WORKSHOP *fib* MC2020 –São Paulo, Brazil, 2017

A CASE STUDY:
The 27F Chilean EQ

February 27th, 2010 – Chile

SOME FIGURES ABOUT THE 27F CHILEAN EARTHQUAKE

Source:Agencia Stock, Ministry of Public Works

LARGEST EARTHQUAKES RECORDED

1. **Valdivia,** May 22, 1960, Chile
   9,5 Richter. 1.655 fatal victims

2. **Alaska**, March 28, 1964, United States of America
   9,2 Richter. 128 fatal victims

3. **Sumatra Island**, December 26, 2004
   9,0 Richter. **227.898 fatal victims**

4. **Tohoku,** March 11, 2011, Japan
   9,0 Richter. **14.941 fatal victims**

5. **Kamchatka**, November 4, 1952, Russia
   9,0 Richter. No fatal victims

6. **Concepción/Constitución**, February 27, 2010, Chile
   8,8 Richter. **524 fatal victims** (156 by tsunami).

https://earthquake.usgs.gov/earthquakes/browse/largest-world.php

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THE VERY BAD NEWS OF THE DISASTER 27F EARTHQUAKE

Source:Agencia Stock, Ministry of Public Works

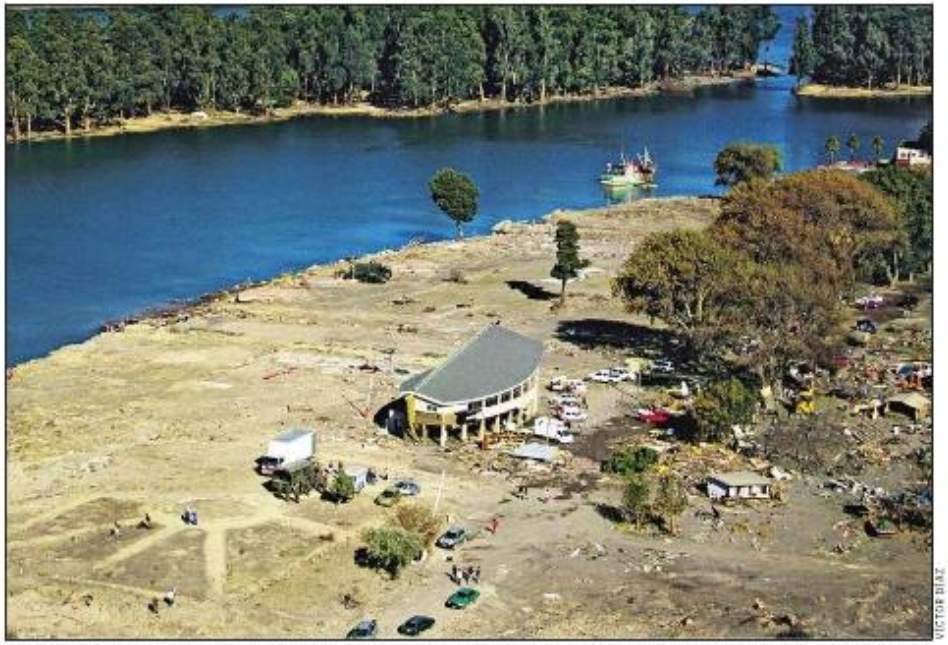
Maremoto = Tsunami

Testimonio gráfico del esfuerzo de los habitantes de Constitución por normalizar su vida:

El desolador rastro del maremoto

VICTOR DIAZ

Éste es el sector La Poza en Constitución, a orillas del río Maule. Antes del *tsunami* había casas particulares, como las de techo rojo a la izquierda, y estaban las dependencias de la capitanía de puerto (al medio).



VICTOR DIAZ

Después de la destrucción causada por las olas del maremoto sólo se mantuvo en pie parte de la Casa de Botes, un moderno recinto municipal equipado con instalaciones para los cultores del canotaje. **C 12**

Dead people: **525**
(156 by tsunami)

Disappeared people: **23**

Ministry of the Interior,
31/01/2011

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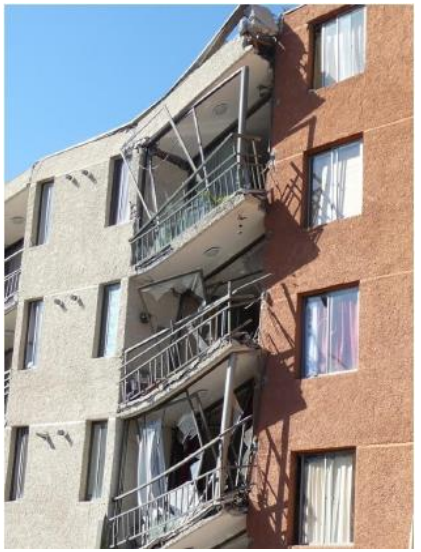
CONSEQUENCES OF THE CATASTROPHE

- Fatalities: 525 (156 by tsunami)
- Disappeared: 23
- Houses destroyed or damaged: 220.000 (mainly adobe)
  (11% of total in affected area)
- Hospitals destroyed or damaged: 79 of 130
  - 22% critical and standard hospital beds;
  - 39% of hospital surgery rooms
- Schools destroyed or damaged: 3.049
  (76% of total schools in affected area)
- Bridges destroyed or damaged: 221
- MOP Public Infrastructure: 1.720 points affected.
- More than 900 towns, rural and coastal communities
- Reconstruction: Initial estimated cost for Chile (damage and loss of product): US$ 30 Billion. 17% of GDP



Source: Ministry of Public Works

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Typical Chilean Farm House

Adobe construction

THE GOOD NEWS
EXAMPLES OF BUILDINGS WITHOUT STRUCTURAL DAMAGE

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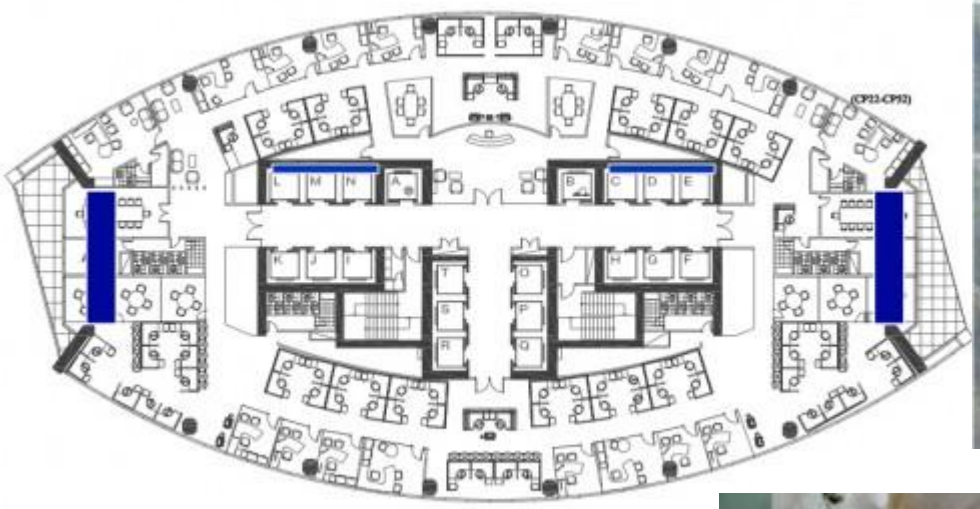
Titanium Tower – Santiago, Chile (2010)

- Years of construction : 2006- 2010
- **Stories: 52**
- **Height: 192 meters**
- Total surface: 140.000 m^2
- Structural System: R.C. Walls (core) and Frames.
- **Seismic Protection: Energy dissipation devices**

Carlos Videla © 2010

Titanium Tower



45 Energy dissipation devices

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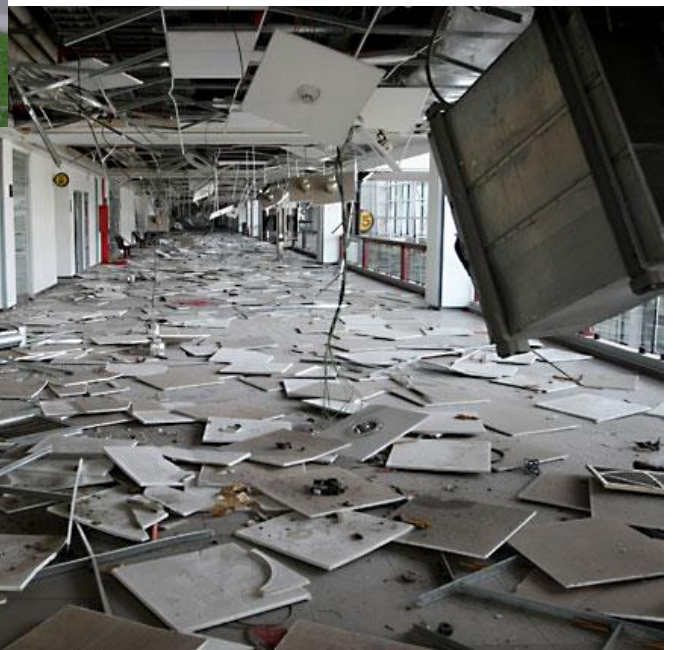
Failure of Non Structural Members

- *Finishing*
- *Equipment*
- *Partition walls*
- *Ceilings*
- *Glasses*
- *Feetings*
- *Veneer*



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CAUSES & EXAMPLES OF BUILDING FAILURES

Edificio Alto Río, Concepción

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27F CHILEAN EQ

- 50% of buildings that were declared uninhabitable or be decreed its demolition, its failure was due to a **sub-classification of the type of soil**. This resulted in greater demands of horizontal displacements than expected.

- The other 50% of these buildings had failures due to purely **structural causes of both project and construction** that could be avoided.

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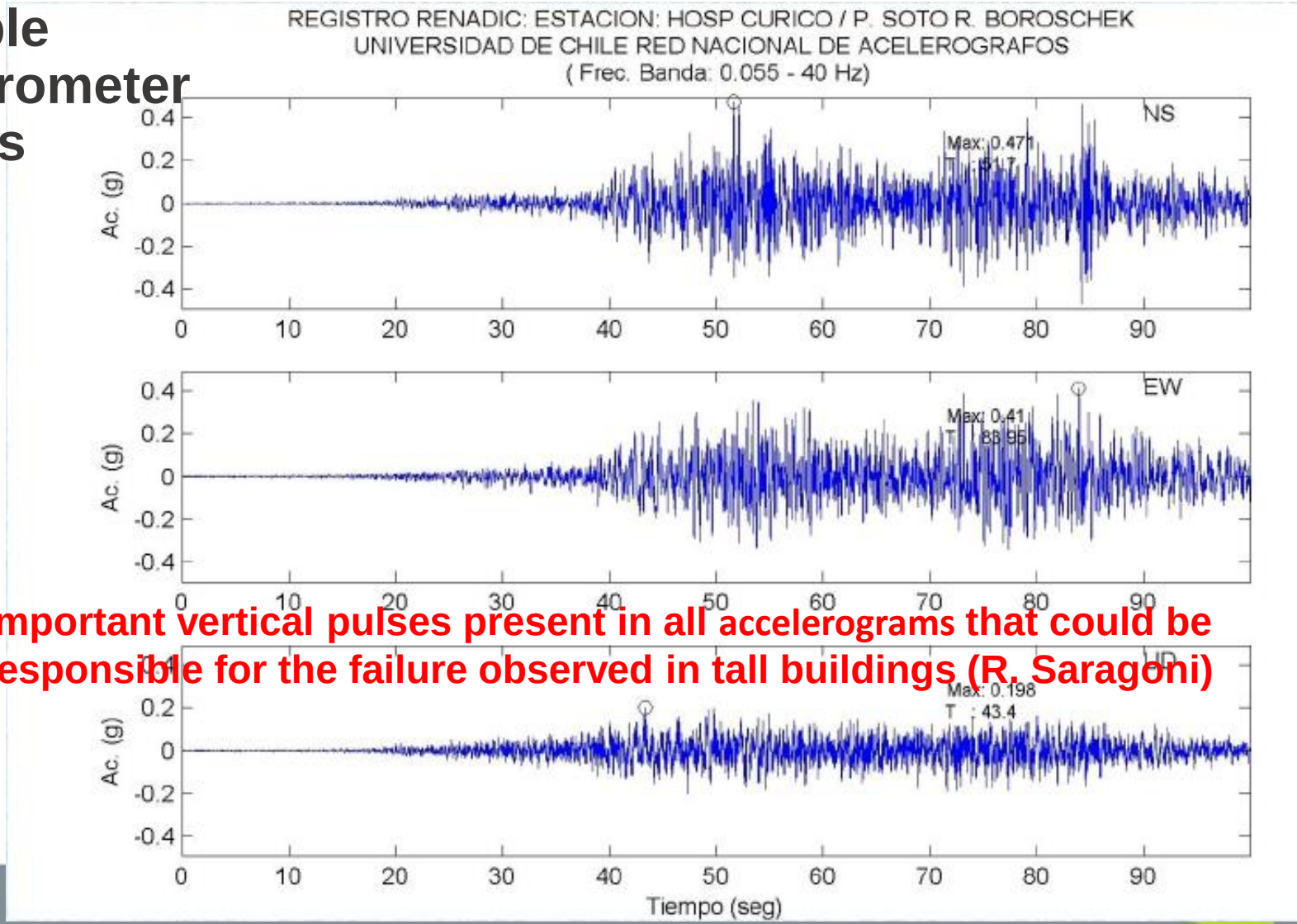
Main Causes of Failures

- ***Earthquake Characteristics & Location***
- ***Architectural Design Irregularities***
- ***Structural Design and Analysis Errors***
- ***Deficiencies in Standards of Analysis and Design***
- ***Construction Defects***

Damages were usually due to a combination of several of the named causes.

Uncertainty of the demand for structural design

Example accelerometer records



Important vertical pulses present in all accelerograms that could be responsible for the failure observed in tall buildings (R. Saragoni)

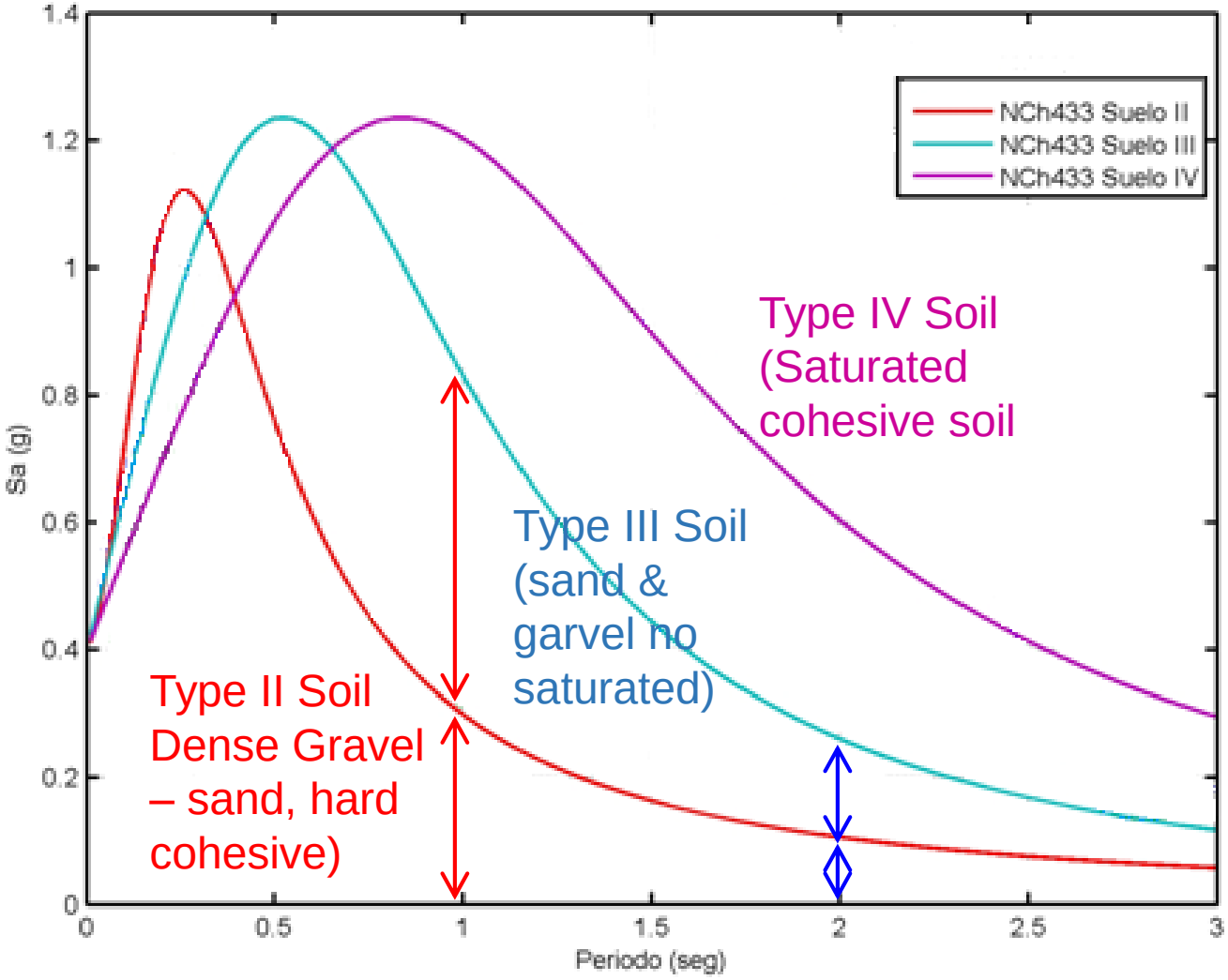
Registro Estación: Hospital Curicó (P. Soto y R. Boroscheck)

Maximum Soil Accelerations for Different Locations

Estación	Aceleración Máxima Horizontal (g)	Aceleración Máxima Vertical (g)
Metro Mirador R.M.	0.24	0.13
CRS Maipú R.M.	0.56	0.24
Hospital Tisné R.M.	0.30	0.28
Hosp. Sótero del Río R.M.	0.27	0.13
Hospital Curicó	0.47	0.20

De Informe Preliminar de R. Boroschek, P. Soto, R. León, D. Compte (15-03-2010)

Effect of Type of Soil on Maximum Horizontal Acceleration for Zone 3 (NCh)

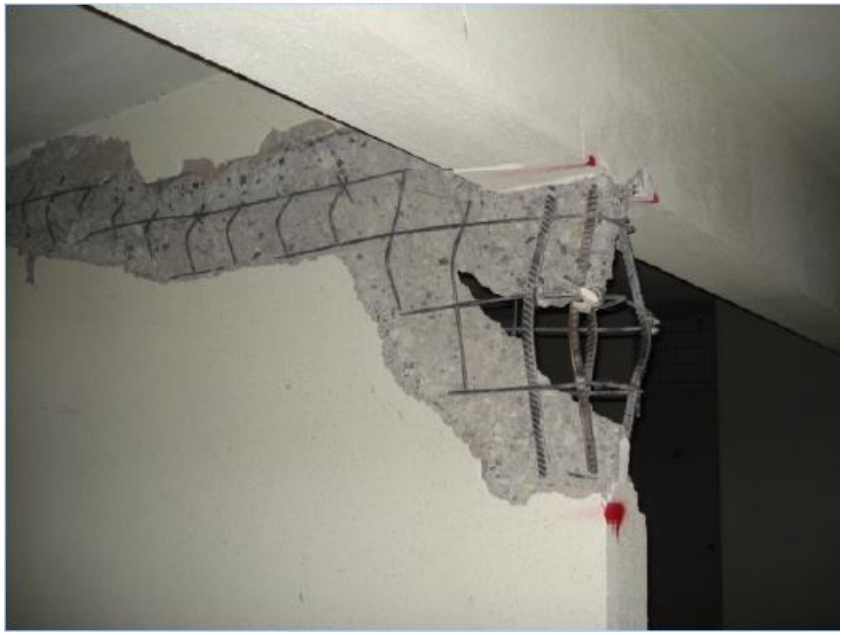


Response Spectrum: Seismic Zone 3

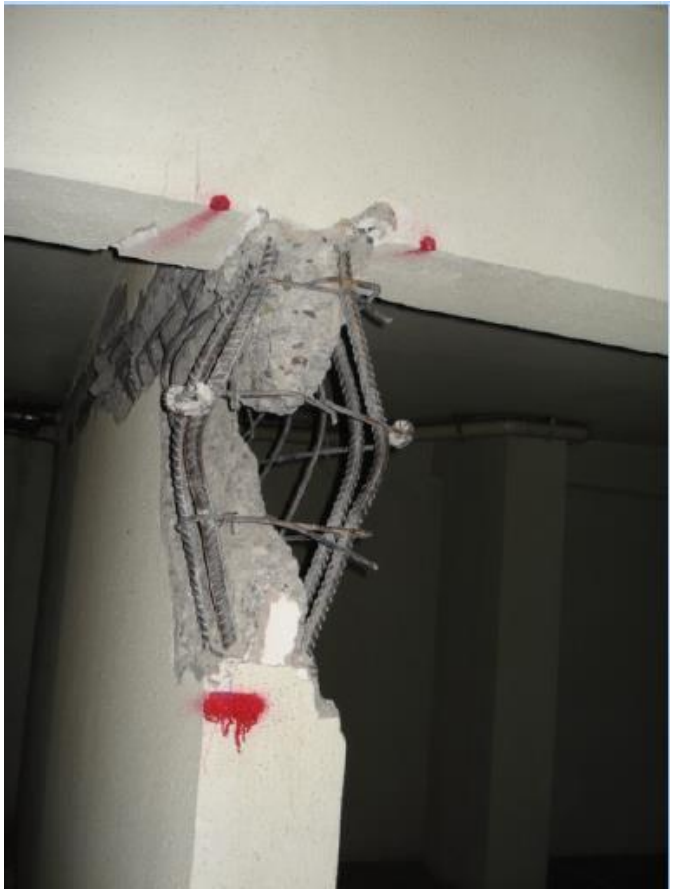
- Spectra obtained from records in Santiago for Type II soil gave displacements between 50% and 120% higher than the NCh433.of 96 standard

Uncertainty of the demand for structural design due to Vertical Acceleration

- Important vertical pulses present in all accelerograms that could be responsible for the failure observed in tall buildings.



Failure without compression for **no evidence of cover cracking (**R. Saragoni)



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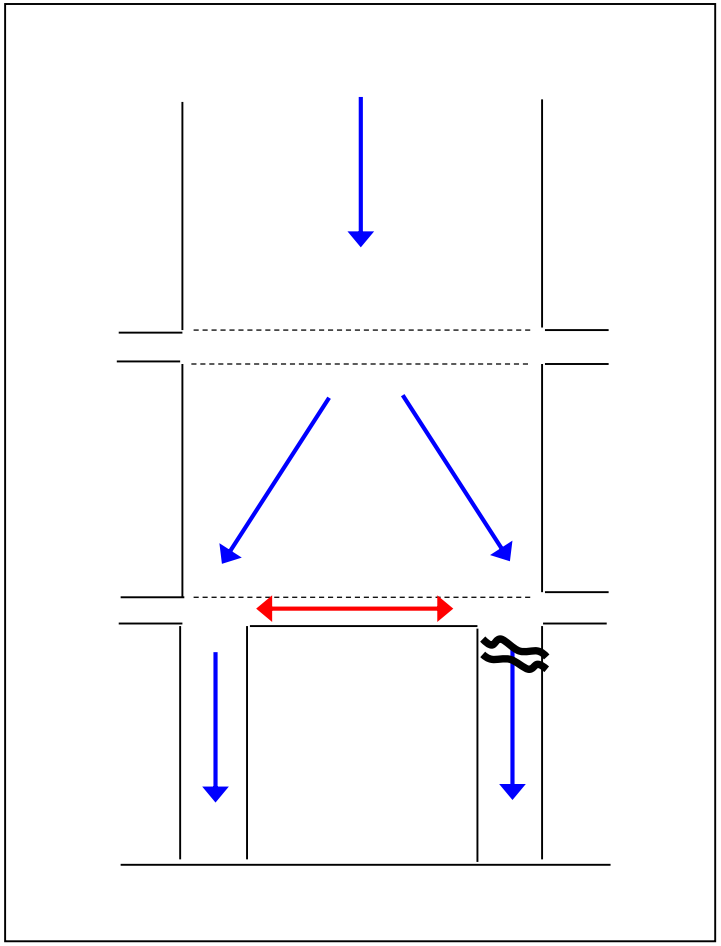
Architectural Design Irregularities

- Walls Discontinuities
- Columns Deviation
- Diaphragms Discontinuities

Wall Discontinuities



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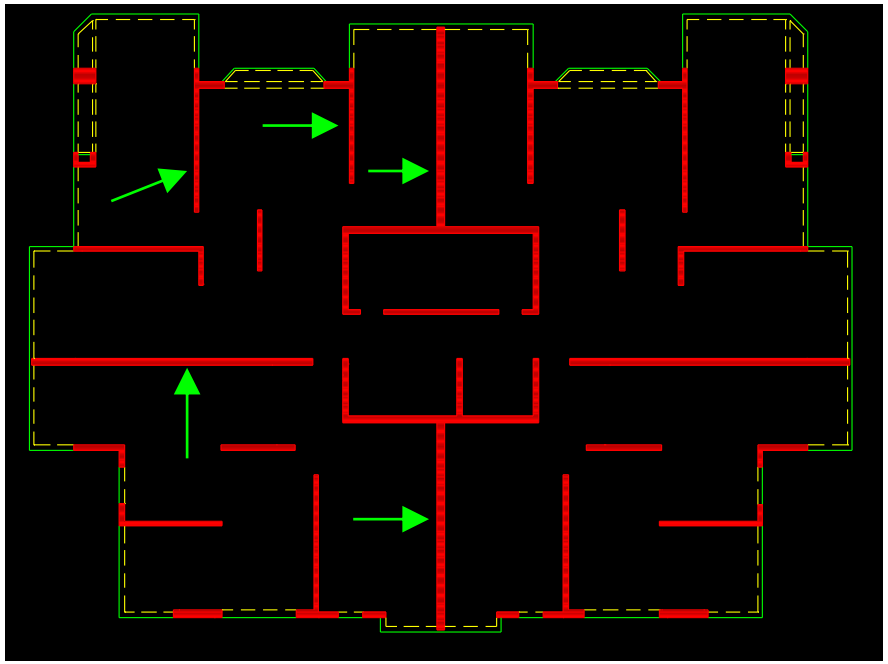
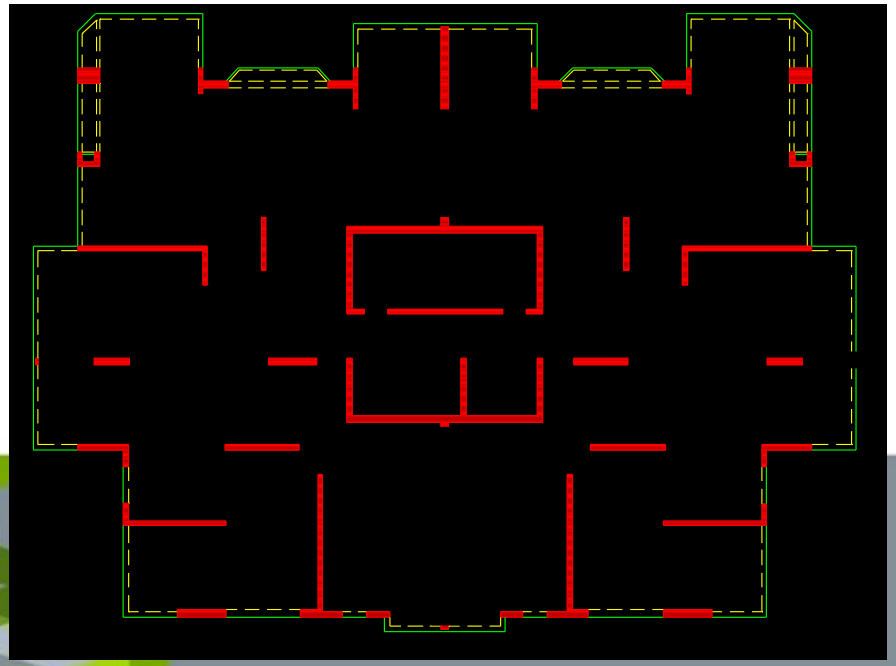
Architectural Design Irregularities



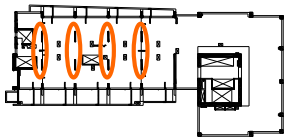
Typical plant floor: 2 to 22



Ground 1st floor

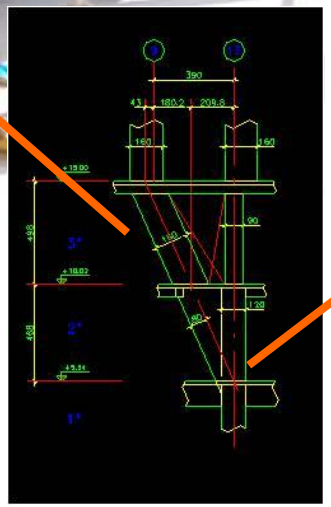
Structural Singularities:

❖ Columns Deviation



Isidora 3000 Building

3rd floor



2nd floor

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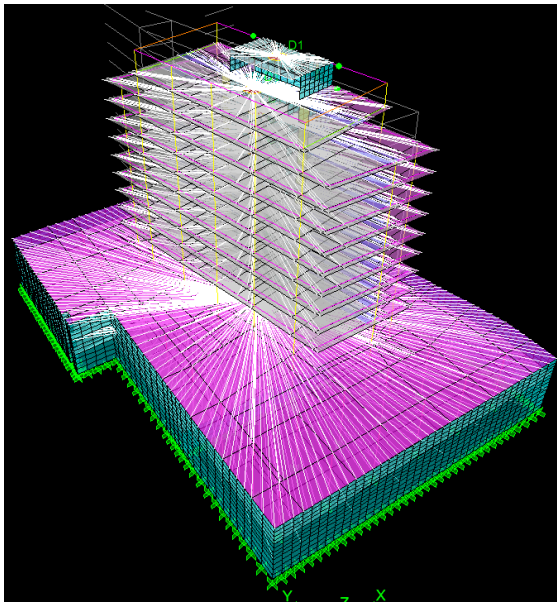
Structural Design and Analysis Errors

- Numerical errors (infrequent)
- Uncertainties in structural modeling (singularities)
- Uncertainties of design properties of locally available materials
- Divorce between Structural Engineering and Construction Engineering
- Defective detailing (singularities)
- Incomplete drawings

Sophisticated modeling programs tools for structural design, but…

Possible weakness: Uncertainty on structural modeling



- Modeling of foundations:
  - Vertical rigidity of the soil
  - Rigid base restraint versus foundation rotation
  - Lateral confinement of the underground
- Modeling of structural elements:
  - Use of finite elements versus uniaxial elements
  - Rigid or flexible diaphragms
  - Geometrical properties with or without cracking
  - Etc.

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Structural Modelling

Structural Engineer must:

- Know the potentialities and limitations of the used analysis tools.
- Verify the validity of the implicit assumptions in the models of analysis.
- Carry out alternative analyzes to verify the sensitivity of the solution to the adopted assumptions.
- Verify the design of the structural elements and its connections (load path).

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Divorce between Structural Engineering and Construction Engineering

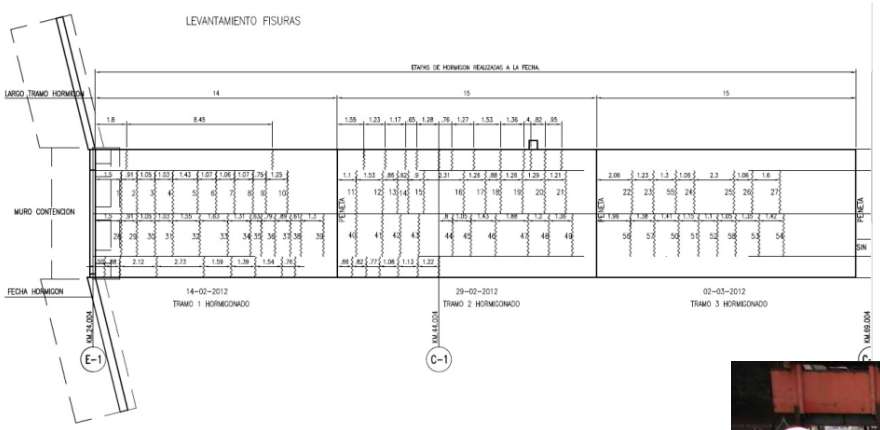

Figura 4-6: *levantamiento de fisuras / grietas en obra.*

Excessive cracking due to construction sequence

Structural Engineers do not usually consider the construction process at the design stage

Magellines Pier, V&A 2012

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Designing something difficult to built (common sense)

Sup. ϕ16@20 + E ϕ12@40

Inf. ϕ18@

Sup. ϕ25@10 + Suple ϕ28@10

Inf. ϕ25@10 + Suple ϕ28@10

1.0 m. height
R.C. Slab
V&A, 2008

Moving reinforcing bars with a bar to vibrate concrete

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Most Typical Structural Failures

- ✓ *Flexural-compression brittle failures*
- ✓ *Walls too slender (thickness 20 cm)*
- ✓ *Overall buckling of thin walls*
- ✓ *Very heavy loaded walls*
- ✓ *Concrete crushing and rebar buckling*
- ✓ *Soft floor (irregularities)*
- ✓ *Lack of concrete confinement*
- ✓ *Deficient reinforcement detailing*
- ✓ *Splice failure*
- ✓ *Few shear failures*
- ✓ *Shear failures in short columns*
- ✓ *Shear failures in coupling lintels*
- ✓ *Special failures*

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Walls too slender (thickness 20 cm)

P. Bonelli

Edificio Toledo, Viña

Edificio Alto Río, Concepción

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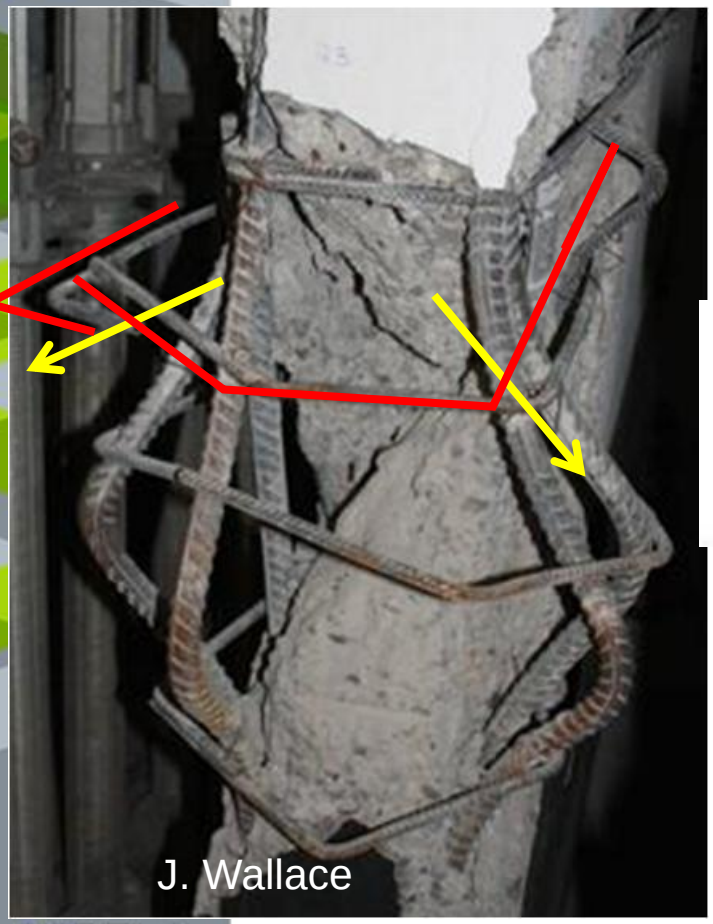
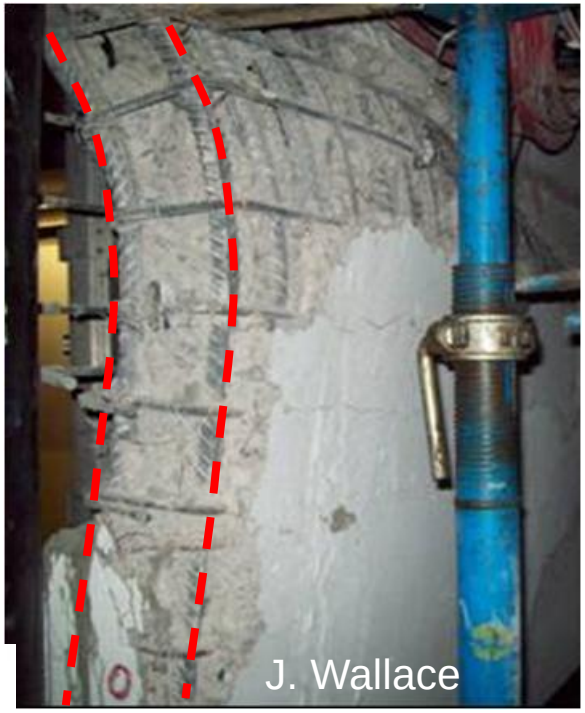
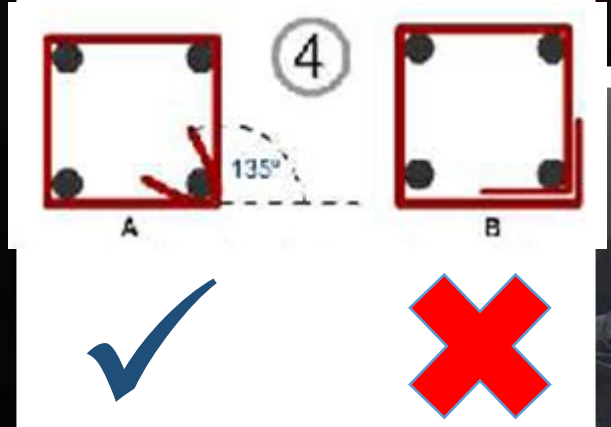
Overall buckling – thin walls

concrete crushing and rebar buckling & fracture





Stirrups



Very heavy loaded walls

Edificio El Parque

Edificio Central Park

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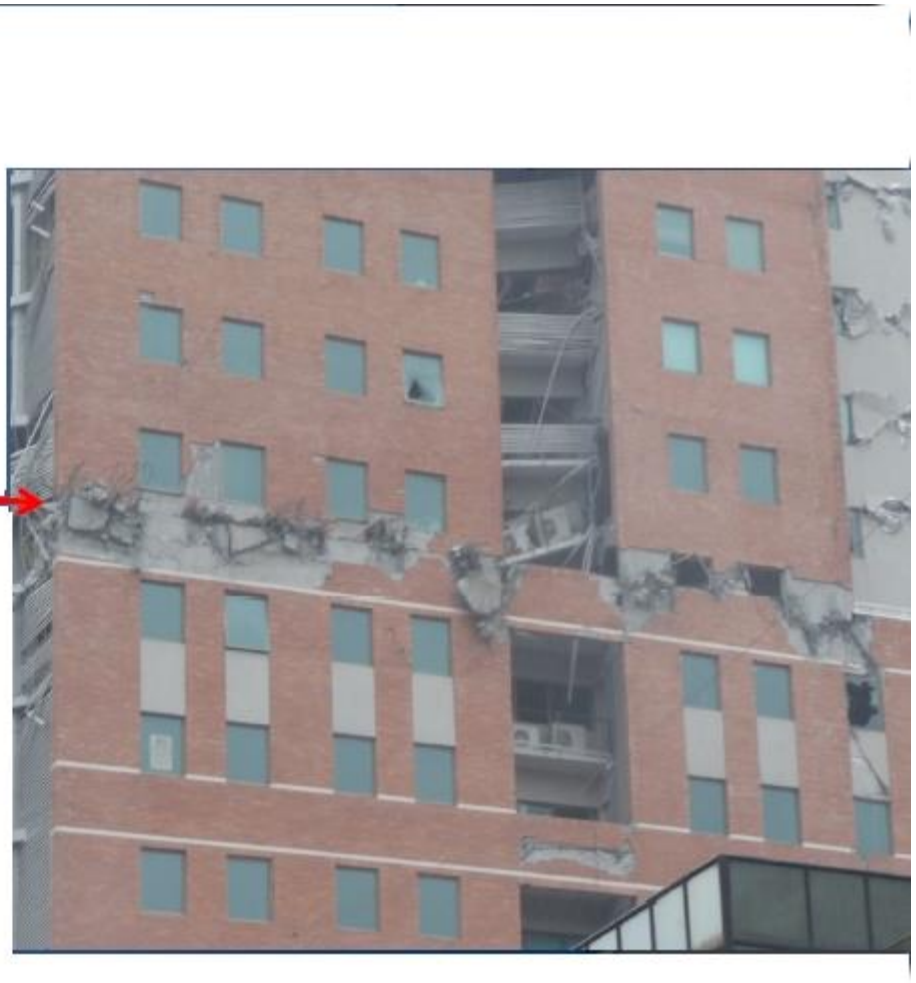
Soft floor



Concepcion

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Lack of concrete confinement

Agglomeration of thick bars without confinement

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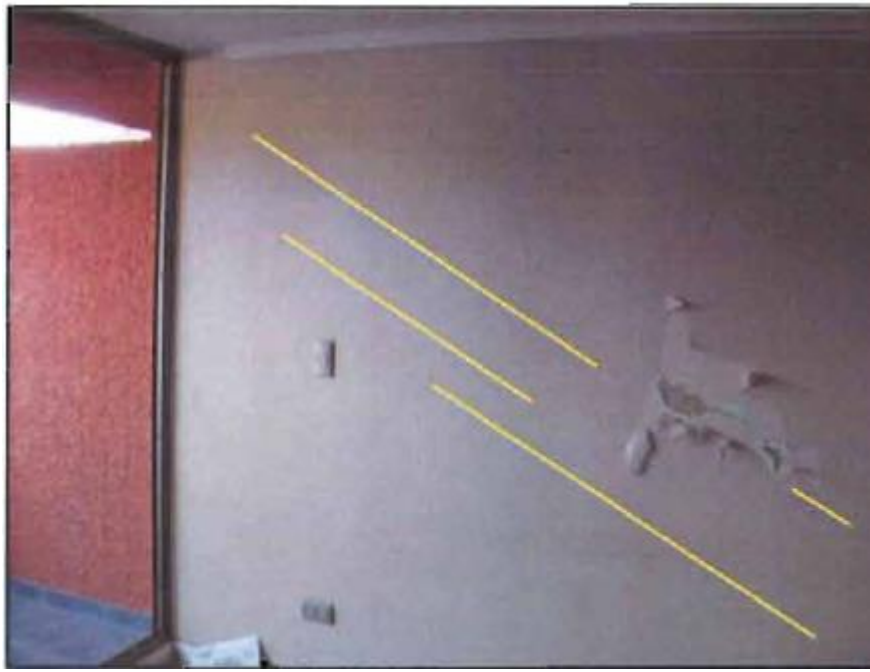
Few shear failures

Edificio Central Park



Edificio El Parque (fisura corte 0,5 mm)

Shear failures in short columns (traditional failure)

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Main Causes of Construction Defects

The vast majority of construction defects is due to a deficient **technical inspection** at the construction site.

(C. Luders)

And the responsibility of the constructor QC&QA systems?

- **ITO** (Technical Inspection of Construction Work)

VMB Ingeniería Estructural

- ***ITE*** *(Technical Inspection of Structures)*

CAUSES

- Irresponsibility.
- Knowledge.
- Reduced number of inspectors.
- Excessive rush.
- Changes.
- Deficient Specifications & Drawings

Most frequently encountered Construction Defects

- *Reinforcement detailing:*
  - → ***Missing confinement reinforcement.***
  - → *Misinterpretation of the drawings.*
  - → *Omission of reinforcements.*
  - → *Deficient placement of reinforcement.*
  - → *Excess reinforcement cover, reducing the lever arm*
- *Bad construction joints*
- *Lack of concrete continuity*
- *Movement joints*
- *Low strength concrete*

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Reinforcement detailing:
Absence of confinement in joints

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Reinforcement detailing:
Misinterpretation of the drawings

- **Different to drawings**

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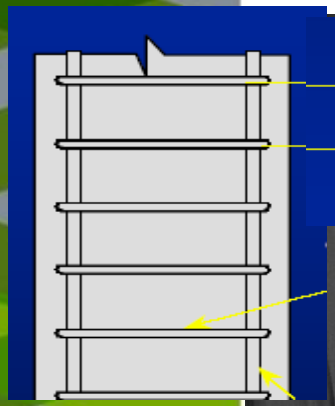
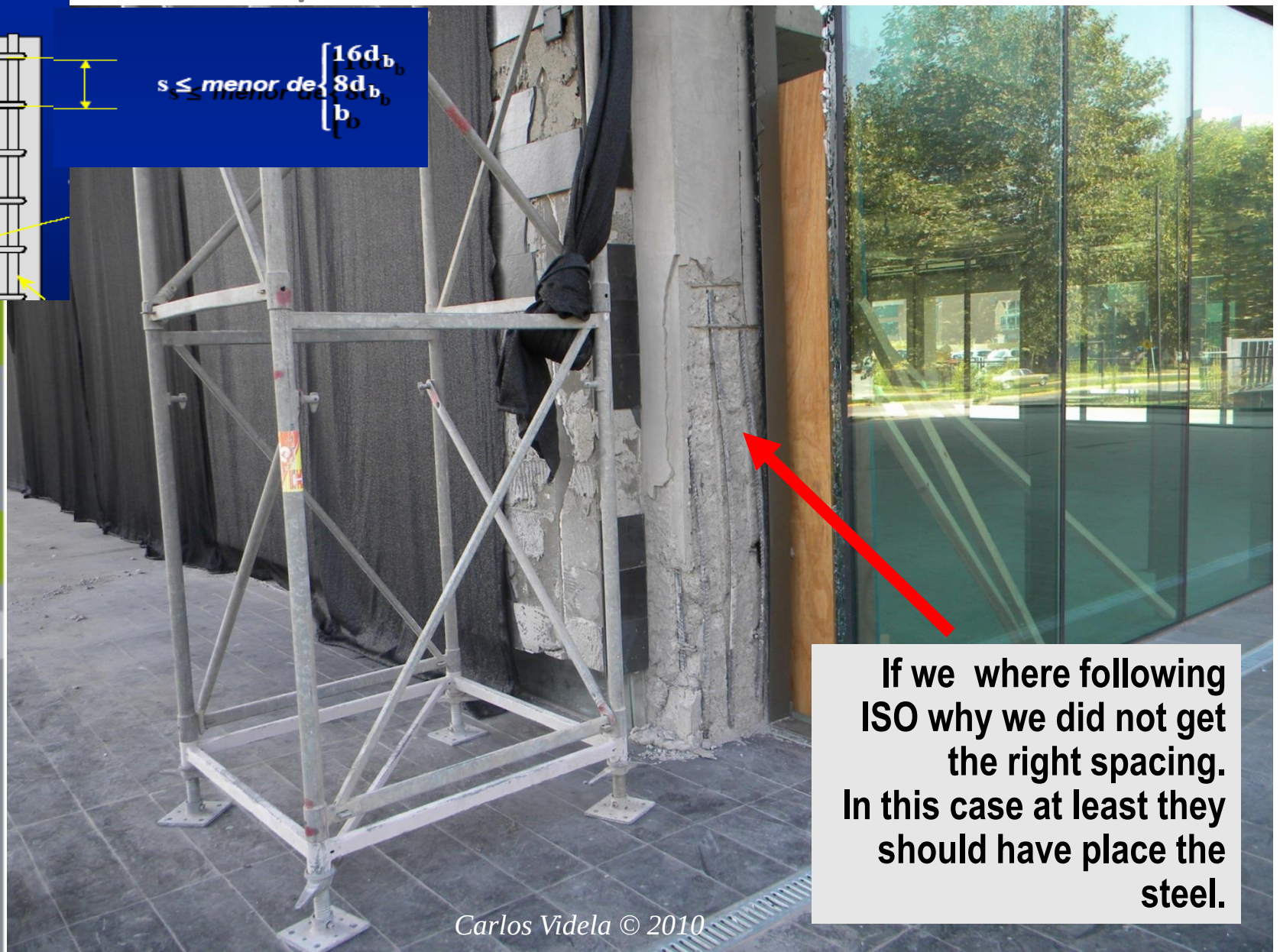
Reinforcement detailing:
Stirrups



$$s \leq \text{menor de} \begin{cases} 16d_b \\ 8d_b \\ b \end{cases}$$



If we where following ISO why we did not get the right spacing.
In this case at least they should have place the steel.

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Reinforcement detailing:
No anchorage

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Bad construction joints

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Lack of concrete continuity

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¡ Thank You !
Dr. Carlos Videla C.
September, 2017
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