Challenges of R.C. Construction

Tall Buildings
- Costanera Center
  - Height: 300 metros
  - Stories: 60
  - $f_c' = 70$ MPa
  - 20xx - ?

- Titanium La Portada
  - Height: 192 metros
  - Stories: 52
  - $f_c' = 60$ MPa
  - 2007-2010

- Marriott
  - 145 m, 1999

Shapes: Spiral Tower – Songdo, Korea
- 175 m, 52 stories, giro 110°

New Technologies
- Concrete Pumping Test over 600 m, Dubai (Feb. 2005)
  - SCC
Dificulties of Design

Ronald Klemencic, Magnusson Klemencic Associates

Wind Tunnel
Costanera Center

SHADOWS OF CONCRETE CONSTRUCTION

The dark side of the force

Carlos Videla © 2010

Deportes

La “joya” está agrietada

El recién inaugurado estadio de Coquimbo presenta notorias grietas en los pasillos y en la bandeja del segundo plano. El alcalde de esa ciudad reconoció que el "problema existe", que se produjo por acelerar la entrega de la obra y llamó a la empresa que edificó el redacto para que asuma su responsabilidad y repare los desperfectos. La alcaldía constructor, en tanto, calificó de "menores" las fisuras del hormigón y garantizó que "los daños no son estructurales", F.C.

Carlos Videla © 2010

Pittsburg garage parking
Even the collapse of the building can be produced

The document detected three types of deficiencies in the structure: bonding in the horizontal concrete construction joints, and reduce the service life of the structures.

Collapse of the works even without loads

Degradación del hormigón producto de la corrosión de las armaduras de la losa

TECHNICAL CAUSES

February 27th, 2010 – Chile
CHILEAN EQ. CASE
Disclaimer

This presentation uses a large number of pictures and evidence that professor Videla has gathered as an evidence of the Earthquake and Tsunami in Chile.

Most photographs where taken personally or by members of his company however, others have been obtained from internet and other sources and makes it very difficult to independently acknowledge some of the sources.

However special thanks are given to:

- Augusto Holmberg, CEO, ICH
- René Lagos, renelagos engineers
- Rodrigo Mujica, VMB Ingeniería Estructural
- Carl Luders, SIRVE S.A.
- Patricio Bonelli, Universidad Santa María
- Leonardo Massone, University of Chile
- René Guerra y Daniel Díaz, Videla y Asociados

Some Figures about the 27F EQ

- Chile 2010 EQ Mw = 8.8
- Epicenter close to Concepción
- Depth: 35 Km
- Subduction zone - Length of rupture 500km (approx.)
- RC building damage
- Affected cities - Concepción, Viña del Mar, Santiago, among others

Accelerations ...

Informe preliminar Nº 3 - 15 de Marzo de 2010
Red Nacional de Acelerógrafos
Boroschek R, P. Soto, R. Leon,, D. Comte
www.renadic.cl
THE GOOD AND THE BAD OF THE 27F EARTHQUAKE

The Very Bad Earthquake Effects...

- Dead or missed people: less than 500 (mainly by tsunami)
- Houses damaged: 300,000 to 500,000 (mainly adobe)
- Reconstruction: 30 US billions (15% GDP)

ICH Non oficial figures

- Maremoto = Tsunami

El desolador rastro del maremoto

Water run-up

Courtesy Universidad Católica Recognition group
Historical Buildings

Museo Nacional de Bellas Artes

- Curico Church
Adobe Construction

Typical Chilean Farm House

Adobe construction

Adobe construction

Adobe construction
• “Modern” adobe construction

> RC Buildings - Good & Bad

How did buildings performed?
Considering only buildings between 1985 to 2009 (CChC)

- Buildings that collapsed: 4
- Buildings to be demolished: 25 - 50 (estimate)
- Buildings heavily damaged: 50 – 100 (< 1% stock of buildings)
- Non structural components: extensive damage
- 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%

> EXAMPLES OF BUILDINGS WITHOUT STRUCTURAL DAMAGE

> Titanium Tower – Santiago, Chile

52 stories
192 meters high
Titanium Tower

Energy dissipation devices

Telefónica Building – Santiago, Chile

- Construction Area: 65,000 m² total
  35,000 m² main tower
- Tower typical floor: 20m. x 47m
- Building height: 140 meters
- Stories: 33 + 3
- Year of Completion: 1996

Isidora 3000 – Chile (2008)

Mix use

Isidora 3000

Structure Singularities

3rd floor

2nd floor
Justice Building
Santiago Chile. (2003)

Office buildings (2008)
Isidora Foster + Magdalena – Chile
• 25 stories
• 9 basement
• 72,000 m²

EXAMPLES OF BUILDING FAILURES

Concepción
Edificio O’Higgins 241

Viña del Mar

Edificio Toledo – Viña del Mar

Edificio Tricahue – Viña del Mar
Design Failures

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

Walls

- T & rectangular walls with flexural-compression damage at 1st floor or basement
- T walls with damage at web
- No SBE – concrete crushing and rebar buckling
- Splice failure
Walls

- No SBE – concrete crushing and rebar buckling & fracture
- Overall buckling – thin walls

Soft floor

- Muro discontinuo de zócalo
  (Edificio Hipódromo Chile)

Lack of concrete confinement

Compression failure and buckling of vertical bars
Detailing of reinforcement

Reinforcement bent at 90° (Edificio Emerald)

Detailing of reinforcement

Falta de retorno de la malla horizontal (Edificio El Parque)

Detailing of reinforcement - splice

Anclaje vertical de armaduras horizontales (Edificio El Parque)

Edificio Los Cerezos

Flexural-compression failure

Edificio Emerald
Few shear failures

Walls too slender (thickness 20 cm)

Very heavy loaded walls

Car Park
The typical structural wall in a Chilean building need not have boundary elements or special transverse reinforcement. The good performance of the majority of these buildings during the March 3, 1985 earthquake suggests that bearing walls with limited detailing may be an effective construction form for earthquake resistance.

After the 1985 Chilean Earthquake it was thought:

Concrete Design Code
- Limit slenderness of the shear walls
- Limit the compression in shear walls
- Confinement of boundary elements
- Confinement at longitudinal splices

Earthquake Loading
- Revise the design spectrum
- Revise the soil amplification effects
- Define displacements and rotational demands

Construction Failures

De most frequent encountered problems were:
- Reinforcement detailing (Missing confinement reinforcement)
- Bad construction joints
- Lack of concrete continuity
- Excess reinforcement cover, reducing the lever arm
- Movement joints
- Low strength concrete

Reinforcement detailing

- Confinement
- Location
- Righteousness
- Cleaning
- Stirrups
- Ties
- Splices
Reinforcement detailing: confinement

- Horizontal mesh reinforcement not closed
- Missing confinement reinforcement

Reinforcement detailing

I never thought that this could really happen.

Reinforcement detailing: stirrups

If we were following ISO why did we not get the right spacing. In this case at least they should have placed the steel.
Reinforcement detailing: detailing

- Different to drawings

Reinforcement detailing: location

- No cover

Eccentric reinforced bars

Bad construction joints
Lack of concrete continuity

Movement joints

Excess reinforcement cover

Low strength concrete (poor) (furtive – covert)
FAILURES OF NON STRUCTURAL MEMBERS

Failure of Non Structural Members

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

Partition walls

Gypsum

Tabiques de yeso (Edificio en Santiago, Ñuñoa)

Ceilings

Pudahuel Airport

The Chilean International Airport was out of service at the most critical time for Chile.
**Glasses**

Windows

**Equipment**

Machine room and heaters equipment (Ciudad Empresarial Building, Santiago)

**Fittings**

Daños en sistema de aire acondicionado y protección contra el fuego (Santiago y Concepción)
**Furniture**

Daños del contenido (Edificio Stgo., Ciudad Empresarial)

Carlos Videla © 2010

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**Finishing**

- **Veneer** → 90% OK

DUDEC, San Carlos de Apoquindo

V&A

Carlos Videla © 2010

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**Finishing**

- **Stucco**

Excessive thickness of stucco to rectify plumbs

Universidad del Desarrollo

V&A

---

**Finishing**

- **Architectural Details**

Universidad del Desarrollo

V&A
> Finishing

- Curtain Walls
  OK

> Secondary Structures

- Pudahuel Airport

> Schools

- Mall Portal La Dehesa

- V&S A

- Danos no Estructurales: Colegios
The human factor

García Meseguer A.

CAUSES: Ignorance
Carelessness
Negligence
Excess of confidence
Apathy
Lust

The Pareto variable of construction quality, whose improvement has the largest impact on the improvement of the total, been equal the rest of the factors is THE HUMAN FACTOR.

Causes of the Pathologies of RC Structures

- Ignorance or Irresponsability?
- Incapacity or Indifference?
- Inexperience or Negligence?
- Incompetency or lack of foresight?

Let see the knowledge

Let see the knowledge
From an Ancient English Proverb

...... (Structural) Engineering is the art of moulding materials we do not wholly understand into shapes we cannot precisely analyse, so as to withstand forces we cannot assess, in such a way that the community has no reason to suspect our ignorance.......  

Ironbridge, 
Cast-iron arch bridge-1779, 
River Severn, 
Coalbrookdale, Shropshire, 
England

A. Neville (1981)
If the reader is unable to design a satisfactory mix he should seriously consider the alternative of construction in steel

Including Remarks

The procedure of trial mixes and consecutive adjustments in all methods of design must seem empirical and gives the impression of being un-scientific, but the variability of the properties of both cement and aggregate is such that our calculations are really only guesses. However, better our knowledge of the various properties of the ingredients of concrete the more accurate our guesses can be. With this knowledge and science in the use of the materials involved, satisfactory mixes can be designed, although the process can never become automatic but an art as much a science.

(Note: If the reader is unable to design a satisfactory mix he should seriously consider the alternative of construction in steel.)

IF WE KNOW SO MUCH, WHY THE FOLLOWING FAILURES OCCUR?
Postensioning of Flat Slabs
(Quito, Octubre 2002)

Unshoring of slabs

Slab camber and make perpendicular walls during construction

COULD BE THAT WE ARE NOT DOING AND APPLYING SOUND ENGINEERING PRINCIPLES?
Sophisticated modeling programs tools for structural design, but…

Possible weakness: Uncertainty on structural modeling

• Modeling of foundations:
  - Vertical rigidity of the soil
  - Empotramiento at the base 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.

Divorce between Structural Engineering and Construction Engineering

Structural Engineers do not consider the construction process in the design stage

Construction Engineers used to point out that structural engineers were standing far from the actual constructions sites. This still remains true but, …
Divorce between Structural Engineers and Reality

Massive R.C. Mat Foundations, Costanera Center Building, 2010
SCC - 50 MPa

Divorce between Construction Engineering and Construction Management

Since construction management arrived in our field we have been talking to different language.
Divorce between Construction Engineering and Construction Management

Since construction management arrived in our field, we have been talking to different language.

Many construction engineers are also looking the construction site through the computer screen. This is ok since they make take advantage of many new application tools for planning, programming and building; however.....

Drawings are a window through which the knowledge is seen (or measured)

Some phrases about Constructors

• Drawings must be very detailed to avoid constructors to think or interpret (design office).
  • Information for in situ engineers must be very concise and simple and a maximum of 2 pages extension because they don’t read. (visiting engineer of a construction company).

• Constructors don’t have the capacity nor the knowledge allowing them to place in doubt structural design drawings (owner of a construction company).

• In situ professionals don’t like to write to register anything (all the previous).
More phrases

- Constructors are only worried about administrative duties like acquisitions, quotations, budgets, programming; they don’t care about the execution of the work in-situ and rely on the work of the technical labor (me).

- The main work of the ITO is administration of the contract: approve payment, check productivity, evaluate time, etc.; they don’t verify the quality of the construction (structural engineers).

Mass Concrete Case

**Early-age Mechanisms**

- Concrete mix and cement type
  - Thermal material prop., Capacity, conductivity
  - Heat of hydration

- External thermal conditions:
  - Batch temp. and ambient temp.
  - Protection and insulation

- Transient temperature field $T(x,y,z,t)$

- Constraints and loading
  - Thermal strains and autogeneous shrinkage

- Risk of cracking?

- Early-age mech. properties:
  - Strength, stiffness, creep

- Maturity field $M(T(x,y,z,t))$
LUST

Where is the concrete?

Tester of Concrete at Yankee Stadium and Freedom Tower Faces Scrutiny

New York Report

The New York Times
Concrete-testing company says NYC results were not faked

American Standard Testing and Consulting Laboratories denies allegations that it falsified thousands of test results on several New York City projects, including a La Guardia Airport control tower and the new Yankee Stadium. Company President Alan Fortich and five staff members Thursday pleaded not guilty to racketeering and other charges. Company's defense attorney, Richard Leff, said the concrete strength tests were done correctly.

• The New York Times
• The Associated Press

The six defendants accused of falsifying concrete tests in State Supreme Court on Thursday.

By William K. Rashbaum

Published: August 4, 2011

Article 18: The first vendor owner of a construction will be responsible for all the damages and financial losses due to faults or defects on it, whether.....
SCIENTISTS

L'Aquila EQ

The Globe and Mail October 23, 2012

Construction Process and Responsibilities

<table>
<thead>
<tr>
<th>STAGE</th>
<th>COMPETENCE</th>
<th>RESULT</th>
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</thead>
<tbody>
<tr>
<td>Design</td>
<td>Architect</td>
<td>Structure Specified Quality</td>
</tr>
<tr>
<td>Fabrication</td>
<td>Construction Engineer</td>
<td>Resistencia prevista en función de los Materiales y Diseño Proceso Constructivo</td>
</tr>
<tr>
<td></td>
<td>Labour</td>
<td>In situ</td>
</tr>
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<td></td>
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<td>Structure Potential Quality</td>
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Structural Engineer

Resistencia prevista en función de los Materiales y Diseño Proceso Constructivo

Selection of more suitable and economical materials.

Fabrication

Transport

Colocación

Colocación

Compactación

Curado

Would you buy this Lamborghini Murciélago?

And now?
It affects the public faith

What can we expect of these cases?

"I put less cement on the foundations, but nobody will never notice"
Movement and distribution moulds

ARCHITECTURAL CONCRETE??

Vertical moulds

Movement

Horizontal moulds

Construction Joints


Embedded pipes in reinforced concrete elements

Slab

Wall

Cover failure

CONCLUSIONS
¡Thanks!

Dr. Carlos Videla
October, 2012