American Concrete Institute®
Advancing concrete knowledge

Post-Earthquake Repairs, Part 2

ACI Spring 2012 Convention
March 18 – 21, Dallas, TX

José I. Restrepo, FACI, is a Professor in Structural Engineering at the University of California at San Diego. He received his Bachelor in Civil Engineering from Universidad de Medellín in Colombia; and PhD from the University of Canterbury in Christchurch, New Zealand. He has research and educational interests in reinforced and precast/prestressed concrete, in particular in seismic design. Professor Restrepo is a member of ACI Committee 550, Precast Concrete. He is also a past recipient of the Chester Paul Siess Award for Excellence in Structural Research.

UNIVERSIDAD TECNICA FEDERICO SANTA MARIA

Repair of R/C Buildings Damaged in Viña del Mar During the 27 February 2010 M_w8.8 Maule Earthquake

Patricio Bonelli[1], Gilberto Leiva[2], José I. Restrepo [3] and Jorge Federico Carvallo[4]

[1]Universidad Santa María, patricio.bonelli@usm.cl
[2] Universidad Santa María, Gilberto.leiva@usm.cl
[3] University of California, San Diego, jrestrepo@ucsd.edu
[4]Pontificia Universidad Católica de Valparaíso, jorge.carvallo@ucv.cl

Introduction

The 27 February Earthquake 2010

- Six largest Magnitude earthquake recorded in modern history
- Subduction type earthquake: shallow and long-duration, similar to that expected in the Cascadia region of the North America's Pacific Northwest
- Strong intensity (MMVII or higher) shaking over a 100 km wide by 580 km long corridor in Central Chile and Tsunami over the coast around and south of the epicenter

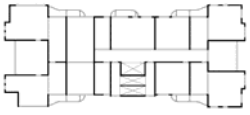
Chile

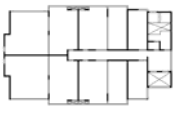
PNW

- The earthquake hit the industrialized and densely populated central region of Chile
  - 7 million people live in this corridor
  - Only 8 out of 525 people died on modern buildings
  - Most casualties were due to the tsunami and to the collapse of non-engineered dwellings
  - There was disproportionate structural damage in medium-height buildings built on soft soils and designed using the building code current at the time of the earthquake

Introduction

Predominant Mid-Height Building Archetype in Chile

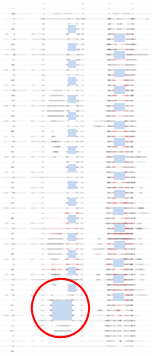




Introduction

Predominant Mid-Height Building Archetype in Chile

- Solid R/C slabs, 150 mm to 200 mm thick
- Load bearing walls are often significantly perforated near the base of the building
  - Difficult assessment of load paths
  - Validity of plane section hypothesis in critical regions is questionable
- Most modern buildings have one of two underground parking garages
- Foundations are typically solid mats, piles are seldom used
- Thin gravity columns are sparingly used
- Trends towards the use of thinner walls/taller buildings

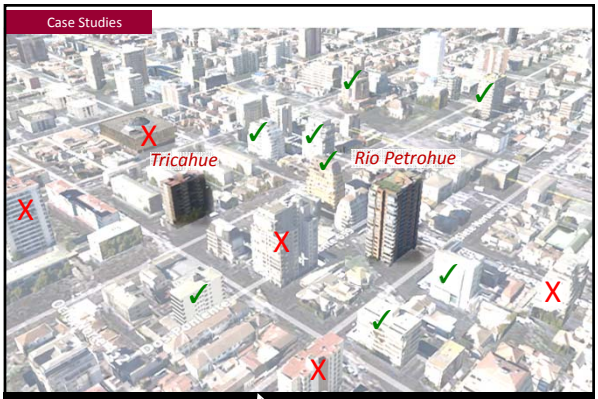


Design Approach

- Design requirements have changed over the years, but the base shear coefficient and detailing have remained similar over the years
- Design base shear force in medium-rise buildings ranges between V_{bu} = 0.12-0.15W
- Detailing is generally poor with little aim for ductility
  - Working stress design up until 1995
  - Chile adopted ACI-318 back in 1993 but specific seismic detailing requirements for walls were excluded
- Load bearing walls of complex configuration are often analyzed as a composite of rectangular walls
- Walls are often thin (h/12 to h/15) and have deep neutral axis depths, displaying compressive controlled failures

Case Studies

Case Studies



Case Studies

General Damage and Repair Schemes

- Extensive crushing of the concrete in lower level walls
- Endemic buckling and fracture of the longitudinal reinforcement

- Closure of wall openings
- Increase wall thickness
- Additional walls
- Epoxy injection of small width cracks in walls and slabs
- Use of wet layoff carbon fiber strips

Case Studies

Río Petrohué

- 6860 m^2, 17 stories

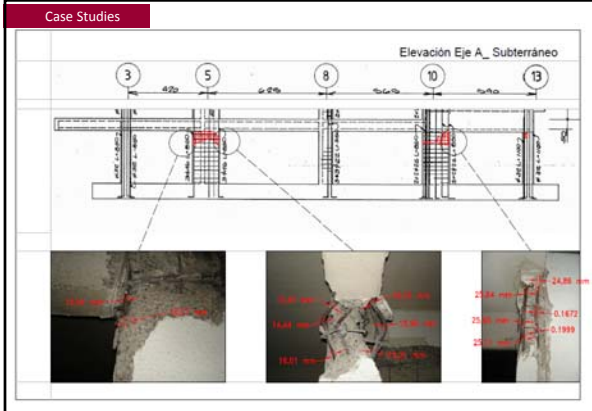
- Total repair cost = $2 565 000
- Structural repair cost = $ 941 000
- Structural repair cost/Total repair cost = 0.3
- Total repair cost / Replacement cost= 1/3

Case Studies

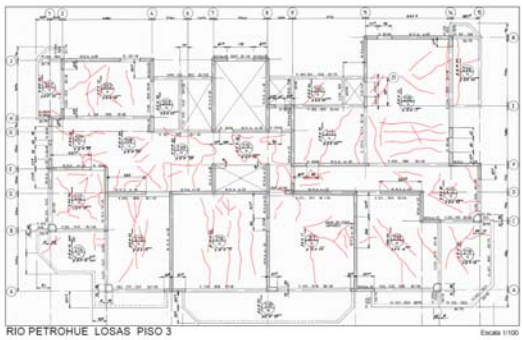
Case Studies

Case Studies

Case Studies



Case Studies



Case Studies

Case Studies

Case Studies

Case Studies

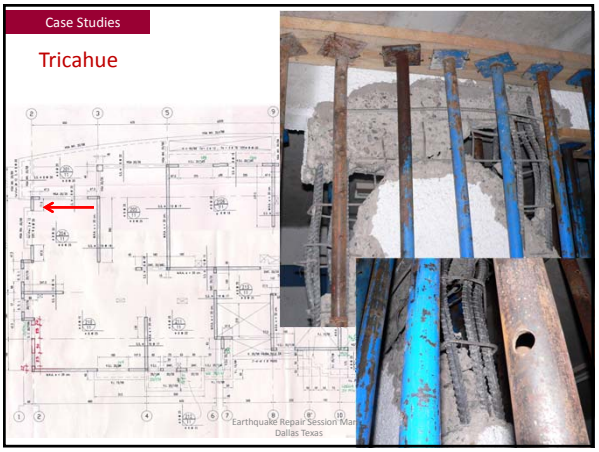
Edificio Tricahue

- 5000m^2, 12 stories
- Structural repair cost = $ 1 500 000
- Structural repair cost = $ 600 000
- Structural repair cost / Total repair cost = 0.4
- Total repair cost / Replacement cost = 1/3

Case Studies

Case Studies

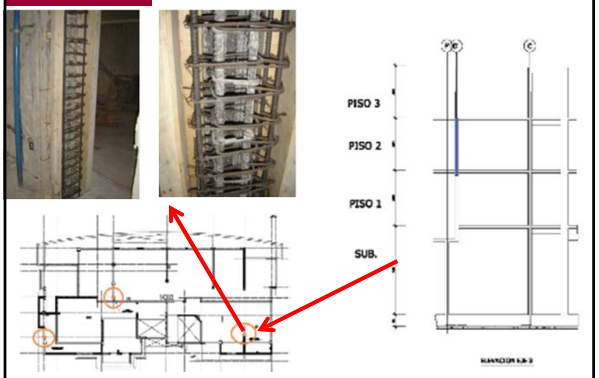
Tricahue



Case Studies

Tricahue

Case Studies



Conclusion

Conclusions

- Repairs of earthquake damaged medium-rise buildings in Viña del Mar, Chile have gone ahead when the cost of repair to replacement cost is less than 0.35
- Repair methods are traditional and consist in removal of crushed concrete, replacement of buckled or fractured longitudinal reinforcement, increase wall thickness and removal of openings in critical levels of the building
- In some cases carbon fiber strips have been used to enhance the shear strength in critical regions of walls

Conclusion