EVIDENCE FOR

SUBMISSION TO THE ROYAL COMMISSION OF INQUIRY:

AN ALTERNATIVE COLLAPSE SCENARIO FOR THE CTV BUILDING

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Purpose (p1)

1. Review the findings of the DBH report.

2. Present new material
   - Ground motions
   - Concrete cylinder tests
   - Column tests

3. Alternative collapse hypotheses

1. *Critique of H-S Report*

The principal conclusion in the H-S Report states:

> *"The investigation has shown that the CTV Building collapsed because earthquake shaking generated forces and displacements in a critical column (or columns) sufficient to cause failure. Once one column failed, other columns rapidly became overloaded and failed."* (Executive Summary)

- Too vague to be meaningful, a casual observer could have concluded that from the sidewalk on 22/2/11!

1. *Critique of H-S Report*

1.1 Higher than expected horizontal ground motions

1.2 Exceptionally high vertical ground motions

1.3 Lack of ductile detailing in critical columns

1.4 Low concrete strength in the critical columns

1.5 Interaction of perimeter columns with the spandrel panels

1.6 Separation of the floor slabs from the North Core

1.7 Accentuated lateral displacements of columns due to the asymmetry of the shear wall layout

1.8 Accentuated lateral displacements due to the influence of masonry walls on the west face

2. SUPPLEMENTARY INVESTIGATION WORK CONDUCTED ON THE CTV BUILDING COLLAPSE

2.1 Ground motions

2.2 Concrete Testing

2.3 Additional Concrete Testing on CTV Building Columns

2.4 Column Performance Analysis

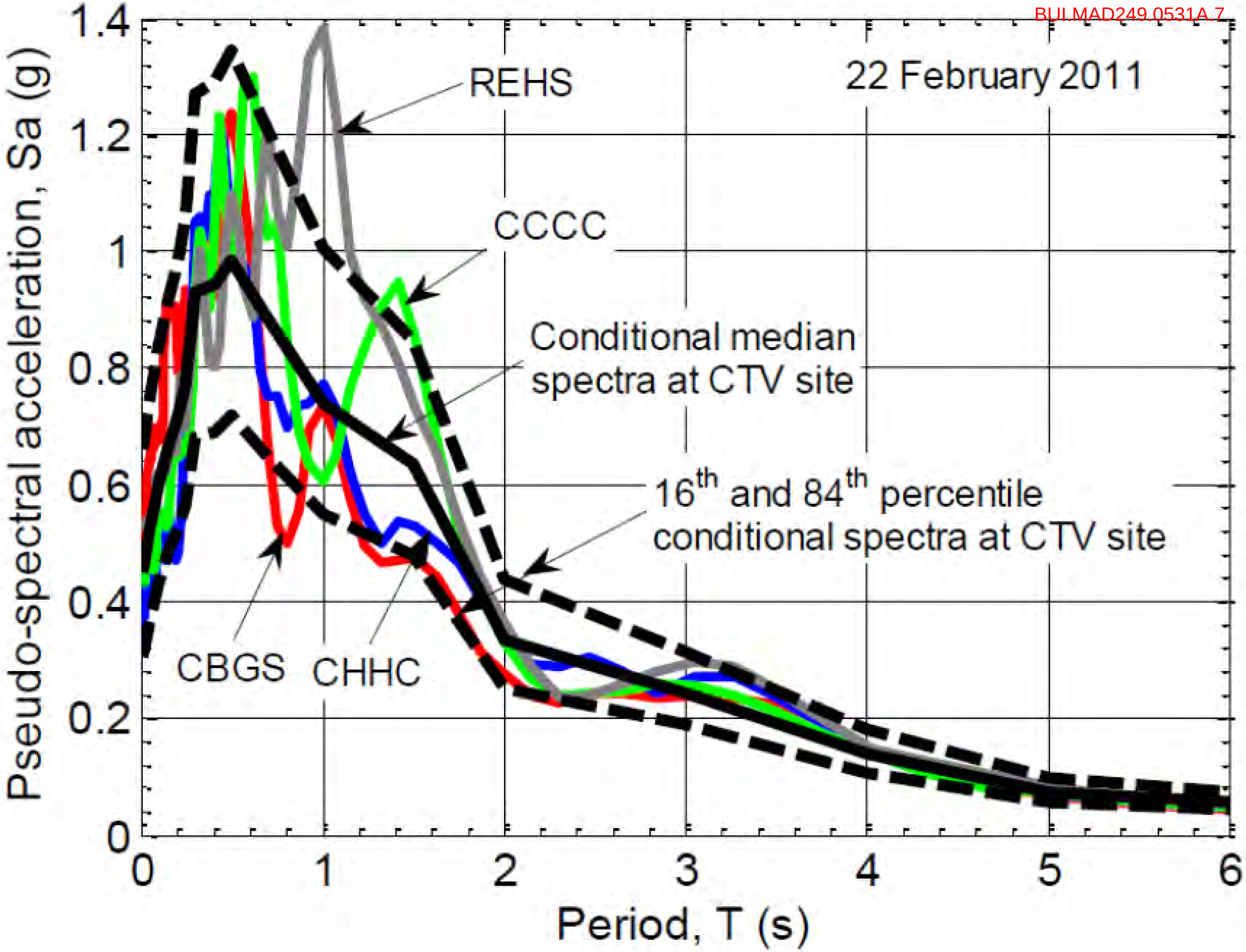
2.5 The Problem with the Beam-Column Joints

2.1 Ground motions

Surrounding the Christchurch CBD are four ground motion recording stations as part of the Geonet monitoring platform. These stations are:

- CCCC at the Christchurch Catholic Cathedral College
- CBGS at the Botanical Gardens
- CHHC at Christchurch Hospital
- REHS at Resthaven Home

- REHS: conspicuous by its absence, why?



22 February 2011
REHS
CCCC
Conditional median spectra at CTV site
16th and 84th percentile conditional spectra at CTV site
CBGS
CHHC
Pseudo-spectral acceleration, Sa (g)
Period, T (s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
1
2
3
4
5
6

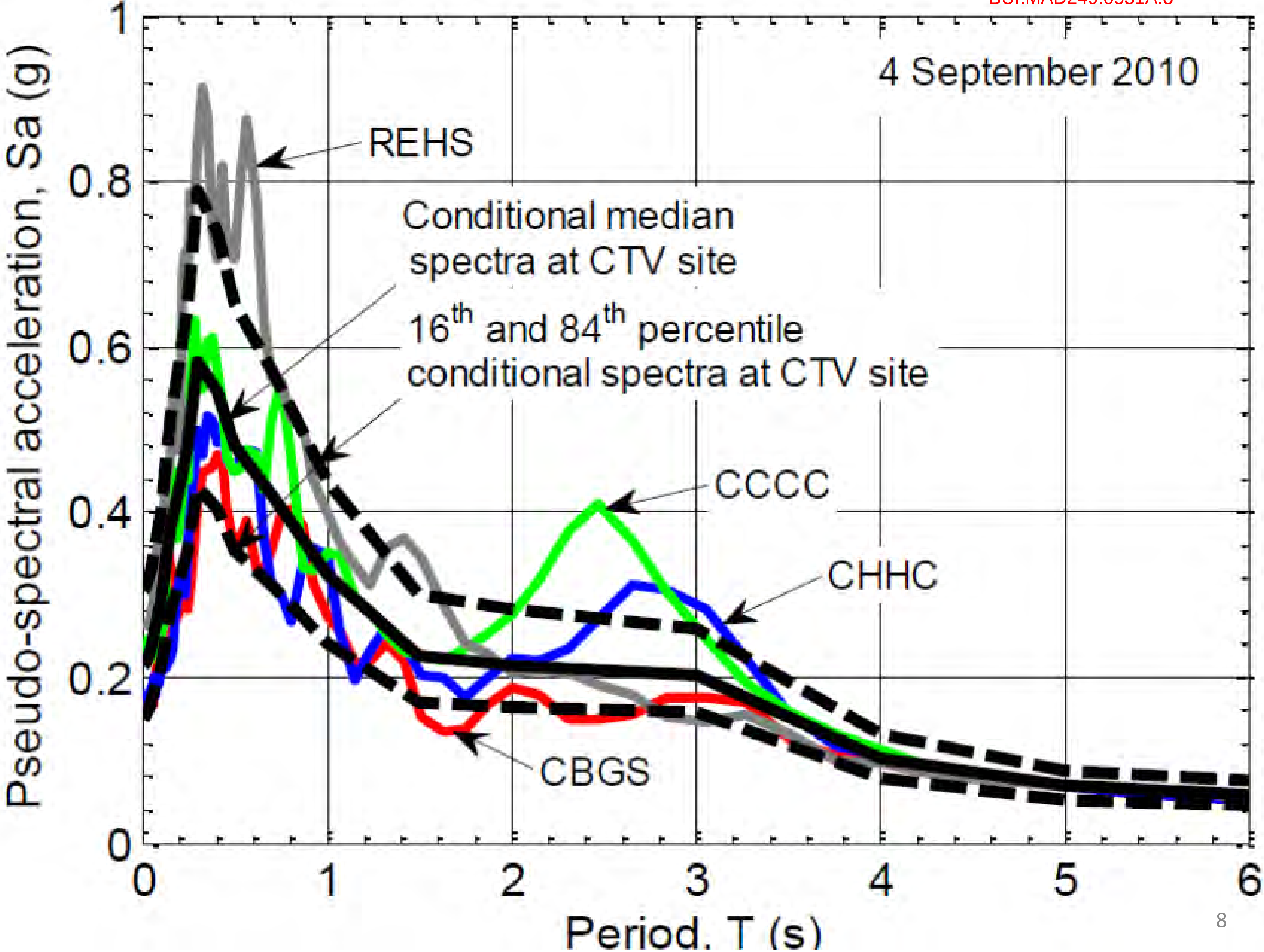
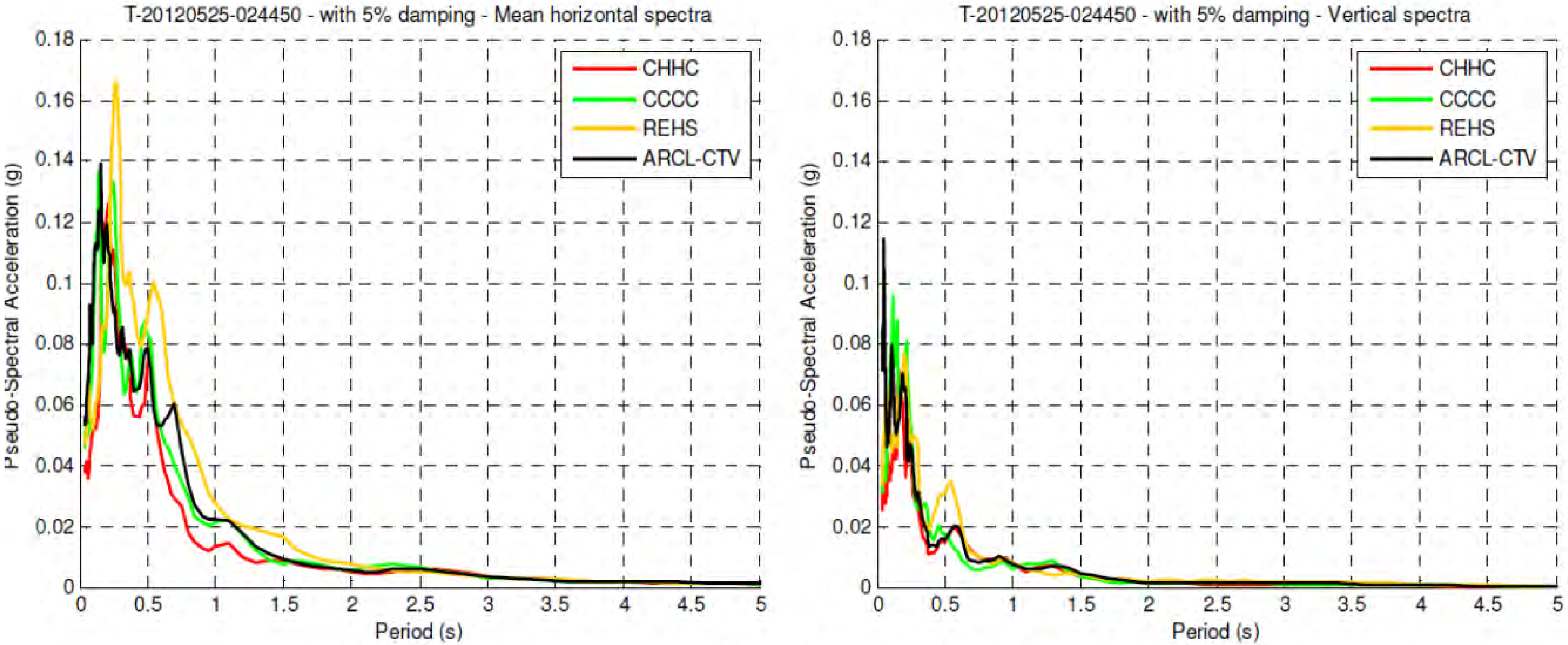

4 September 2010
REHS
Conditional median
spectra at CTV site
16th and 84th percentile
conditional spectra at CTV site
CCCC
CHHC
CBGS
Pseudo-spectral acceleration, Sa (g)
Period, T (s)
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4
5
6

Fig 2.2. Acceleration response spectra comparison at the CTV Building site with the other Geonet recording stations within the Christchurch CBD (when actively recording).



(a) M5.2 26 May 2012

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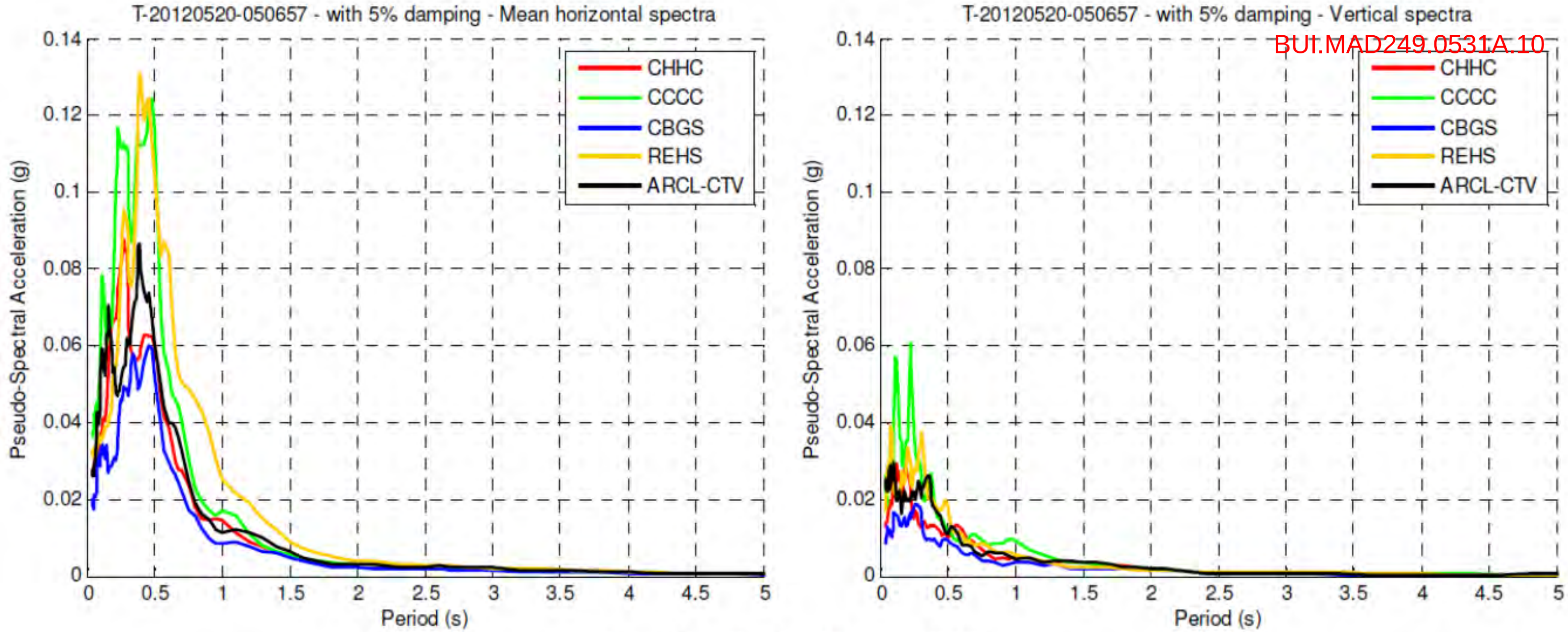
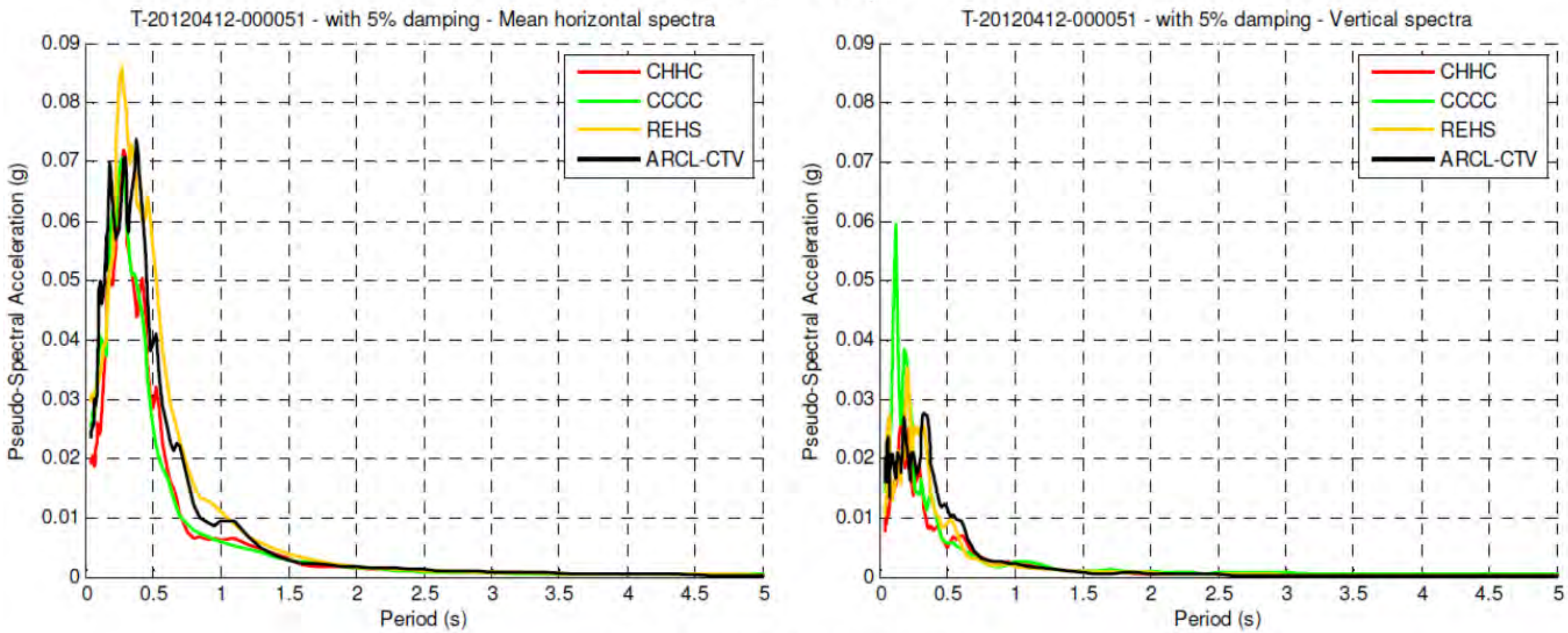


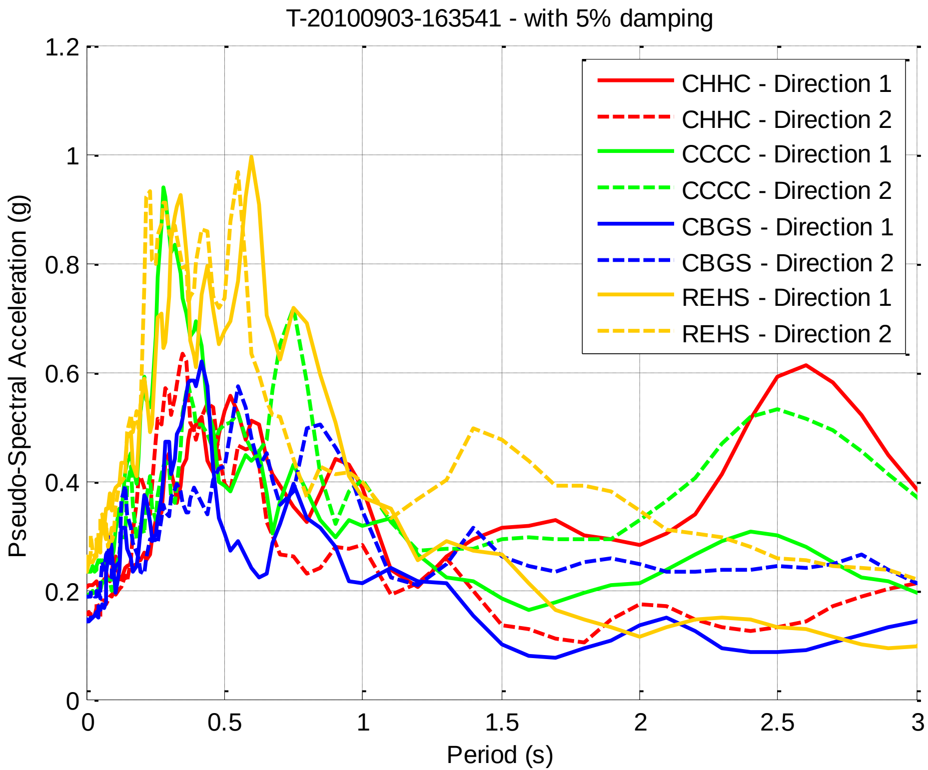
(b) M4.8, 21 May 2012

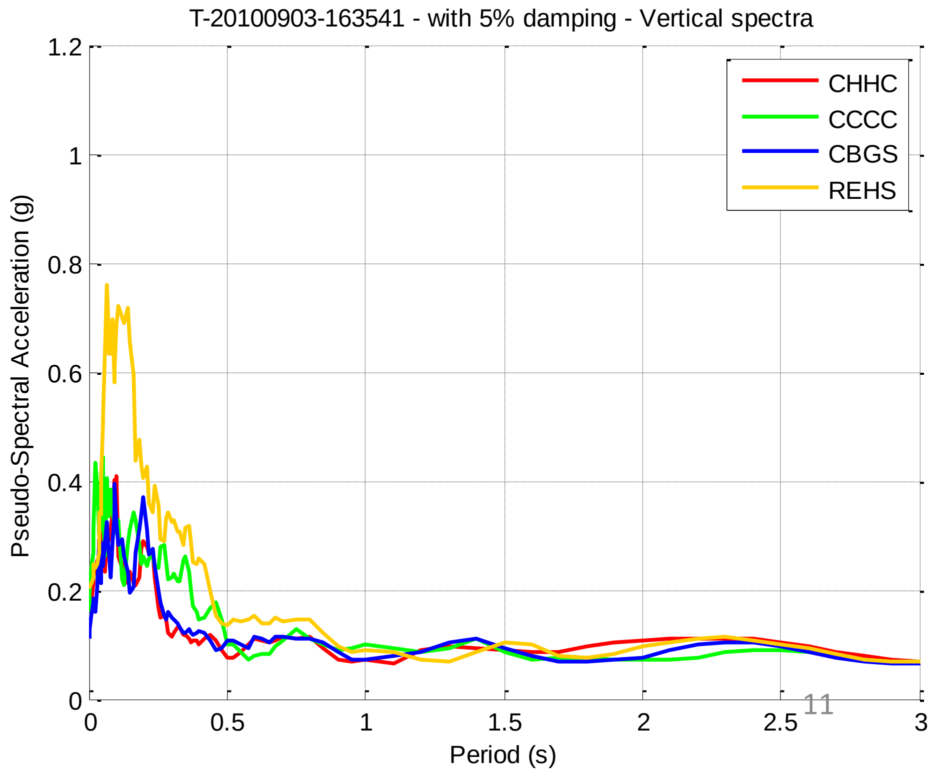


(c) M4.6 13 April 2012

Matters arising from last week:

Some have claimed that the Darfield Earthquake vertical motions were not exceptionally high, is this true or false?





Response Spectra

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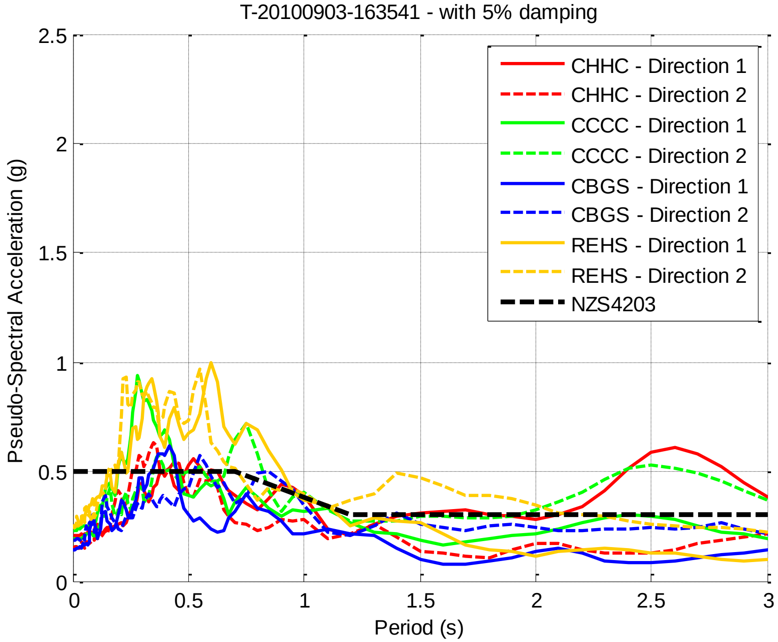

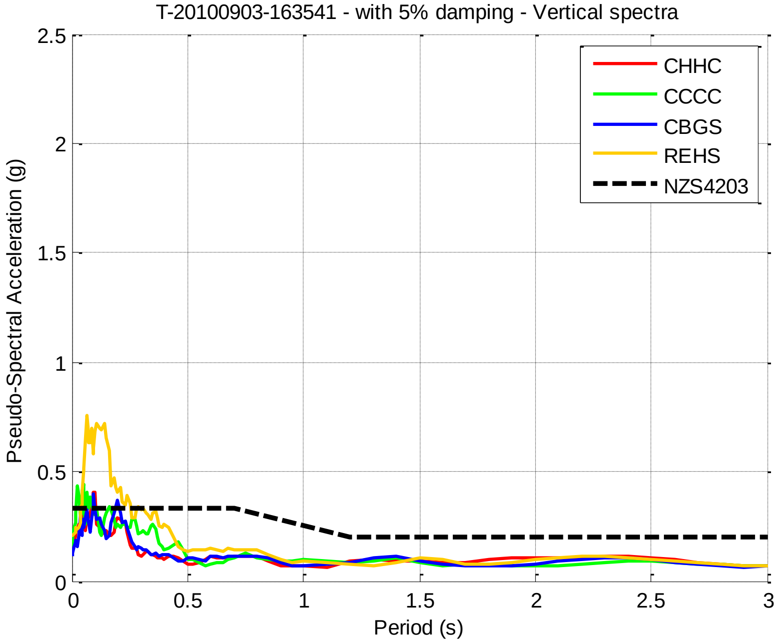

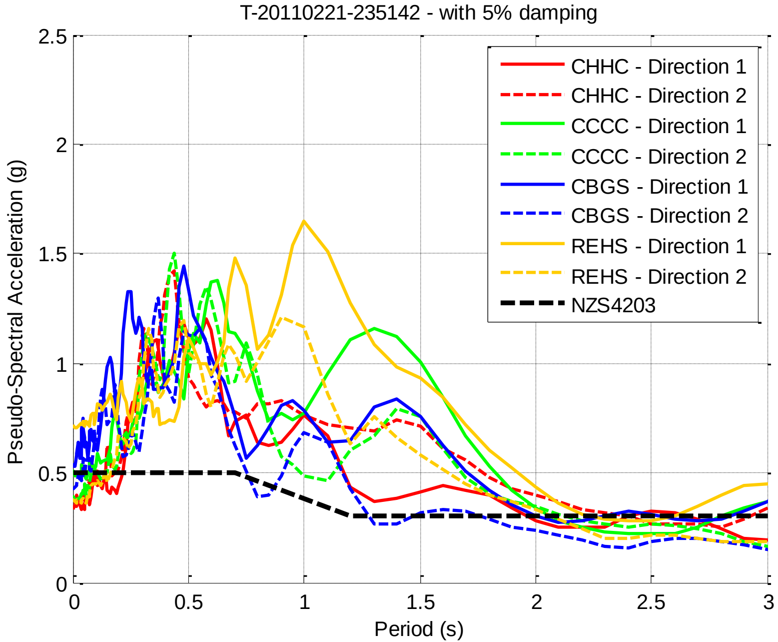

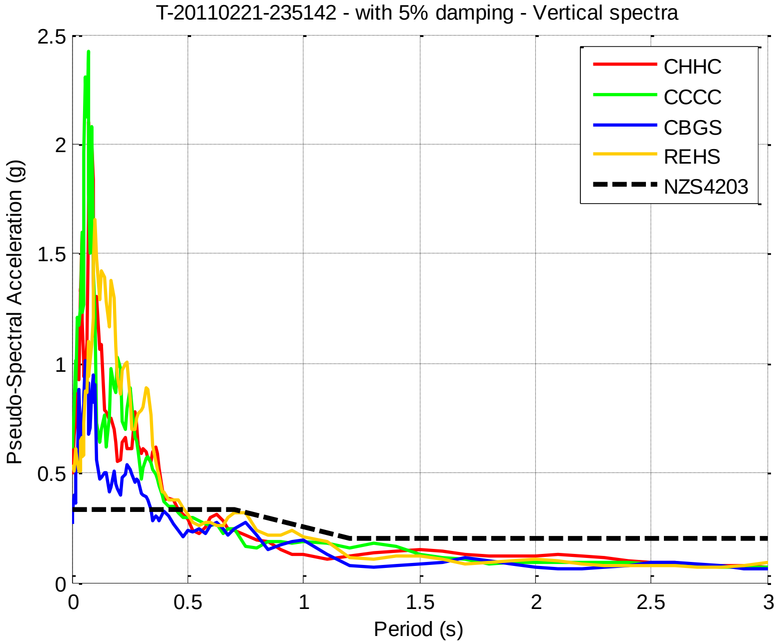

2.2 Concrete Testing

- What is the alarm all about?

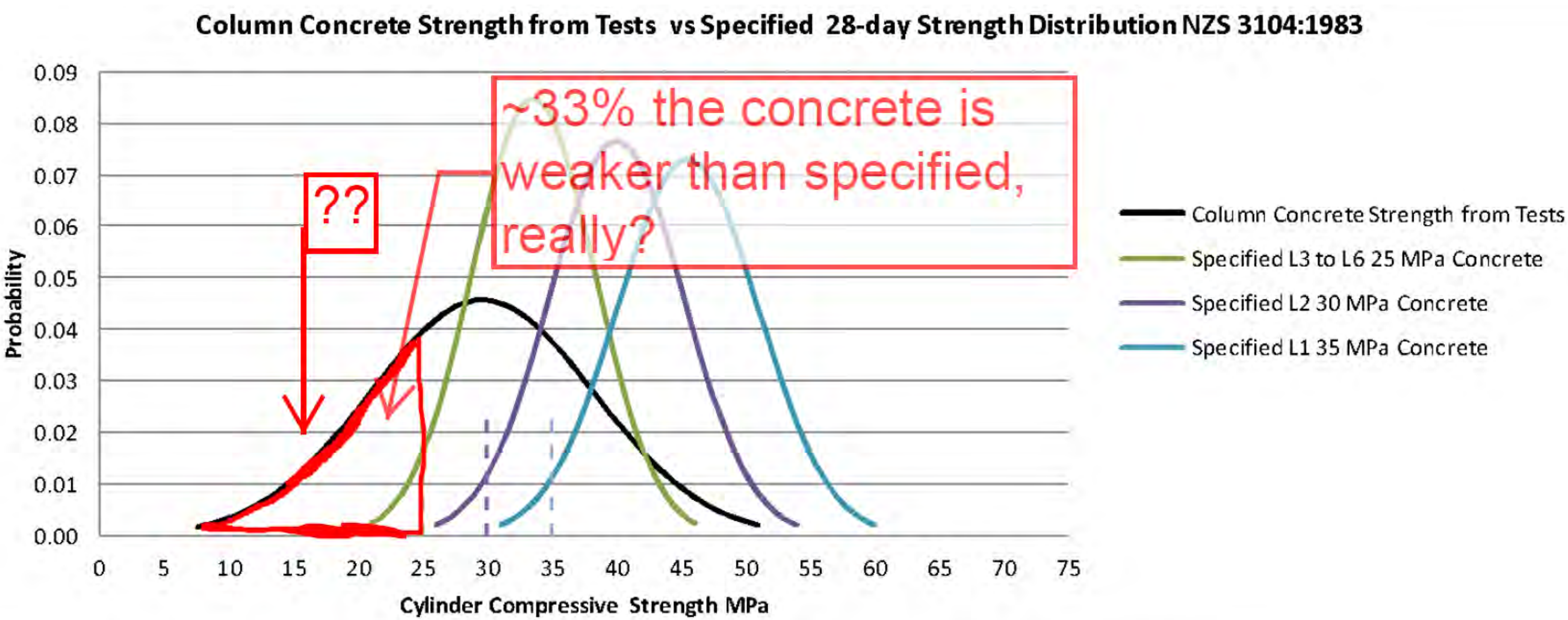

Fig. 2.3. Cumulative distribution plot of the normalized concrete strength from the CTL test results.

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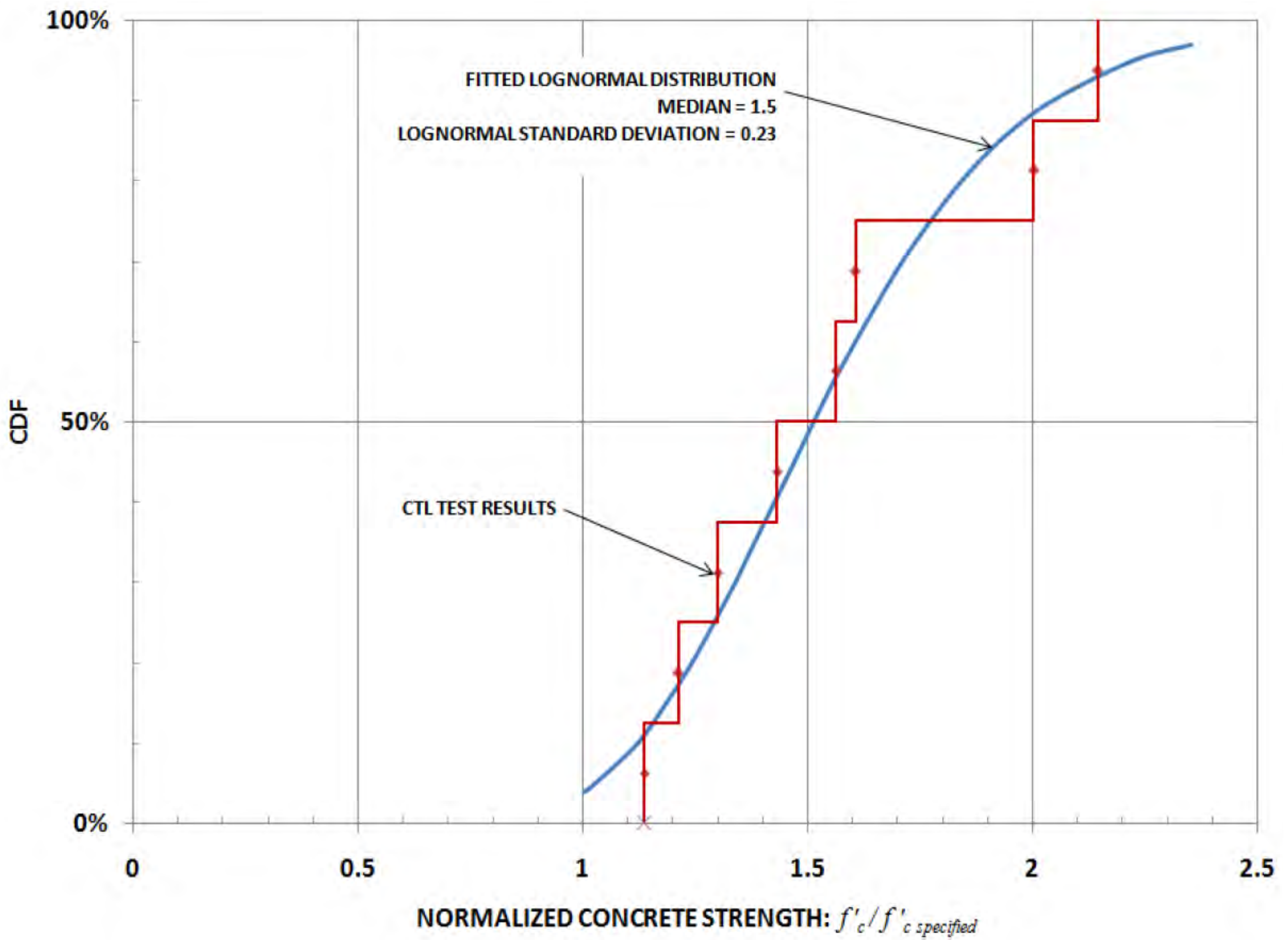

- When conducting an advanced analysis such as NLTHA, it is always prudent to perform a few “swing analyses” to examine the sensitivity of the overall outcomes to values adopted for certain key parameters. In the case of the CTV Building, the concrete strength is a very important parameter, largely because the columns are compression-critical. It is for this reason that the lower values previously used by Compusoft should be retained to model the extreme possibility of weaker concrete.

- The Compusoft analyses used concrete strengths amplified some 10% above the specified strength. With respect to the median concrete strength observed in the CTL tests, the Compusoft assumed concrete strengths fall approximately on the 10th percentile of the distribution (see the blue curve in previous Figure)

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2.3 Additional Concrete Testing on CTV Building Columns

1. Compare the results obtained from the CTV Building columns with similar well-known test results on unconfined and confined concrete columns in the 1980s.

2. Investigate any size effect that may have been present.

3. Examine the performance of concrete column elements that exhibited a poor post-collapse condition.

Fig. 2.4. The three column portions retrieved from the CTV Building used in the full-scale testing conducted at the University of Canterbury

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Provisional Results

- The concrete strength is above the specified value of

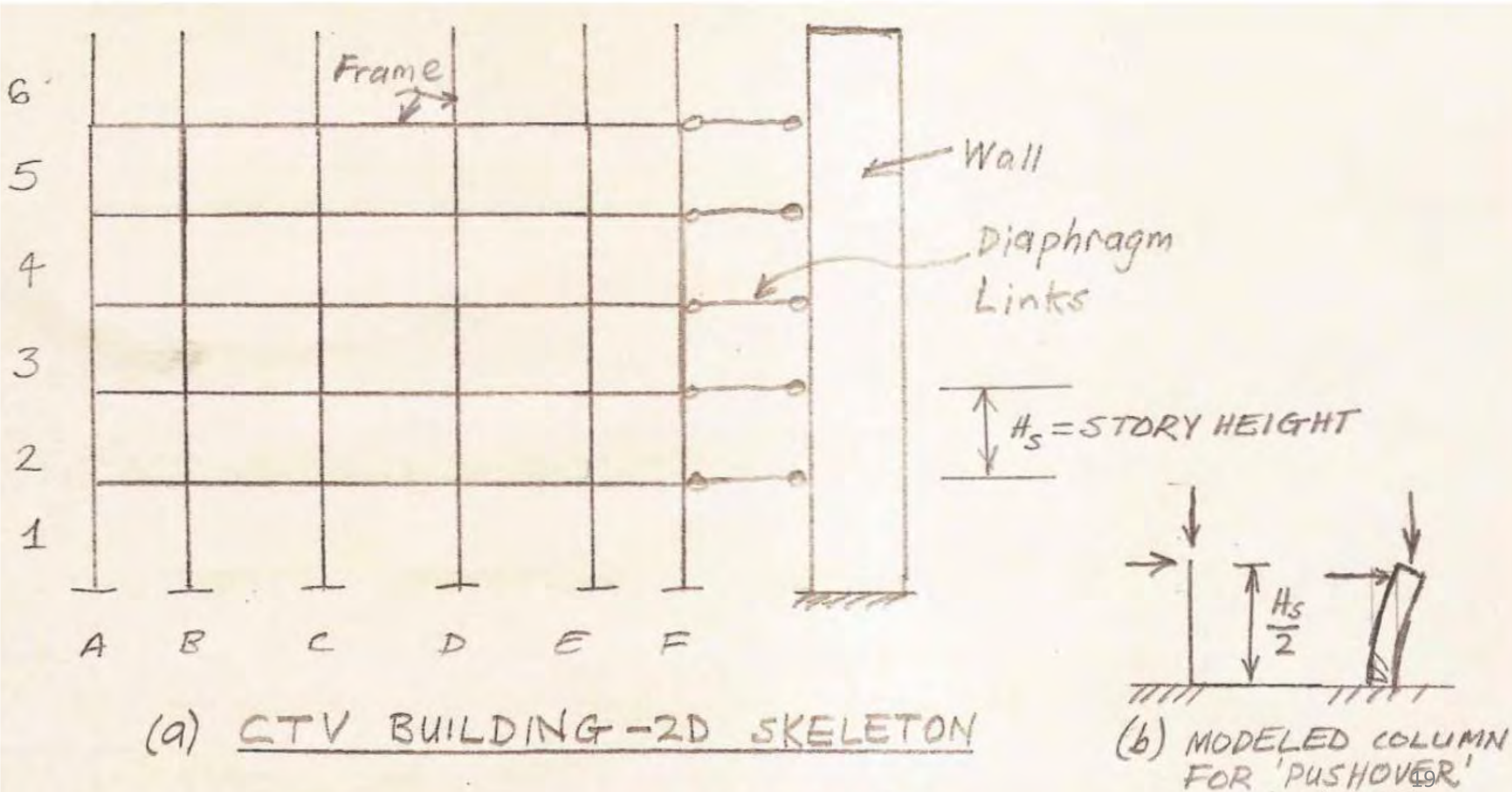
  $f'_c = 25$ MPa.

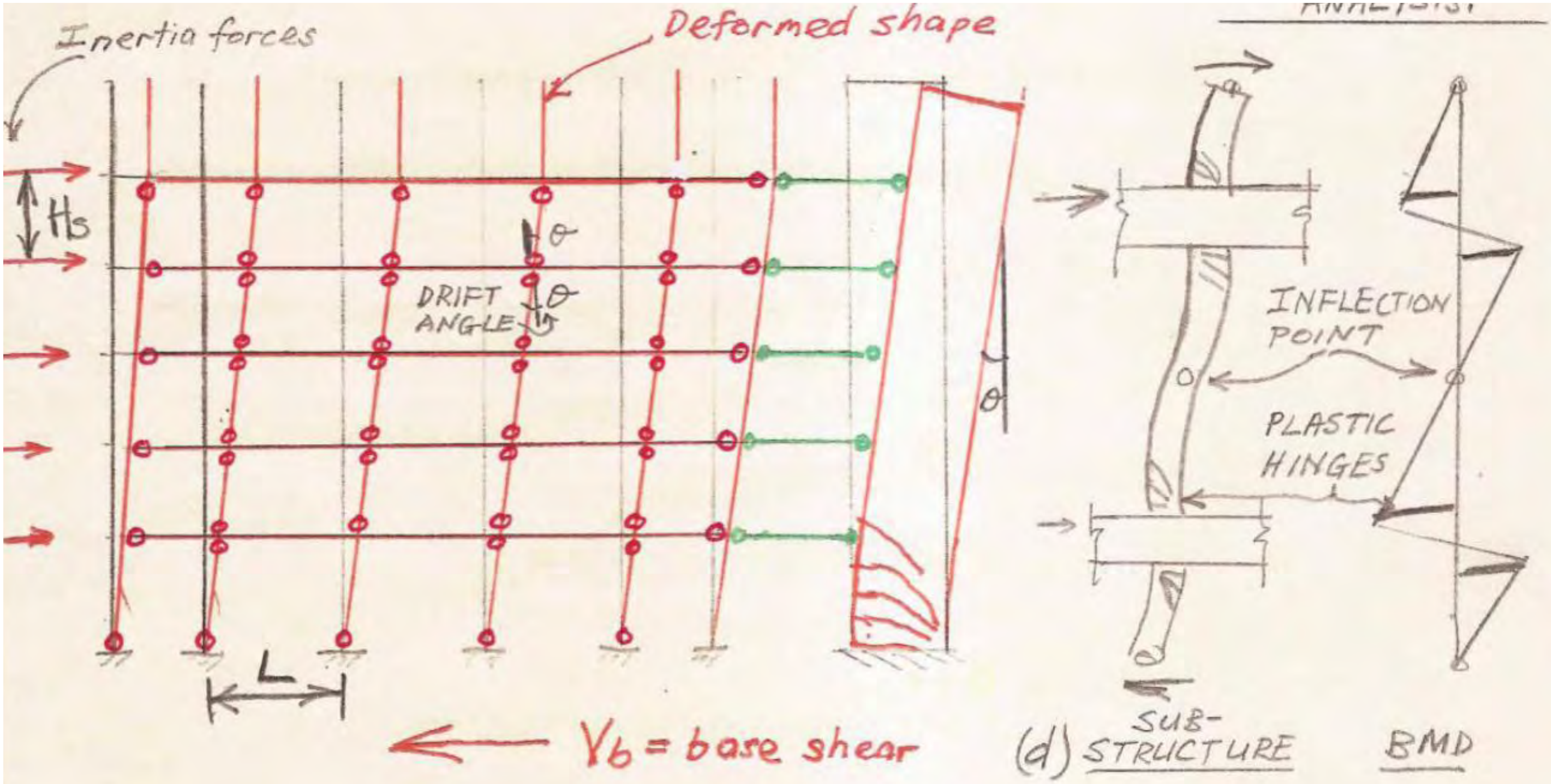
- There is a size-effect present.
  - This may be in the order of $f'_{co} = 0.85\, f'_c$,

where:

- f'_{co} = the in-situ strength of the full scale structural concrete; and
- f'_c = the standard 100 mm x 200 mm test cylinder strength for the concrete taken from the same pour

2.4 Column Performance Analysis





Inertia forces
Deformed shape
Hs
θ
DRIFT ANGLE
θ
θ
L
Vb = base shear
INFLECTION POINT
PLASTIC HINGES
(d) SUB-STRUCTURE
BMD

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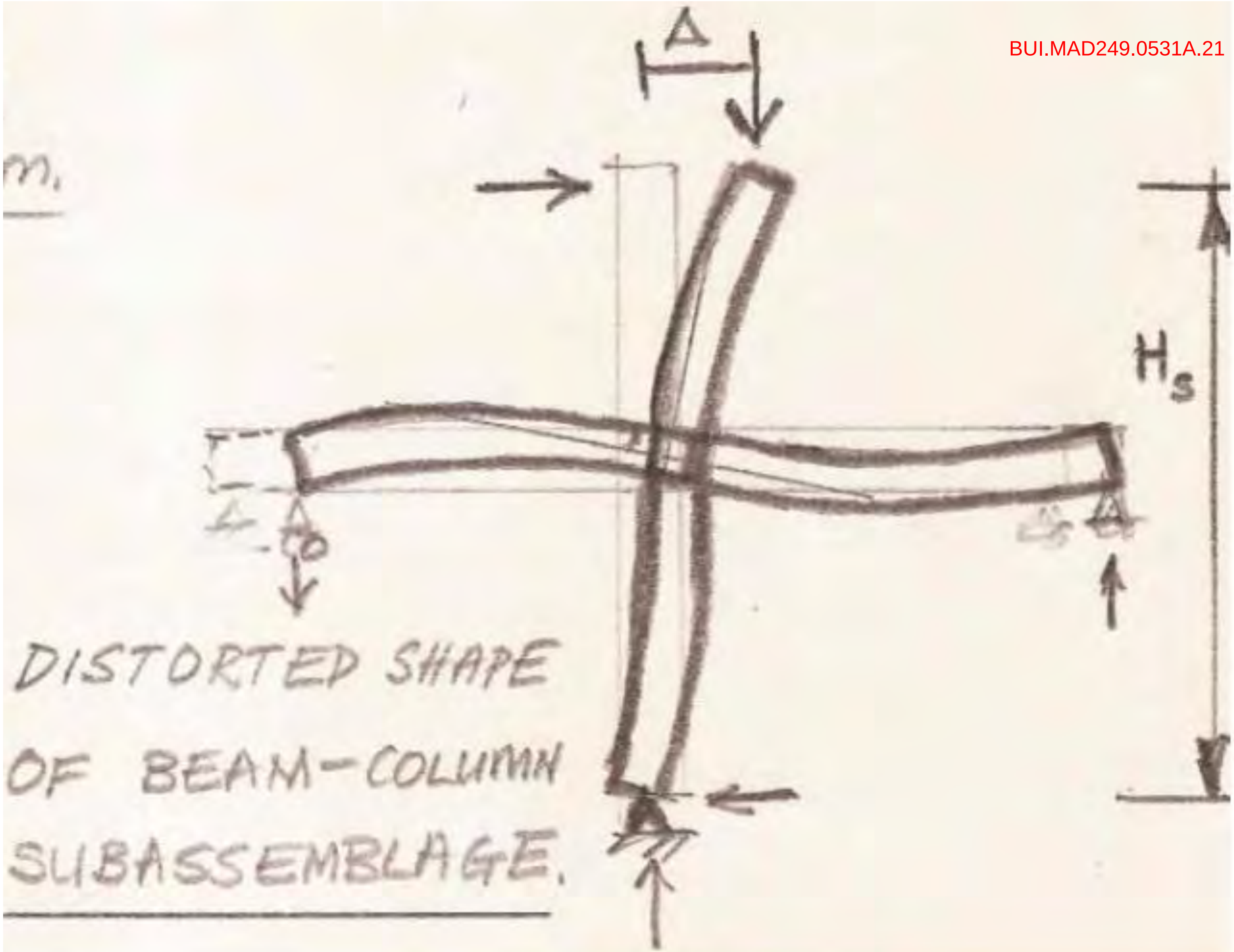

$$\theta_t = \theta_c + \theta_b + \gamma_j$$

Normal gravity axial load effects

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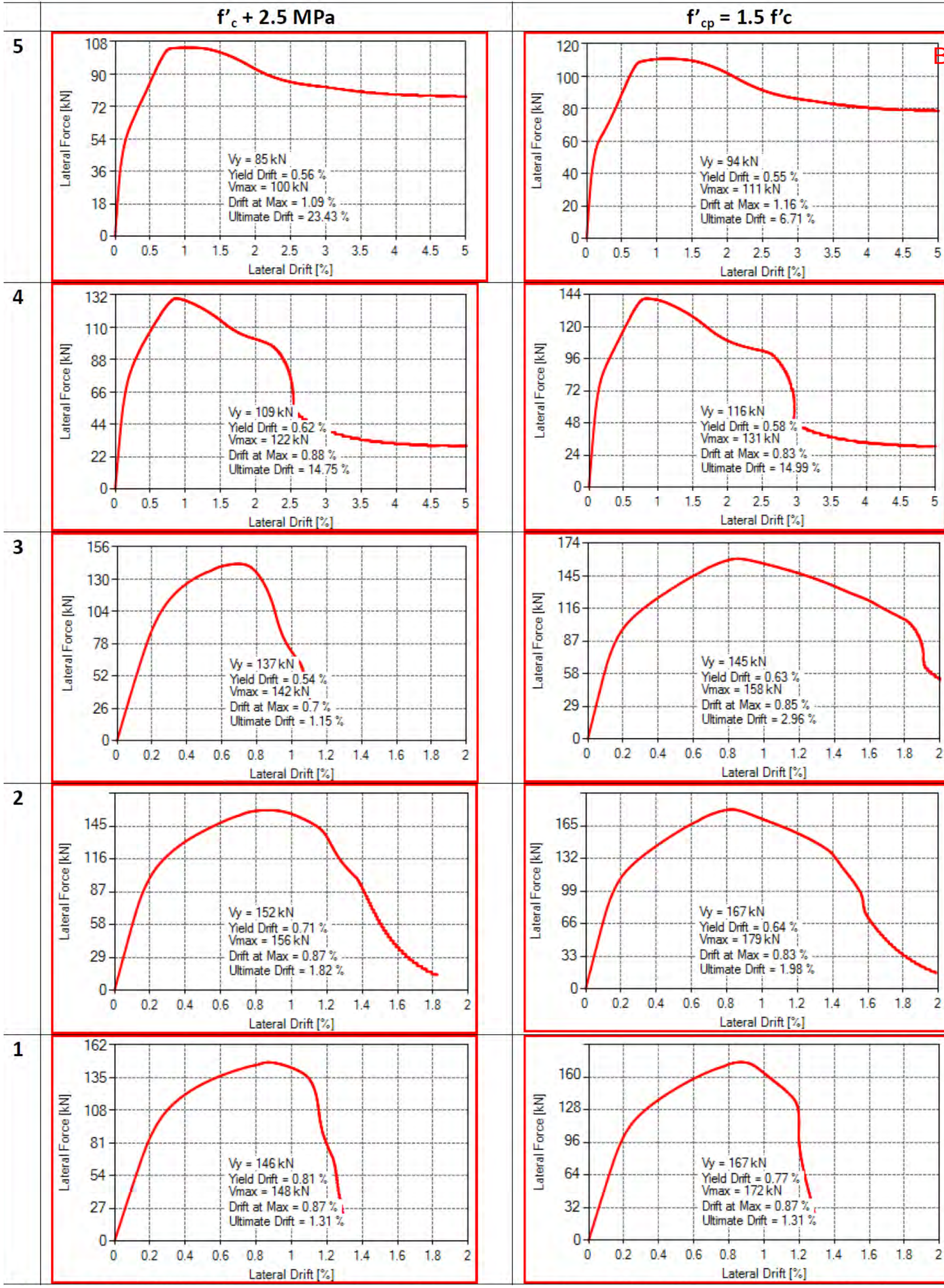

Gravity axial plus seismic axial load effects.

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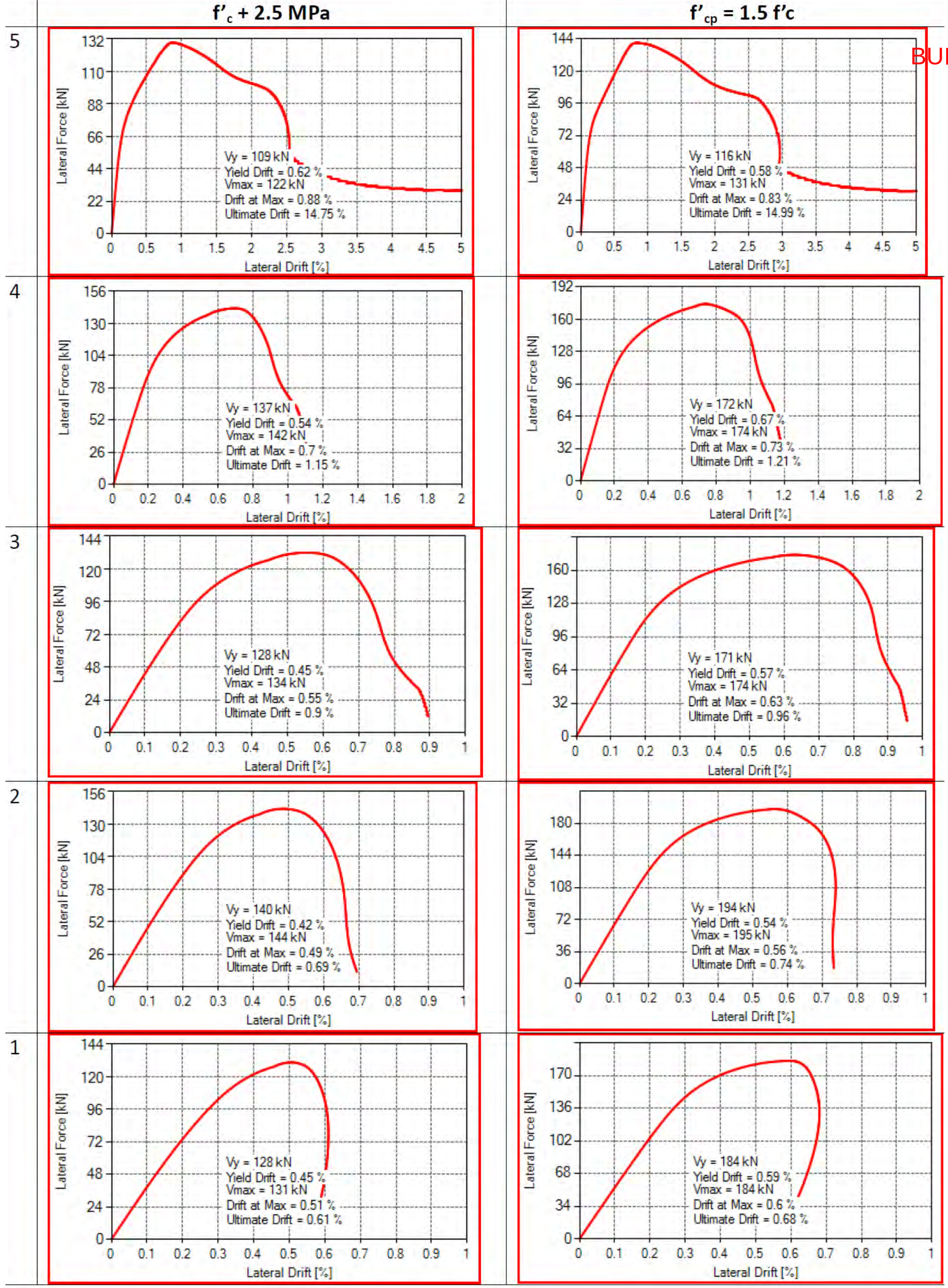


2.5 The Problem with the Beam-Column Joints

Normal capacity design

desired strength hierarchy
(from weakest to strongest)

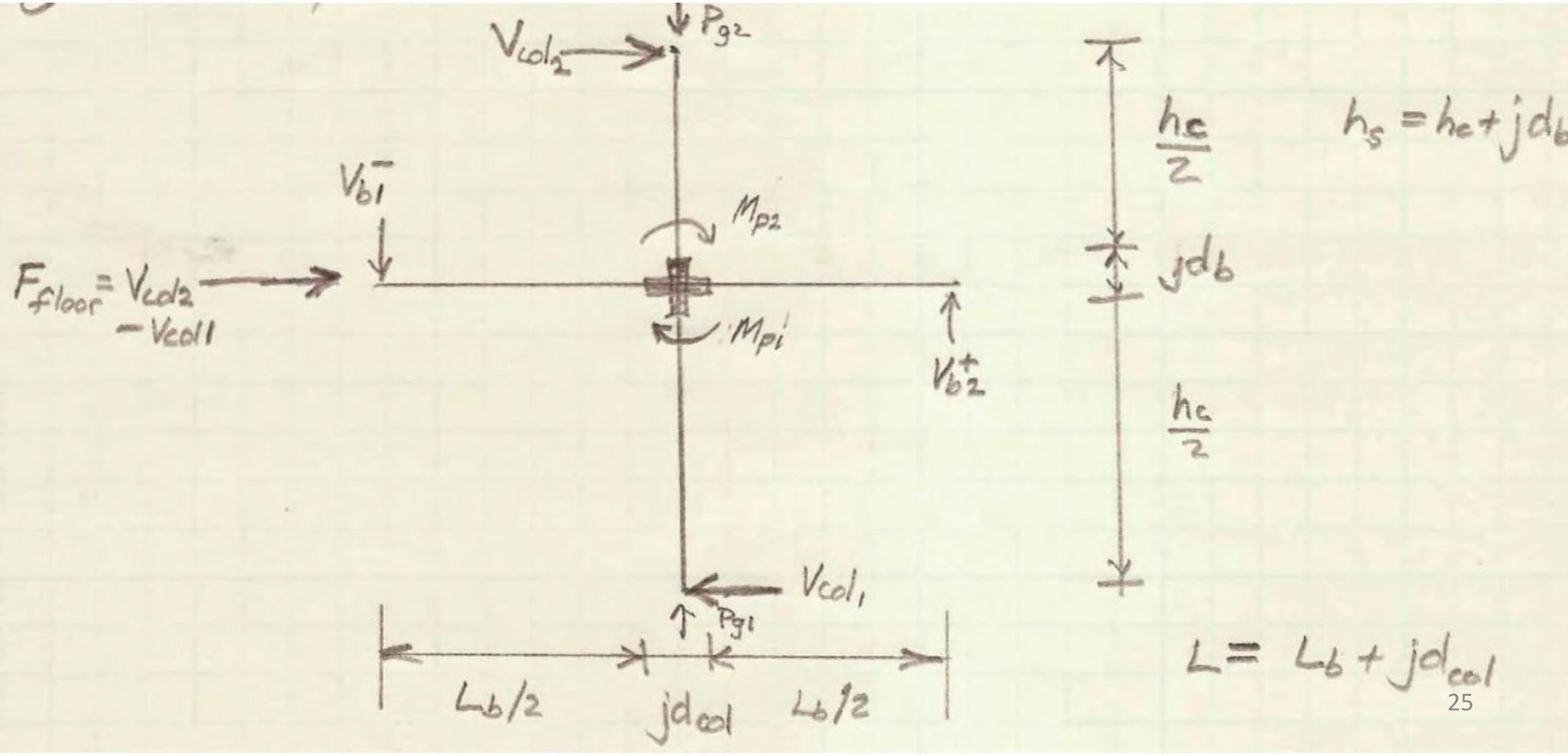
1. Beam bending (flexure)
2. Column bending/flexure
3. Joint shear
4. Foundation capacity

CTV Building

under an E-W sidesway
(from weakest to strongest)

1. Joint shear
2. Column flexure
3. Beam flexure
4. Wall Capacity or foundation rocking

(a) A typical interior beam column joint subassemblage showing the seismic loading actions under the frame, sidesway from left to right



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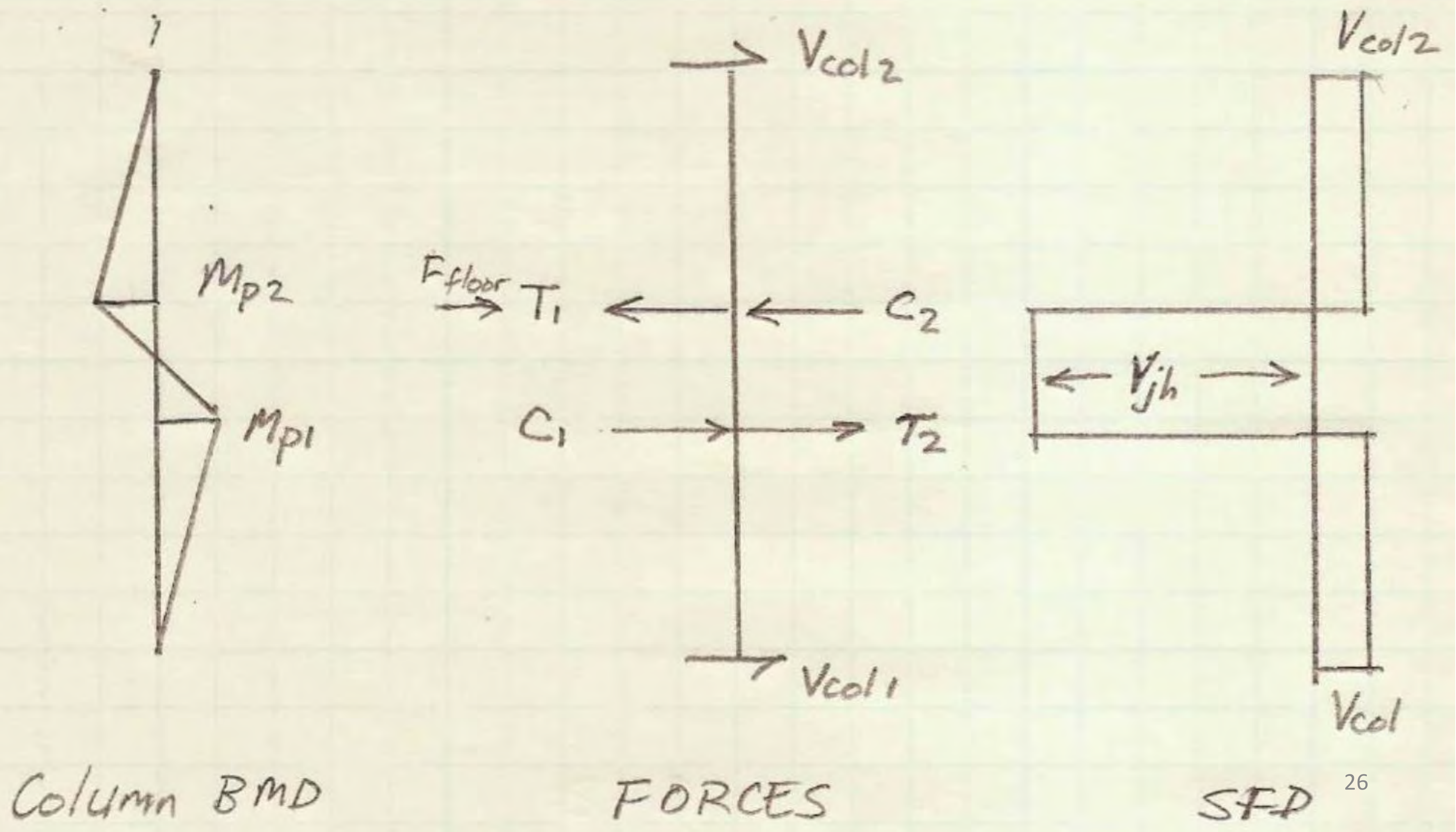
(b) The column extracted from the subassemblage

Note: ***the beams have been removed, but the incoming and outgoing forces provided by the beam reinforcement are shown instead***



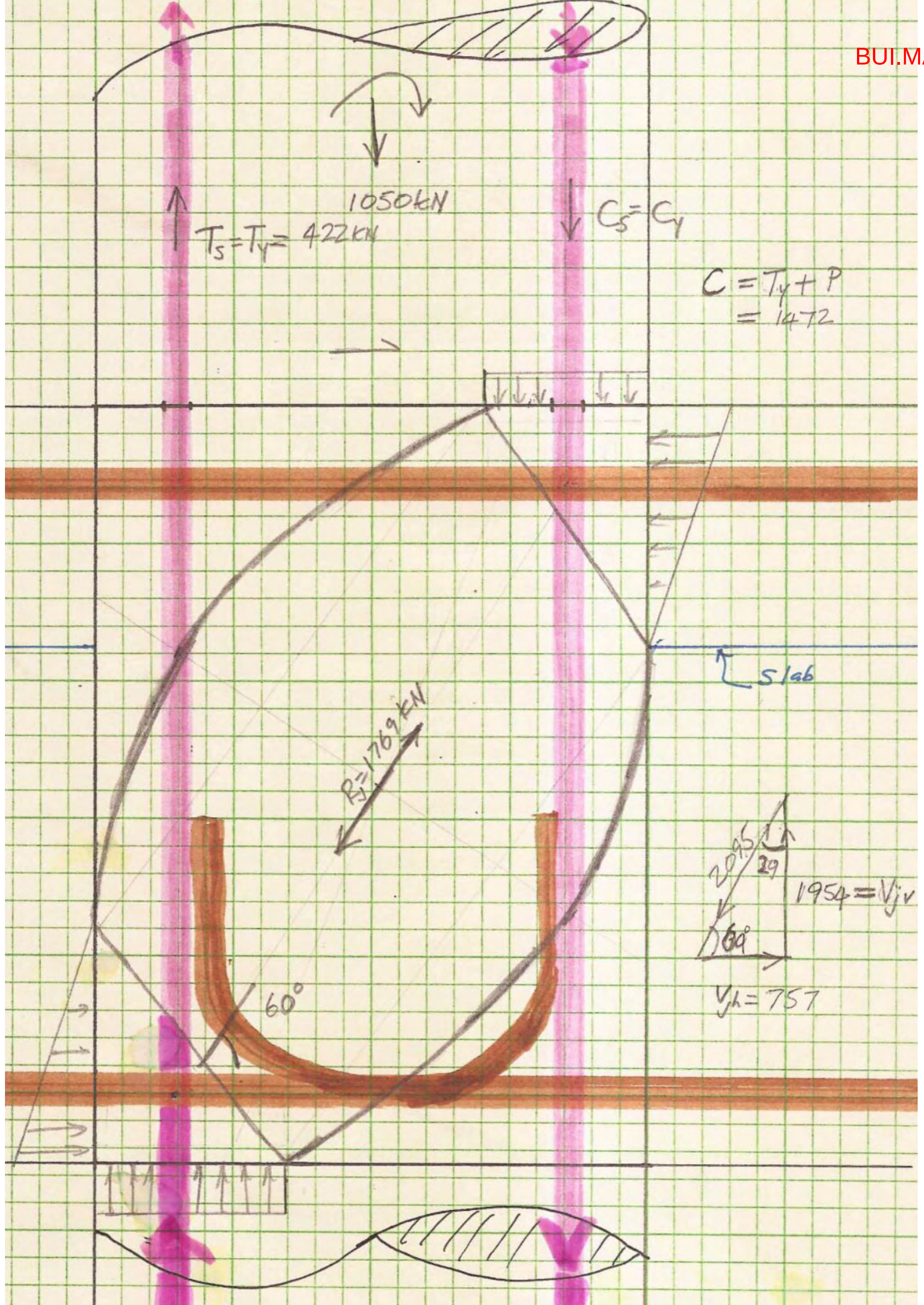
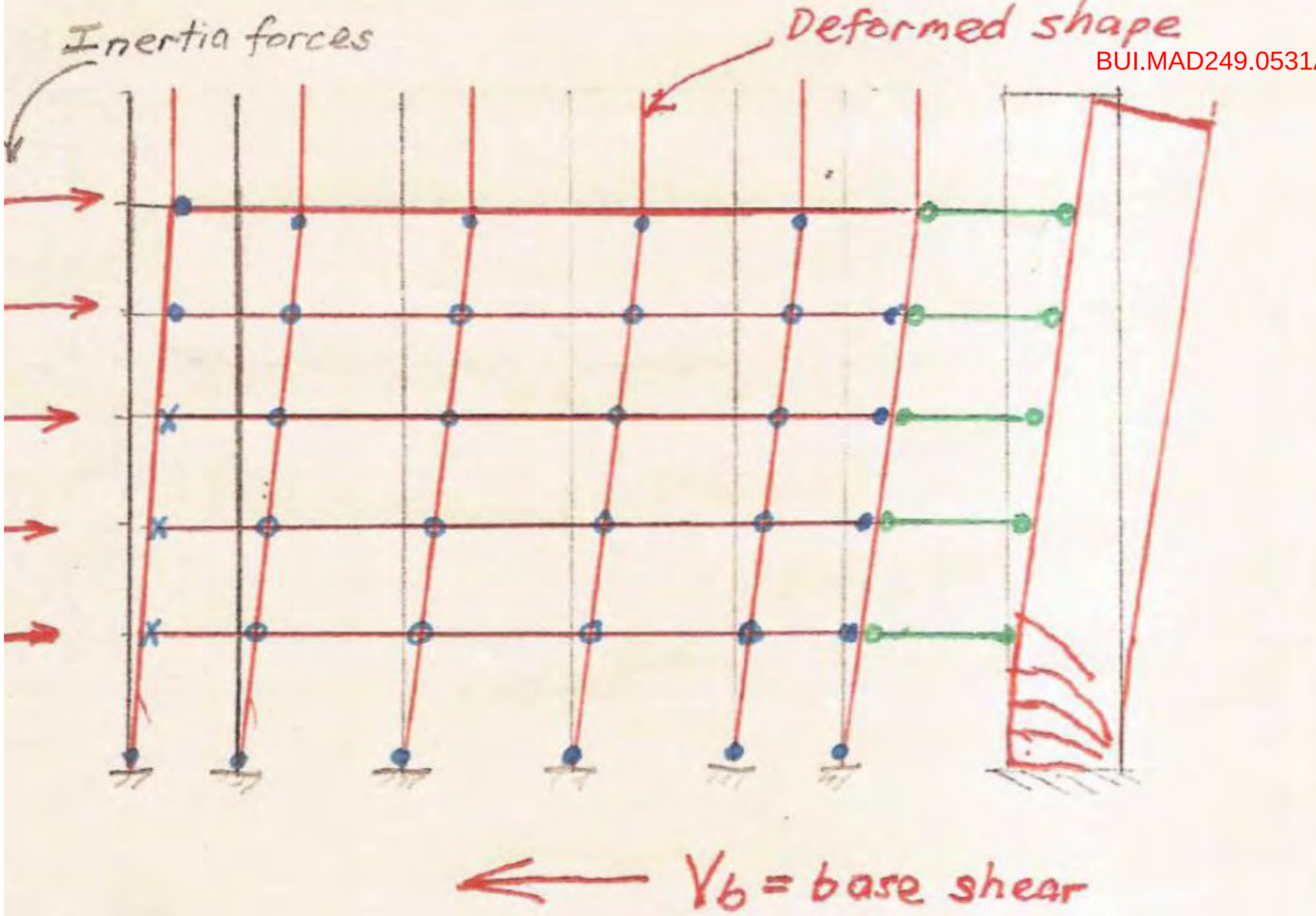


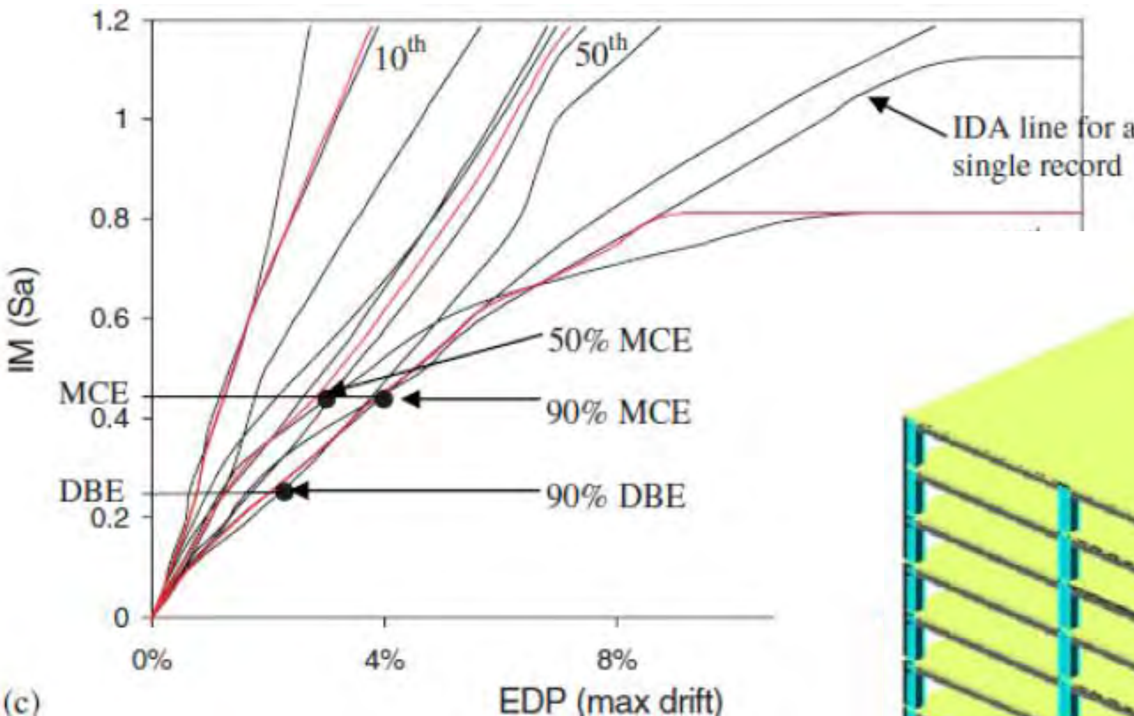
Fig 2.9. The beam column joint region



- ● Plastic hinge zones at member ends
- x Failed plastic hinge zone through joint pull out
- o Beam-column joint regions where the joints are weak in shear or failed in shear trying to resist high column and beam moment effects.

Fig 2.10. *The modified sidesway mechanism arising from the presence of "weak" beam-column joint regions*

2.6 Expected Seismic Performance of an Exemplar Structure in the Christchurch Earthquake



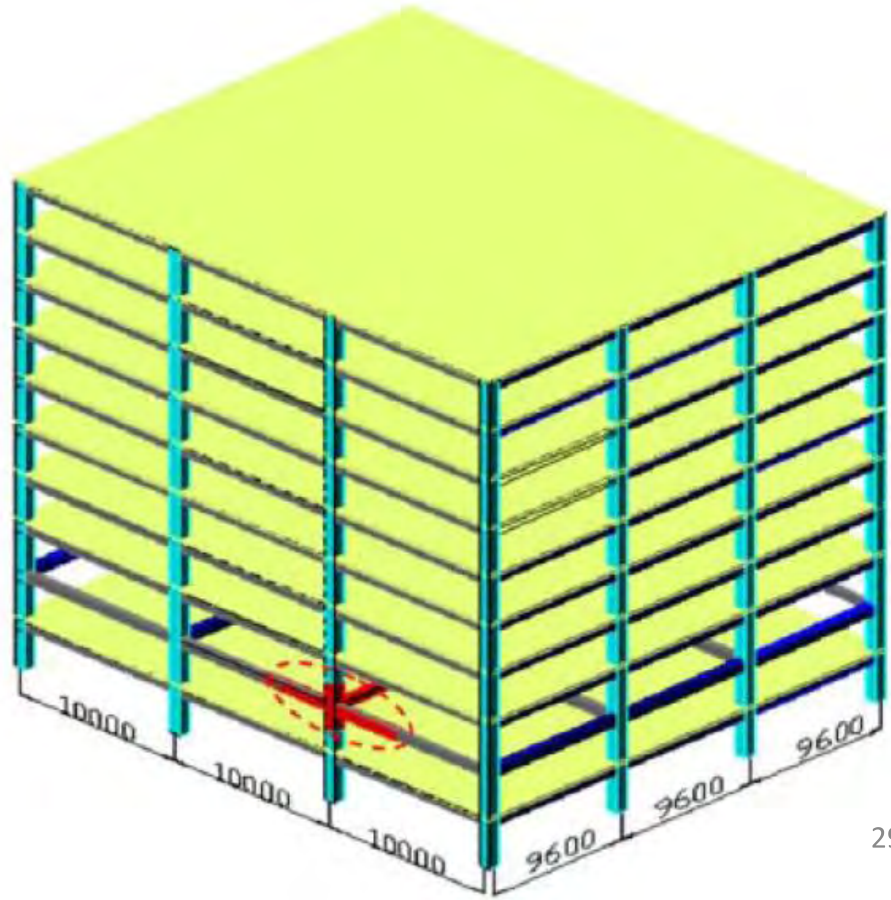


Fig. 2.11. Damage loss attenuation of the ***REDBOOK BUILDING*** *for the Christchurch Earthquake.*

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