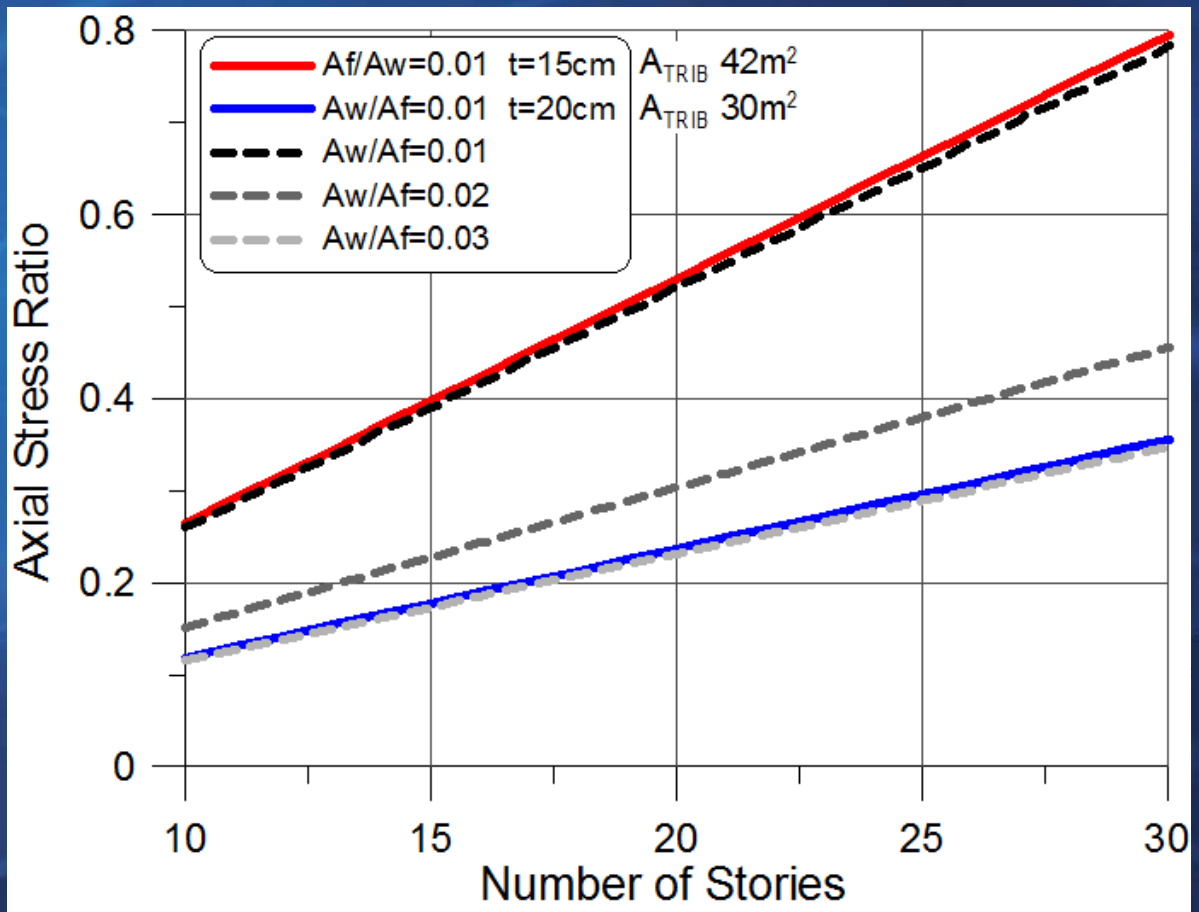
Unit Weight: 150 to 200 psf

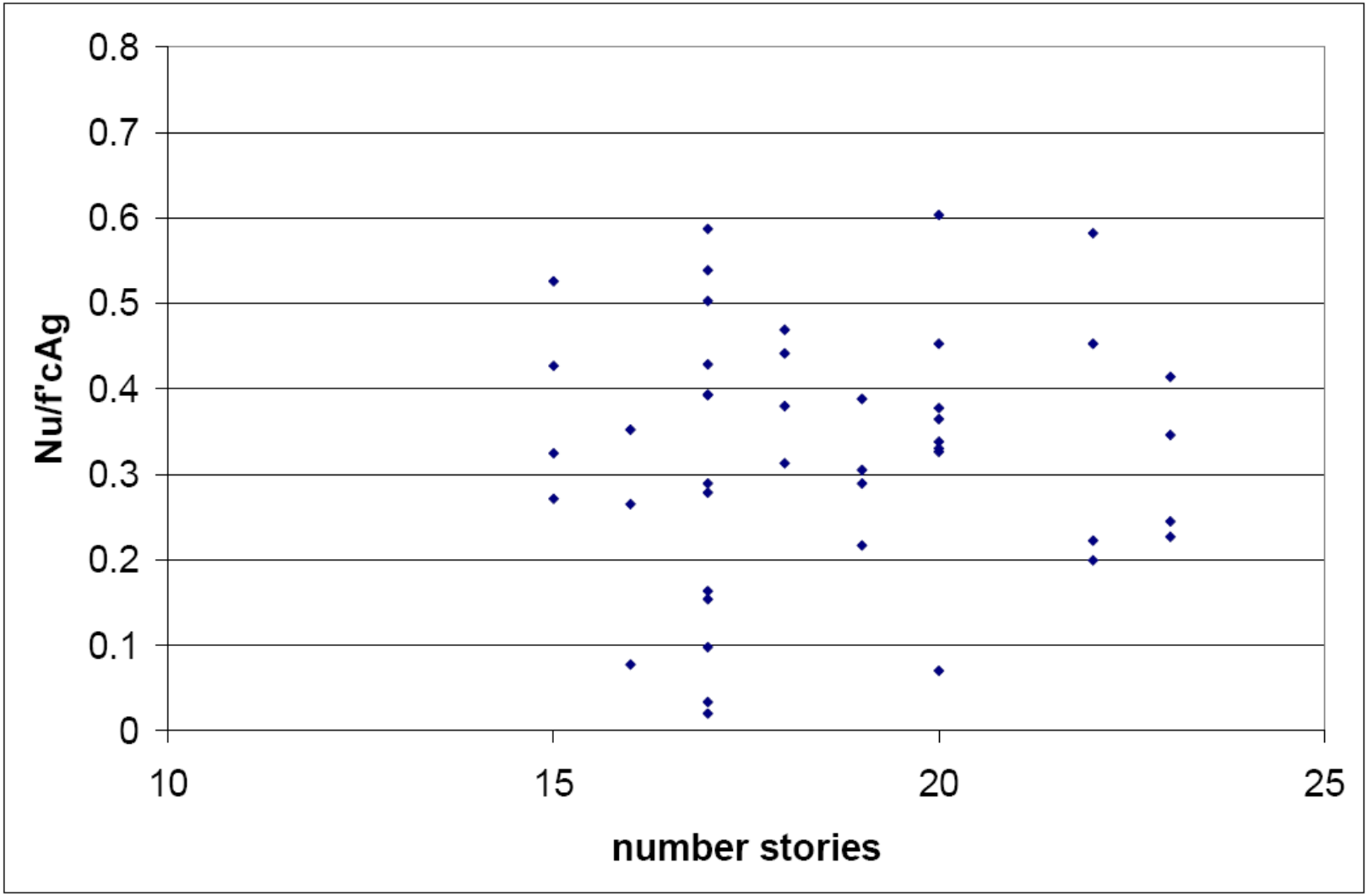
1. Wall Axial Stress

- Impact of lower wall area to floor area ratios
  - 1985 (6% - 3% in each direction; Festival)
  - 2010 (2% - 1% in each direction)



4000 ps

1. Wall Axial Stress



Dr. Leo Massone, U. de Chile; 10 buildings, 1 designer; 2000 to 2006; Gravity + EQ

1. Wall Axial Stress – Limits?

- UBC 97 S19.21.6.6.3
  - Walls and portions of walls with Pu > 0.35Po shall not be considered to contribute to the calculated strength of the structure…
- LA Tall Buildings 2008 – Supplement #1
  - Frame members subjected to high axial stress
  - Column axial load under governing load combinations (average of the values from the seven or more ground motion pairs per Section 3.4. of 2008 LATBSDC) shall not exceed $0.40f'_cA_g$

2. Wall Boundary Detailing

- Chile Code NCh 433.Of96 is based on ACI 318-95 with important exceptions
- Chapter 21 – Section 21.6.6
  - "Special Boundary Elements"
  - Transverse reinforcement at wall boundary to confine the concrete and restrain rebar bucking is not required based on the good performance of wall buildings in Viña del Mar in the 1985 earthquake.
- ACI 318-02 added modified requirements for required transverse reinforcement at splices

2. Wall Boundary Detailing

Large spacing – 20cm [8”]
90 degree hooks

2. Boundary Detailing

- Special RC Walls
  - Displacement-based approach introduced into ACI 318-99; Trigger for special boundary elements based on DBE.
    - Should it be based on MCE [or alternative approach for NRHA]?
    - Modeling assumptions that produce design displacement
  - Minimum transverse reinforcement (s<8”) for cases where special boundary elements are not required if $\rho > 400/fy$;
    - Should we always confine the hinge region?
    - Above the hinge?

2. Boundary Detailing

- Ordinary RC walls
  - For MCE, and maybe even a DBE, are we designing walls that are likely to experience damage similar to what was observed in Chile?
    - Repair cost, disruption cost? Relocation cost?
    - Require some level of detailing for all walls in certain regions
  - Maybe we need to rethink our expectations for code-compliant buildings?

2. Boundary Detailing – Revise?

- Study a statistically significant sample of buildings in Chile:
  - Using common modeling approaches and code procedures to assess if observed damage is consistent with expectations
  - With a focus on both Special Walls and Ordinary Walls

3. Wall Vertical Reinforcement

- Lightly-reinforced and poorly-detailed walls

3. Wall Vertical Reinforcement

3. Wall Vertical Reinforcement

- Lightly-reinforced or poorly-detailed walls
  - Tension fracture [lightly-reinforced]
  - Tensile yielding, followed by buckling and concrete spalling, followed by fracture [poorly-detailed]
  - Concentration of nonlinear deformation over short length or at a single crack
  - Potential for unzipping of wall

3. Wall Vertical Reinforcement

3. Wall Vertical Reinforcement

- "Unconfined Splices"

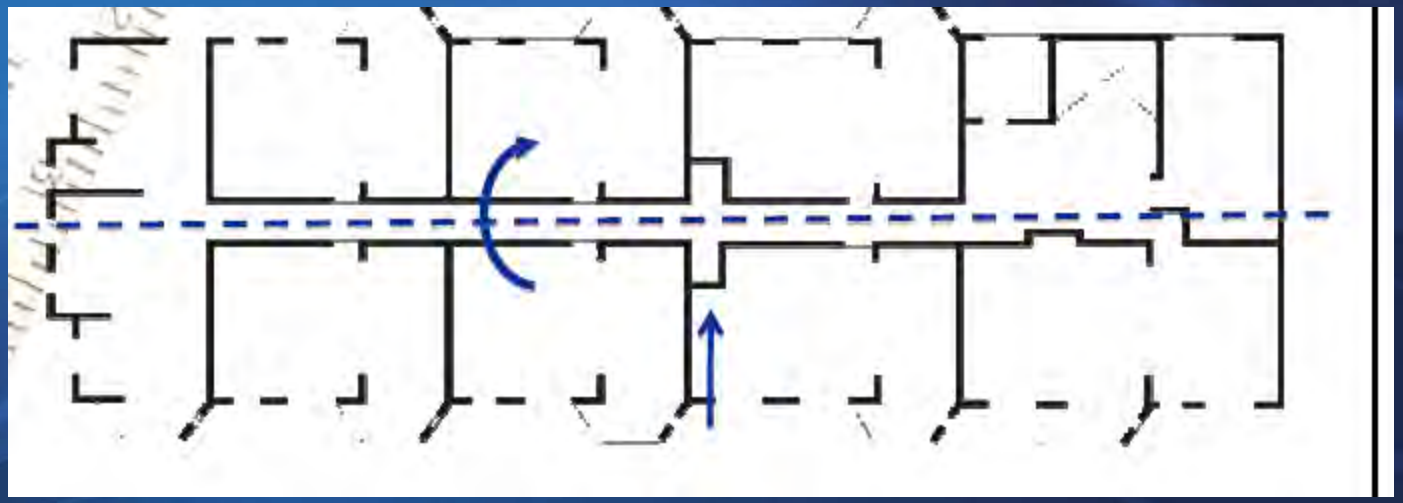
4. Configuration Issues

4. Configuration Issues - Vertical

4. Configuration Issues – Studies?

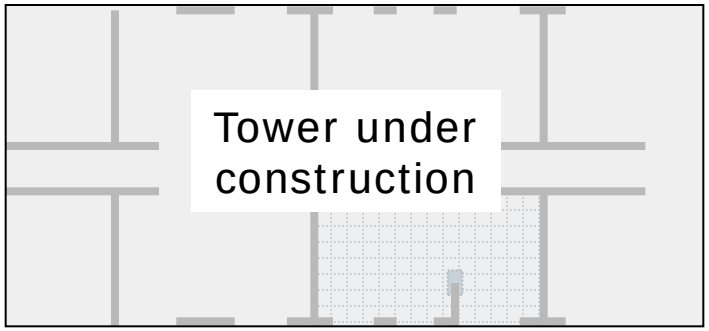
- Chilean code does not have specific provisions that limit irregularities
  - NCh 433.Of96 5.5.2.4: At levels where there is a stiffness discontinuity in the resisting planes or other vertical substructures, it must be verified that the diaphragm will be capable of redistributing the forces.
- ASCE 7-05
  - Table 12.3-1 Horizontal Structural Irregularities
  - Table 12.3-2 Vertical Structural Irregularities
- Detailed study of buildings with various degrees of irregularities to assess ASCE provisions

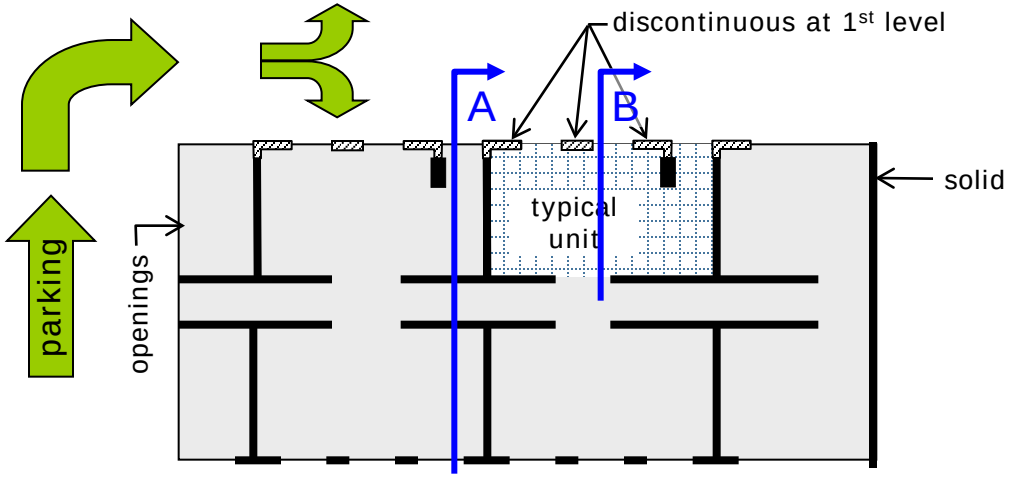
5. Building Collapse I



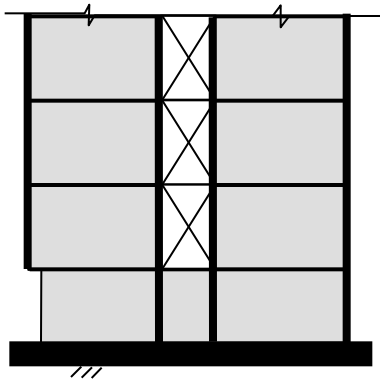
LA Tall Buildings Presentation

5. Building Collapse I

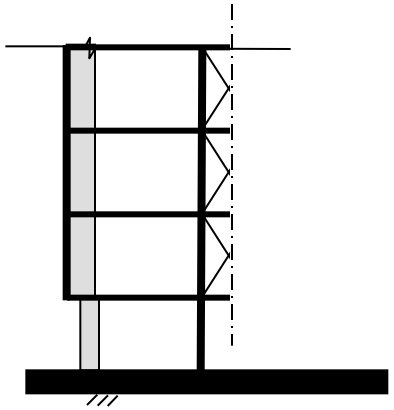




Plan



Section A



Section B

5. Building Collapse I

- Detailed study of this building to ascertain:
  - If our best analysis tools are capable of predicting this result,
  - What were the key attributes that contributed to the collapse, and
  - Whether the building satisfies U.S. codes and, if not, to what extent does the lack of compliance identify potential problems.

6. Building Collapse II

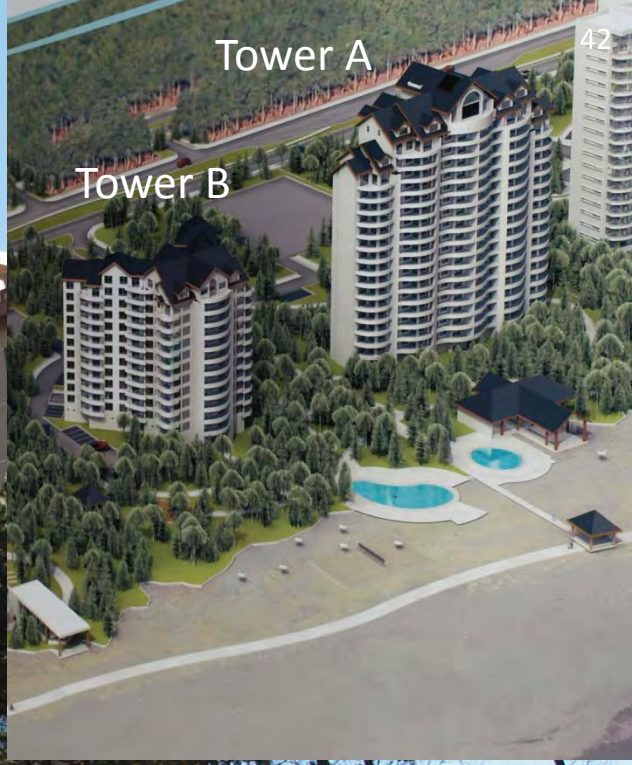
6. Building Collapse II

Photo: P. Bonelli, U Técnica Santa Maria

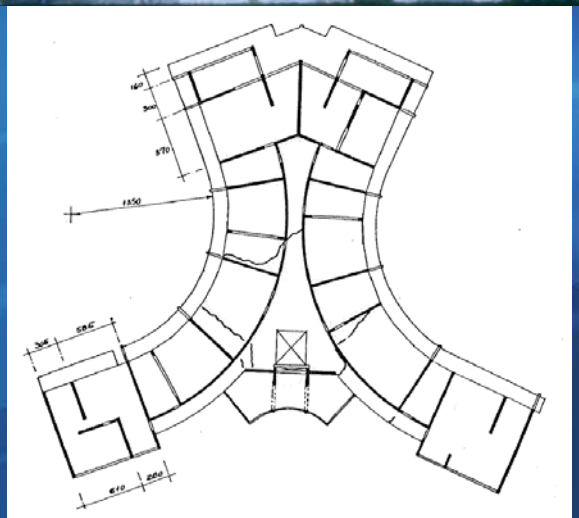
6. Building Collapse II

- Detailed study of several buildings that did not collapse to:
  - Ascertain if our best analysis tools are capable of predicting this result,
  - Determine key modeling limitations/shortcomings,
  - Assess uncertainties associated with modeling parameters, and how they impact the collapse assessment,
  - Determine if the building satisfies U.S. codes and, if not, to what extent does the lack of compliance identify potential problems,
  - Proximity of similar buildings without damage

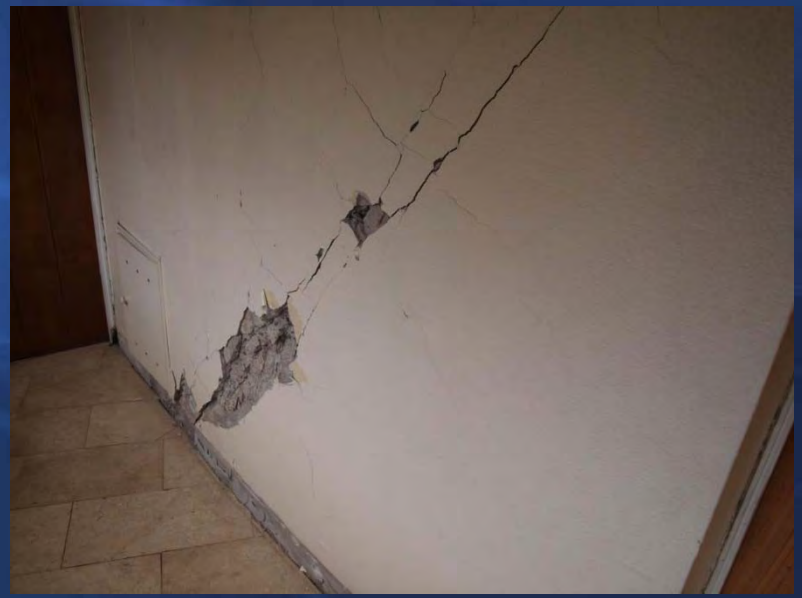
Bosque Mar – San Pedro – 23 stories



7. Rehabilitation: Hanga Roa 1985



7. Rehabilitation: Hanga Roa 2010



7. Rehabilitation: Festival (Viña)

7. Rehabilitation: Festival 2010

Post-1985 study indicated shear stress of about 1.3Vn

Demands (spectral) similar for 1985 and 2010 earthquake

7. Rehabilitation: Festival

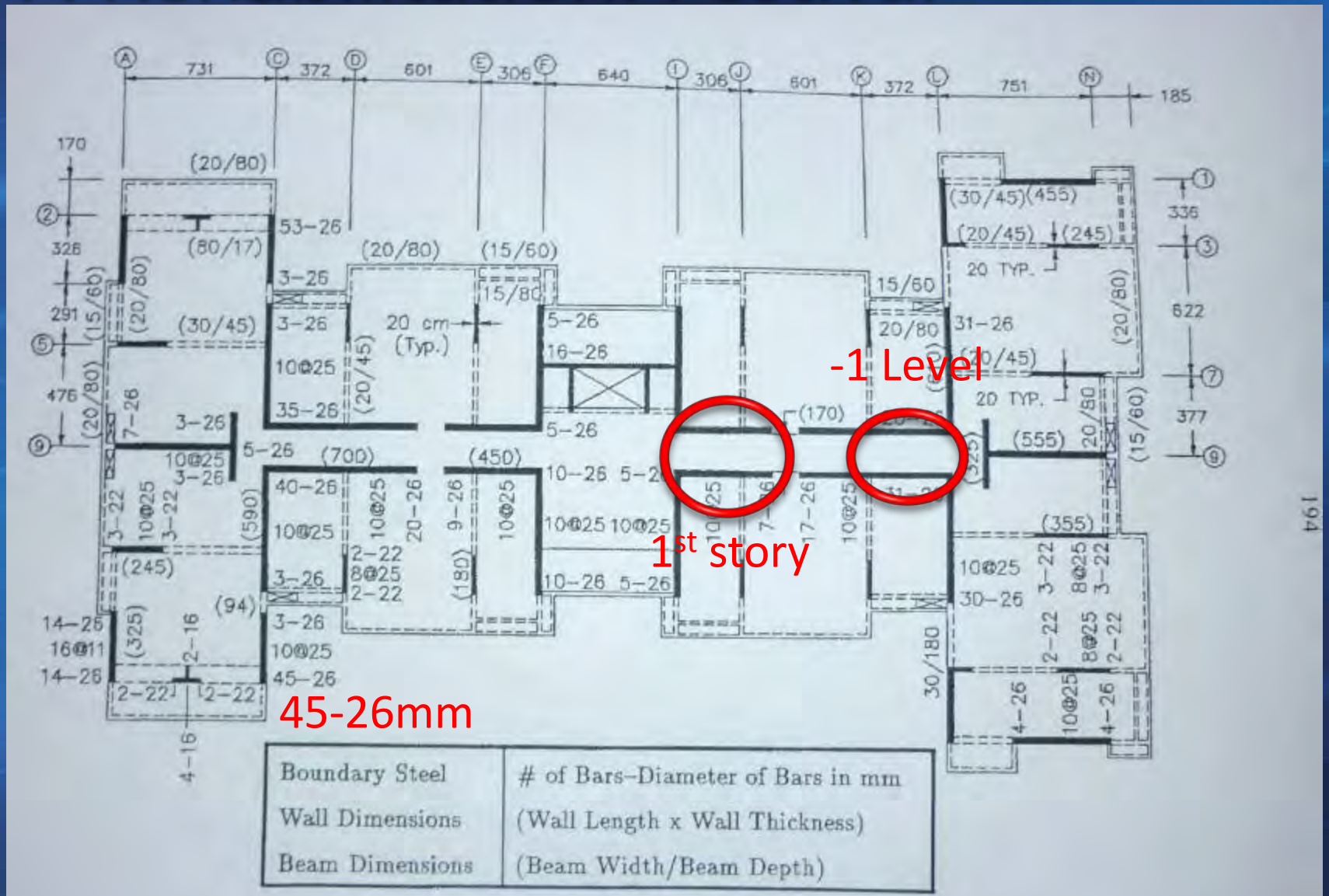
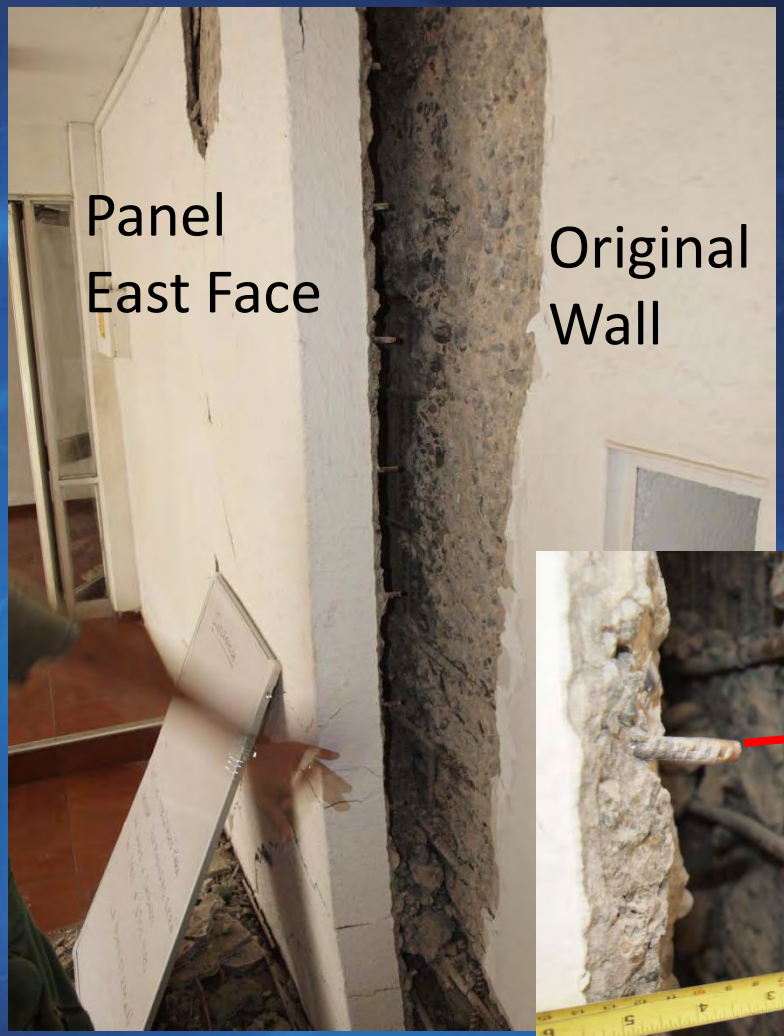


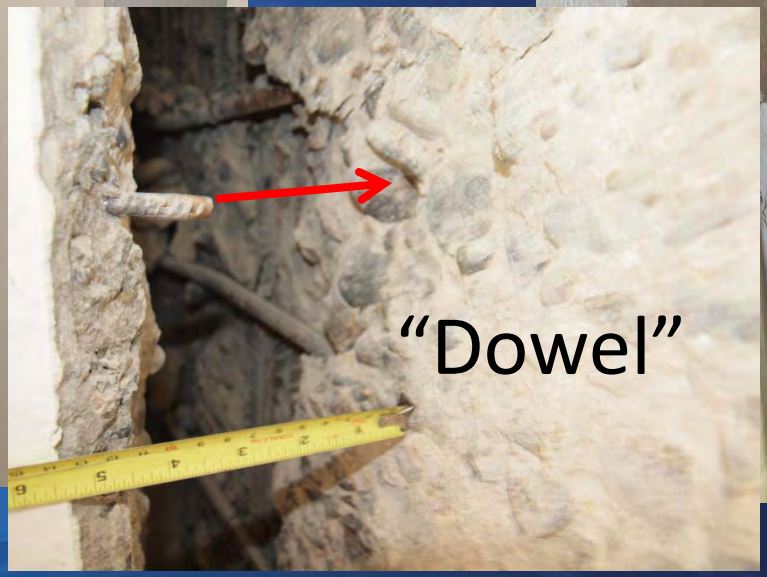
Fig. 7.18 Festival Building – Geometry and Steel Quantities

7. Rehabilitation: Festival

-1 Level Parking

7. Rehabilitation: Festival





1st Level corridor walls @ Axis 9

8. Instrumented Buildings

- In support of modeling studies

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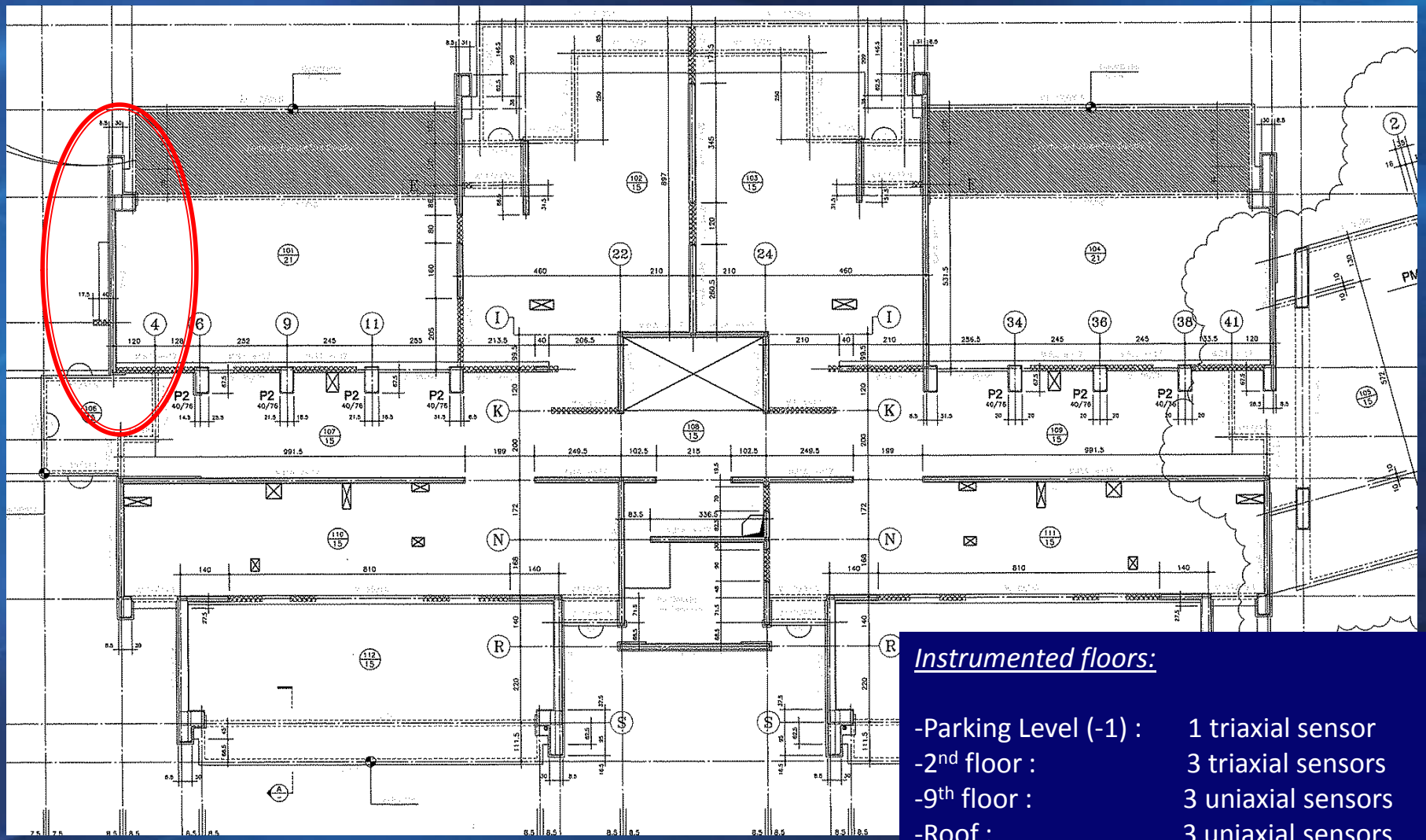


Instrumented floors:

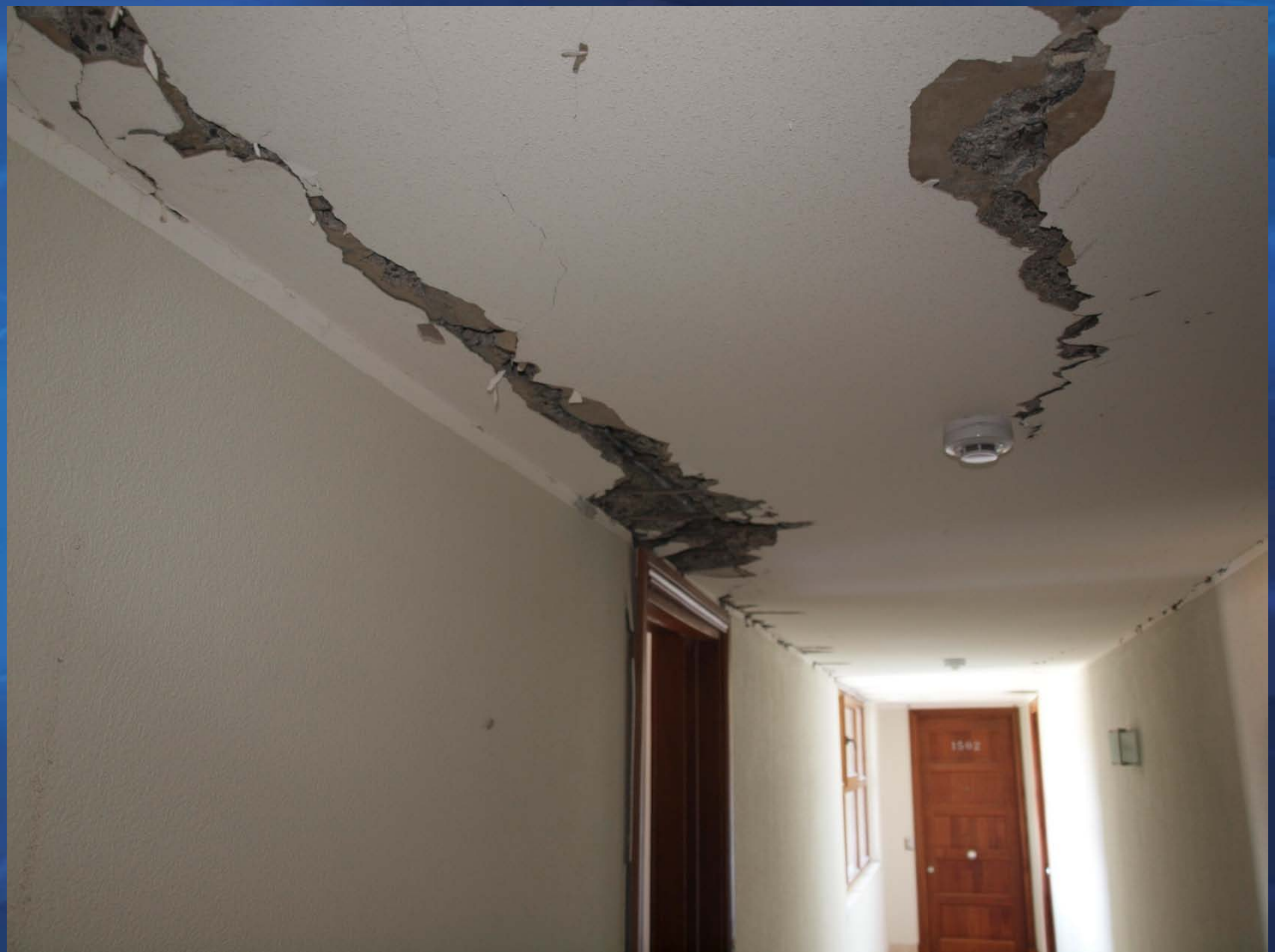
-Parking Level (-1) :	1 triaxial sensor
-2nd floor :	3 triaxial sensors
-9th floor :	3 uniaxial sensors
-Roof :	3 uniaxial sensors

9. Ground Motion - Directionality

- Viña del Mar:
  - Damage generally more concentrated in buildings with short plan dimension in the north-south direction [preliminary spectra – roughly same demands NS & EW, and wrt 1985]
- Concepción:
  - Damage generally more concentrated in buildings with short plan dimension in the east-west direction [Alto Rio, Centro Mayor, Salas 1343A]
- Study of similar buildings with different orientations [Salas 1343, Concepción]

10. Slab coupling [Gravity Elements]

- Impact of slab coupling on system responses



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