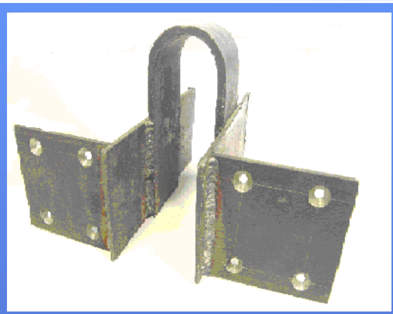
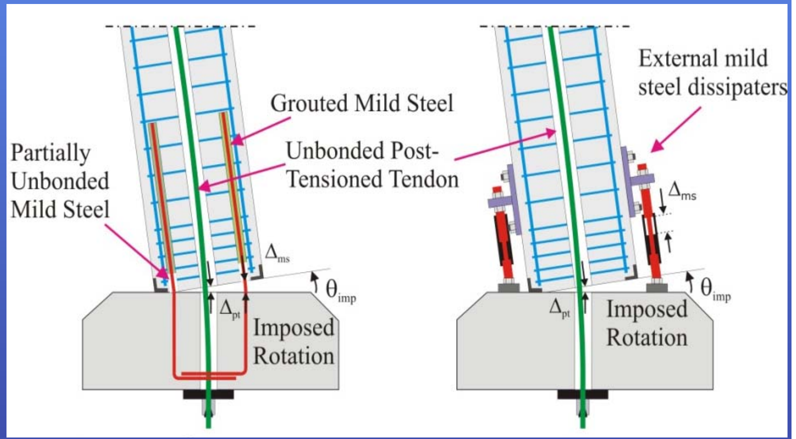
Canterbury Earthquake Royal Commission Hearings - 12-15 March 2012

Damage-Resistant Technologies for Improved Seismic Performance of Buildings: an Overview





Stefano Pampanin

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CHRISTCHURCH NEW ZEALAND

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CHRISTCHURCH NEW ZEALAND

How many **"Lessons"** do we still need?

1999 → **2009** → **2011**

Izmit-Kocaeli, 1999
(photo courtesy: Berkeley Library)

L'Aquila, 2009
(photo courtesy: Anna Brignola)

Christchurch, 2011
(photo courtesy: Kam Weng)

NZCS | NZ Society for Earthquake Engineering Incorporated | SESOC | New Zealand Timber Design Society Incorporated – A technical group of IPENZ Engineers New Zealand | Seismic Retrofit Solutions

Extensive (beyond reparability?) damage to modern Buildings

Typical plastic hinges in beams (intended to act as sacrificial fuses)

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Shear walls

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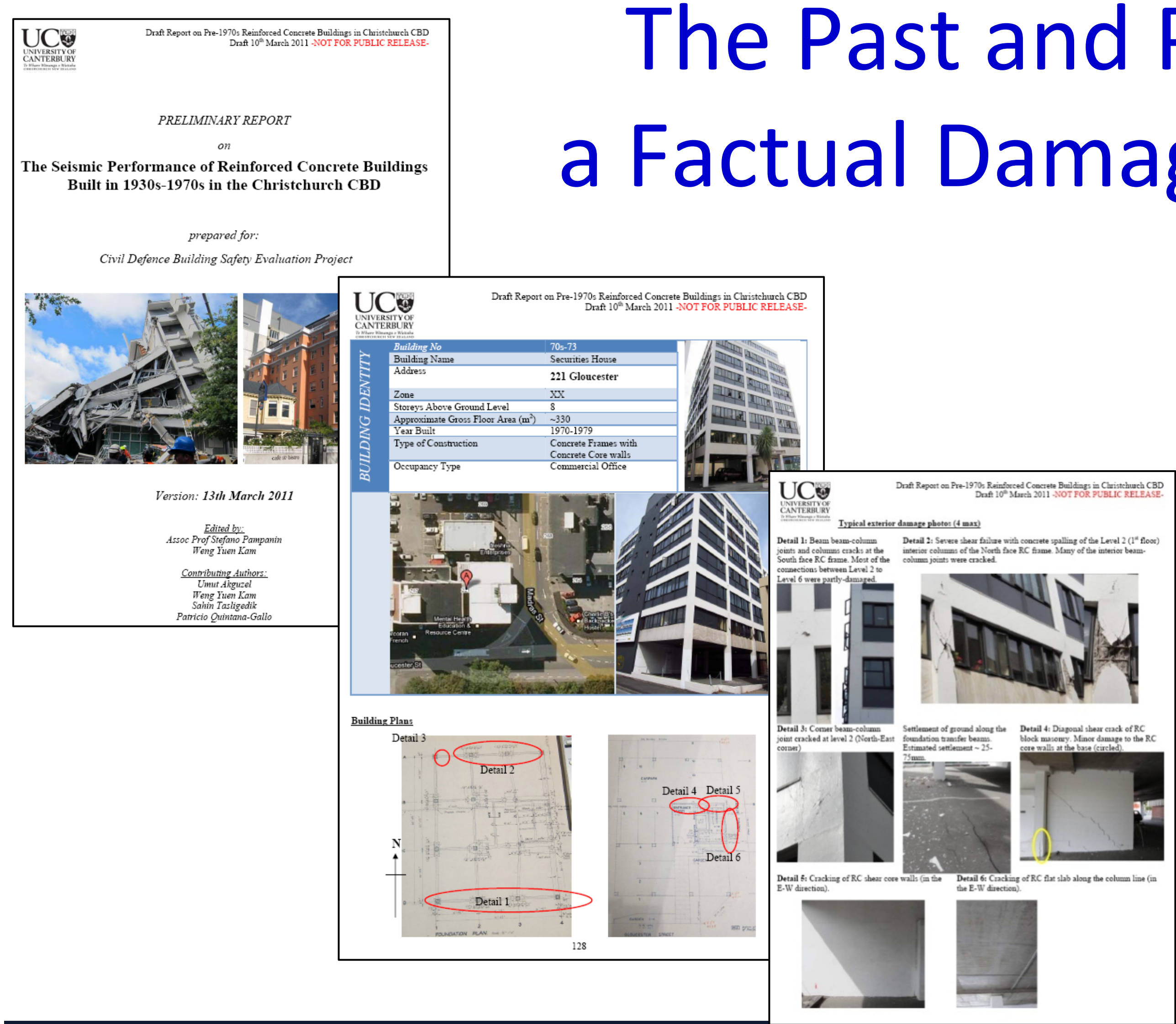
The Past and Present: a Factual Damage Report


Draft Report on Pre-1970s Reinforced Concrete Buildings in Christchurch CBD
Draft 10th March 2011 -NOT FOR PUBLIC RELEASE-

PRELIMINARY REPORT
on
The Seismic Performance of Reinforced Concrete Buildings Built in 1930s-1970s in the Christchurch CBD

prepared for:
Civil Defence Building Safety Evaluation Project

Version: 13th March 2011

Edited by:
Assoc Prof Stefano Pampanin
Weng Yuen Kam

Contributing Authors:
Umut Akguzel
Weng Yuen Kam
Sahin Tasligedik
Patricio Quintana-Gallo

BUILDING IDENTITY

Building No	70s-73
Building Name	Securities House
Address	221 Gloucester
Zone	XX
Storeys Above Ground Level	8
Approximate Gross Floor Area (m^2)	~330
Year Built	1970-1979
Type of Construction	Concrete Frames with Concrete Core walls
Occupancy Type	Commercial Office

Building Plans
Detail 3, Detail 2, Detail 1, Detail 4, Detail 5, Detail 6

128

Typical exterior damage photos (4 max)

Detail 1: Beam beam-column joints and columns cracks at the South face RC frame. Most of the connections between Level 2 to Level 6 were partly-damaged.

Detail 2: Severe shear failure with concrete spalling of the Level 2 (1st floor) interior columns of the North face RC frame. Many of the interior beam-column joints were cracked.

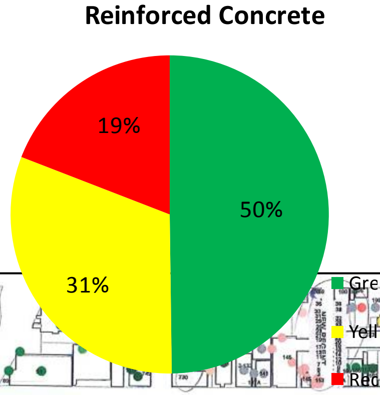
Detail 3: Corner beam-column joint cracked at level 2 (North-East corner)

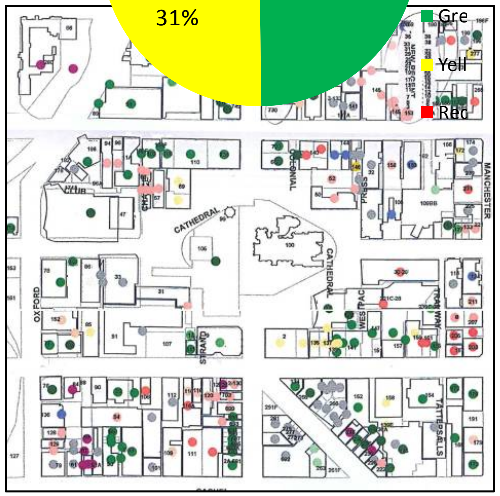
Settlement of ground along the foundation transfer beams. Estimated settlement ~ 25-75mm.

Detail 4: Diagonal shear crack of RC block masonry. Minor damage to the RC core walls at the base (circled).

Detail 5: Cracking of RC shear core walls (in the E-W direction).

Detail 6: Cracking of RC flat slab along the column line (in the E-W direction).





NZCS | NZ Society for Earthquake Engineering Incorporated | SESOC | NEW ZEALAND TIMBER DESIGN SOCIETY INCORPORATED | Seismic Retrofit Solutions

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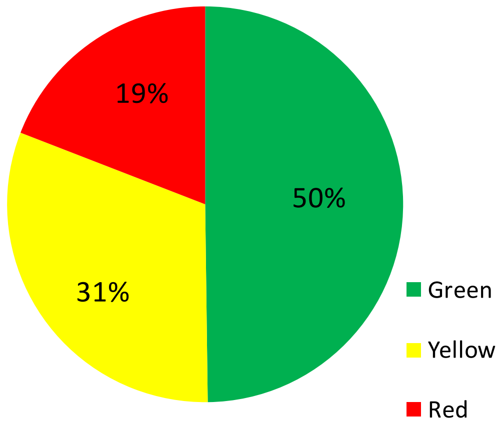
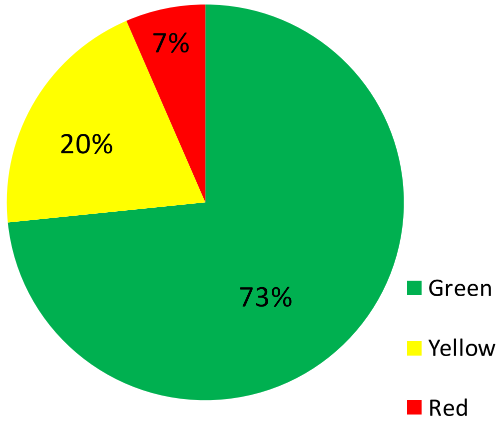
Damaged buildings (22 Feb 2011)

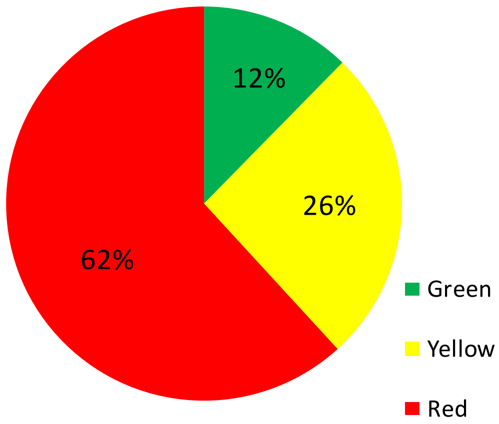
Reinforced Concrete



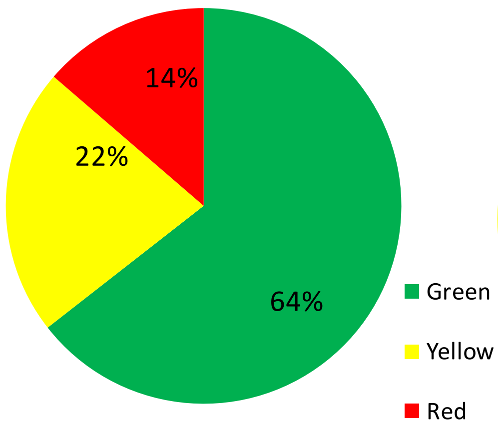
Steel



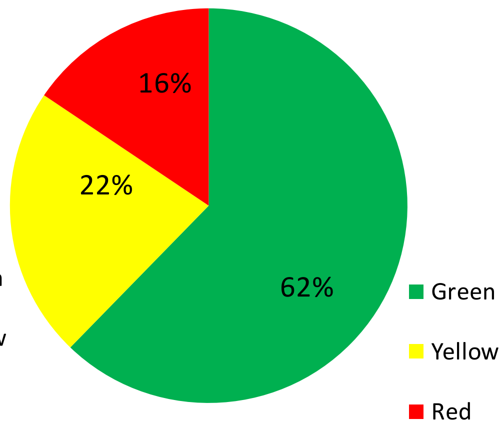
Unreinforced Masonry



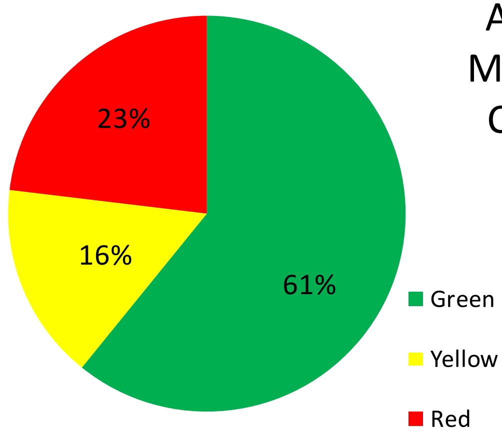
Timber



Reinforced Masonry



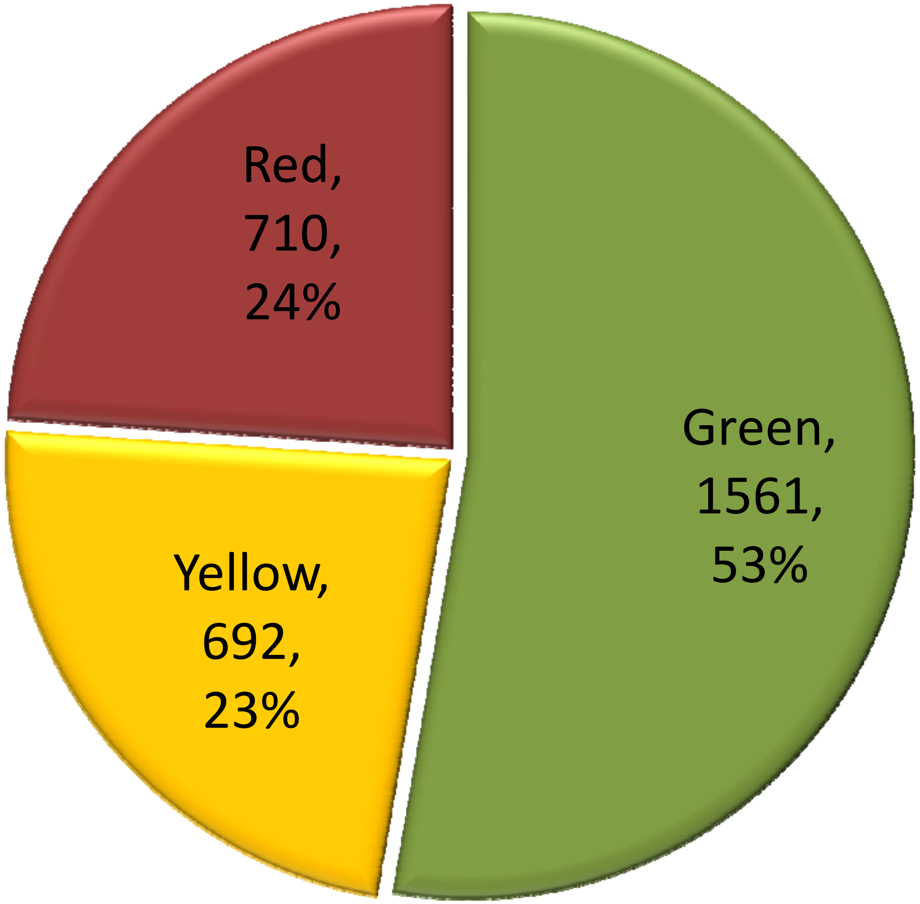
Unknown / Not reported



As per 18 Mar 2011 – CCC Data

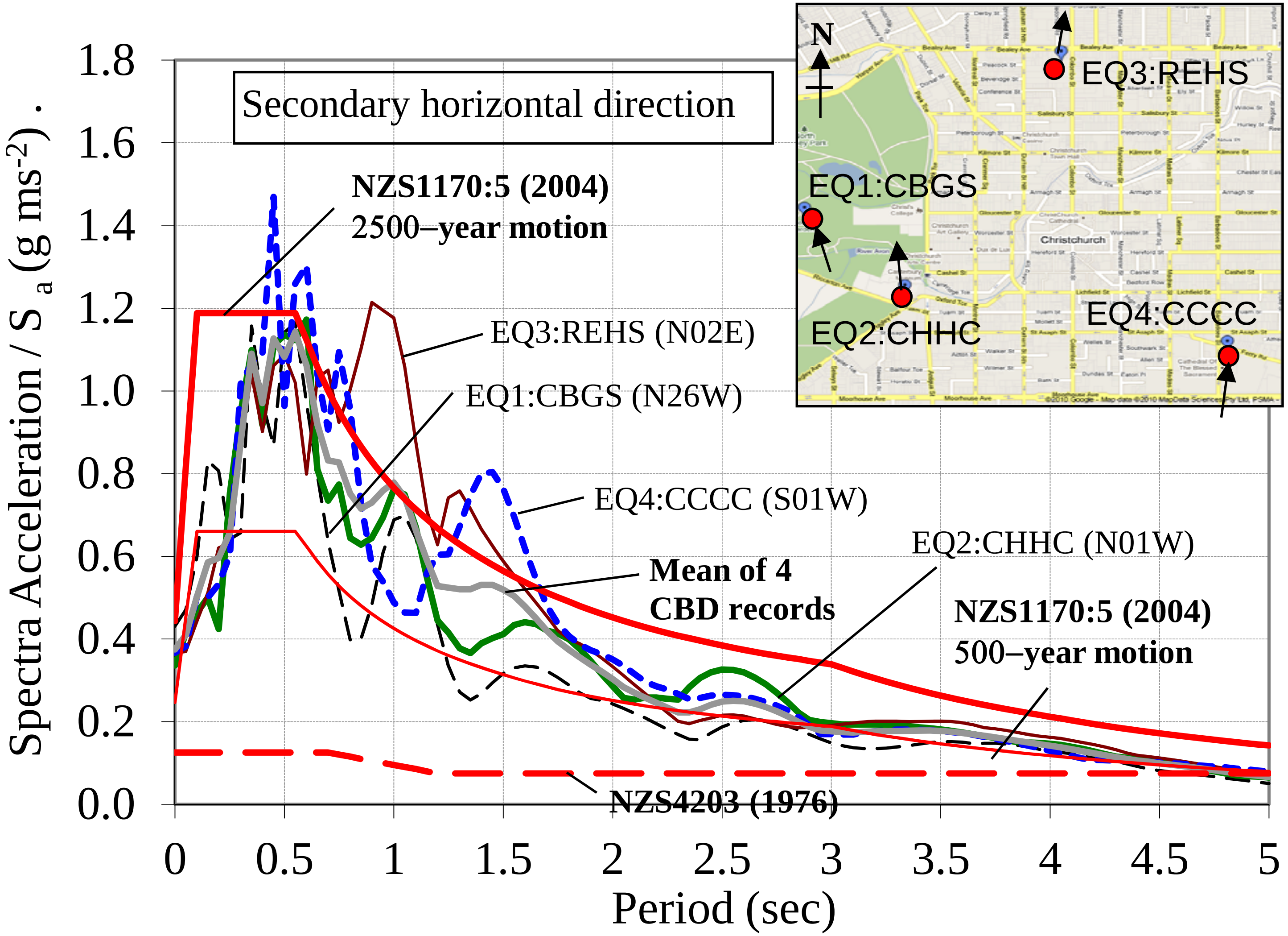
Number of Buildings in Demolition List: 1300-1400

All CBD Buildings



As per 12 June 2011
Source: CCC Data
(Kam, Pampanin, Elwood, 2012)

Bigger than "code-design" level….



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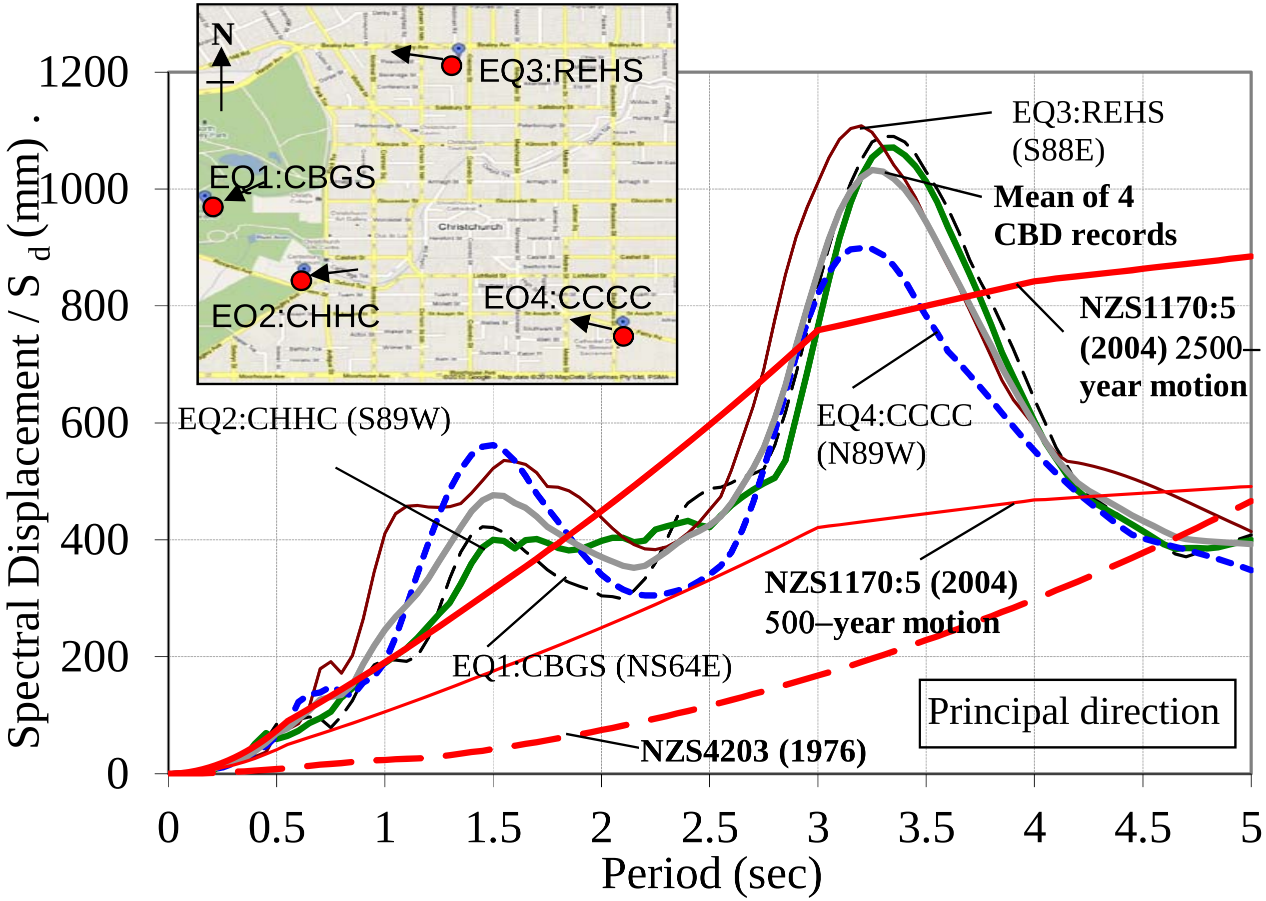
Higher than expected displacement demand…



Fallacy n.2:

"The earthquake does not read the seismic codes."

- late Prof Tom Paulay

Fallacy n.3:

"How many unknown faults are still there?"

-(Almost everyone)

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Facts: The Higher Expectations from the Society

- **No victims** nor **collapse** (Deaths)
- Minimum level of **damage** or direct costs (Damage = Dollars)
- Minimum **business interruption** and recovering (indirect) costs (Downtime)

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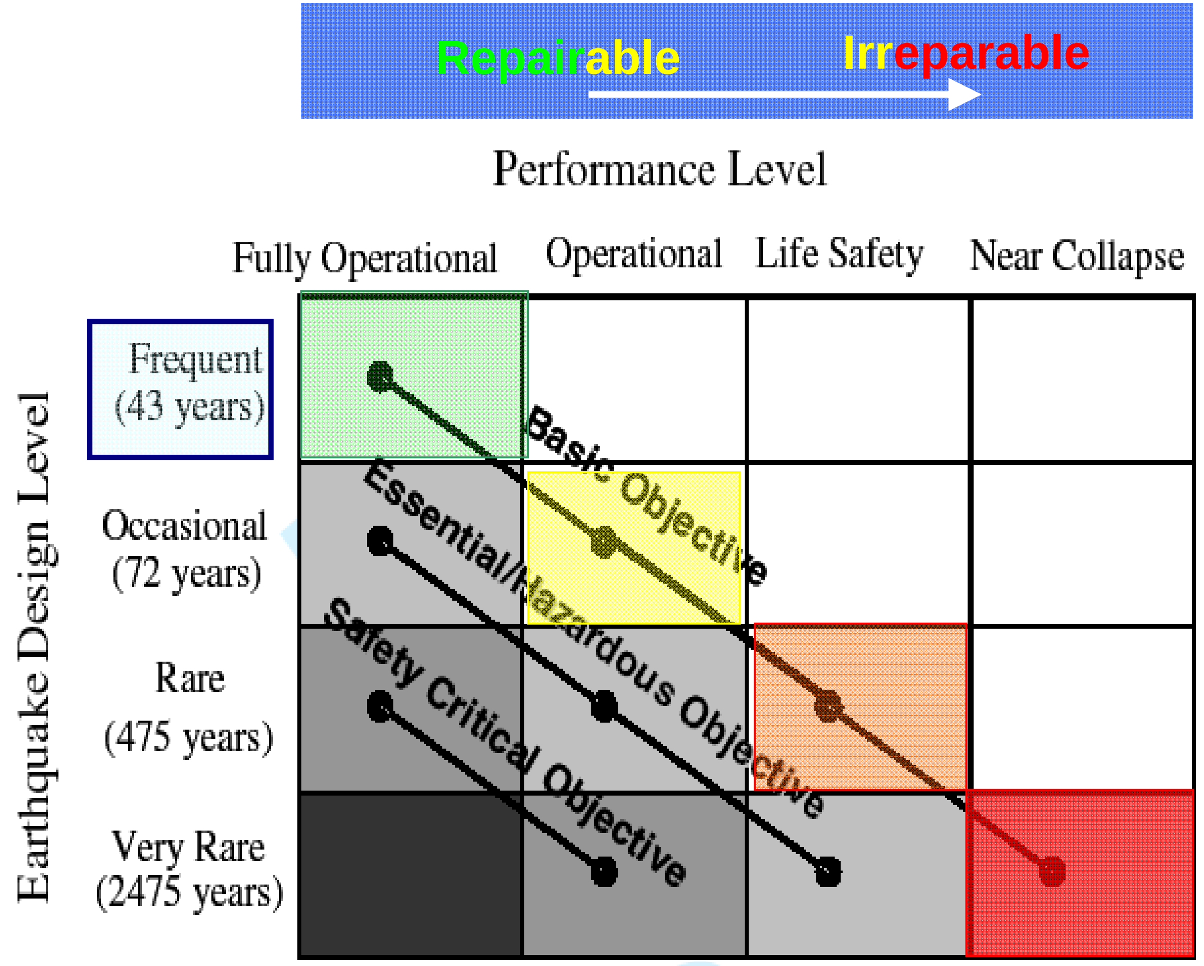
Current Performance-Based Design Philosohy



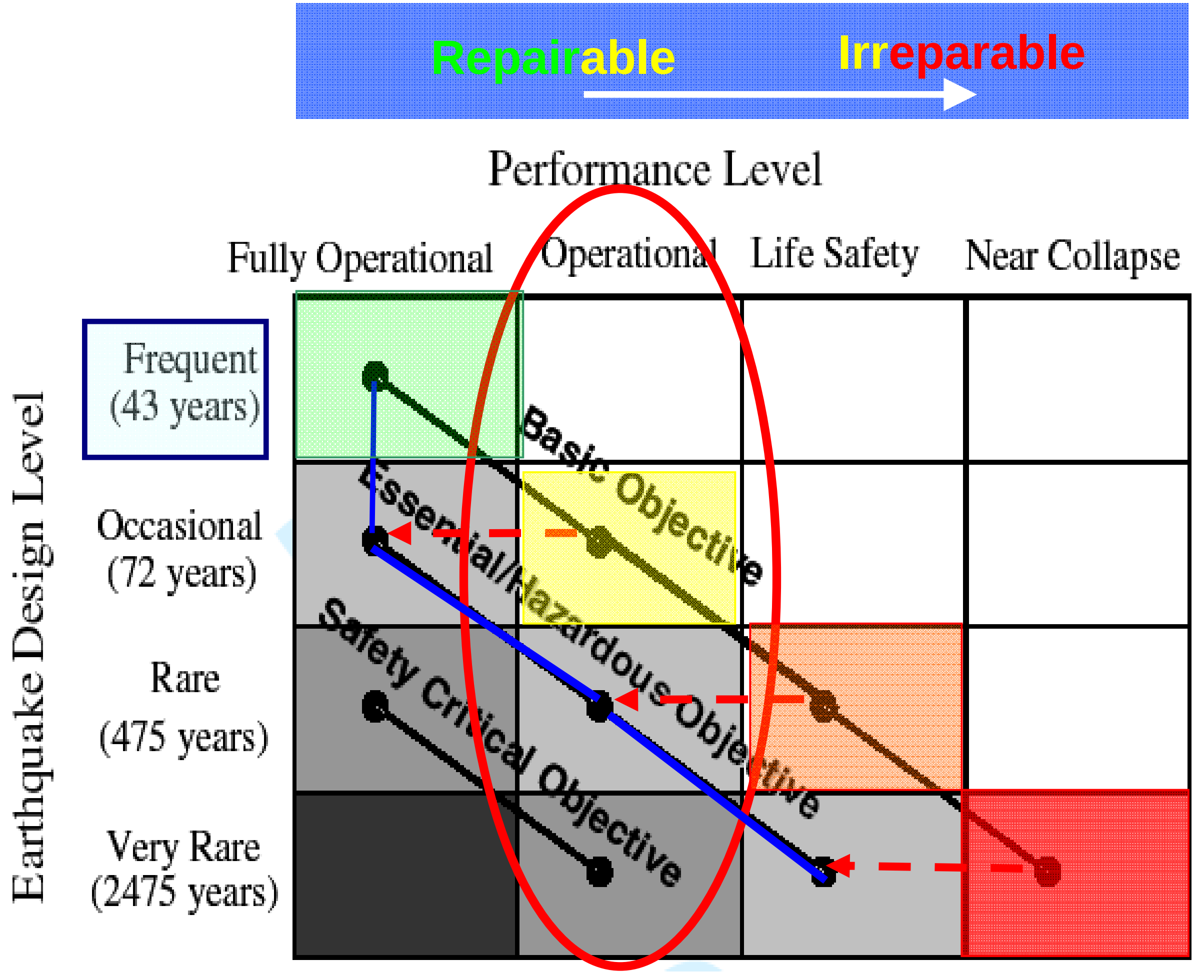
Fallacy

*The Code-Standard is **NOT** meant to be used as a Target or Ultimate Goal but as a minimum by law*

Corollary:

*An Earthquake-Proof Building (following minimum standards and traditional technology) is likely **NOT** to be as "earthquake proof" as people think/wish*

Let us Raise the Bar



Some Good News

*Significant Progress in **Building Technology** for **Damage-Resistant Solutions** has occurred in the recent past, as per other fields (albeit a bit slower)*

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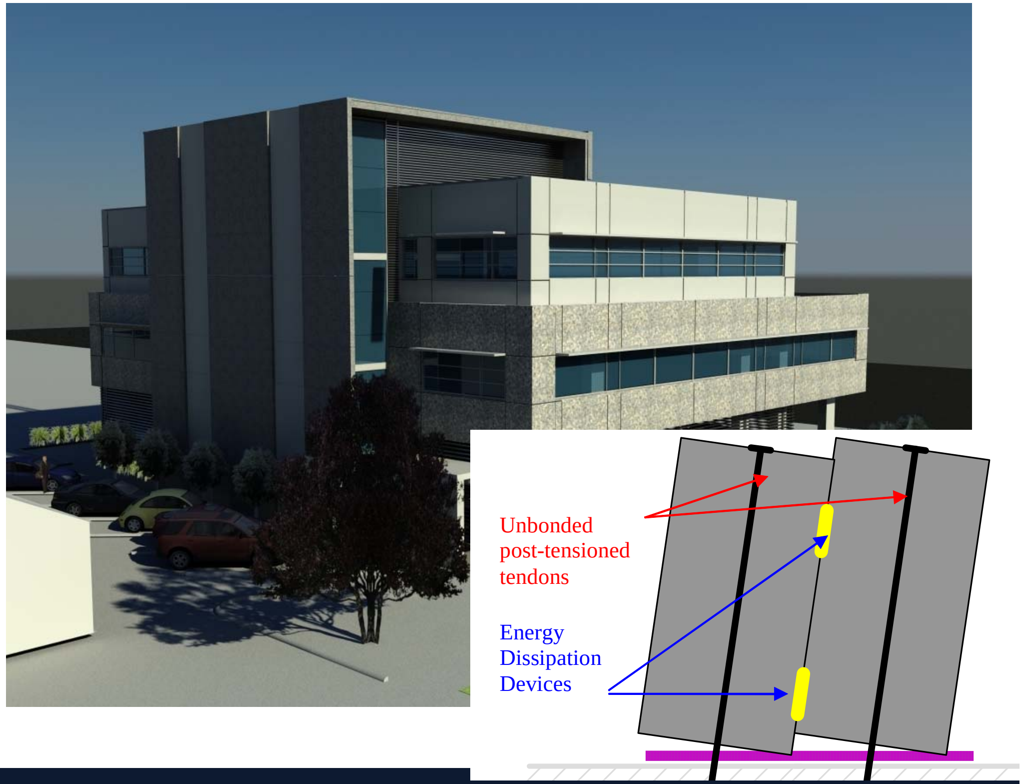
The Opportunity for the Future: the best know-how for the rebuild

Base Isolation

(Christchurch Women Hospital)

PRESSS-Technology

(Southern Cross Hospital Endoscopy Building)



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C.A.S.E Project (L' Aquila Italy – 2009)

Base Isolation combined with Basement for Car-parking

*To house 18000 people semi-permanently. *3 months to completion of 1st blocks.

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C.A.S.E Project (L' Aquila Italy – 2009)

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Base Isolation for residential

Sliders

Why not using Kiwi (shall we say kiwItalian?) Technology and Manufacturing for the Christchurch rebuild?

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New Generation of Damage-Resisting systems

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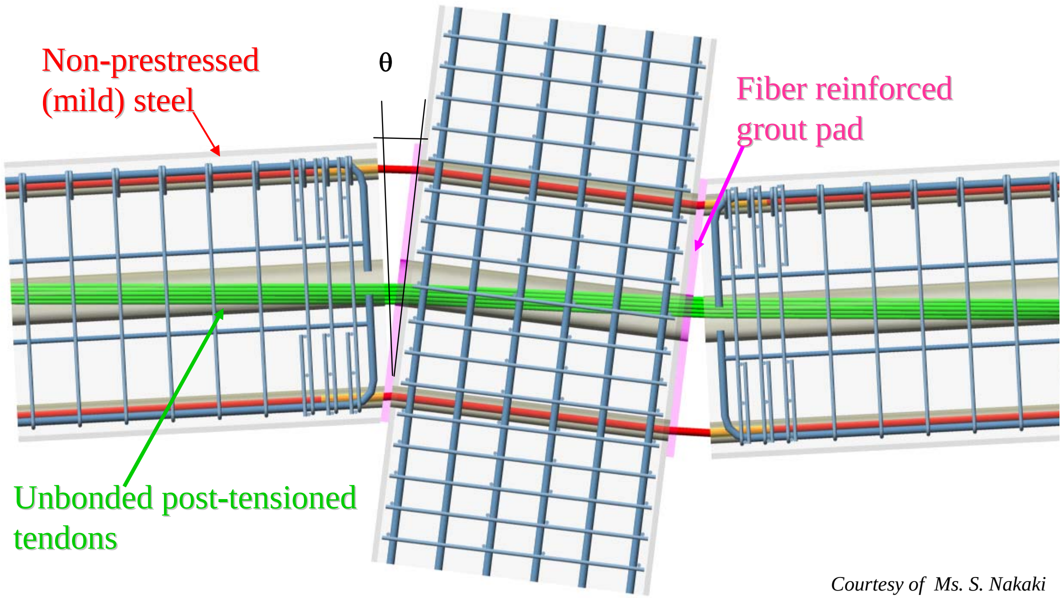
- **Jointed Ductile** DRY connections assembled by post-tensioning techniques
- inelastic demand accomodated within the connection

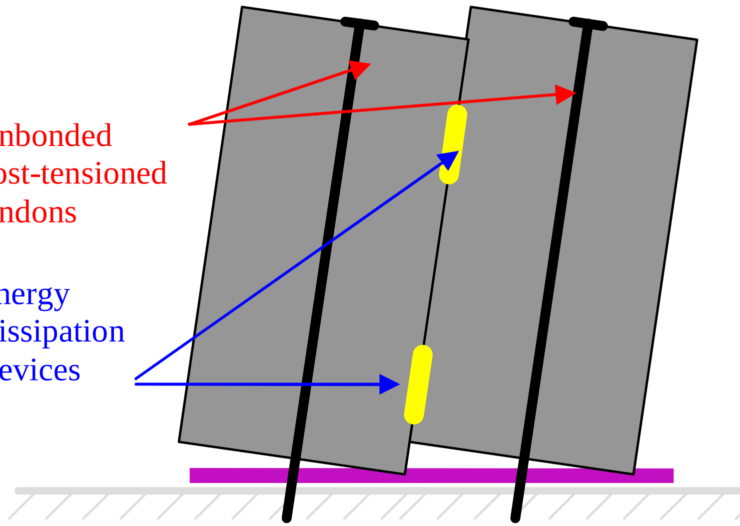
- **Hybrid systems** : combination of unbonded post-tensioning AND dissipaters

- **"Controlled Rocking"** :
  - Reduced *level of damage*
  - Negligible *residual (permanent) deformations* (recentering)

FRAMES



WALLS



PRESSS-Technology (PREcast Seismic Structural System)

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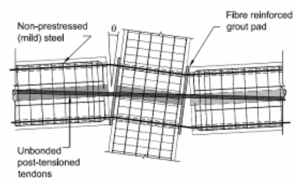
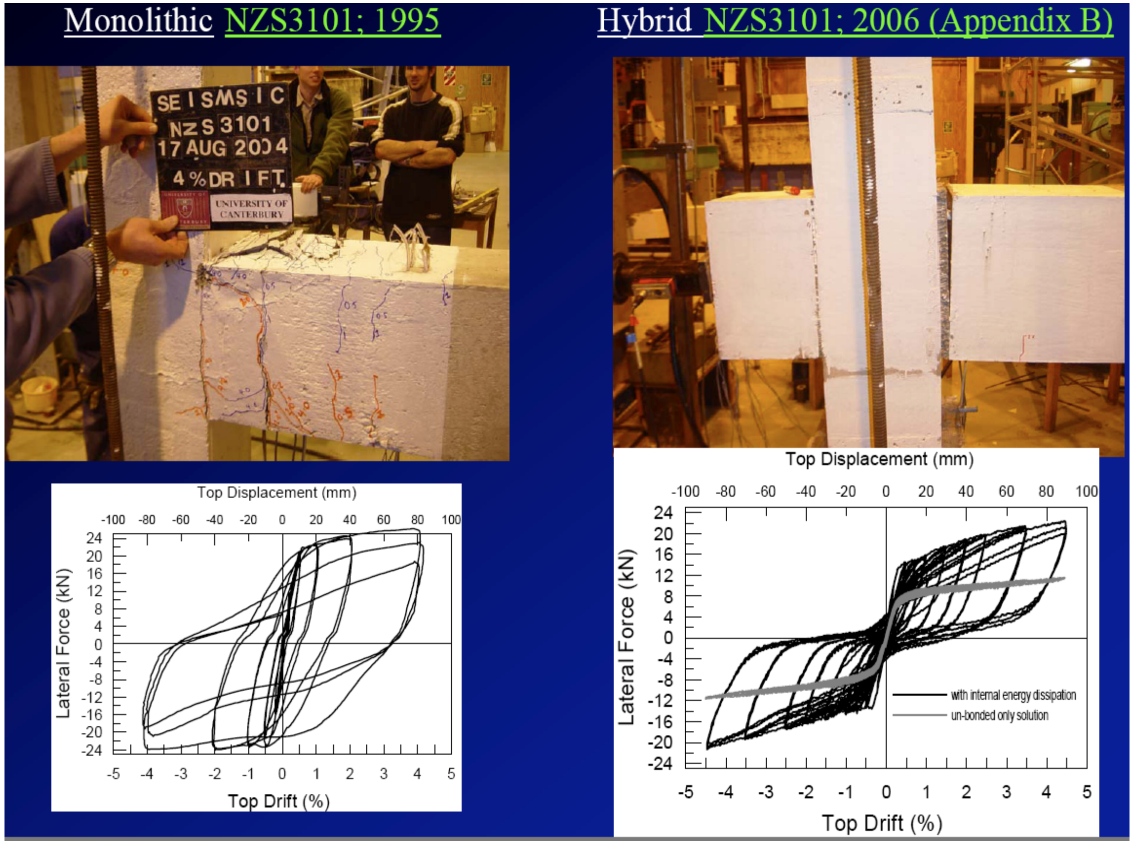
Five-Storey Test-Building (UC San Diego, Aug 1999, coordinator Prof. M.J.N. Priestley)

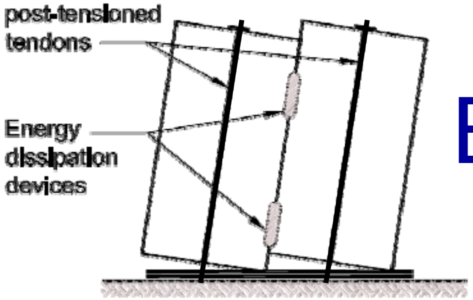


Extensive Laboratory Testing: Frames

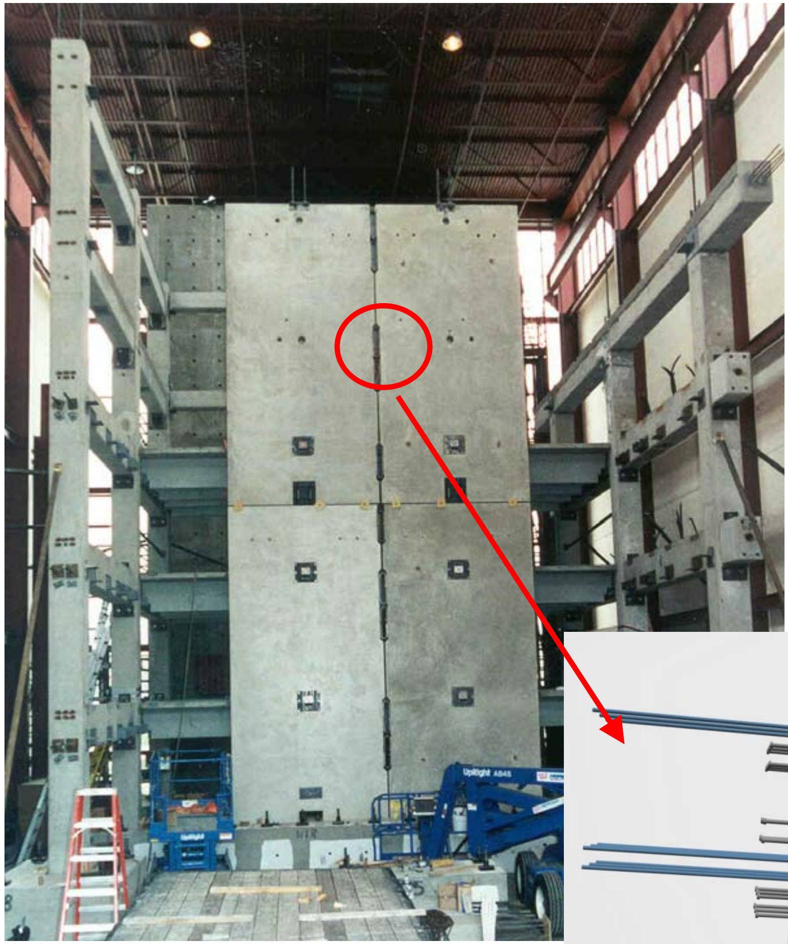
University of California at San Diego
PRESSS Program

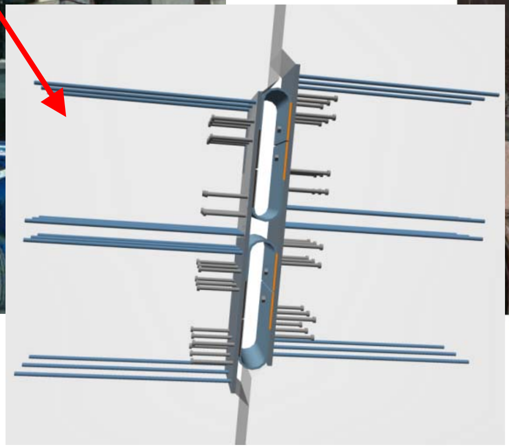


University of Canterbury
Amaris et al., (2004-2008)



Extensive Laboratory Testing: Walls



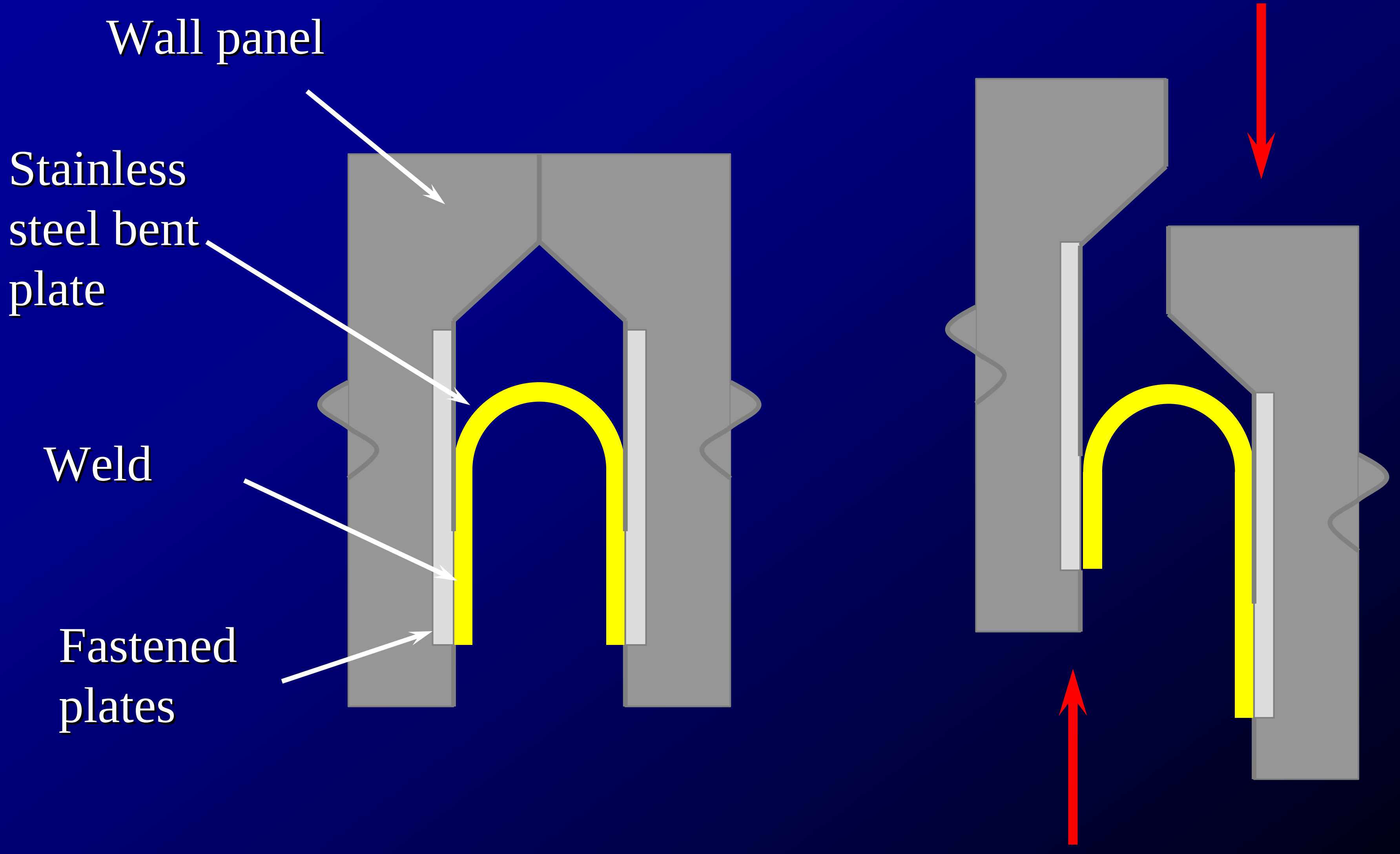


UC San Diego
(Priestley et al., 1999)

University of Canterbury
(Marriott et al., 2005-2009)

U-shape Flexural Plates

(Ivan Skinner and Jim Kelly, 1972)



Courtesy of S. Nakaki & J. Stanton

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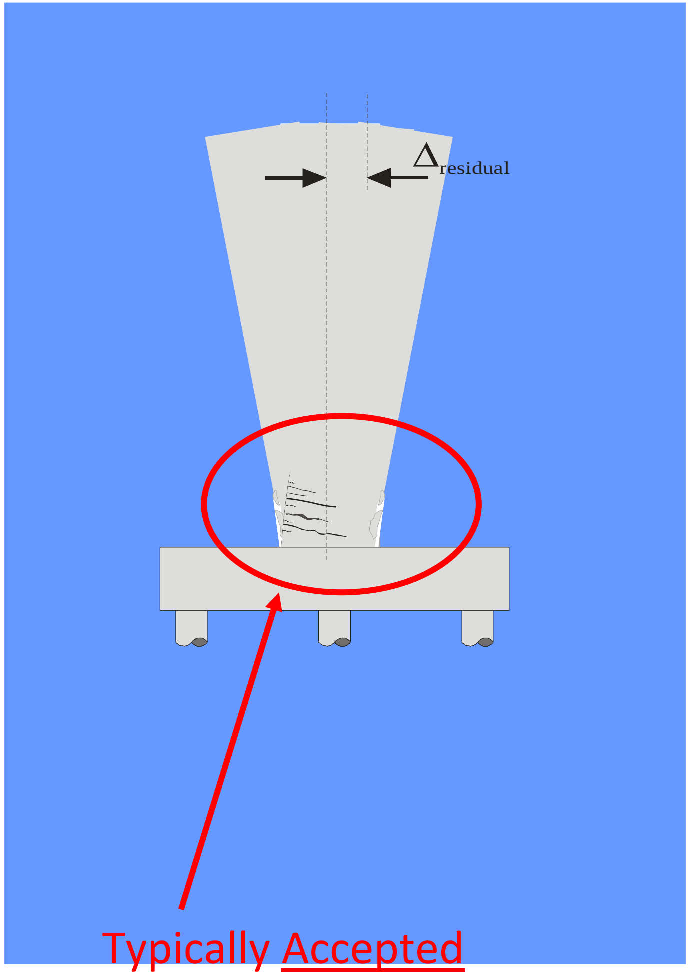
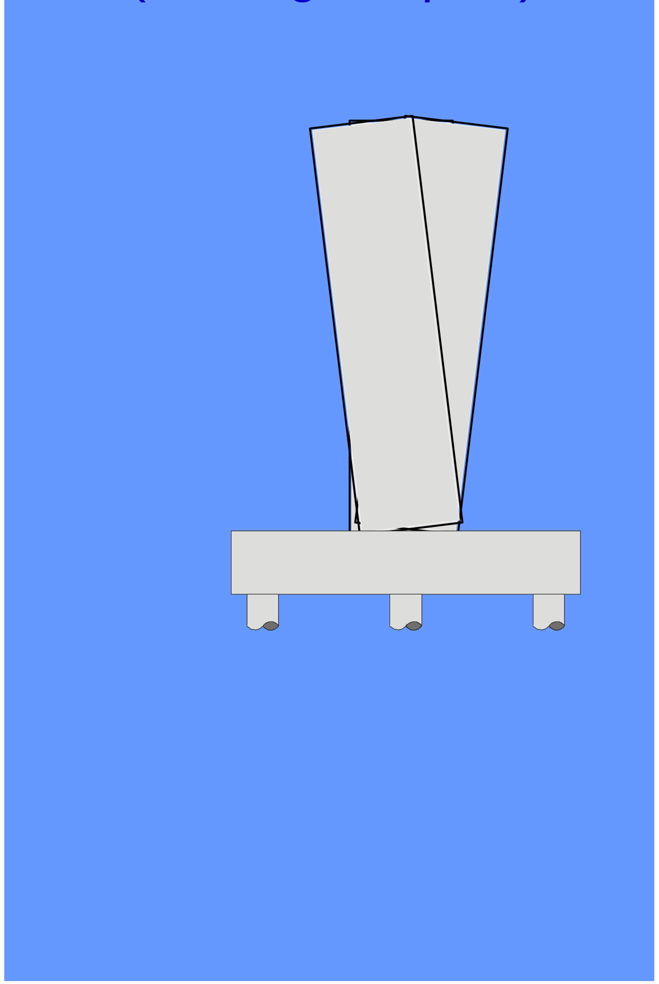
Traditional (monolithic)



Typically Accepted Damage

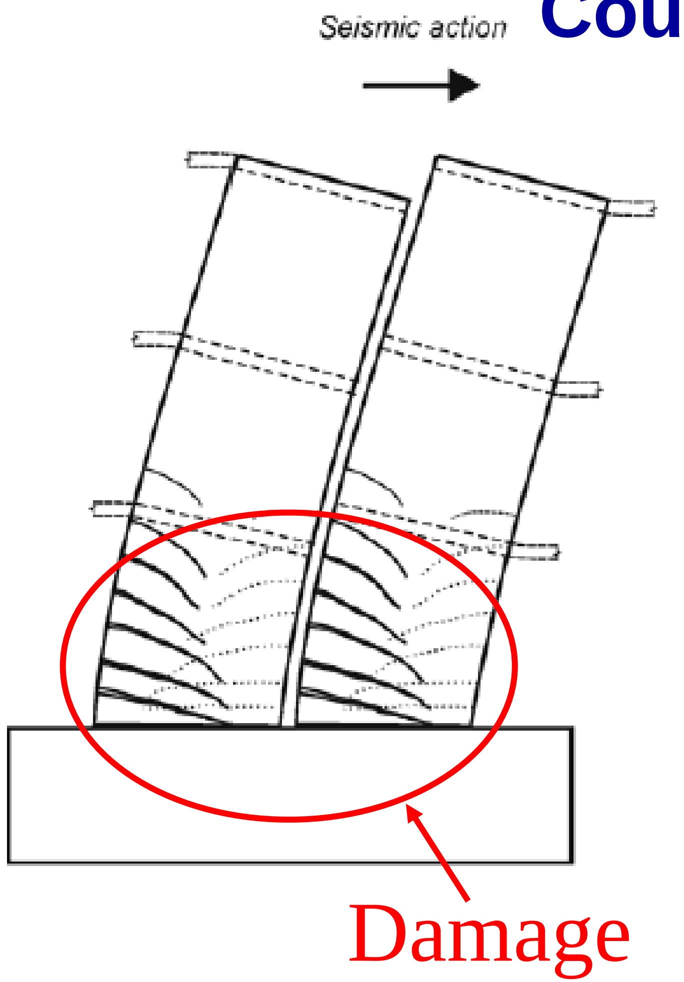
New generation (rocking temples)



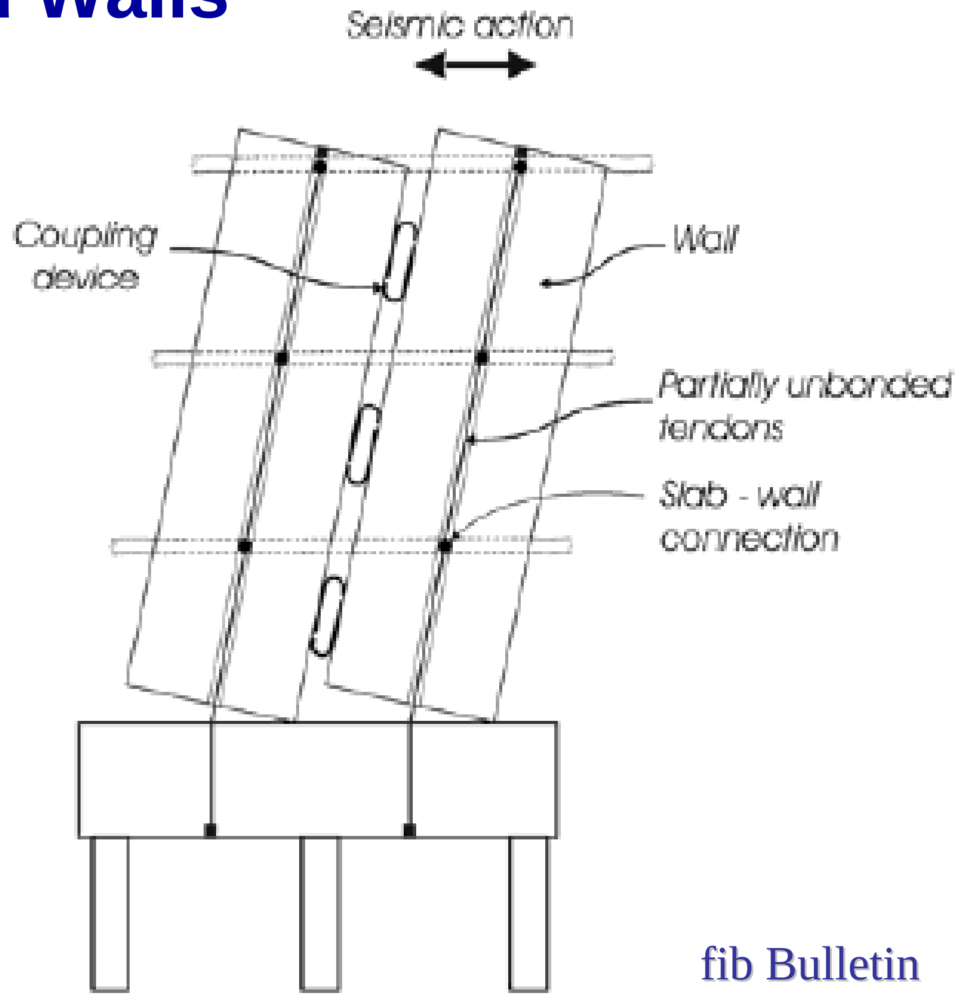
Slide 26

A2 Author, 16/10/2008

Conventional *vs.* Rocking-Dissipative Coupled Walls



(a) Relative vertical displacement in adjacent walls

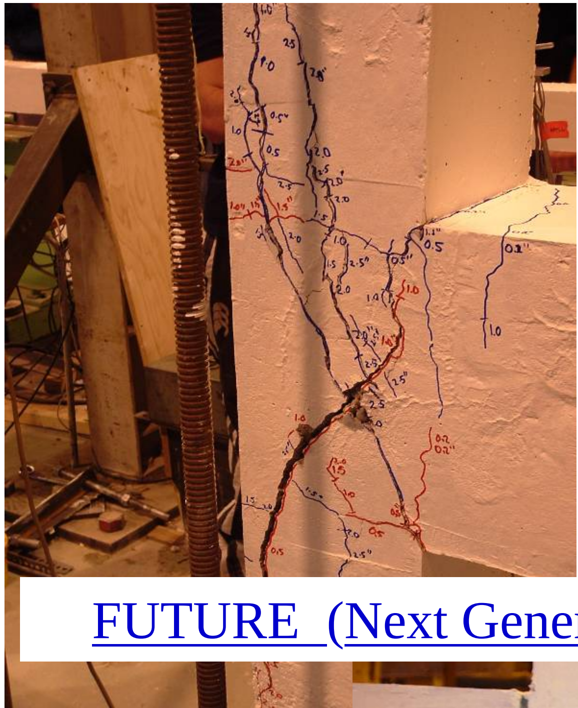


(d) Coupled hybrid walls

fib Bulletin (2003)

Historical Developments in Seismic Design

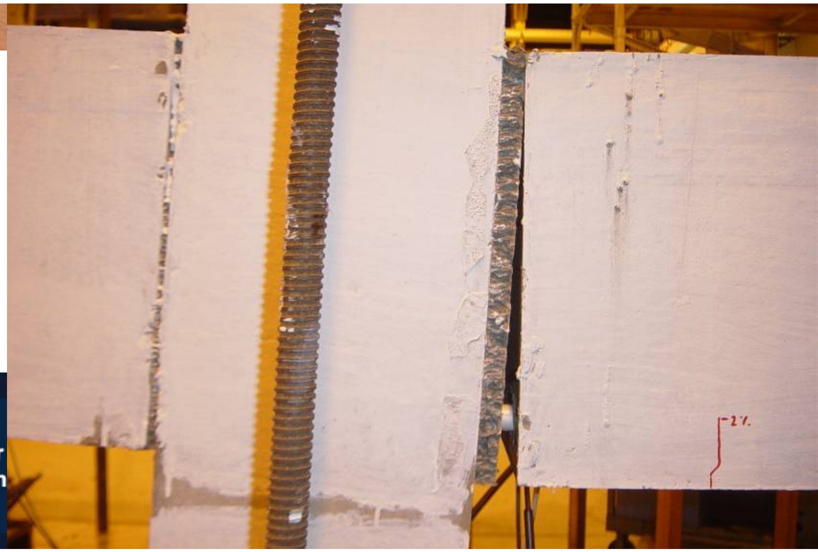
PAST (pre-1970s codes)



PRESENT (post-1970s codes)

After Capacity Design

FUTURE (Next Generation of codes: NZ 3101:2006 (Appendix B)



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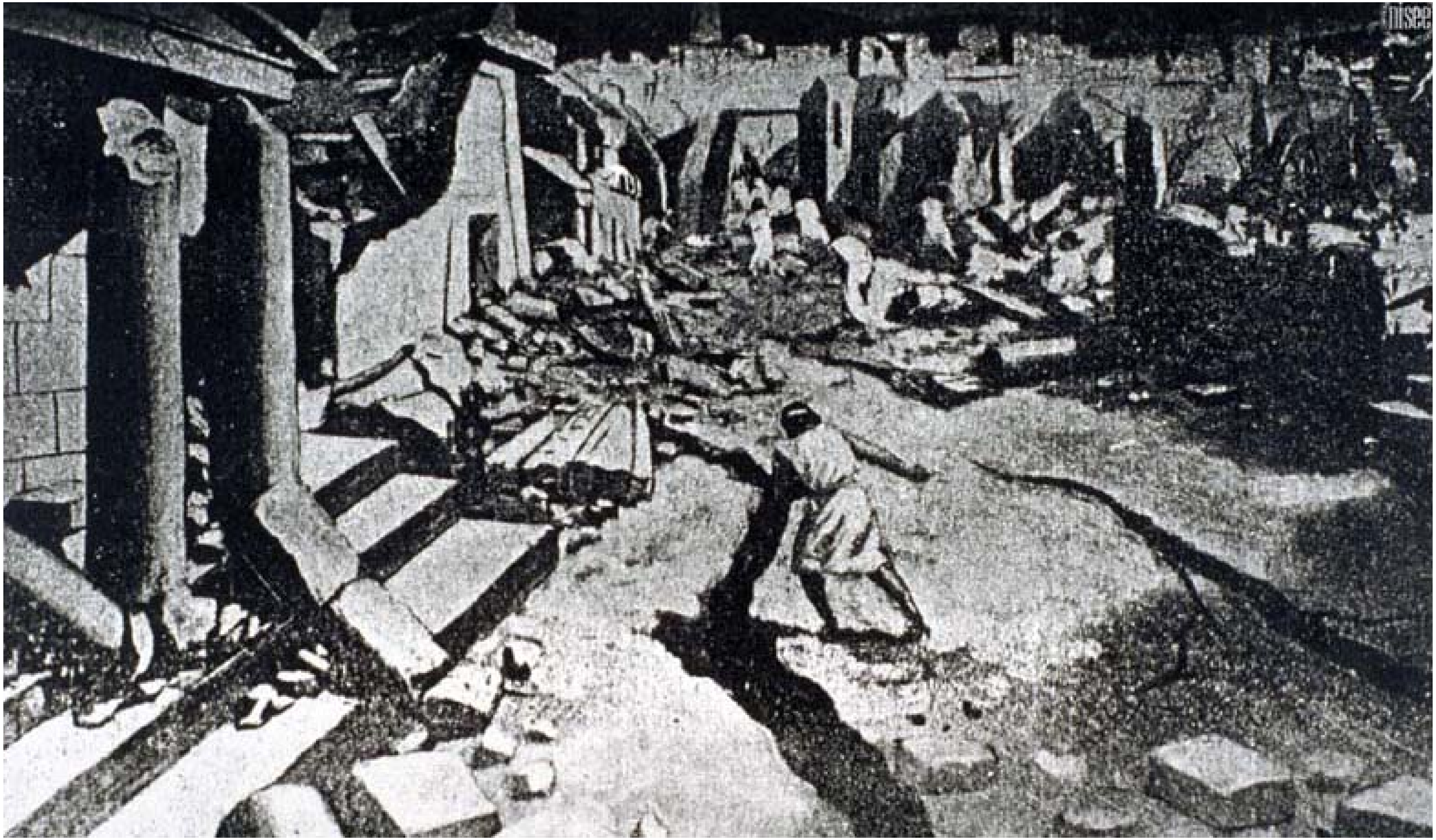
Learning From our Ancestors



Destruction of Sparta in 464 B.C. (frame by Egisto)

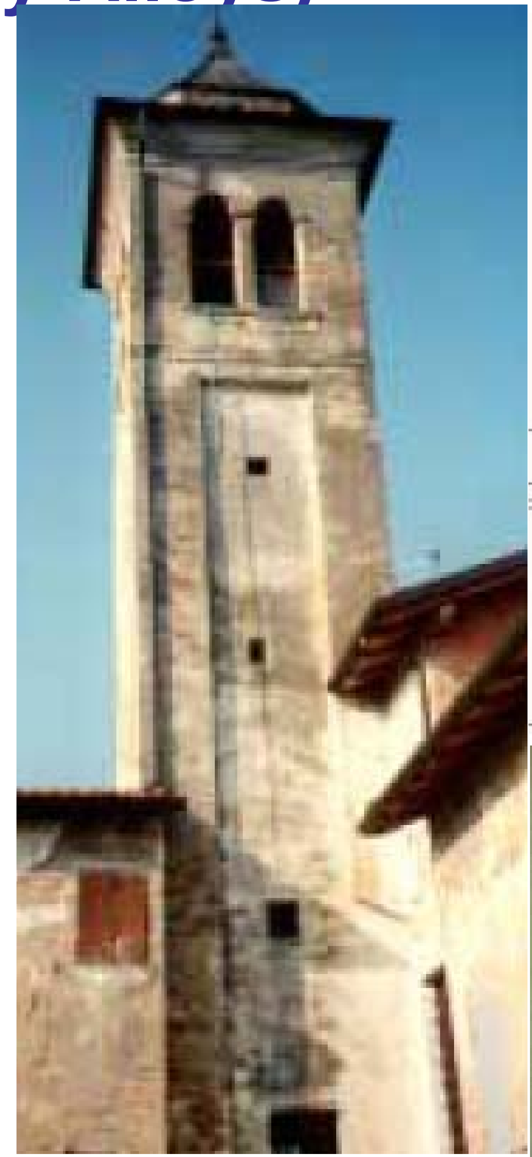
Vulnerability of towers

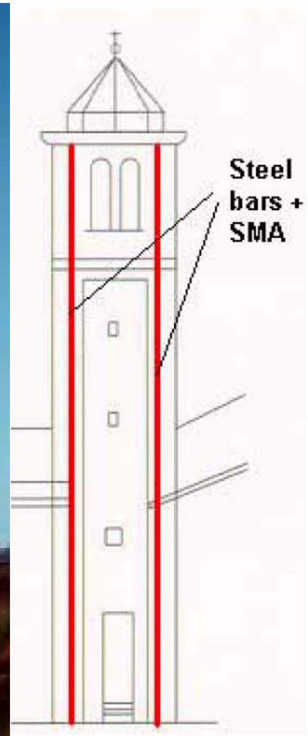
Napoli, 1806

Tuscany, 1896

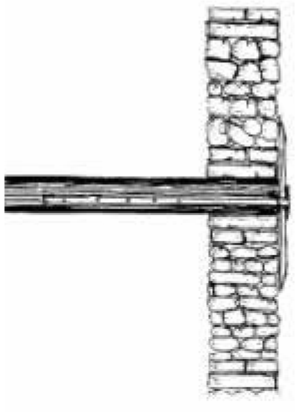
Medieval Tower transformed into a private apartment (Pavia, Italy)

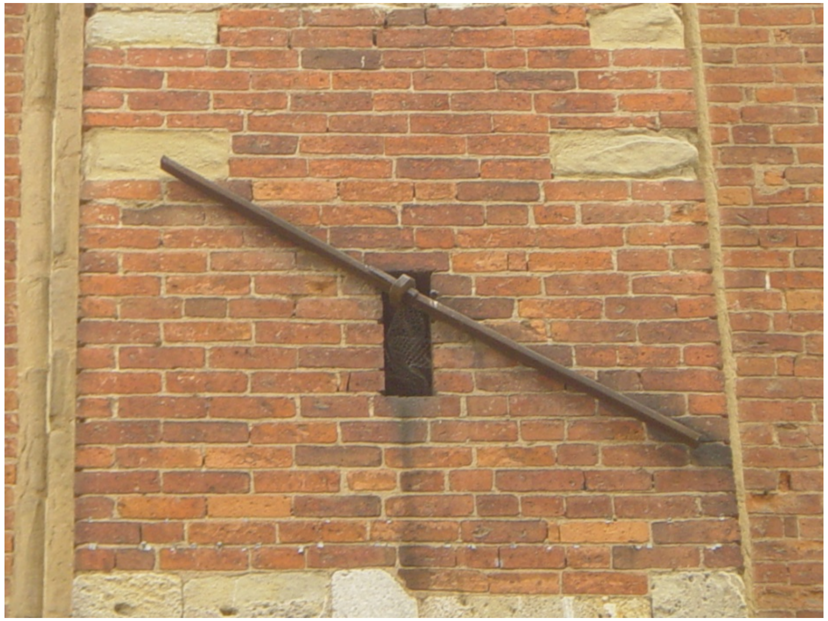
Use of post-tensioning for retrofit/repairing (Shape-Memory-Alloys)





Use of post-tensioning for retrofit





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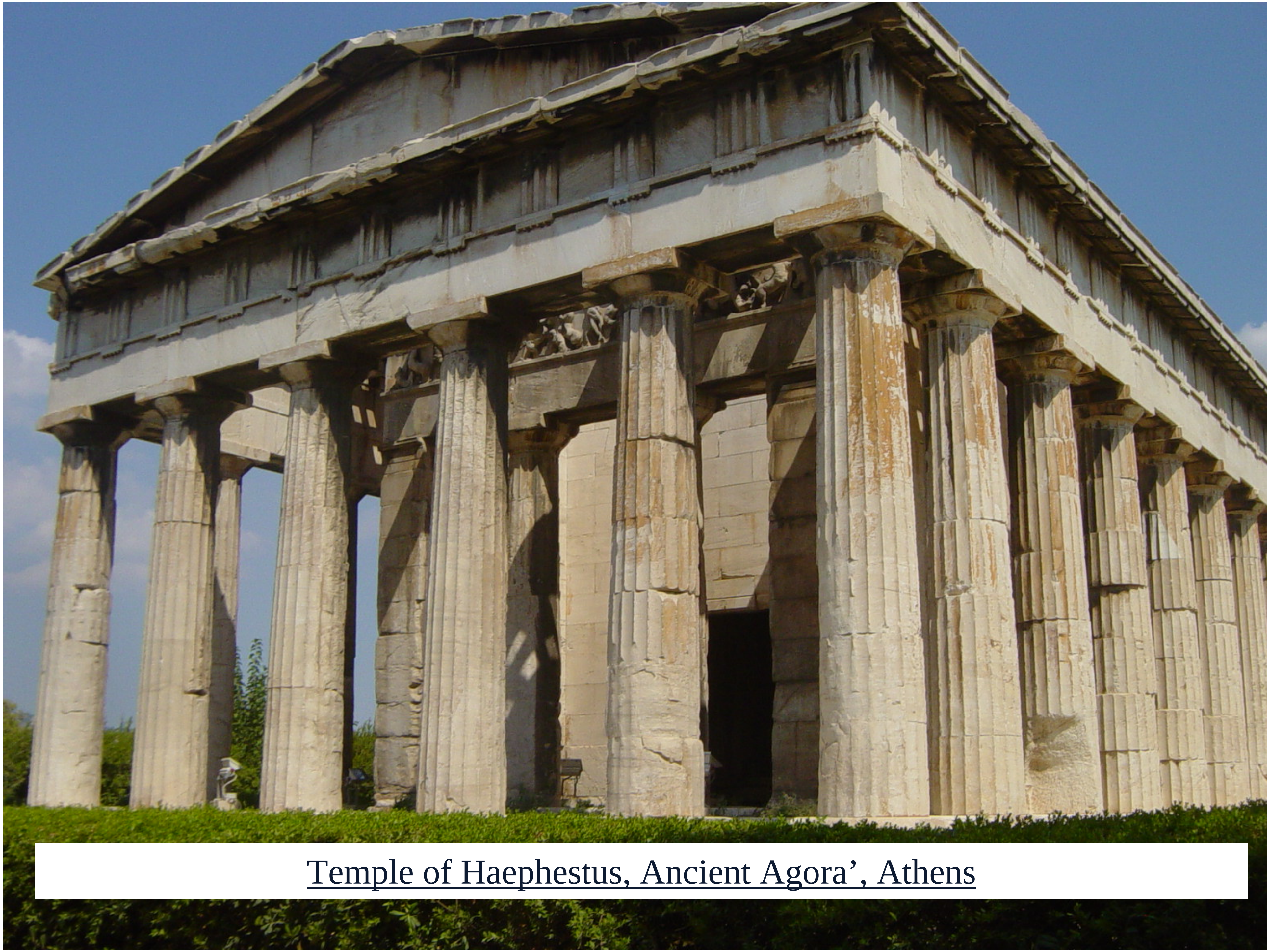
Very effective Earthquake-resistant systems in the past...(rocking marbles blocks)

Multi-block Rocking: Ancient Greek Columns (Athens, Acropolis)

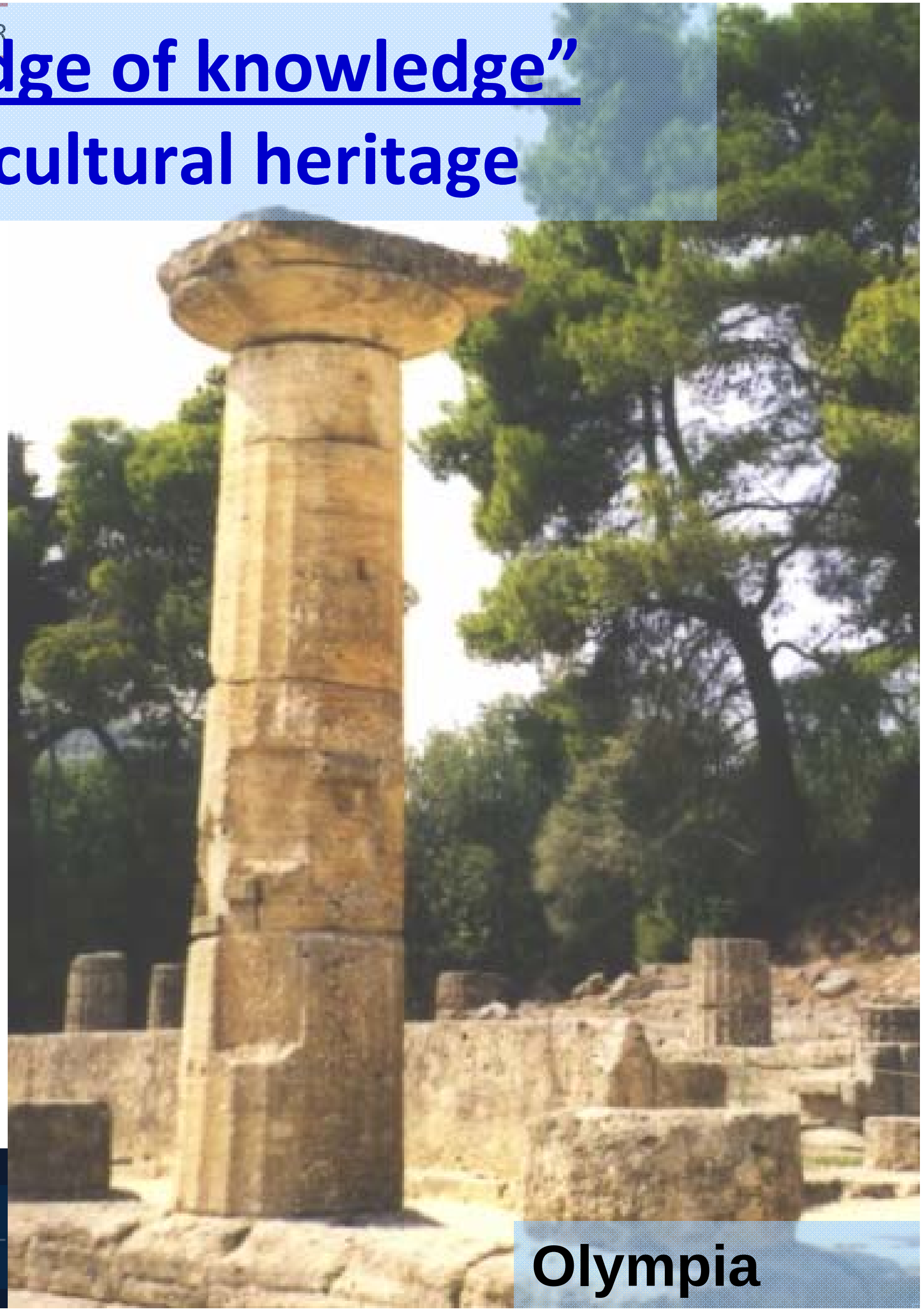

Fori Romani
Rocking at base section
Basement



Temple of Haephestus, Ancient Agora’, Athens

The "bridge of knowledge" of our cultural heritage

Modern segmented Bridge in US



Olympia

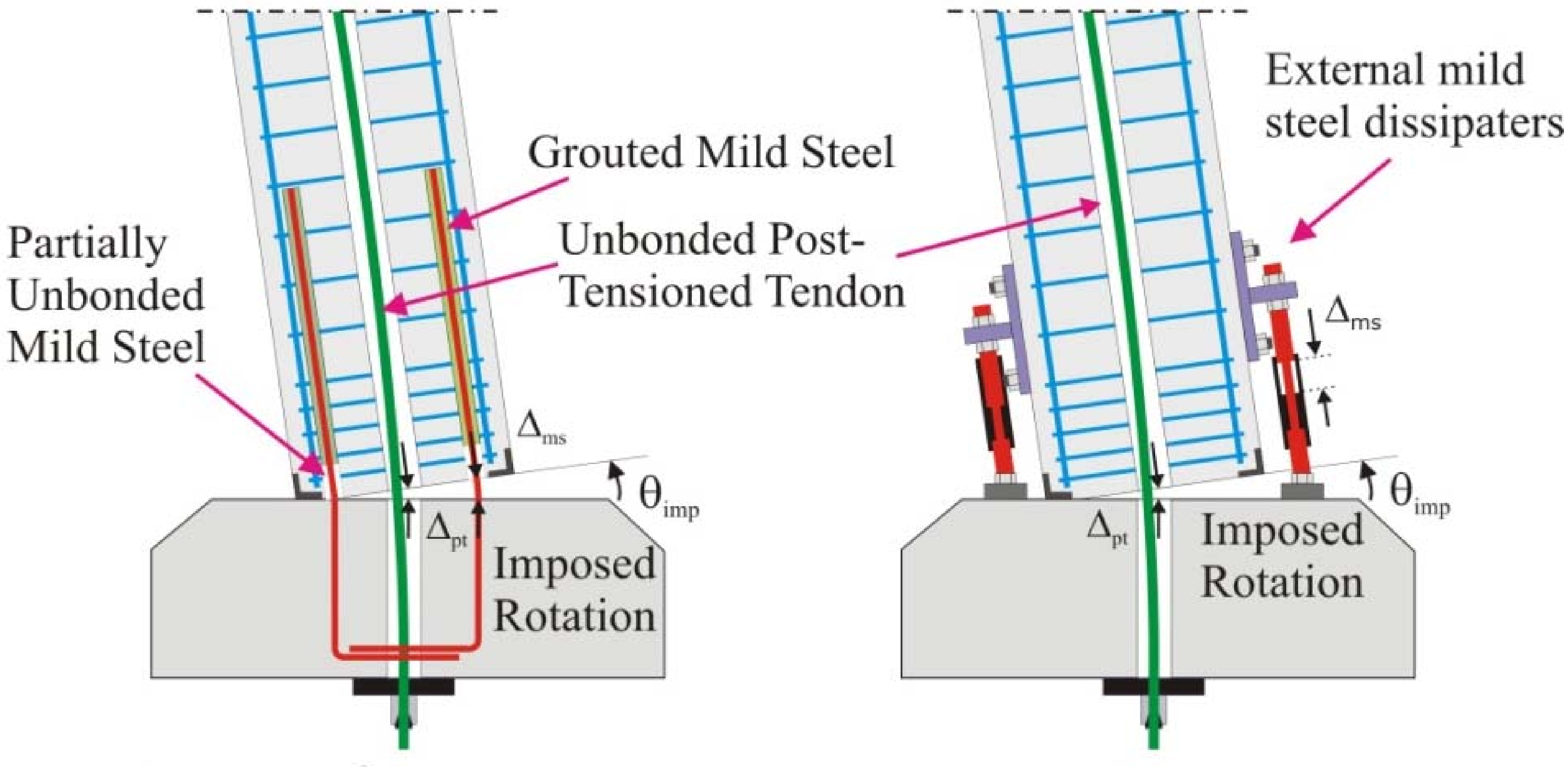
One Further Step Ahead

REPAIRABILITY

OF THE

WEAKEST LINK OF THE CHAIN

Repleacable Dissipaters ("Plug & Play")



Marriott et al., 2008

Amaris et al. 2006

Marriott et al., 2007

Instructions post-aftershock?

(simply check and, if required, replace your Plug&Play dissipater as you would do for a light bulb)

Ordinary steel

Viscous damper

From theory…

to Practice

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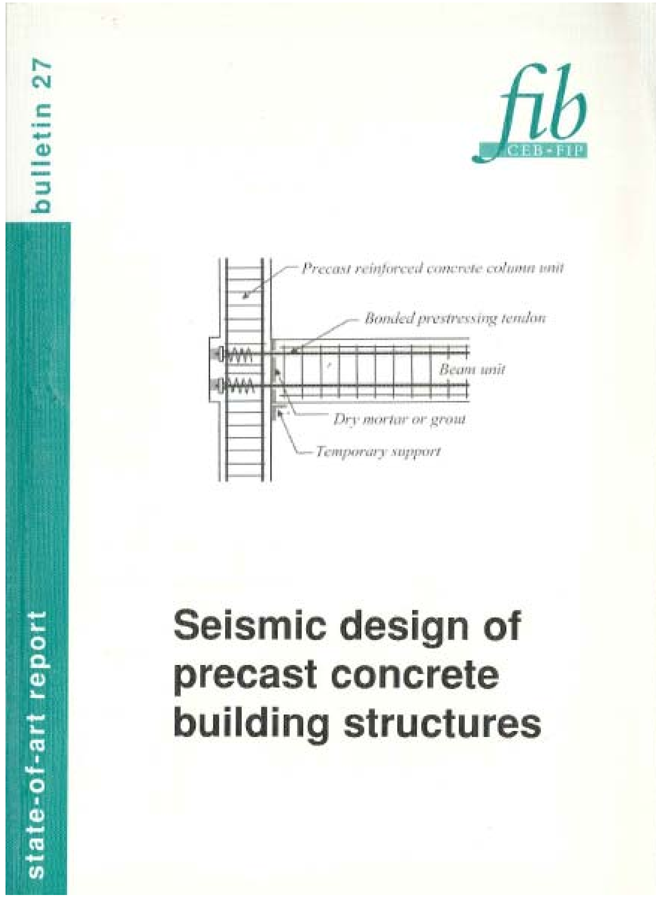
Codes and Design guidelines are available



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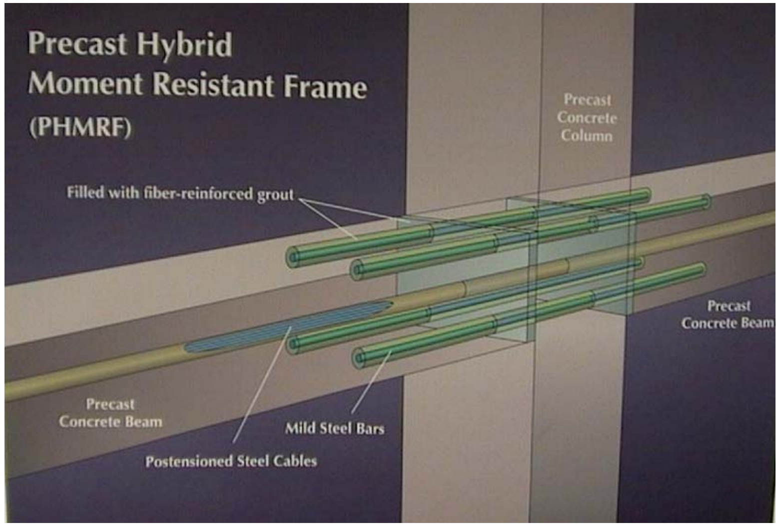
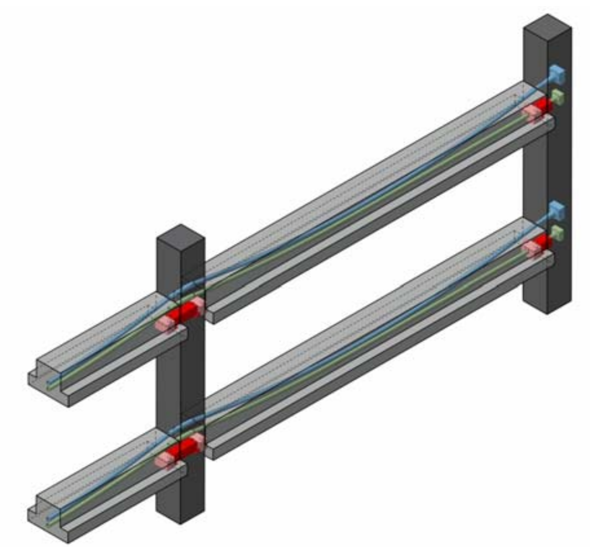
On-site Applications (1)

Paramount Tower, San Francisco (Englekirk, 2002)



On-site Applications (2)



Brooklyn System – Italy
(Pampanin, Pagani, Zambelli, 2004)

On-site Applications (3)

Mendoza, Argentina

On-site Applications (4)

Costarica, Holcim Producto de Concreto

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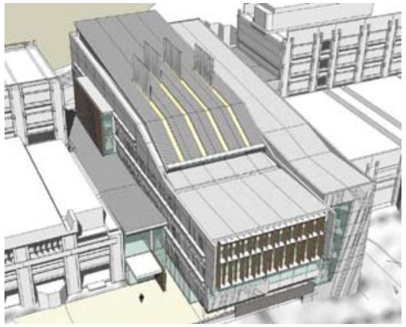
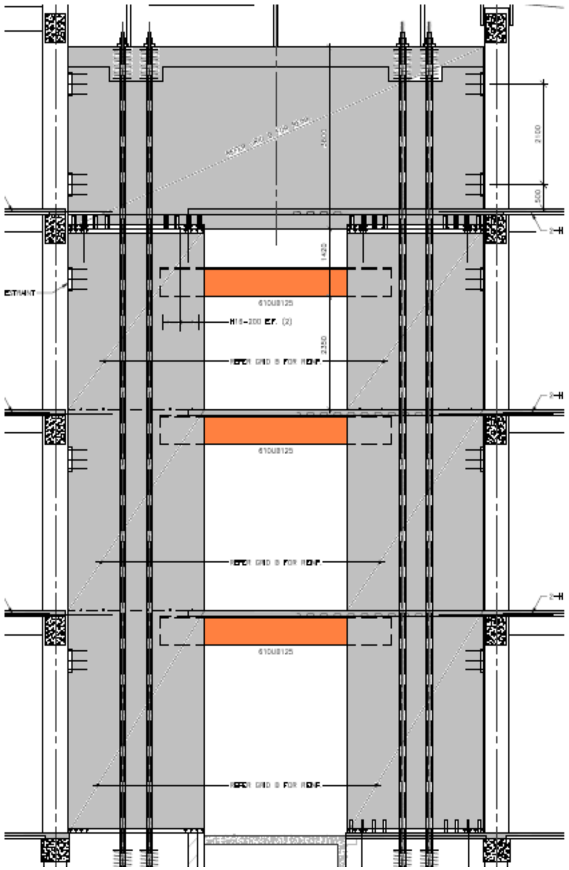
Dunning Thornton consultants

On-site Applications (5)



MacDiarmid Building
Victoria University, **Wellington**



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Dunning Thornton consultants

NZ Concrete Industry
Rotorua, 2-4 October 2008

PRESSS Ltd.

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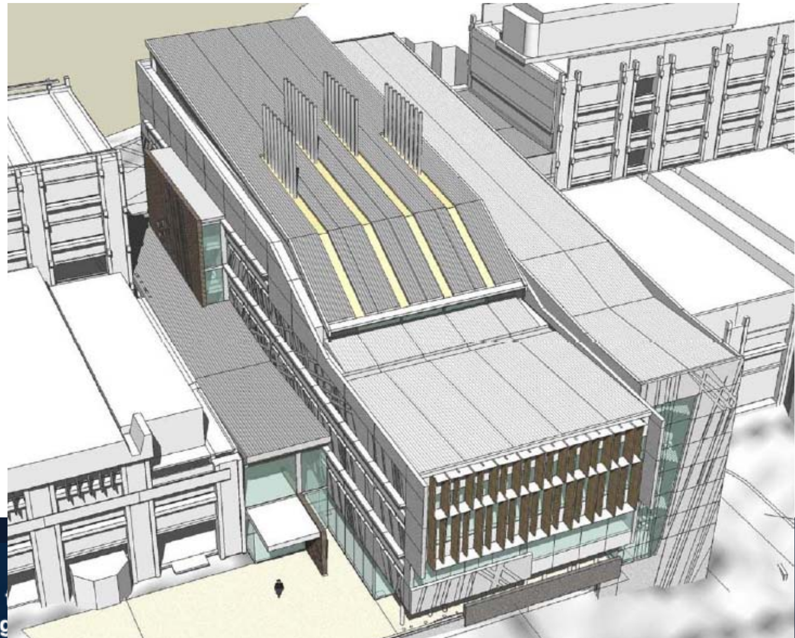
21st Century Precast: the Detailing of NZ's First Multi-storey PRESSS Building

Alistair Cattanach
Dunning Thornton Consultants Ltd.
Stefano Pampanin
PRESSS Ltd./University of Canterbury



NZCS

NZ Society Engineering

The Building:

6000m2 Teaching and Research Laboratories
+ Basement Carparking and Storage

Architect: Jasmax + Labworks
Building Services/Fire: Beca
Contractor: Mainzeal (Staged Procurement)
Precast Sub: Concrete Structures Ltd.

Project Budget: $40M (Large Lab Component)

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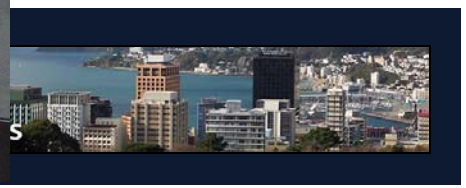
National Hazard Research Pl




492
0800

concrete award

Dunning Thornton Consultants

Alan MacDiarmid Building, Victoria University of Wellington

Entrant: Dunning Thornton Consultants
Owner: Victoria University of Wellington
Architect: Jasmax
Consulting Engineer: Dunning Thornton Consultants
Contractor: Mainzeal

The Alan MacDiarmid Building is the first multi-storey PRecast Seismic Structural Systems (PRESSS) building in New Zealand.

The result of positive collaboration between engineers, academia and contractors, it implements a new technology in seismic and component-based concrete construction.

PRecast Seismic Structural Systems use un-bonded, post-tensioning and rocking joints within the structure to ensure the building returns to upright without significant structural damage, even after a major seismic event.

For Victoria University as a long term building owner, this system provides:

• a significantly reduced cost, aggregated over the life of the building, to repair potential seismic damage. This comes from reducing displacements under small earthquakes with the high pre-rocking stiffness of the pre-stressed system, and from concentrating the seismic damage in replaceable energy dissipaters rather than throughout the structure for larger events.

• reduced in-building accelerations once rocking occurs, due to the flexibility in the superstructure, to almost those of a base isolated building at a fraction of the cost. In a science research building where the fit-out and services can be of higher value than the building itself, this is a huge advantage.

The fully precast system more than equals its steel alternatives in speed, accuracy, safety, quiet erection and seismic performance. The capped rocking walls and the removable/replaceable dissipaters are world firsts.

What the judges said

It is entirely fitting that the Victoria University of Wellington Alan MacDiarmid building, named after the eminent Nobel Prize-winning scientist, should incorporate cutting edge technology.

This is the first time in New Zealand that seismic damage reduction in the form of un-bonded post-tensioning and rocking joints has been used in a multi-storey building.

Although the design has been based upon the PRecast Seismic Structural Systems (PRESSS) research in the US, important aspects have been refined and enhanced. For example, the use of capping beams above rocking shear walls and replaceable mild steel energy dissipators located at beam-column joints are world firsts.

The design, scrutinised by several peer reviews at different stages of completion, provides the client with a high degree of seismic protection. Not only is structural damage significantly reduced, but the expensive fit-out and scientific equipment experience substantial protection from earthquake shaking once structural elements begin to rock.

The innovations, developments and challenges associated with this project have been shared with the industry through a major site run lecture and a technical paper to the 2009 Concrete Conference.

Dunning Thornton consultants

Benefit/Risk Matrix

PRESSS Ltd.

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Issue:	Option One	Option Two	Option Three	Option Four
Propping	As per traditional frame, plus additional delay for pre-stressing	Similar to traditional frame but reduced strike time due to pre-tensioning of beams	None	None
Pre-stressing	Draped tendon duct placement accuracy/tolerance required, plus difficult "saddle" across central columns	Simple straight tendon	Simple straight tendon	Simple straight tendon
Speed	Similar to traditional frame + pre-stressing time	Similar to traditional frame + pre-stressing time	Similar to a steel frame	Similar to steel frame 8 days P&G Saving 2-3 weeks site saving
Offsite risks	Typical plus draped tendon duct accuracy	Typical	Precast column hole positions and beam ends need close tolerance 2-5mm - (CAD cut plates)	Typical
Onsite risks	Duct joints/column duct placement	Duct joints/column duct placement	Fit (if not pre-QA'd/preassembled) Column erection/bracing	Column erection/bracing
Client benefits	Expected benchmark	Lower risk site work	Less site noise "Retrofit-able" system after major shake	Faster Less site noise "Retrofit-able" system after major shake
ESD benefits	Self centring building with lower structural damage and lower floor accelerations	As Option 1	Option 1, plus retrofittable, demountable and prefabricated off site	Option 1, plus retrofittable, demountable and prefabricated off site
Relative cost	QS priced to date	Additional pre-tensioning strand over QS price. Less site propping	Additional strand and hardware over QS price. Significantly lower site costs	$300-$350k over Option 2

The New Zealand Concrete Industry Conference 2011

Expectation Meets Reality:

Seismic Performance of Southern Cross Hospital Endoscopy PRESSS-Building after Feb 22 Earthquake

Stefano Pampanin and Kam Weng

University of Canterbury

Gary Haverland and Sean Gardiner

Structex Metro Ltd

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NEW ZEALAND TIMBER DESIGN SOCIETY INCORPORATED

Seismic Retrofit Solutions

Associate Professor Stefano Pampanin

National Hazard Research Platform: Resilient Buildings and Infrastructure

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NZ's second PRESSS-Building and World's first **REAL Earthquake Test**

Southern Cross Hospital, Endoscopy Building

NZCS | NZ Society for Earthquake Engineering Incorporated | SESOC | New Zealand Timber Design Society Incorporated – A technical group of IPENZ Engineers New Zealand | Seismic Retrofit Solutions

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The Building

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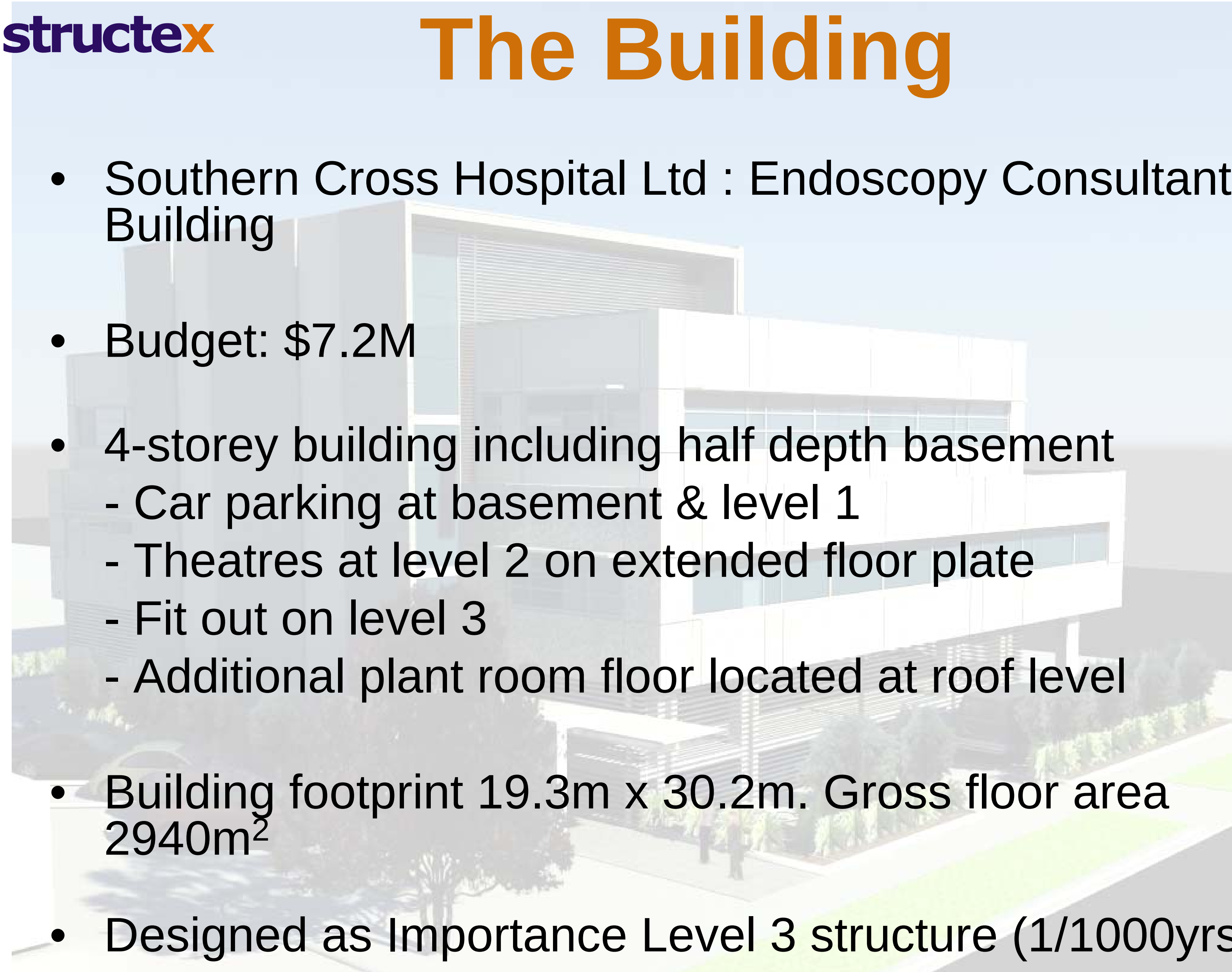

- Southern Cross Hospital Ltd : Endoscopy Consultants Building
- Budget: $7.2M
- 4-storey building including half depth basement
  - Car parking at basement & level 1
  - Theatres at level 2 on extended floor plate
  - Fit out on level 3
  - Additional plant room floor located at roof level
- Building footprint 19.3m x 30.2m. Gross floor area 2940m^2
- Designed as Importance Level 3 structure (1/1000yrs)

The Team

Client:	**Southern Cross Hospitals**
Project Manager:	**Pragmatix**
Architect:	**Warren & Mahoney**
Structural Engineer:	**Structex**
Services Engineer:	**Beca**
Principal Contractor:	**Fletcher Construction**
Post Tensioning Sub-contractor:	**Fulton Hogan**
Peer Reviewer:	**Stefano Pampanin (PRESSS Ltd/ University of Canterbury)**

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Advantages (1/2)

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Proposed PRESSS structure with the following **(anticipated)** advantages:

- No plastic hinges resulting in very little structural damage
- Building structure is self centering resulting in very little residual lean following an earthquake
- Building accelerations are lower than a RC frame or shear wall building resulting in less risk of damage to contents

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Advantages (2/2)

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- More rapid construction time as less insitu concrete on site
- Construction uses conventional building components such as precast beams, walls, drossbach ducts & starters
- Lower foundation actions resulting in pile savings
- Reduced wall reinforcing, tendon replacement
- Overall anticipated (then confimed) comparable (if not reduced) costs


structex
11/12/2009


structex
Texco

Associate Professor Stefano Pampanin

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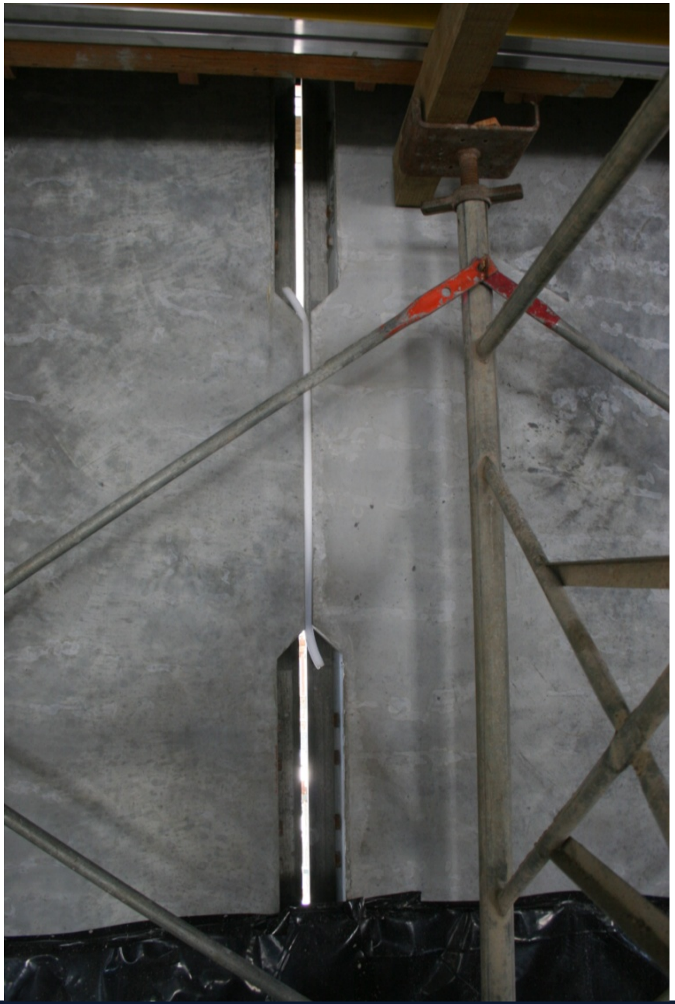
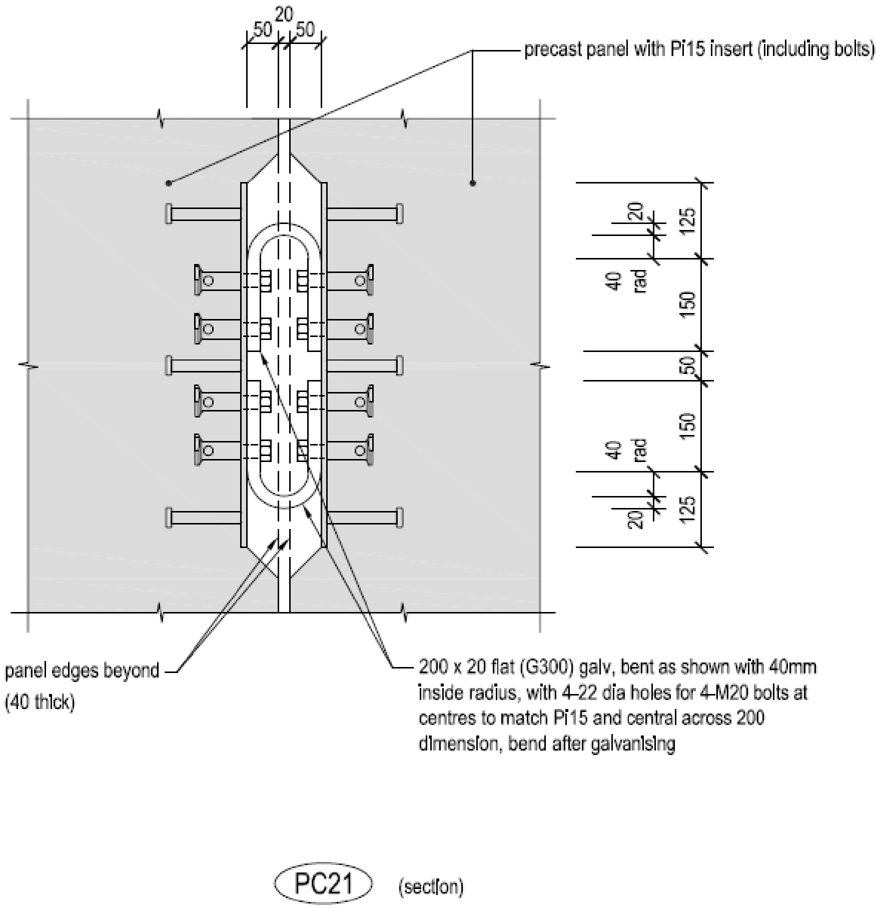
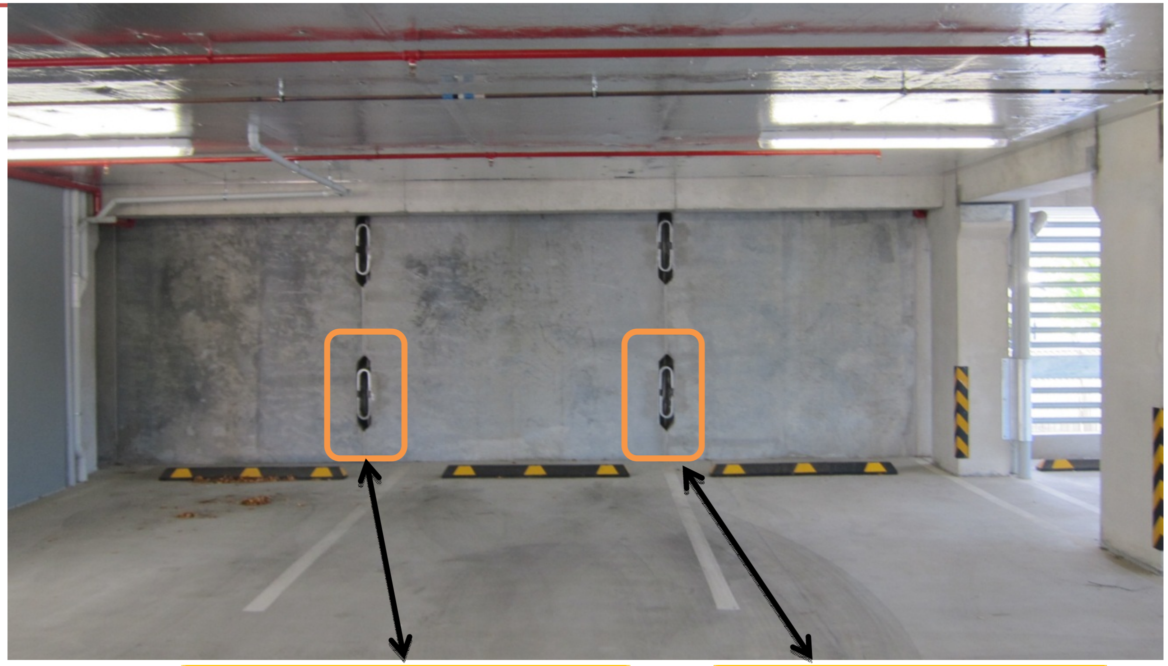
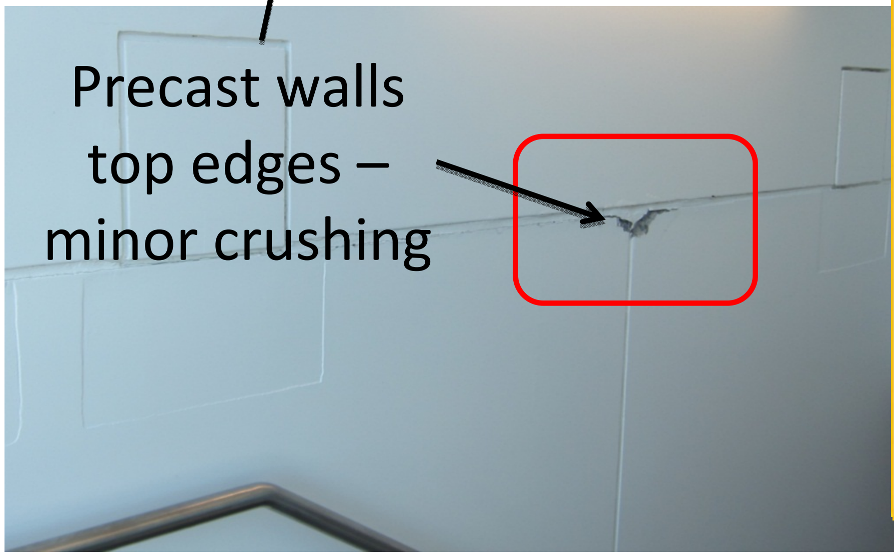
Wall Coupling (UFPs)





Excellent Performance after Feb 22





Precast walls top edges – minor crushing

Associate Professor Stefano Pampanin

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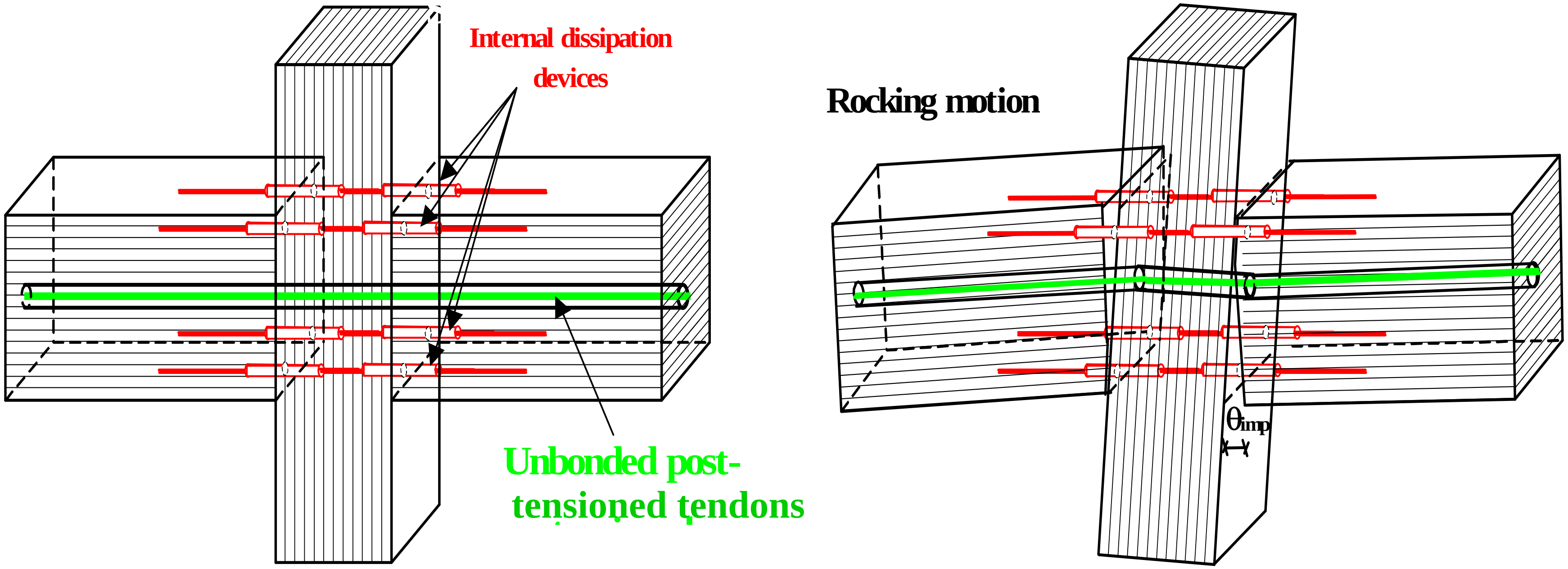
Continuous functionality and immediate re-occupancy

Isn't this the GOOD NEWS

that our Society deserves to receive?

Why not in Timber?

The Timber "Revolution"



- Post-tensioned tendons/bars (typical high strength steel or FRP) with alternative longitudinal profile (straight, draped/parabolic)
- Internal or external reinforcement (also used as dissipaters)

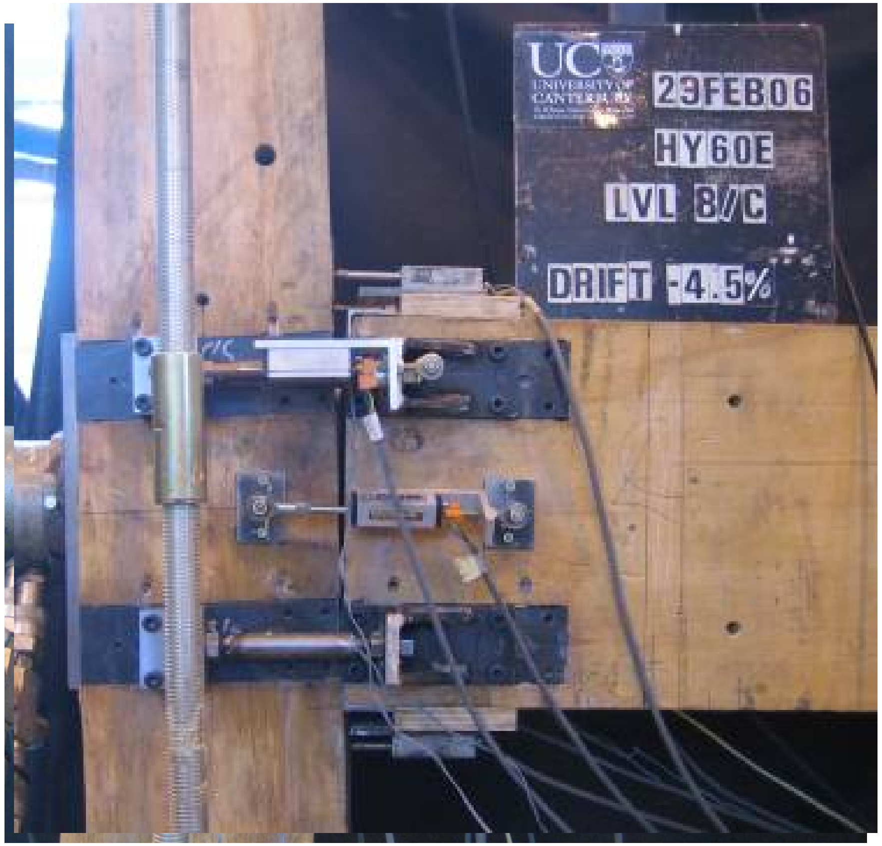
Engineered Wood Products

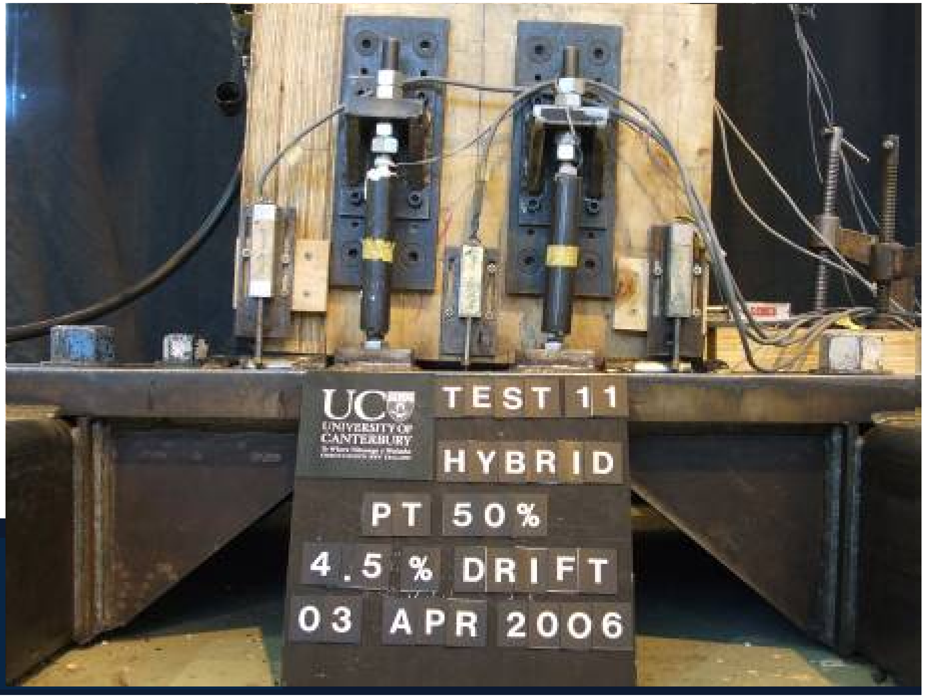
Laminated Veneer Lumber - LVL
Glued Laminated - GluLam
Cross Laminated - X-Lam

Prestressed Laminated

PRES-LAM

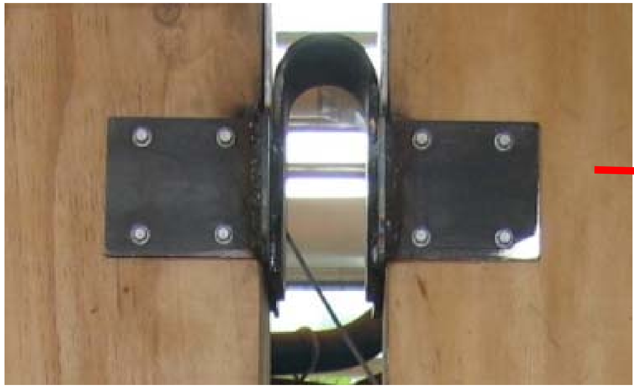
"Controlled rocking" mechanism

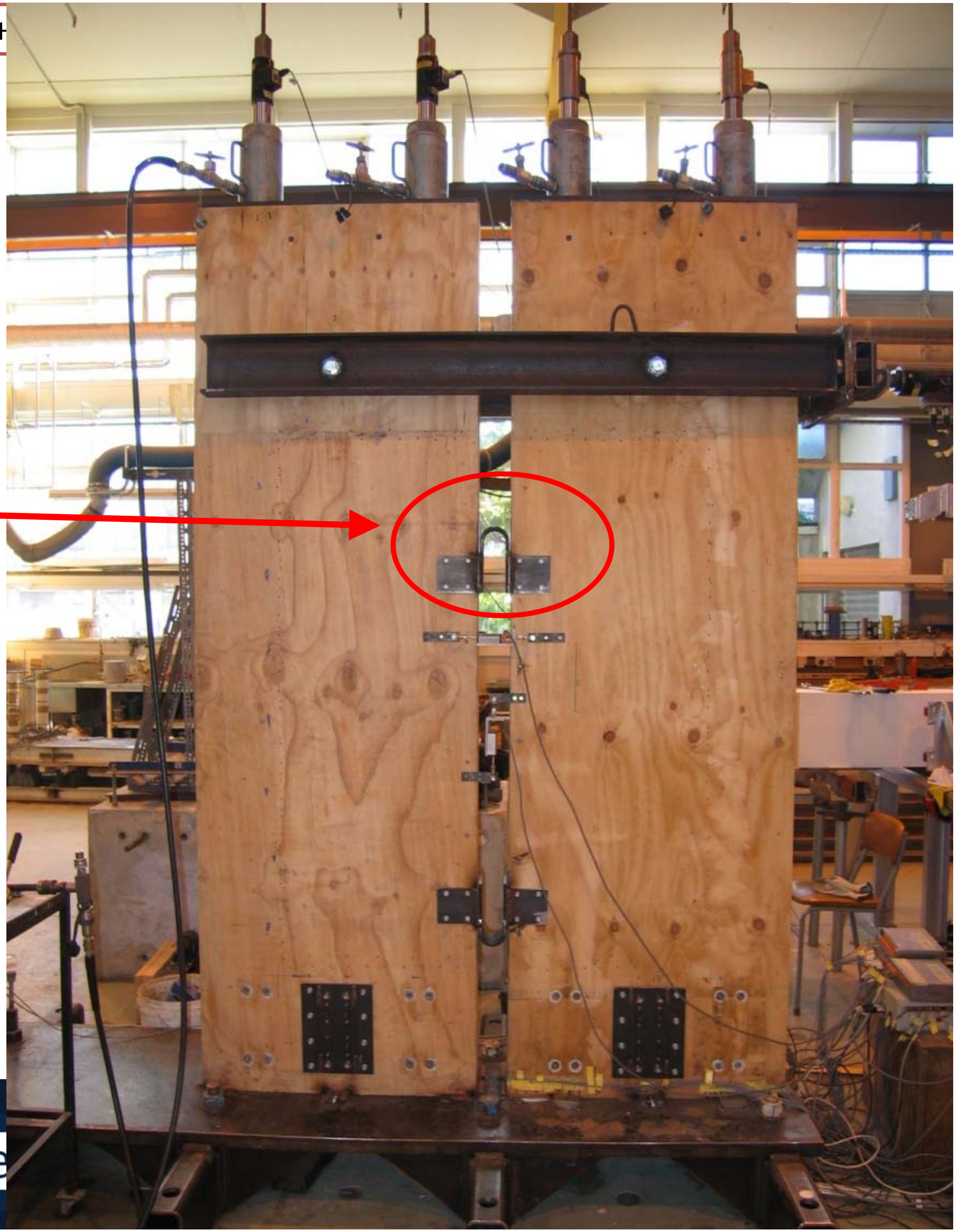




Associate Professor Stefano Pampanin

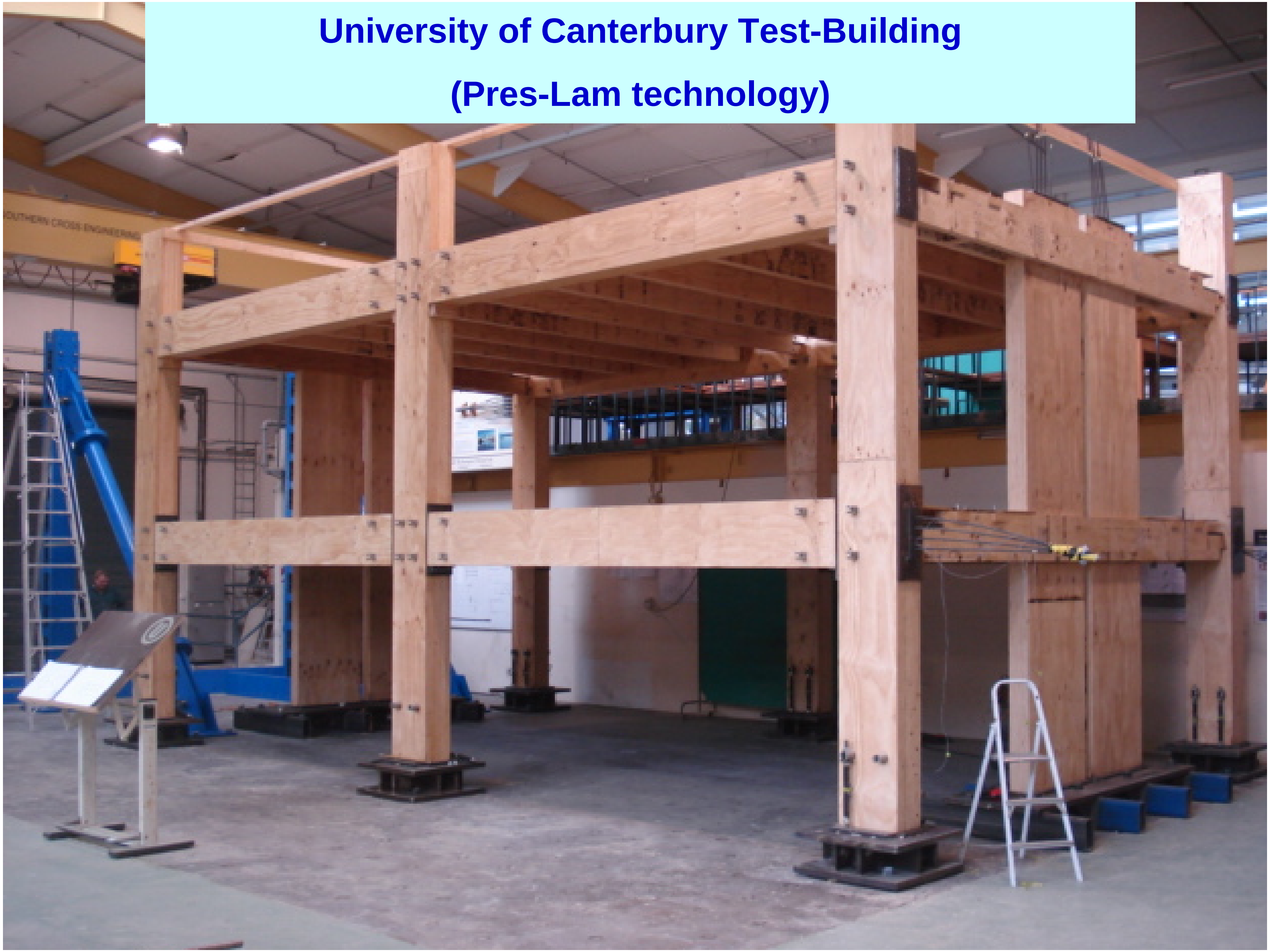
UFPs Coupled Post-tensioned Walls





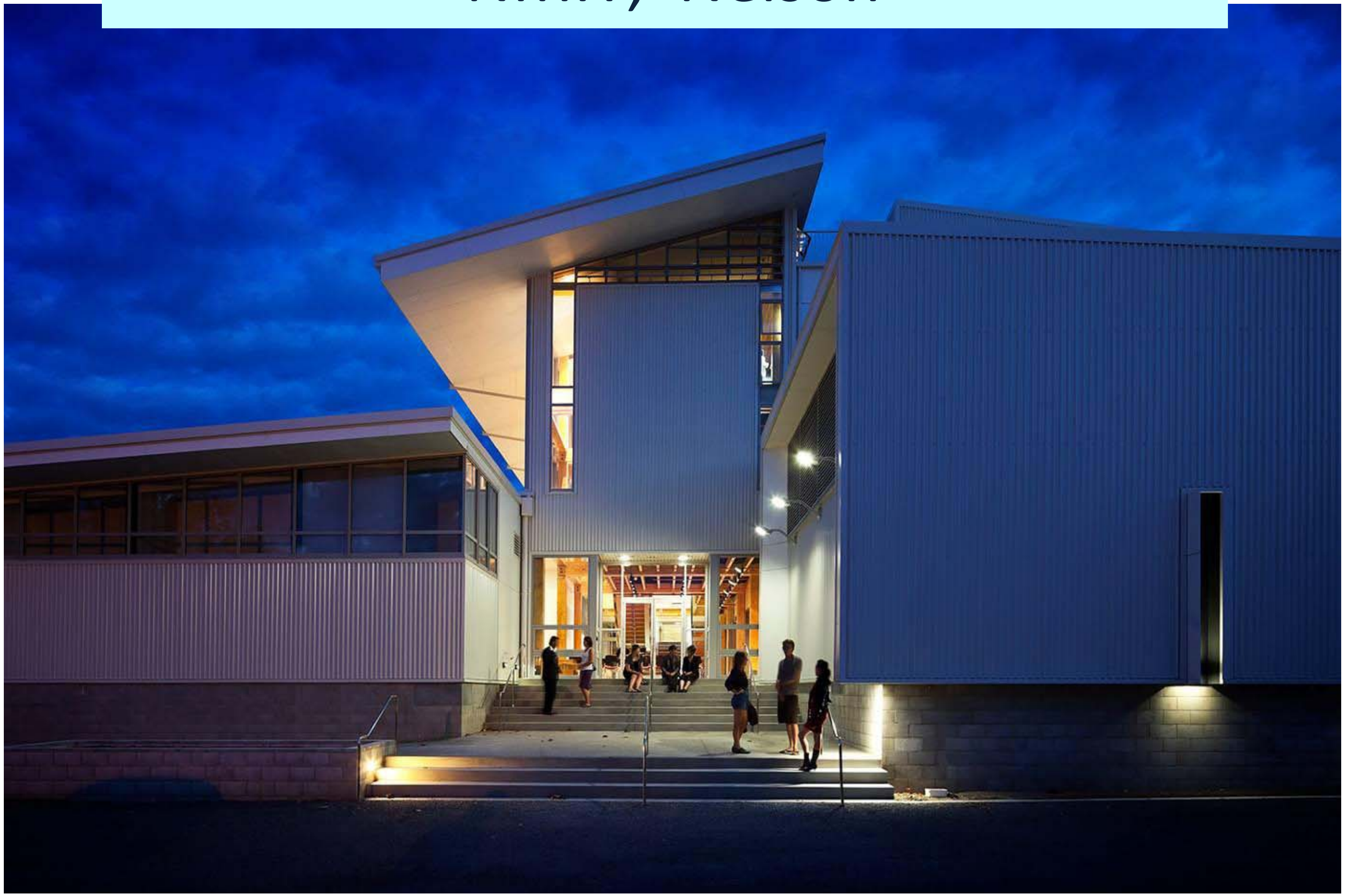
University of Canterbury Test-Building

(Pres-Lam technology)



(Again)
From theory...
to Practice

World's First Pres-Lam Building: NMIT, Nelson



NMIT, Nelson

Associ

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TIMBER DESIGN
SOCIETY INCORPORATED
OUP OF IPENZ ENGINEERS NEW ZEALAND

Carterton Events Centre

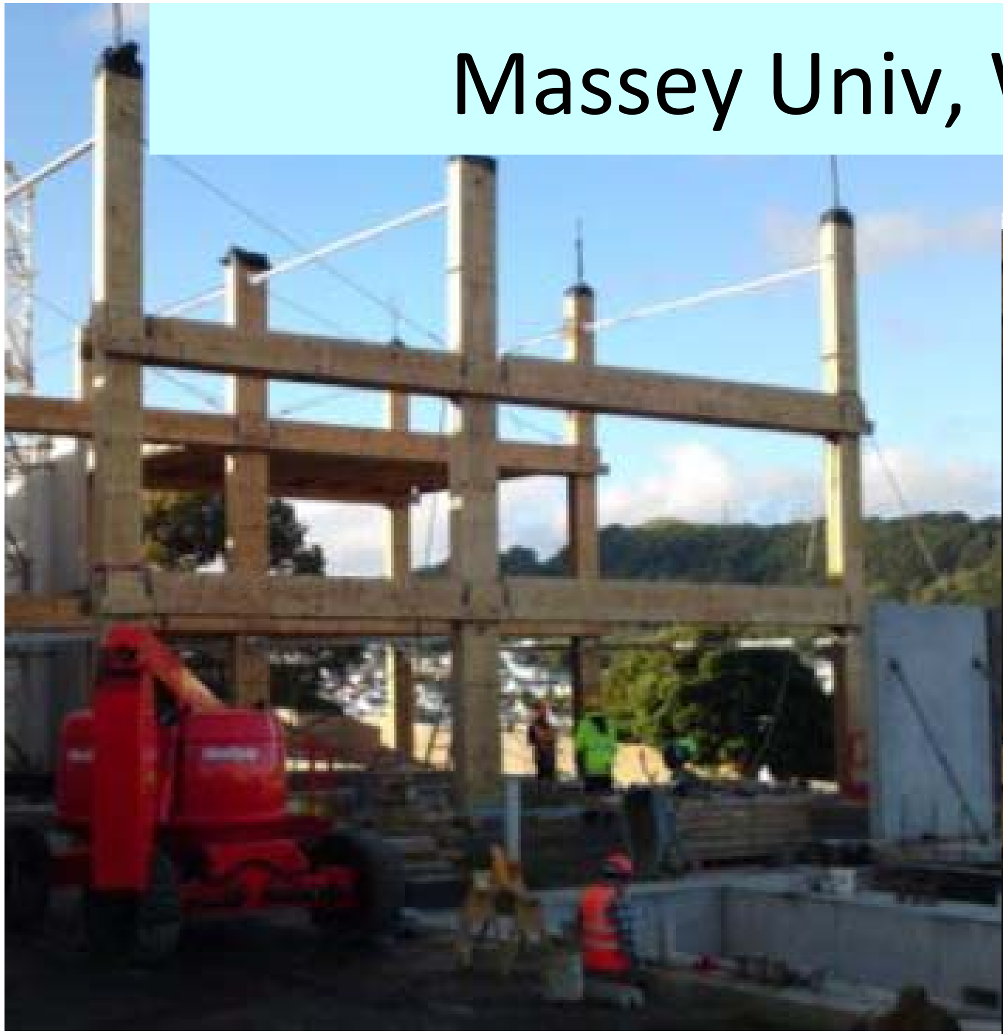
Architect: Opus

Engineer: Opus

QS: David Langdon

Builder: Holmes

Massey Univ, Wellington



Architect: Athfield Architects

Engineer: Dunning Thornton

QS: Rider Levett Bucknall

Massey Univ, Wellington

Progetti Concorsi

Il sistema Pres-Lam debutta in Europa con il Palazzo dell'Ambiente vinto da Archest

Provincia di Parma, uffici in legno hi-tech

First Pres-Lam Building that could have appeared in Europe

Associate Pr

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nt Buildings and Infrastructure

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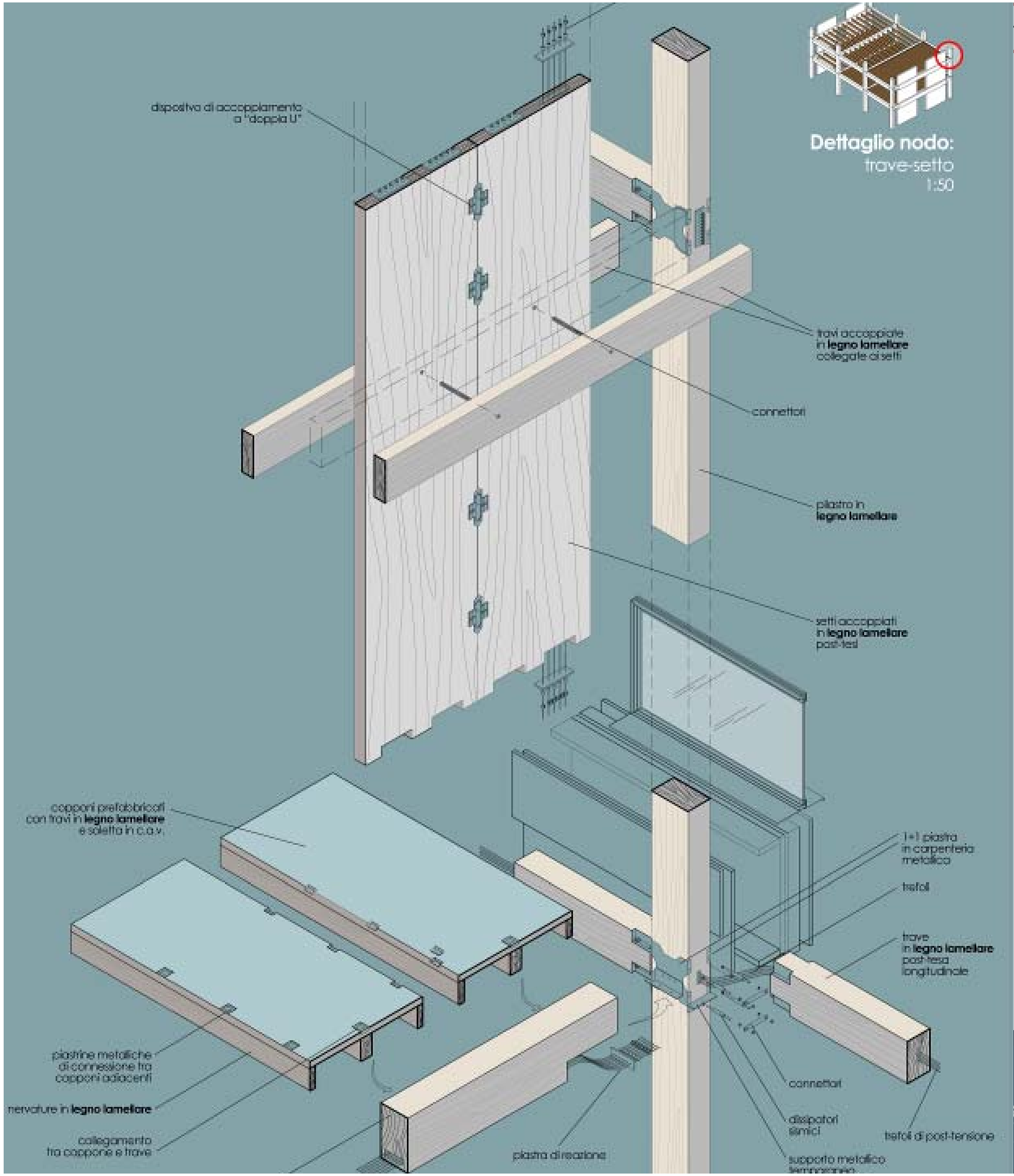

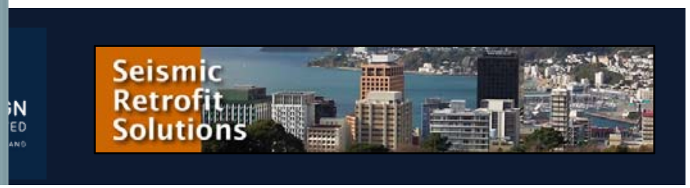

How Much do they cost?

Considerations on cost (-efficiency)

- Overall **cost-comparable** to their traditional counterparts
- The more they are being developed and constructed (learning the ropes) the more they can result in less expensive whilst higher performance solutions
- **Material cost** approximately the same of conventional solutions (Post-tensioned costs is balanced up by some lower section sizes).
- Quantity Surveyors might for the first applications tend **to identify and predict higher premium** due to the novelty of the system and lack of comparison with previous case

Fundamental benefits *(often over-looked)*

- **Larger spans**, bigger open space, higher interstorey height can result in significant **occupancy benefits** and thus financial advantages
- **Speed of construction** can lead to significant savings (mortgage, earlier selling, less crew on site etc)
- Advantage of higher seismic performance was often (prior to the Chch EQs) not “rewarded”, whilst now it is more clearly understood and appreciated
- **Reduced direct** (due to damage and repairing costs) **and indirect** (business interruption) l**osses** can result in significant savings (e.g. beyond cost of the structure itself)
- The latter now fundamental to negotiate a **reduced level of insurance premium** (of just guarantee insurance coverage)

Associate Professor Stefano Pampanin

National Hazard Research Platform: Resilient Buildings and Infrastructure

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CHRISTCHURCH NEW ZEALAND

Christchurch Vision 2050: Re-building with damage-resisting technology


How would WE like this to look like?
Photos courtesy of Weng Y Kam

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SESOC
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A TECHNICAL GROUP OF IPENZ ENGINEERS NEW ZEALAND
Seismic Retrofit Solutions

VIBRANT STREETS AND COURTYARDS

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Seismic Retrofit Solutions

TIME FOR A RADICAL STEP-UP

THE WORLD is **HELPING**.. and **WATCHING**

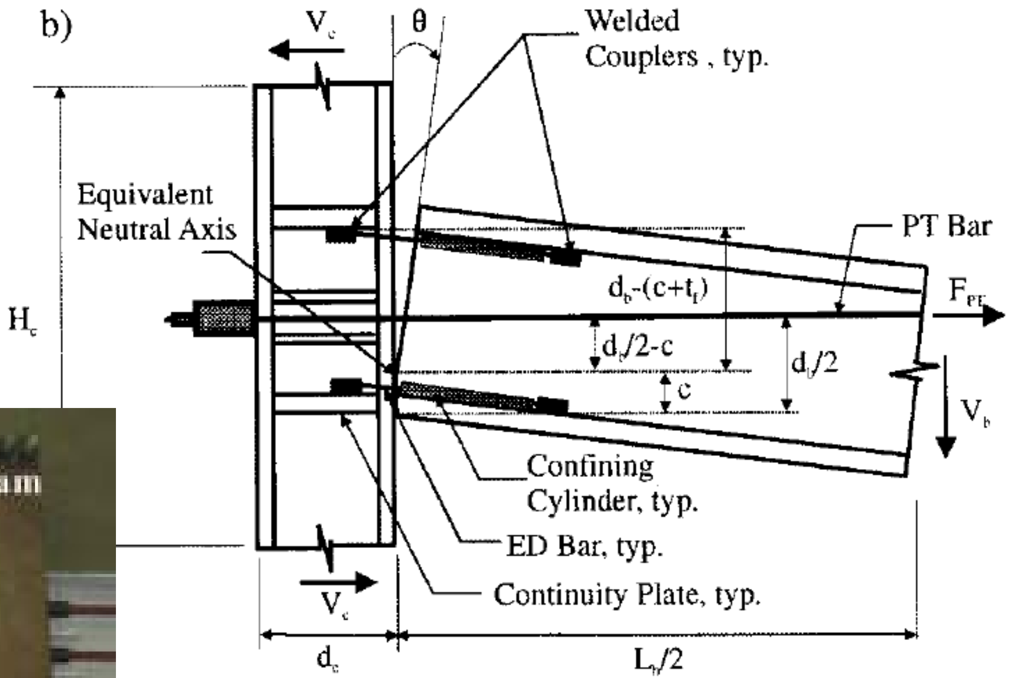
We must give a ***Strong Example***

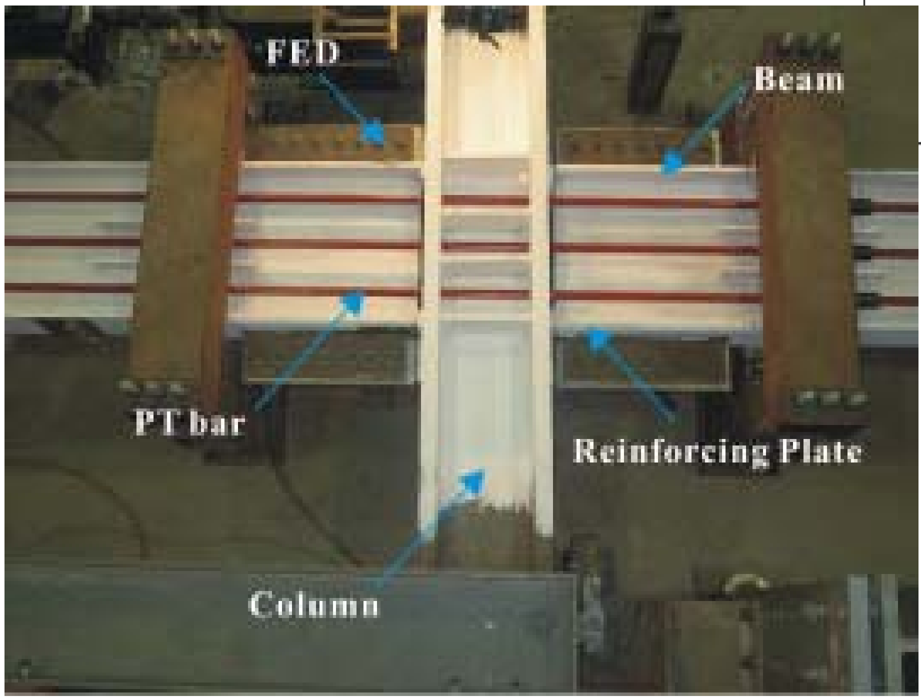
Thanks for your attention

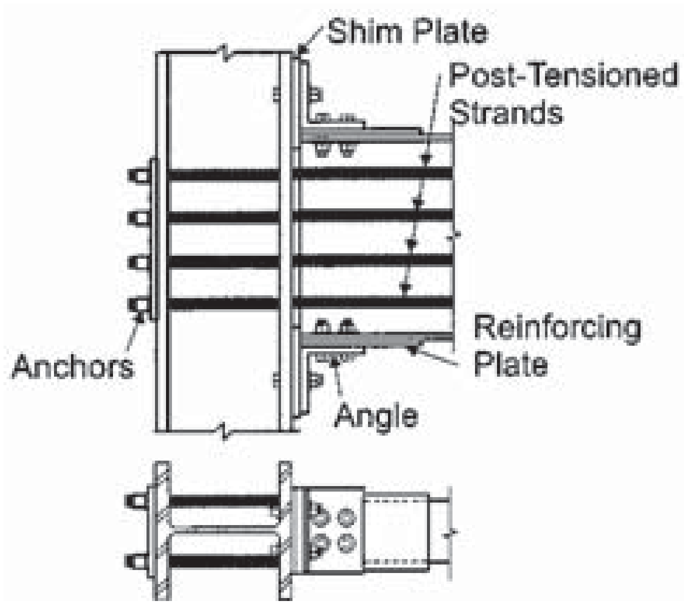
Appendix A:

Extension of of PRESSS-technology to other materials

Adaptation to Post-Tensioned Steel Connections

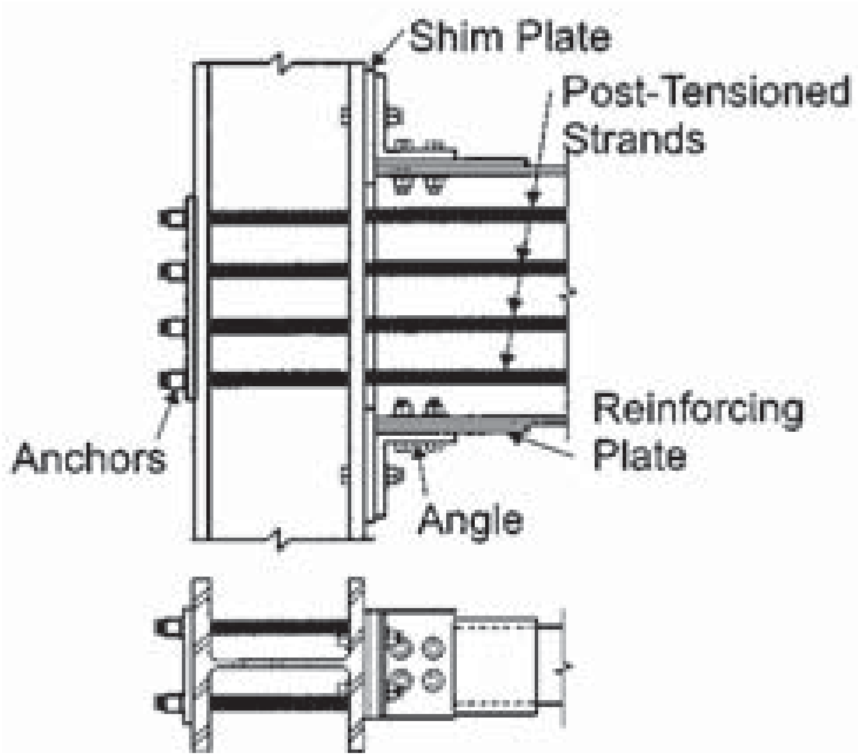


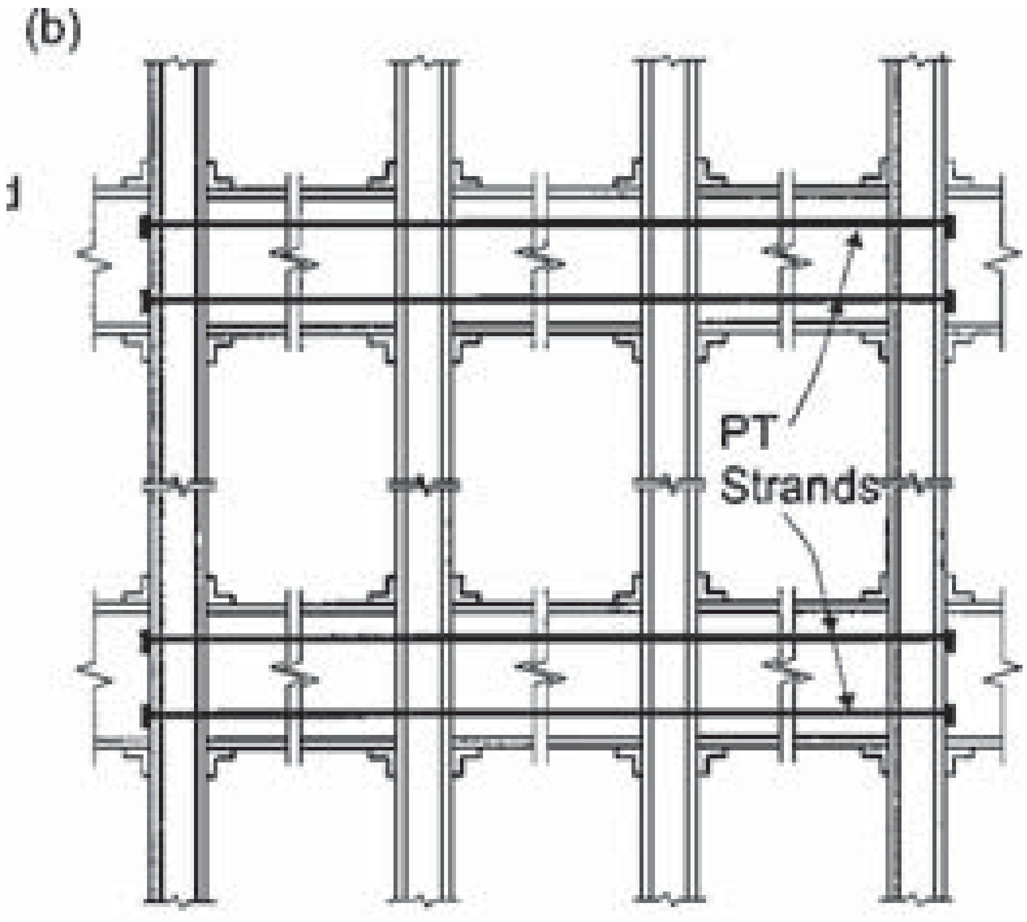




Christopoulos and Filiatrault
(UC San Diego, Toronto, Buffalo)

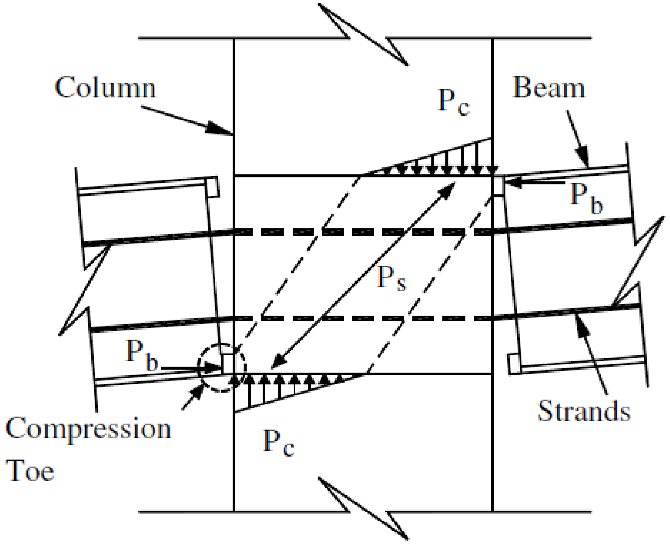
Adaptation to Post-Tensioned Steel Connections



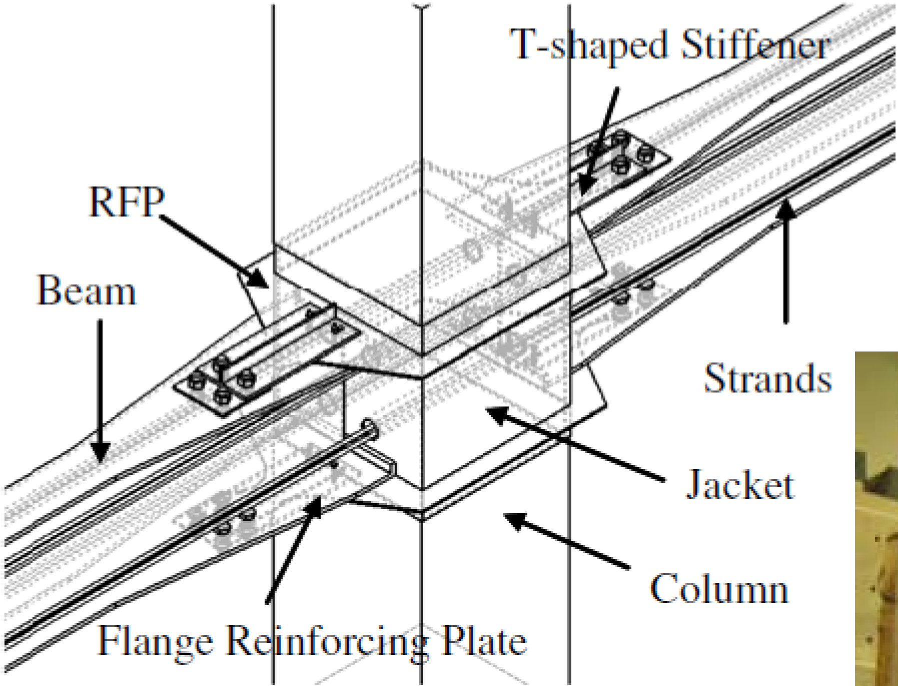


Ricles, Sause et al.
(Lehigh University)

Post-tensioned Steel beams and Concrete columns



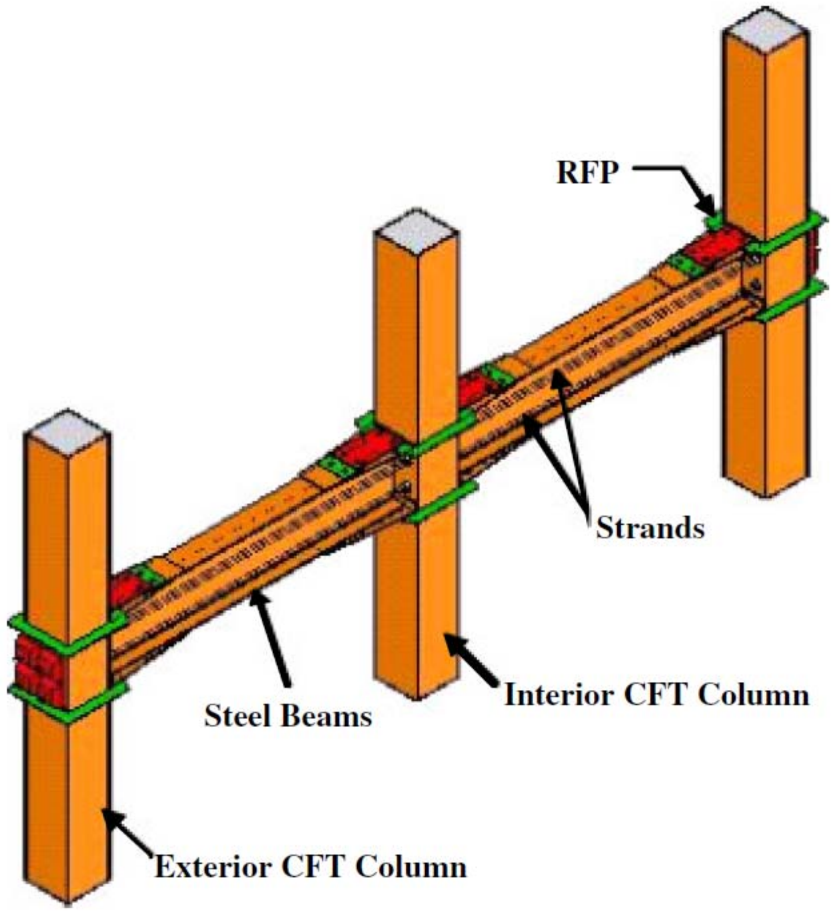
(c) Concrete strut in connection.



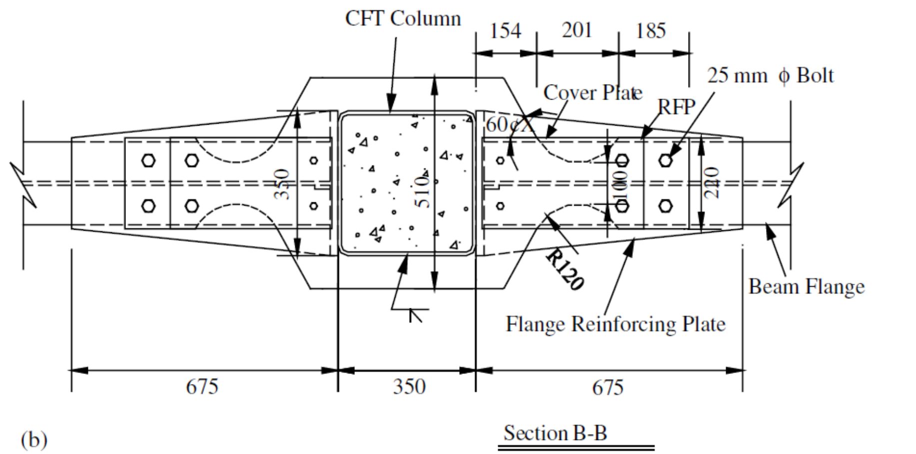
(b) PT beam–column connection and RFP details.

Chou and Chen (Taiwan)

Post-tensioned Steel beams and ConcreteSteel (CFT) columns

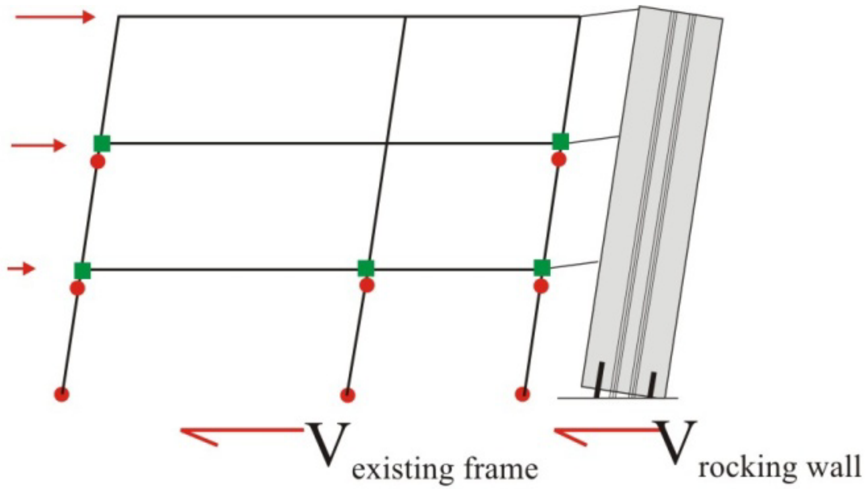


Chou and Chen (Taiwan)

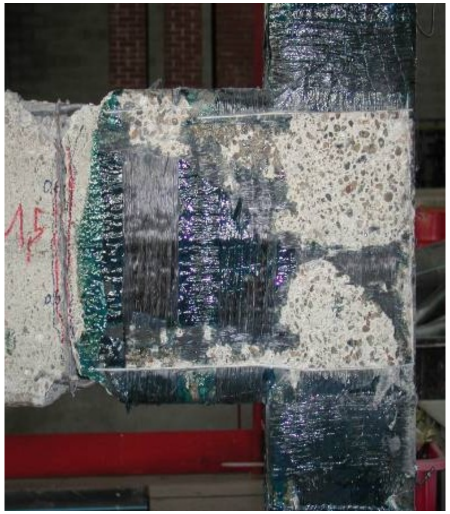


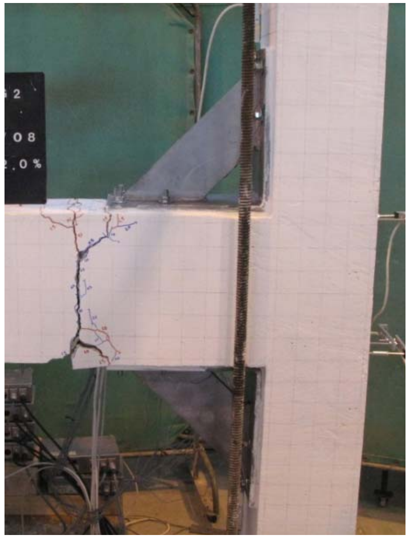
Appendix B:

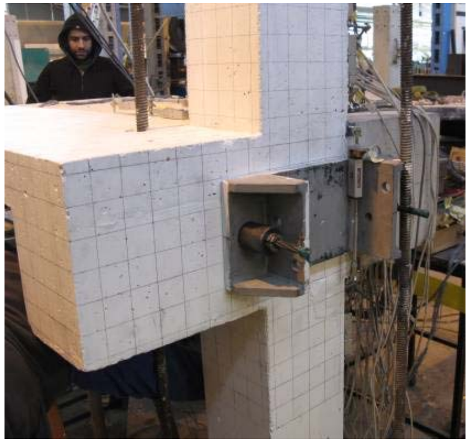
How can we use this new technology to Retrofit ***Existing Buildings?***



NZ FRST-Funded Project
"Retrofit Solutions" (2004-2010)







Pre 1970 Concrete Buildings

- **Seismic Assessment**
- **Seismic Retrofit Solutions**
  - FRP
  - Metallic Haunch
  - Post-Tensioned Rocking-Dissipative Walls
  - Selective Weakening
- **Seismic Risk Analysis and Retrofit Strategies at Territorial Scale**
  Damage Scenario

(PI-Stefano Pampanin)

www.retrofitsolutions.org.nz

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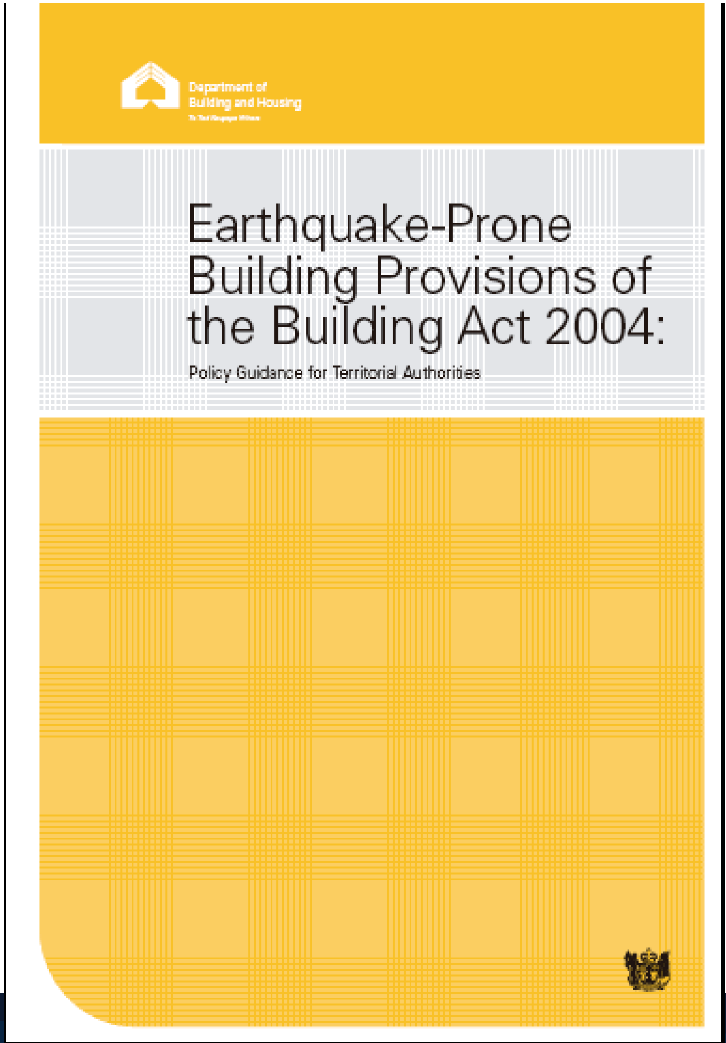
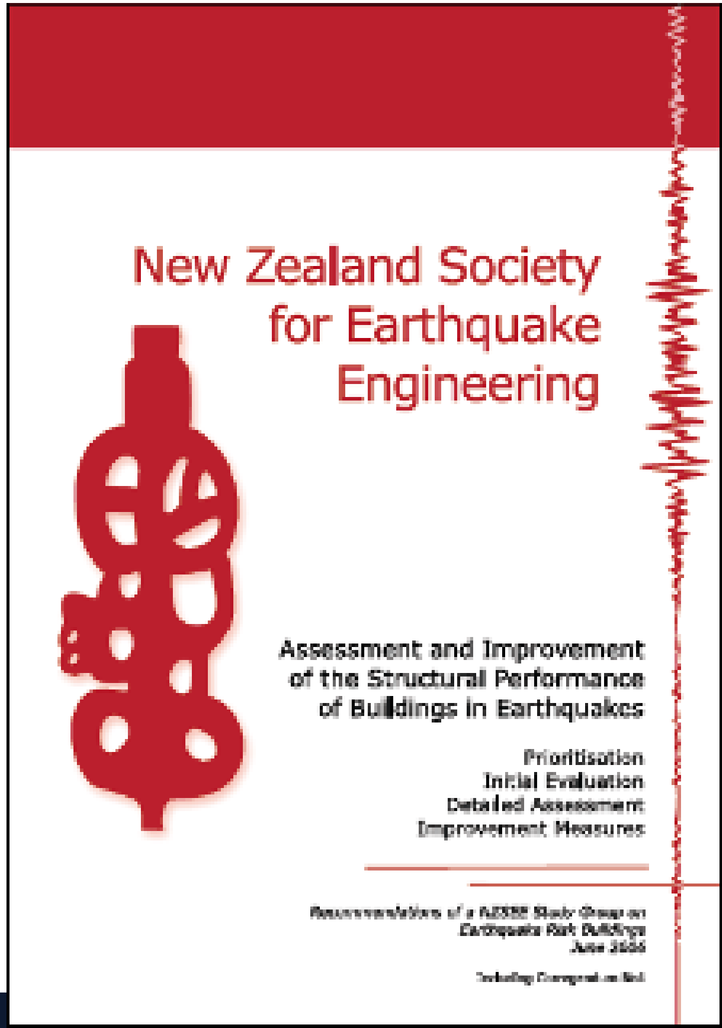
A TECHNICAL GROUP OF IPENZ ENGINEERS NEW ZEALAND

Preparation of a **Retrofit Design Handbook** (End of 2012?)



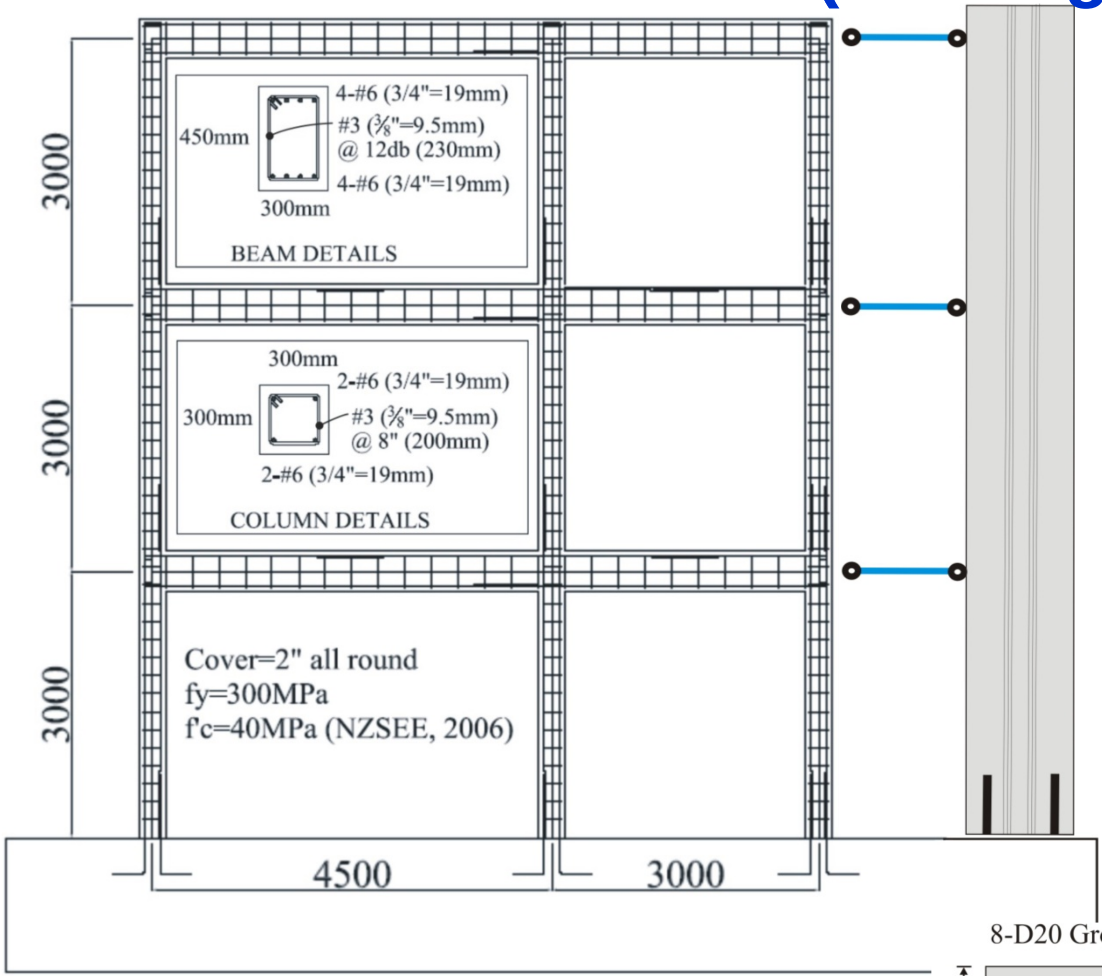


NZCS | NZ Society for Earthquake Engineering Incorporated | SESOC | New Zealand Timber Design Society Incorporated | Seismic Retrofit Solutions

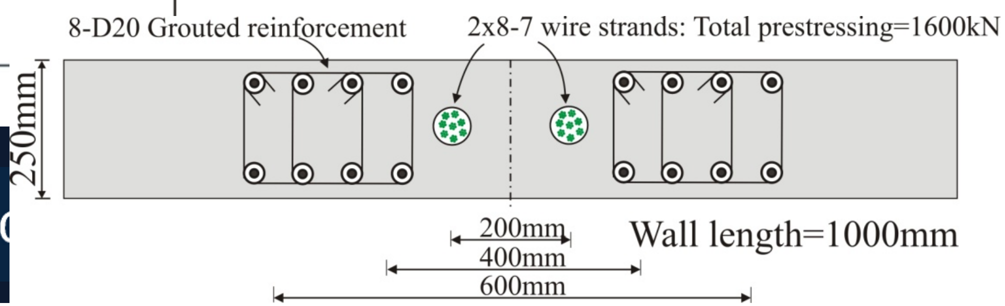
Associate Professor Stefano Pampanin

National Hazard Research Platform: Resilient Buildings and Infrastructure

Retrofit of existing pre-1970s RC frames using a Post-tensioned (rocking-dissipative wall)

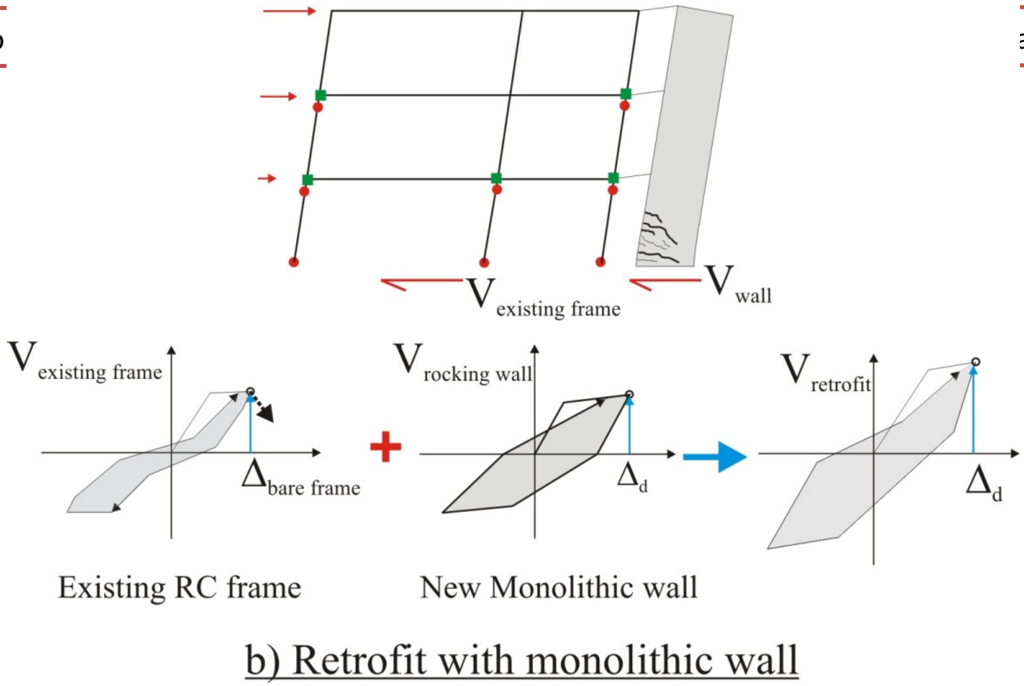


Marriott et al.

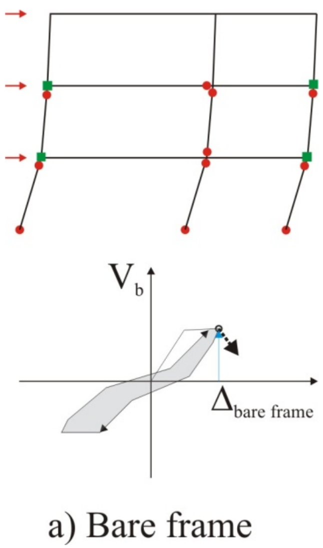


Associate Professor Stefano ... and Infrastructure
UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

Retrofit A



b) Retrofit with monolithic wall

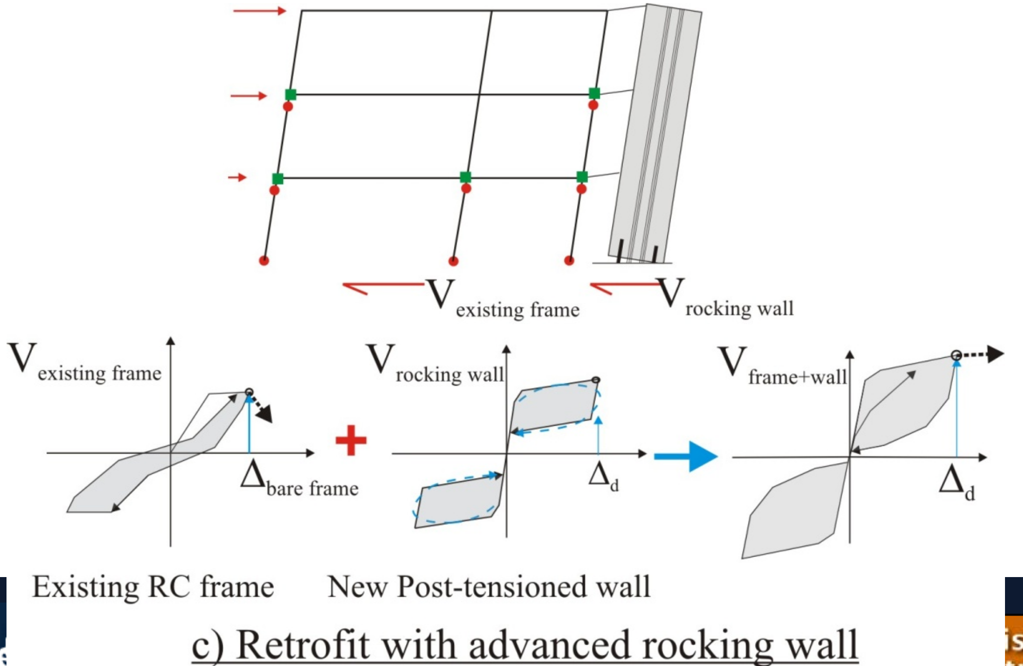


a) Bare frame

Retrofit A-Limitations

- Residual displacements
- Physical Damage

Retrofit B



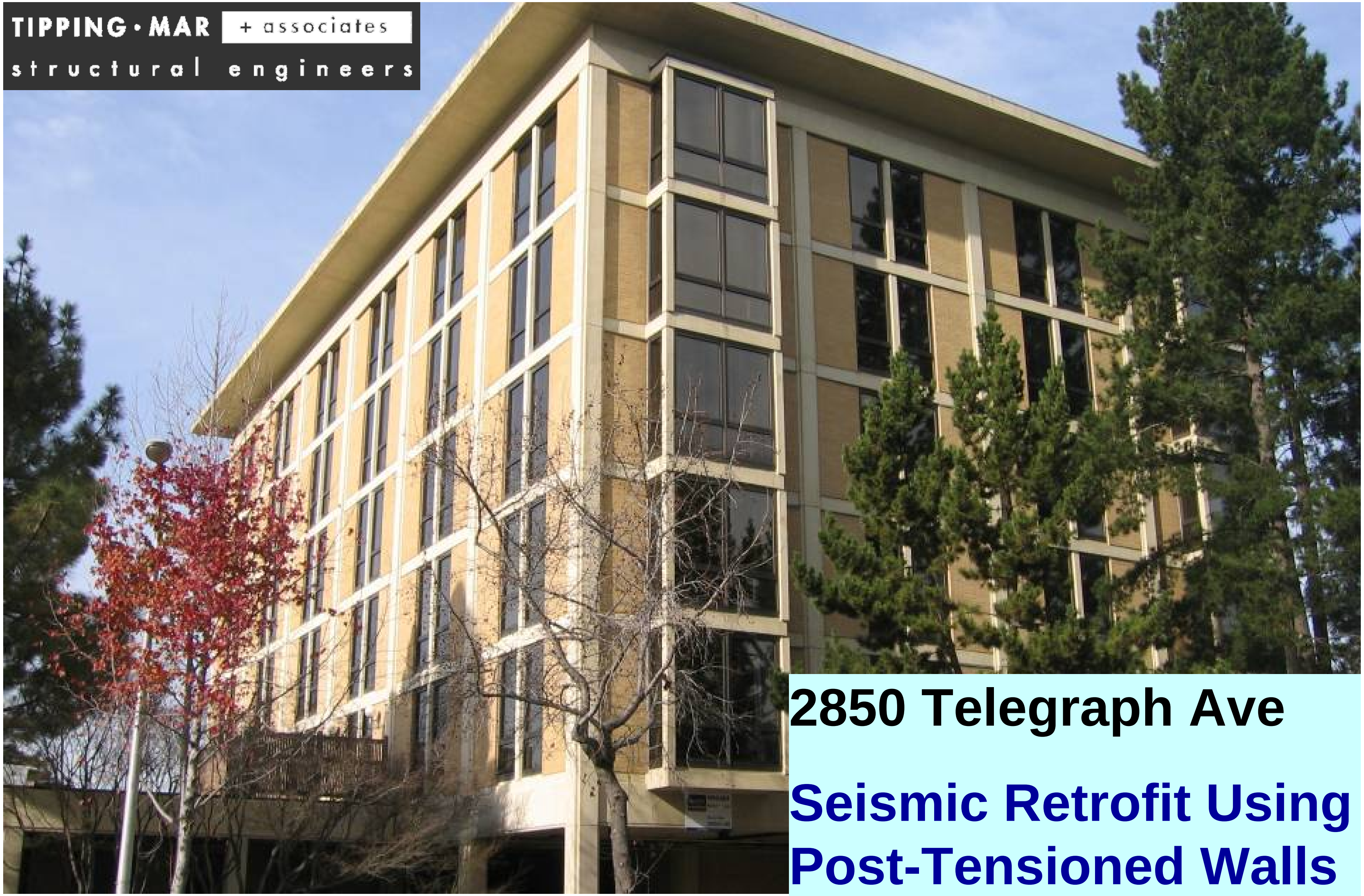
c) Retrofit with advanced rocking wall

Retrofit B-Benefits

- Minimal physical damag
- System re-centring
- Design flexibility
- Near field protection
- Foundation protection

From theory…
to Practice

TIPPING · MAR + associates
structural engineers



2850 Telegraph Ave

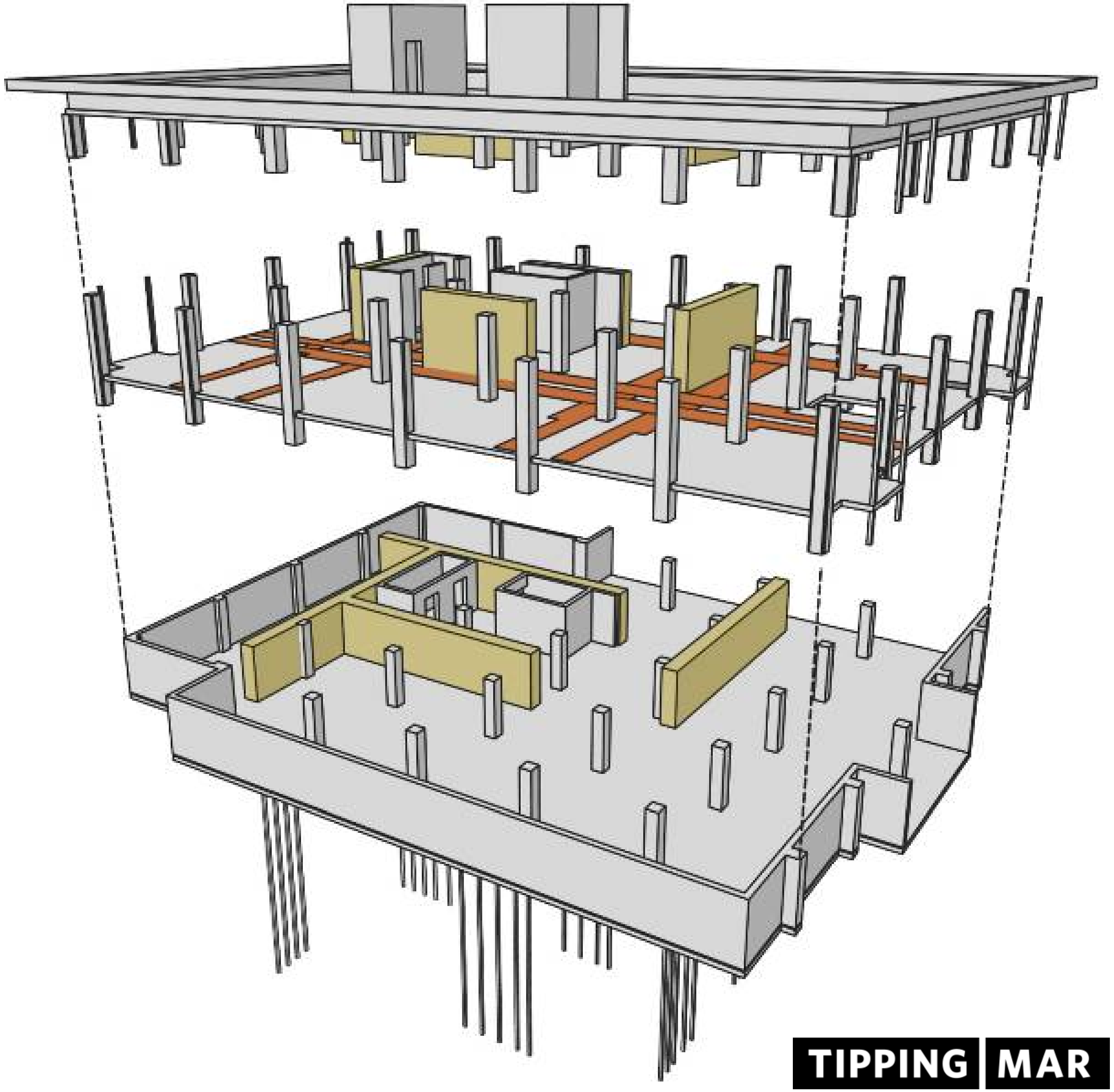
Seismic Retrofit Using Post-Tensioned Walls

Associate Professor Stefano Pampanin

2850 Telegraph Ave

Berkeley, CA

- 6-story 1970 non-ductile concrete frame
- Reinforced masonry in-fills
- < 1 mile from Hayward Fault



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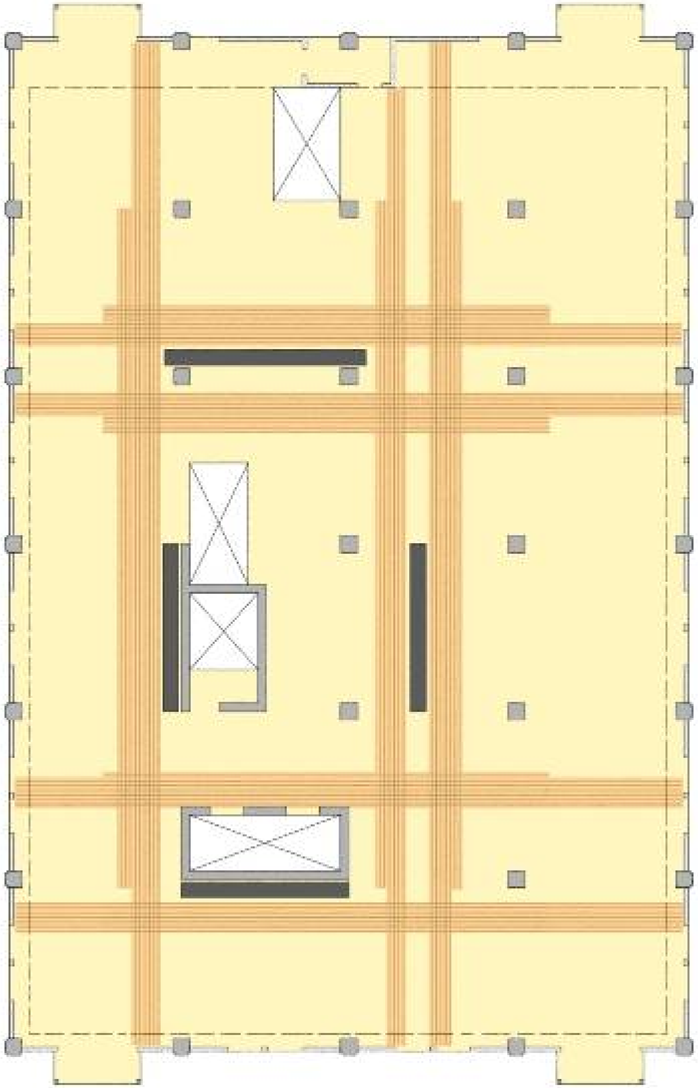
2850 Telegraph

- Voluntary upgrade
- No exterior modifications
- UC Berkeley seismic criteria
- New walls resist all loads



Floor Plan

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Seismic Retrofit Solutions

TIPPING MAR


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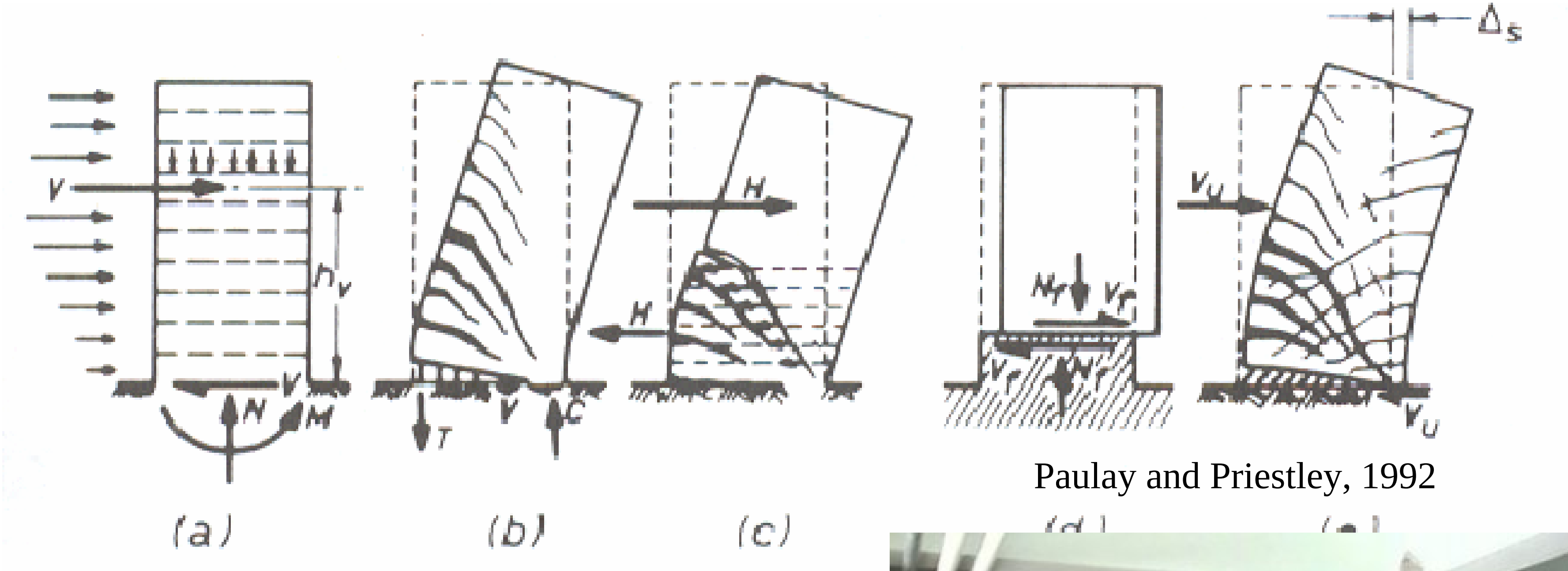
RETROFIT = STRENGTHENING?

Why not <u>WEAKENING?</u>

Failure mechanisms in walls



Paulay and Priestley, 1992

The surgery intervention…

Horizontal saw cutting at the wall base (**Acknowledgments to Contech**)

Vertical saw-cutting

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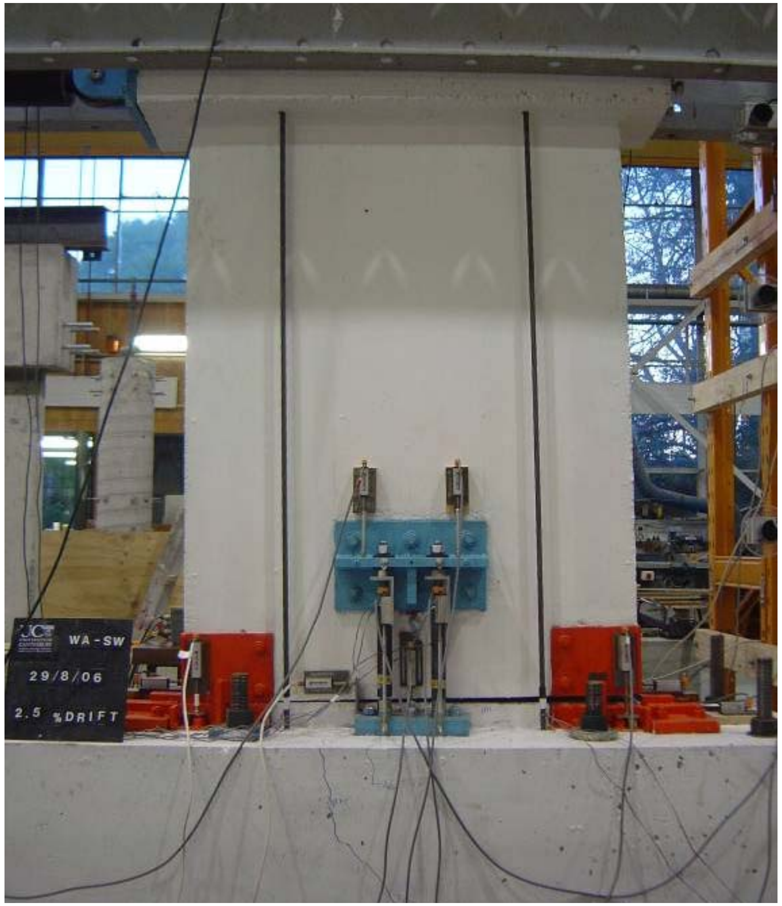
CHRISTCHURCH NEW ZEALAND

Selective Weakening for wall systems

(Report 2007: experimental validation,

Ireland, Bull, Pampanin, 2007**)**

As built solution



Retrofitted solution using the proposed selective weakening strategy