CTV Seismic Analysis and Review of Secondary Frames

Evidence for the Canterbury Earthquakes Royal Commission of Inquiry

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Context of Review

- 1986 context
- Application of applicable standards NZS 4203:1984 and NZS 3101:1982
- Does not intend to replicate what was done in the original design
- What could have been done in 1986

Process of assessment

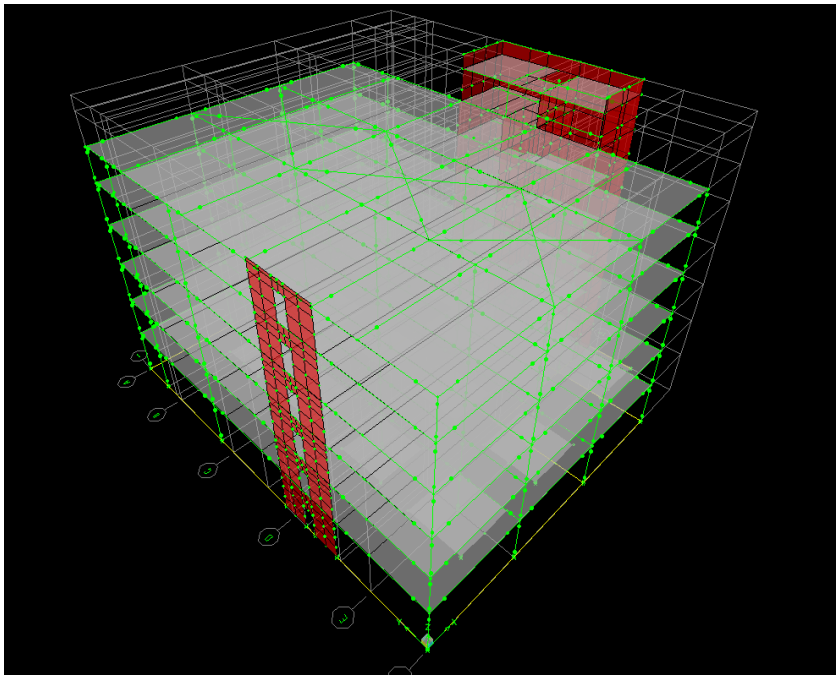
Two phases:

1. Lateral analysis using ETABS to determine the drifts and displacements under code loads
2. Assessment of columns under the drifts determined above

The assumptions must be consistent between the two phases

DBH Analysis

- 3D ETABS model developed by Compusoft
- Flexible foundations using upper bound soil stiffness recommended by Tonkin & Taylor (2011)



ERSA Panel

- Panel set up by RC to determine whether the Compusoft model was the most reliable
- ARCL requested that:
  - The foundation stiffness should reflect the recommendations by the original geotechnical engineer Mr Ian McCahon
  - The masses should reflect the 1986 information and assumptions

Further analysis

ARCL made adjustments to the DBH ETABS model:

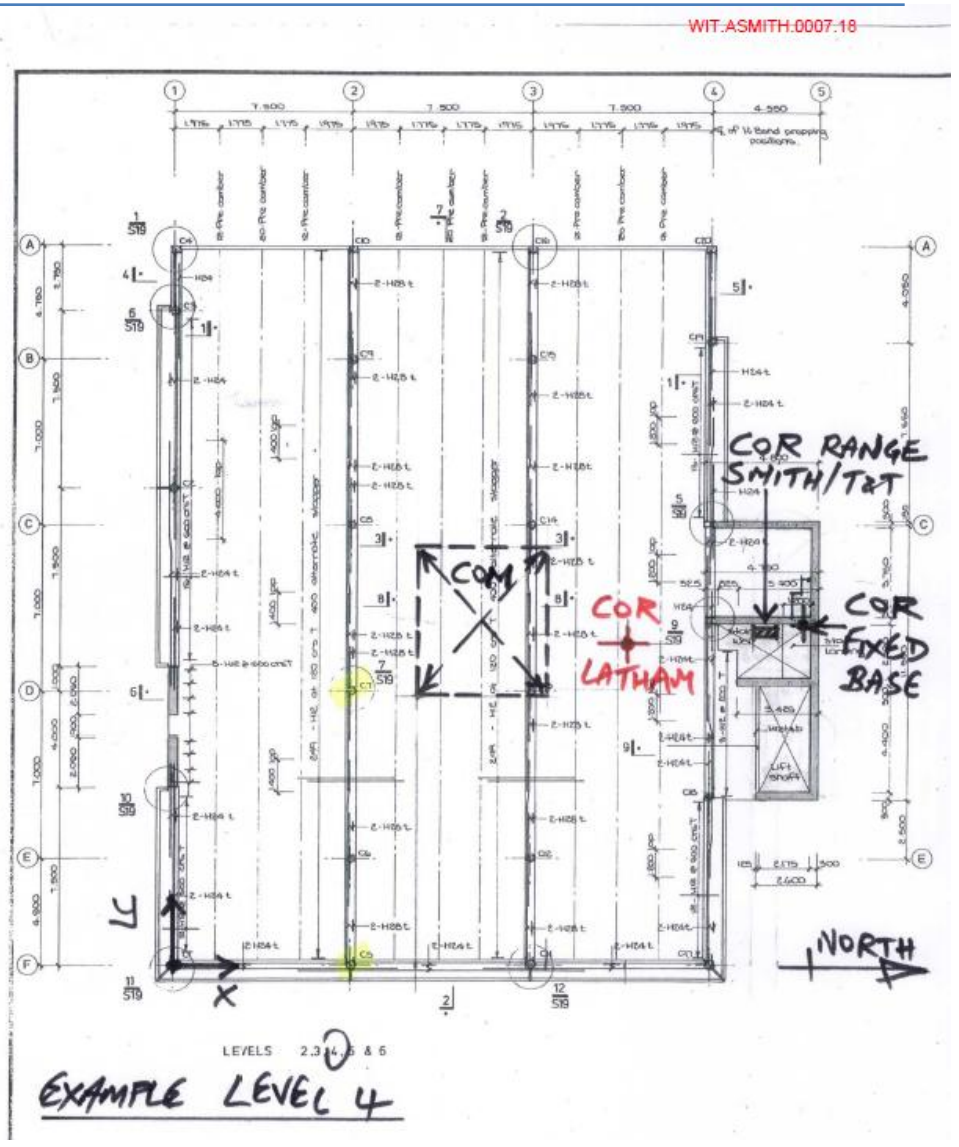
- Used soil stiffness recommended by the original geotechnical engineer Mr Ian McCahon (along with other minor changes such as adjusting the building mass)

In response to ARCL analysis, Compusoft presented further analysis using:

- A fully rigid base
- Most probable soil stiffness values recommended by T&T
- Lower bound soil stiffness values recommended by T&T

Effects of Foundation Stiffness

- Building natural period of vibration
- Relative stiffness of north core walls to south coupled wall
- Moderate eccentricity with McCahon stiffness vs. high degree of eccentricity with rigid base or T&T stiffness



Foundation Rotations

Clause 3.8.1.2 of NZS 4203:1984 stated:

"Computed deformations shall be calculated neglecting foundation rotations."

- A flexible foundation model is in conflict with this clause
- No issue with a fixed base model

Summary of Drifts

Grid F, North-South K/SM scaled drifts (%)

Level	Compusoft T&T Upper bound (DBH Report)	Compusoft Fixed Base	ARCL McCahon **
L5-6	0.66	0.47	0.45
L4-5	0.67	0.46	0.44
L3-4	0.64	0.43	0.40
L2-3	0.58	0.35	0.33
L1-2	0.44	0.18	0.19

** Foundation rotations were neglected when determining these drifts

Ref: WIT.ASMITH.0007.19
WIT.LATHAM.0002.22

Summary of Drifts

Grid 1, East-West K/SM scaled drifts (%)

Level	Compusoft T&T Upper bound (DBH Report)	Compusoft Fixed Base	ARCL McCahon **
L5-6	0.80	0.72	0.46
L4-5	0.78	0.71	0.45
L3-4	0.72	0.63	0.40
L2-3	0.59	0.48	0.31
L1-2	0.35	0.22	0.14

** Foundation rotations were neglected when determining these drifts

Ref: WIT.ASMITH.0007.20
WIT.LATHAM.0002.23

Summary of Drifts

Grid 2, East-West K/SM scaled drifts (%)

Level	Compusoft T&T Upper bound (DBH Report)	Compusoft Fixed Base	ARCL McCahon **
L5-6	0.59	0.53	0.36
L4-5	0.58	0.52	0.35
L3-4	0.53	0.46	0.31
L2-3	0.44	0.35	0.25
L1-2	0.26	0.16	0.12

** Foundation rotations were neglected when determining these drifts

Ref: WIT.ASMITH.0007.21
WIT.LATHAM.0002.23

Assessment of Columns

Clause 3.5.14.3 of NZS 3101:1982 outlined requirements for Group 2 secondary elements:

- *"Additional seismic requirements of this Code need not be satisfied when the design loadings are derived from the imposed deformations vΔ, specified in NZS4203, and the assumptions of elastic behaviour."*
- *"Additional seismic requirements of this Code shall be met when plastic behaviour is assumed at levels of deformation below vΔ."*

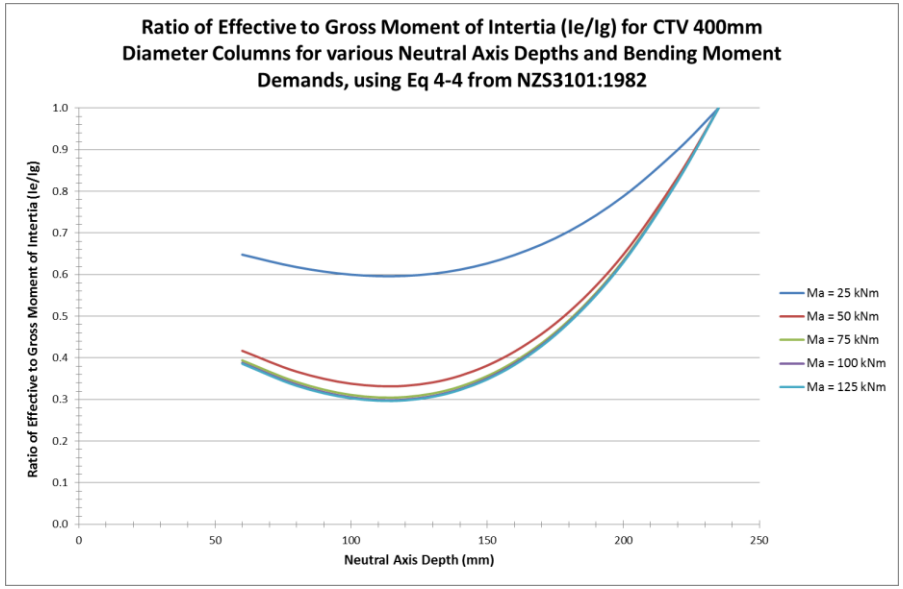
Method of Assessment

How do you determine if the columns remain elastic?

1. Moment-curvature analysis (Hyland and as presented in the DBH Collapse Report)
2. Working stress method Appendix B NZS 3101:1982 (Hyland)
3. Elastic frame analysis using uncracked properties and assessing against dependable strength (Smith)
4. Elastic frame analysis using cracked properties and assessing against dependable strength (Latham)

Degree of Cracking

- Can use simplistic assumption of uncracked properties for all columns
- Can carry out more detailed assessment using Equation 4-4 of NZS3101:1982, where degree of cracking is dependent on axial and flexural demands



Comparison

Grid F, North-South K/SM scaled drifts (%)

	DEMANDS		ELASTIC CAPACITY		
Level	**Compusoft Fixed Base**	**ARCL McCahon ****	**Hyland**	**Smith**	**Latham**
L5-6	0.47	0.45	0.62	0.21	0.52
L4-5	0.46	0.44	0.73	0.22	0.50
L3-4	0.43	0.40	0.69	0.25	0.40
L2-3	0.35	0.33	0.61	0.23	0.40
L1-2	0.18	0.19	0.55	0.24	0.40

** Foundation rotations were neglected when determining these drifts

Ref: WIT.ASMITH.0007.21
WIT.LATHAM.0002.23
WIT.ASMITH.0007.38
BUI.MAD249.0189.288

Comparison

Grid 1, East-West K/SM scaled drifts (%)

	DEMANDS		ELASTIC CAPACITY		
Level	**Compusoft Fixed Base**	**ARCL McCahon ****	**Hyland**	**Smith**	**Latham**
L5-6	0.72	0.46	0.65	0.21	0.52
L4-5	0.71	0.45	0.73	0.22	0.50
L3-4	0.63	0.40	0.64	0.25	0.40
L2-3	0.48	0.31	0.58	0.23	0.40
L1-2	0.22	0.14	0.50	0.24	0.40

** Foundation rotations were neglected when determining these drifts

Ref: WIT.ASMITH.0007.21
WIT.LATHAM.0002.23
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Comparison

Grid 2, East-West K/SM scaled drifts (%)

	DEMANDS		ELASTIC CAPACITY		
Level	**Compusoft Fixed Base**	**ARCL McCahon ****	**Hyland**	**Smith**	**Latham**
L5-6	0.53	0.36	0.65	0.24	0.66
L4-5	0.52	0.35	0.73	0.29	0.59
L3-4	0.46	0.31	0.64	0.39	0.46
L2-3	0.35	0.25	0.58	0.39	0.50
L1-2	0.16	0.12	0.50	0.29	0.51

** Foundation rotations were neglected when determining these drifts

Ref: WIT.ASMITH.0007.21
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Summary

- Columns remain elastic using ARCL drifts and either Latham or Hyland column criteria
- Different methods of analysis, different assumptions, different interpretations of the code clauses
- Conclusions on compliance are dependent on the above methods and assumptions