Seismic Assessment and Improvement of Napier's Art Deco Buildings

UACEER 2012 Earthquake Engineering Research Symposium

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ART DECO TRUST
NAPIER • NEW ZEALAND

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Quantifying Hazard: Recurrence Intervals and Intensity

Design working life	Importance level	Annual probability of exceedance for ultimate limit states			Annual probability of exceedance for serviceability limit states	
		Wind	Snow	Earthquake	SLS1	SLS2 Importance level 4 only
50 years	1	1/100	1/50	1/100	—	—
	2	1/500	1/150	1/500	1/25	—
	3	1/1000	1/250	1/1000	1/25	—
	4	1/2500	1/500	1/2500	1/25	1/500
100 years or more	1	1/250	1/150	1/250	—	—
	2	1/1000	1/250	1/1000	1/25	—
	3	1/2500	1/500	1/2500	1/25	—
	4	*	*	*	1/25	*

Recurrence Intervals (Standards NZ 2002)

Slight to moderate structural damage in ordinary buildings

Considerable structural damage in ordinary buildings with partial collapse

Damage great in substantial buildings with partial collapse, buildings shifted **(1931 Hawke's Bay EQ)**

Most masonry and frame structures destroyed

Location	MM6	MM7	MM8	MM9	MM10
Turangi	13	56	200	710	7900
Napier	**7**	**26**	**110**	**400**	**2100**
Dannevirke	6	24	95	470	7100
Taihape	9	39	250	3700	-
Raupunga	7	29	130	700	8700

= Design Basis EQ (DBE) (e.g., Napier's DBE ≈ MM 9.1)

Recurrence Intervals (GNS Science 2011: *Geology of the Hawke's Bay Earthquake* from Smith, W.D. (unpublished) and Stirling et al. 2002)

1931 Hawke's Bay EQ

(Hawke's Bay Cultural Trust)

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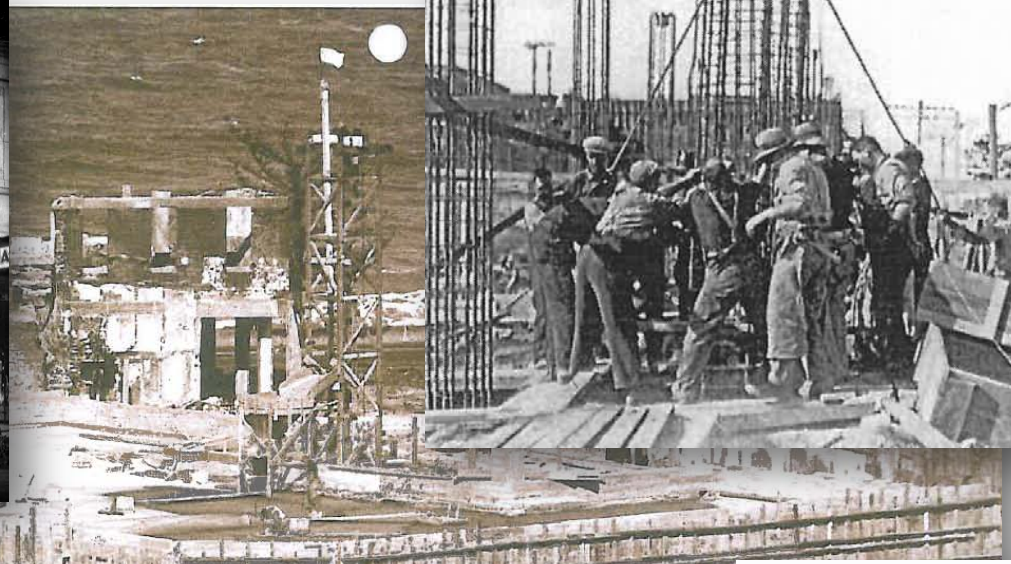
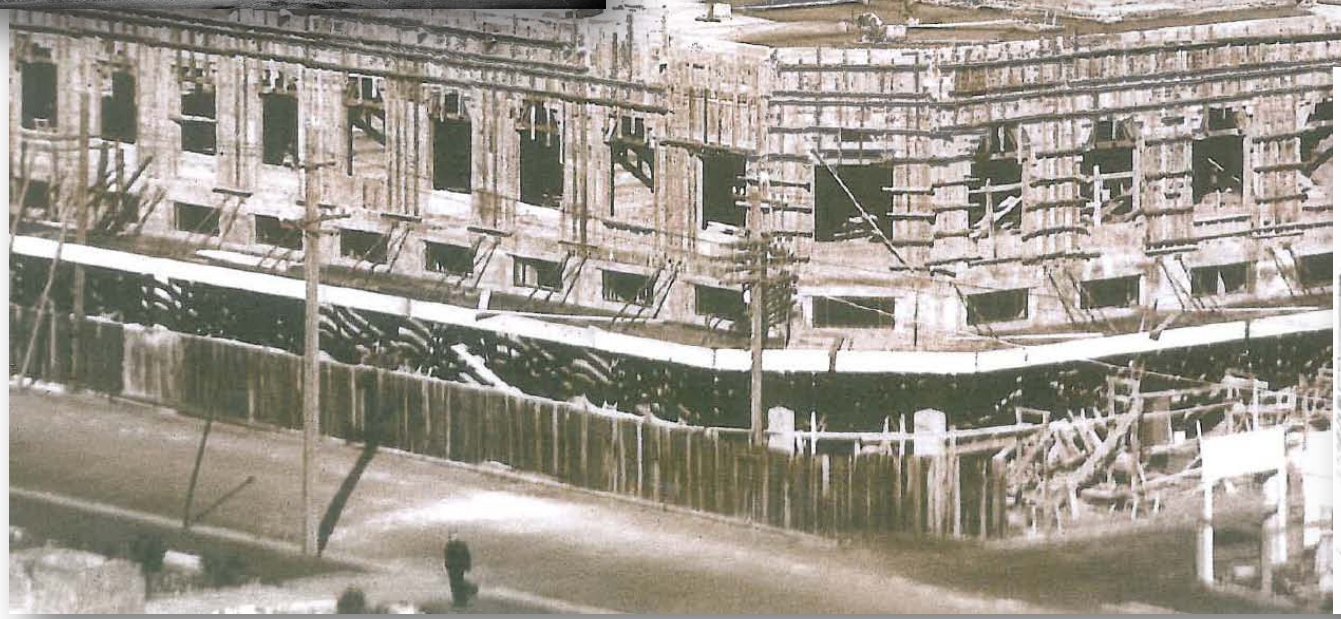
Rebuilding Hawke's Bay





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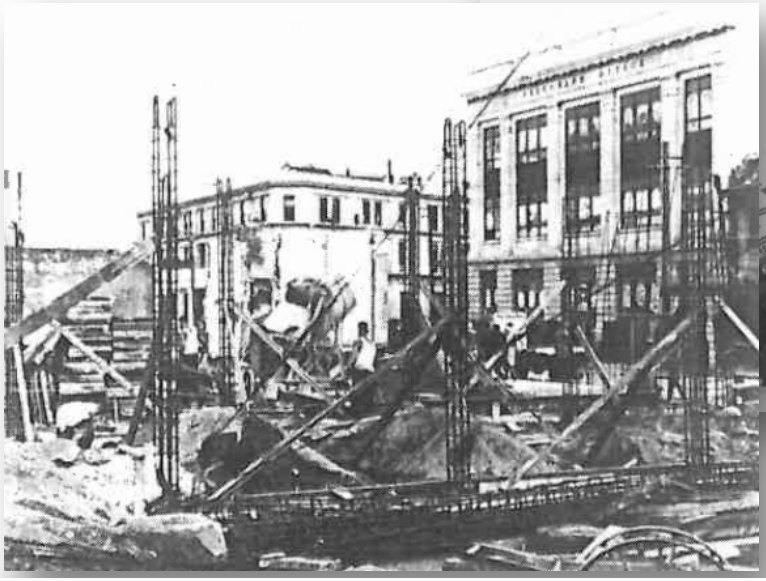
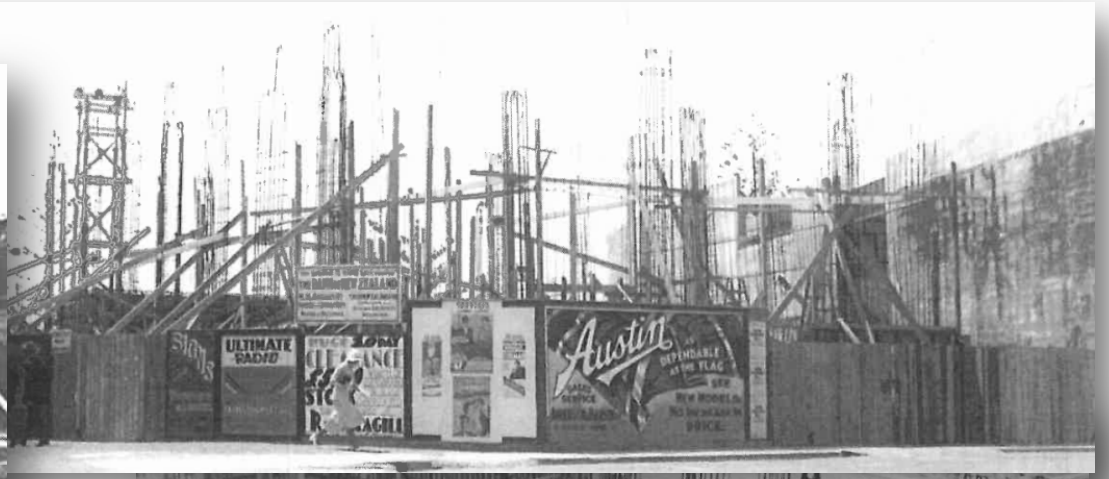
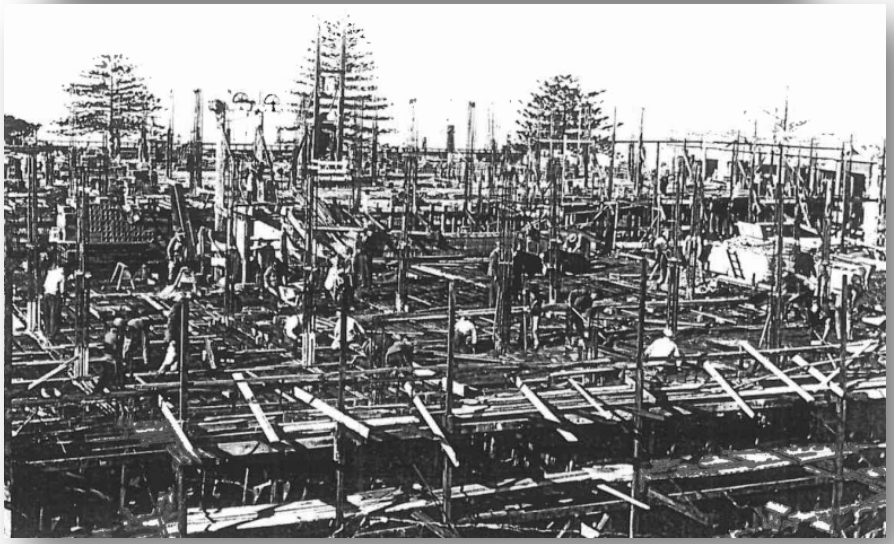
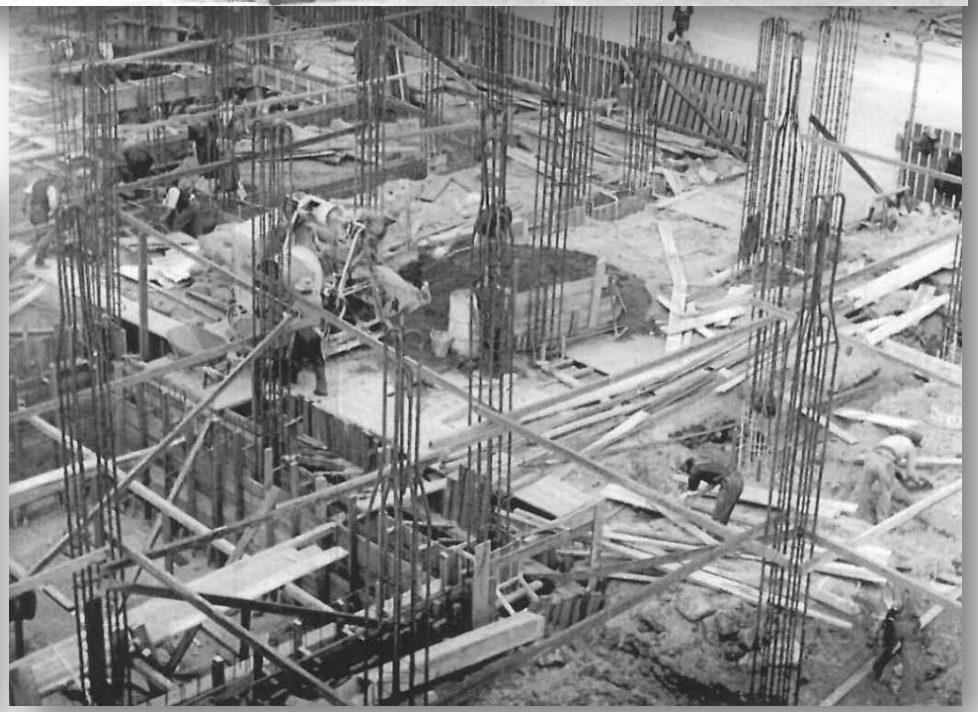
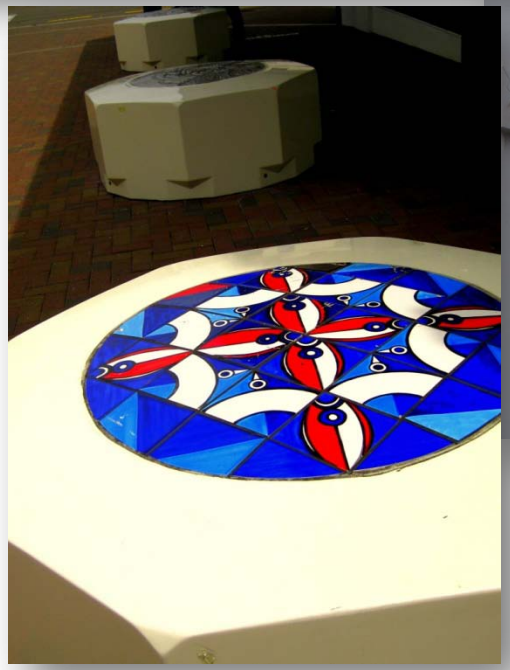








Napier Today



Levels of Analysis of "Art Deco" 1920-1940 Structures

- Level 1 – General Assessment of Existing Building Stock
  - 125 Buildings
- Level 2 – Prelim. IEP of Existing
  - 111 Buildings
- Level 3 – Forensic Assessment
  - 6 Buildings
- Level 4 – Detailed Assessment
  - 1 Prototypical Building
  - Not yet completed

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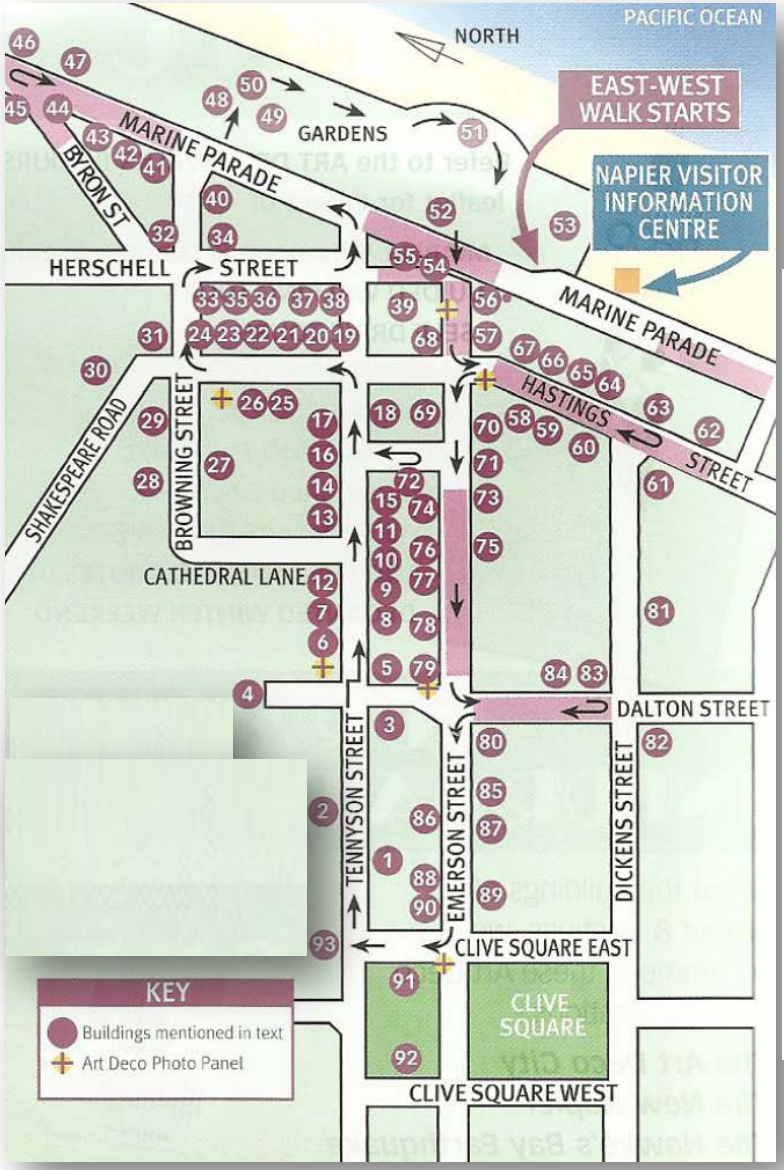
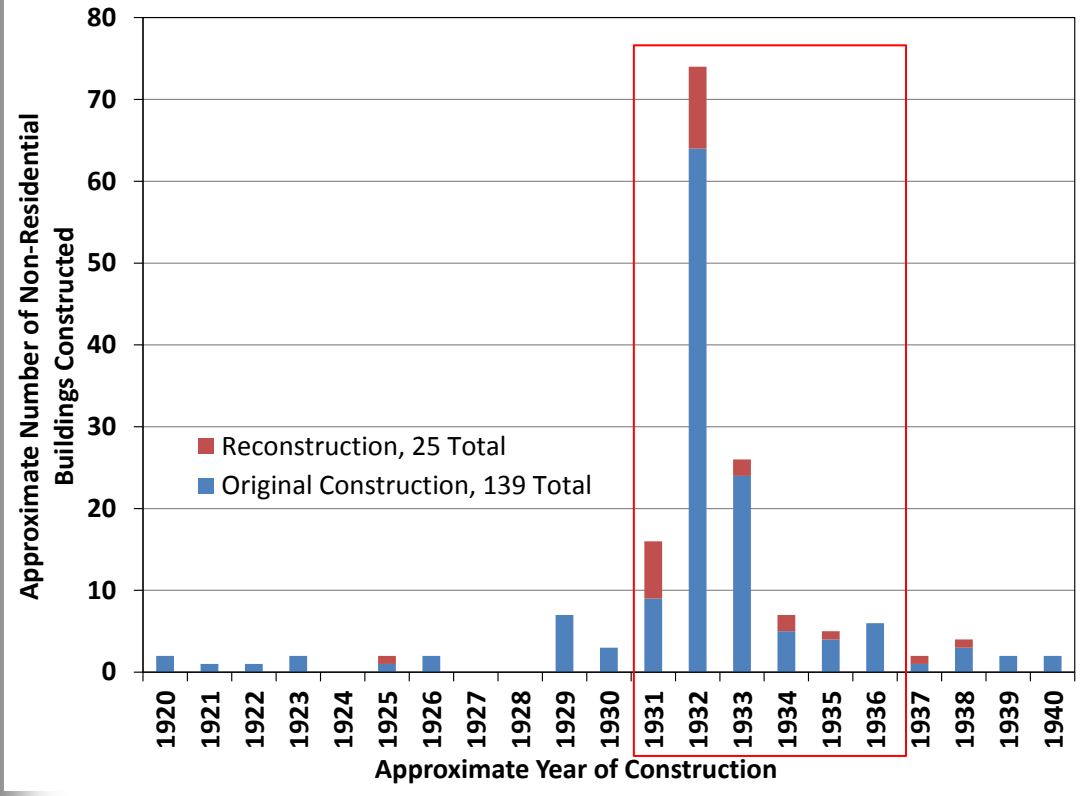
Level 1: Napier "Art Deco" Building Stock (1920-1940)

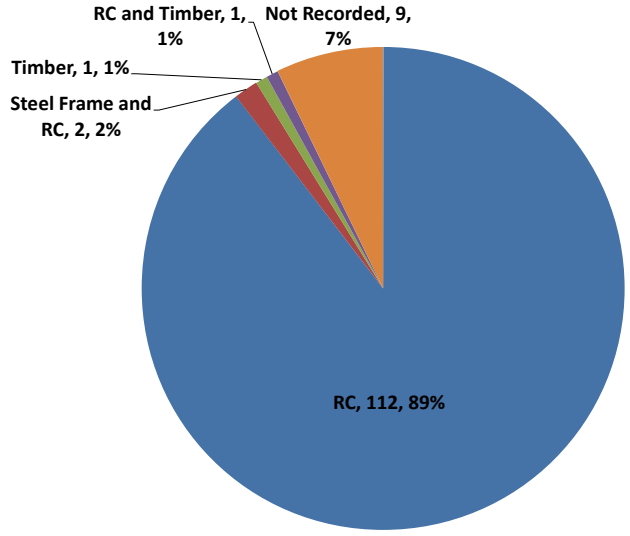


(Art Deco Trust 2012)

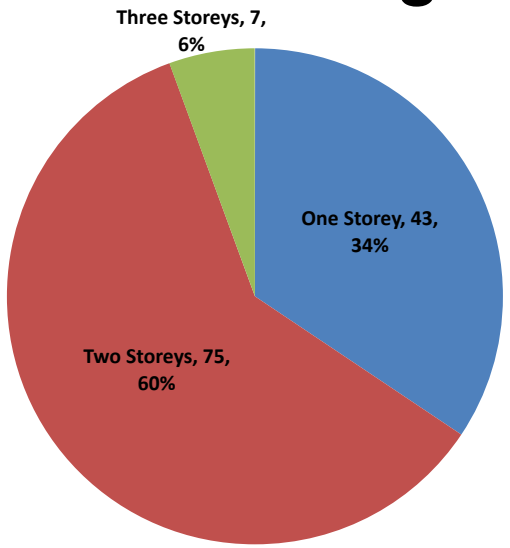


82% constructed/reconstructed 1931-1936

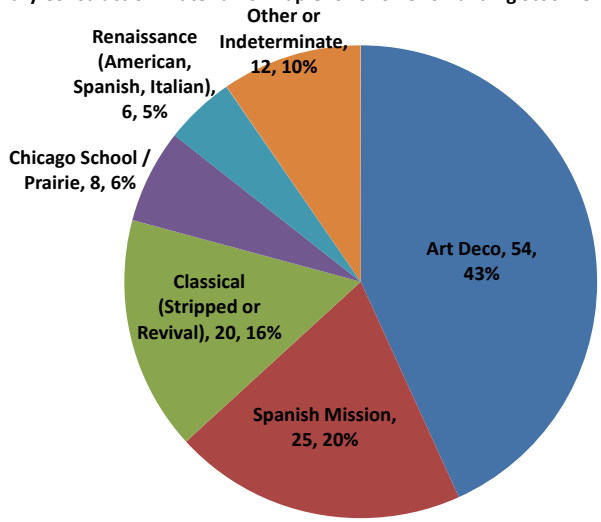
Level 1 – Stock Assessment of Existing:



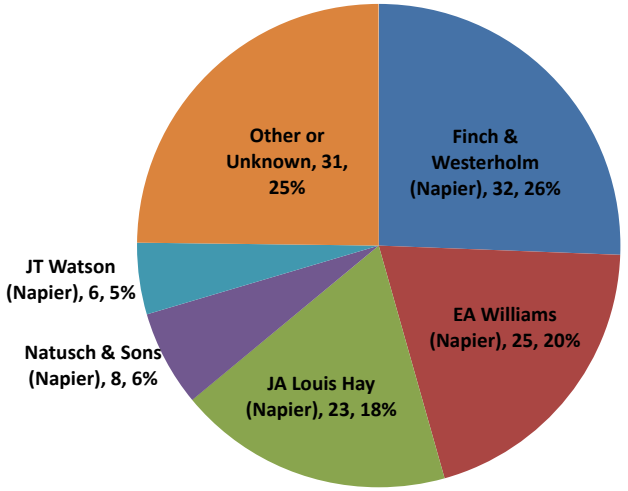
Primary Construction Material for Napier's 1920-1940 Building Stock remaining in 2012



Number of Storeys for Napier's 1920-1940 Building Stock remaining in 2012



Primary Architectural Styles for Napier's 1920-1940 Building Stock remaining in 2012

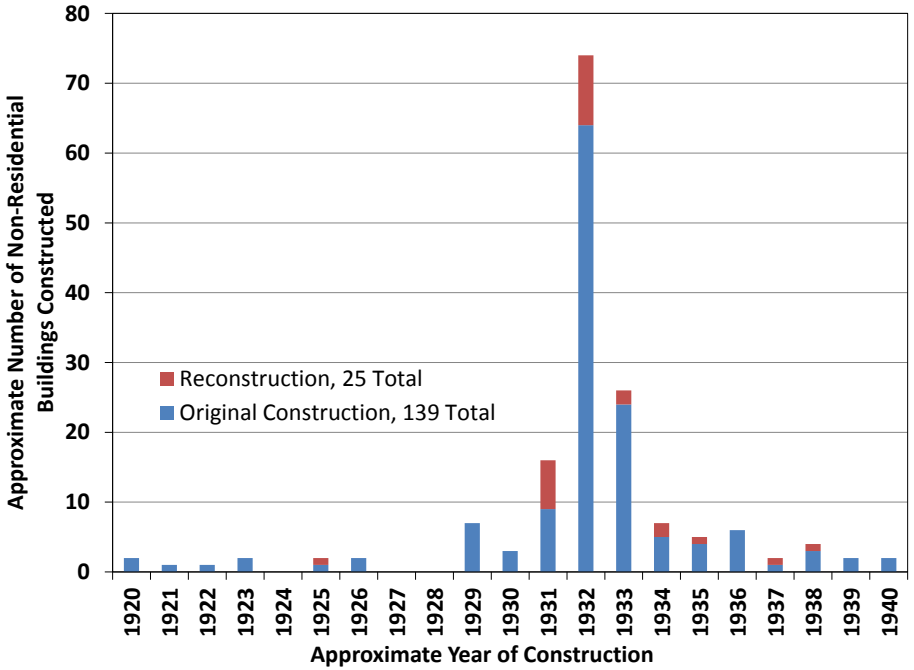


Primary Architects for Napier's 1920-1940 Building Stock remaining in 2012

Level One Summary

- 164 buildings erected 1920-1940
  - 140 remain today
  - 125 considered here, 105 constructed 1931-1936

- Prototypical building in this stock was
  - built soon after the 1931 EQ
  - constructed of RC frame
  - about 2 storeys in height
  - Art Deco in style
  - designed by 1 of 5 firms



Level 2 – Preliminary IEP of Existing (111)

- Most are moment-resisting reinforced concrete (RC) frames
- Some have brick infill walls; floors of concrete or timber; roofs of timber, iron, concrete slab and/or CGI; high parapets
- 1 to 3 storeys (Avg. 1.7)
- Year of construction (or reconstruction if applicable) 1926-1955 (Avg. 1933)
- Remainder of IEP input assumed standard except for Level 3 buildings (i.e., ductility = max, PAR = 1.0, etc.)

Level 2 – Preliminary IEP of Existing (111)

Initial Evaluation Procedure %NBS

- Assuming Soil Type D (deep, soft soils) and PAR=1.0
  - IEP %NBS Range: 13.2 - 17.5
  - IEP %NBS Avg.: 13.7
- Assuming Soil Type C (shallow soils) and PAR=1.0
  - IEP %NBS Range: 17.0 - 25.0
  - IEP %NBS Avg.: 17.8

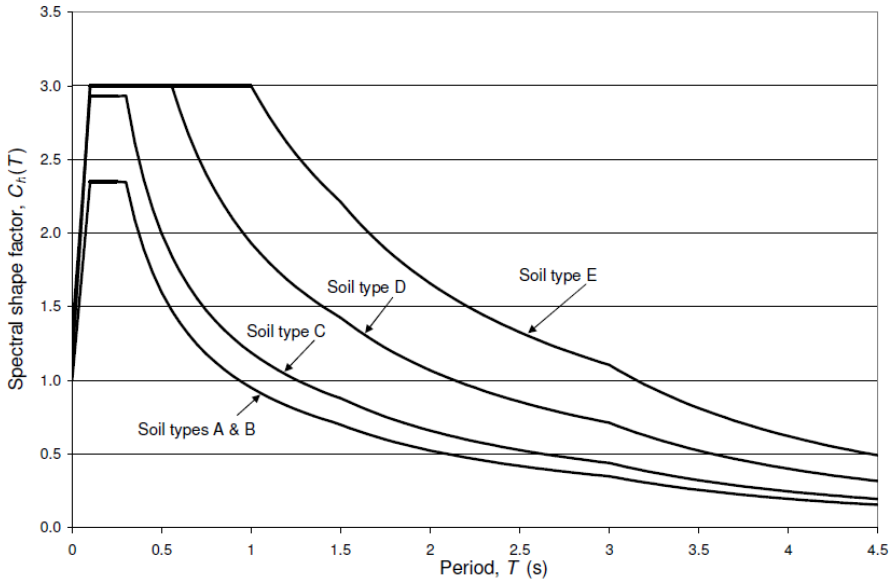


FIGURE 3.2 SPECTRAL SHAPE FACTOR, $C_h(T)$ FOR MODAL ANALYSIS, NUMERICAL INTEGRATION TIME HISTORY ANALYSIS, VERTICAL LOADING AND PARTS

(NZS 2004)

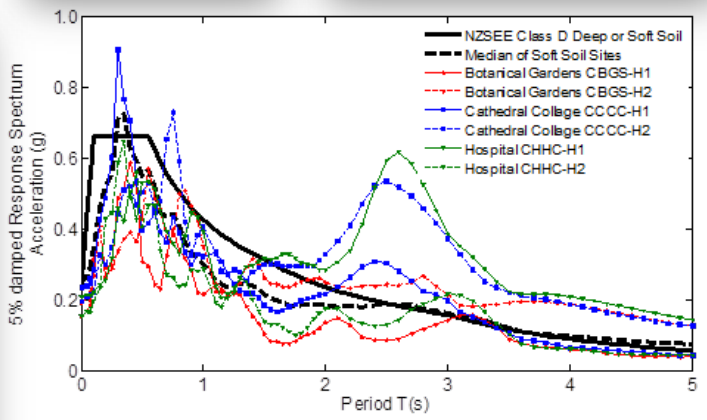
Level 3 – Forensic Assessment (6)

- 6 buildings visited, reviewed, and considered individually
  - Year of construction (or reconstruction if applicable) 1931-1932 (Level 2 Avg. 1933)
  - Moment-resisting reinforced concrete (RC) frames (some with partial steel framing components)
  - Some have brick infill walls; floors of concrete or timber; roofs of timber or iron framing, high parapets
  - All are 2 storeys (Level 1 & 2 Avg. 1.7)
  - Architects: (Level 1 top 4)
  - Styles: 3 x Art Deco (Level 1 top), others Renaissance and Chicago School/Prairie
  - Original plans (and building specs from one)

JA Louis Hay
(Art Deco Trust 2012)

Level 3 – Forensic Assessment (6): Christchurch Experience

- 10 similar buildings considered
  - RC frames, some with brick infill walls
  - built 1920-1940
  - 2-4 storeys
- 4 very similar in size & style



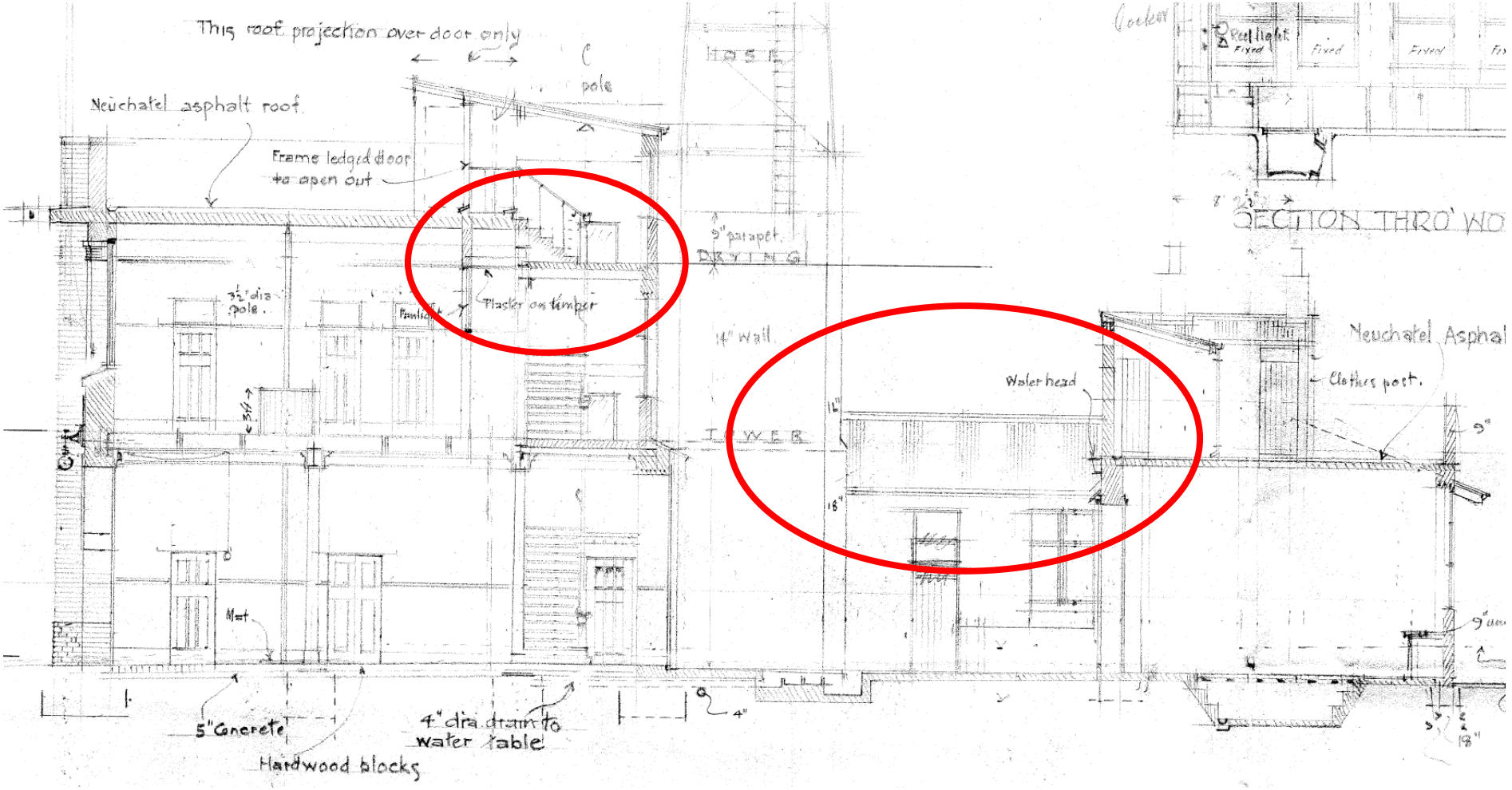
(Photos from W.Y. Kam, U. of Canterbury)

Christchurch Conclusions & Summary

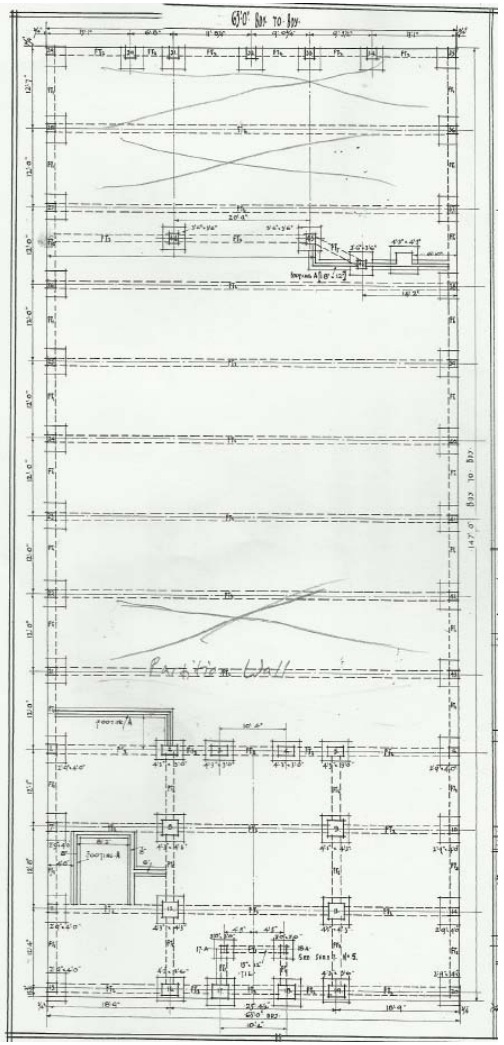
- Inadequate reinforcement detailing in general providing little ductility
- Poor concrete material properties
- Irregular plan and elevation configurations, torsional effects
- Shear cracking in exterior columns
- None of 10 buildings here experienced complete collapse, despite unusually high EQ intensity and unique vertical motions
  - partial collapse of URM infill wall experienced

(Photo from W.Y. Kam, U. of Canterbury)

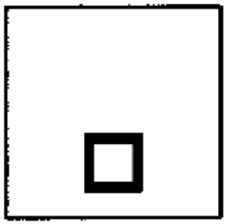
Vertical irregularities (fairly minimal)



Plan irregularities (slightly more substantial)

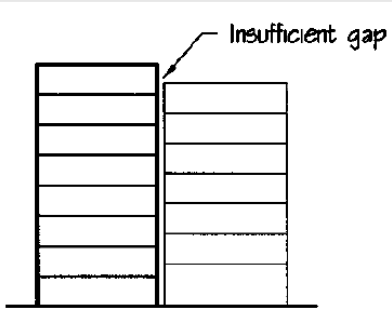


Arched steel truss diaphragm

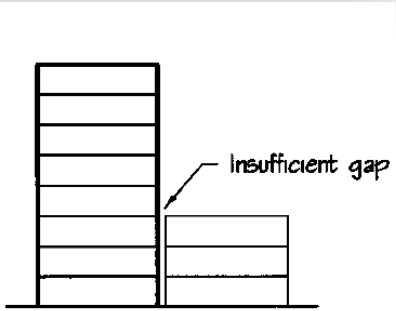


Concrete and timber diaphragms with large discontinuity

Pounding potential (significant in some locations)

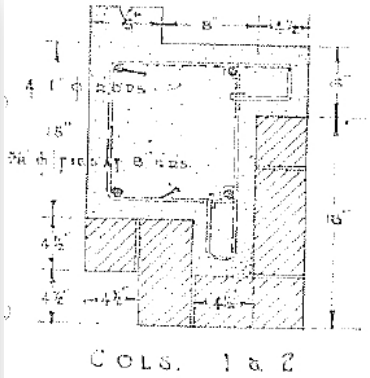


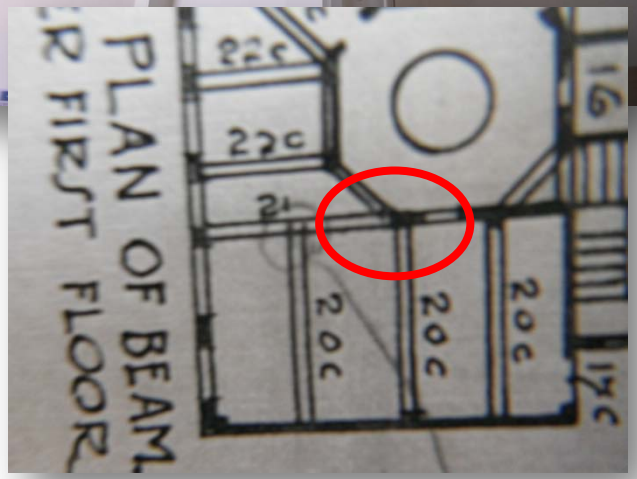
(i) Floor Mis-alignment

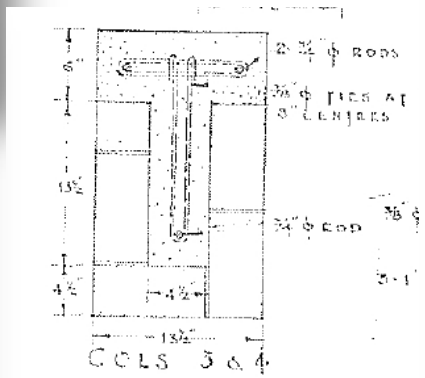


(ii) Height Difference

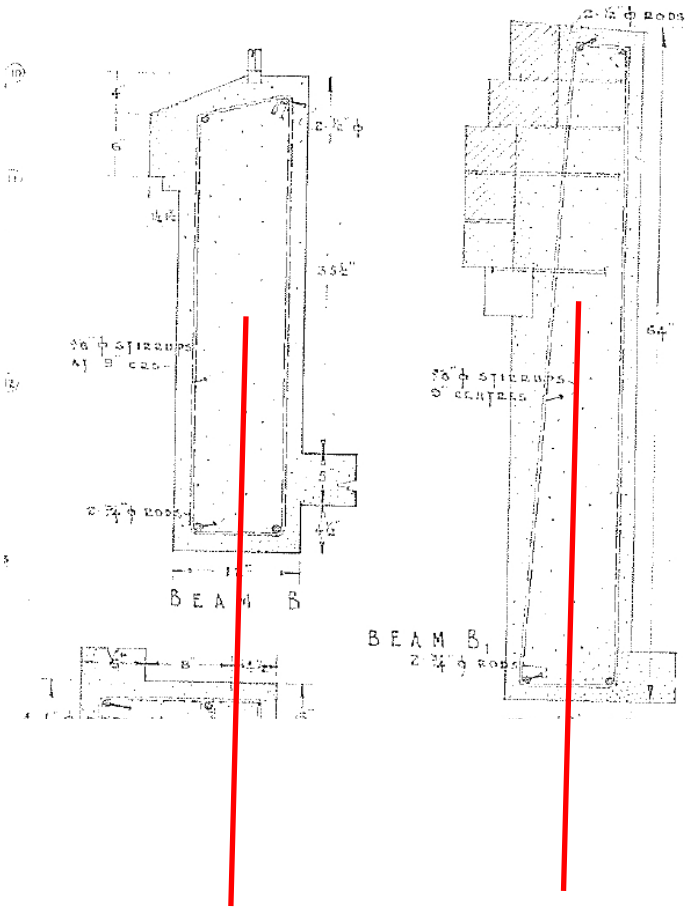
Local eccentricities (torsional reactions)







Parapet anchorage



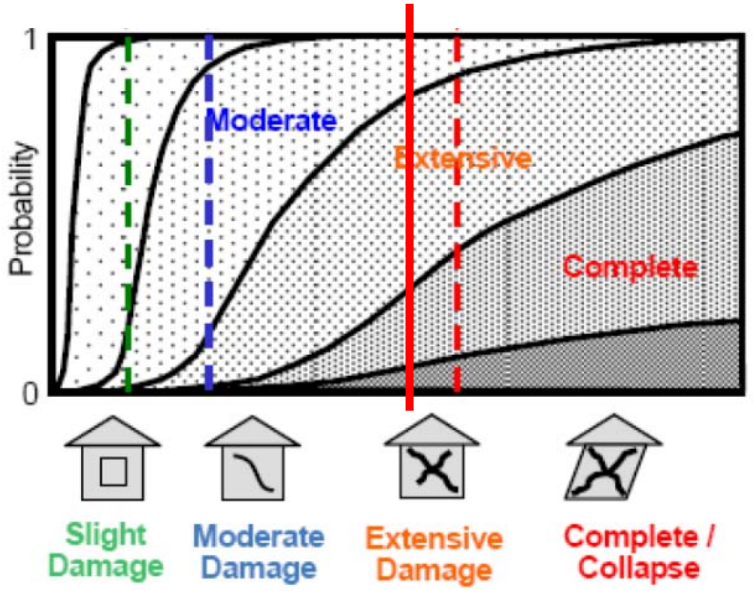
Reinforcement detailing (nominally ductile seismic design philosophy)

- One of JA Louis Hay's Buildings (fairly typical)
  - Longitudinal Column Steel
    - Provided: (4)~3/4"Φ or (4)~1" Dia. Rods = $0.012A_g$ - $0.016A_g$
    - NZS 3101 (2006):
      - $0.008A_g$, OK
      - Min. 8 Longitudinal Bars, Not OK
  - Column Confinement and Beam-Column Connection Transverse Reinf.
    - Provided: 3/8"Φ @ 8" = 203 mm
    - NZS 3101 (2006):
      - Max. spacing of $10d_b$ = 95 mm, Not OK

Forecasting possible building damage from DBE

- Per GNS recurrence intervals v. intensity, DBE (500 years) causes ~MM 9.1 in Napier
  - Widespread damage, especially to buildings with masonry infill walls, subject to pounding, or with irregularities
  - Many buildings likely to need major repair to become serviceable again, some buildings may need to be demolished
- Considering Chch observations, very small likelihood of Napier "Art Deco" buildings experiencing full collapse in DBE
  - partial collapses of infill walls, parapets, chimneys, etc. more likely

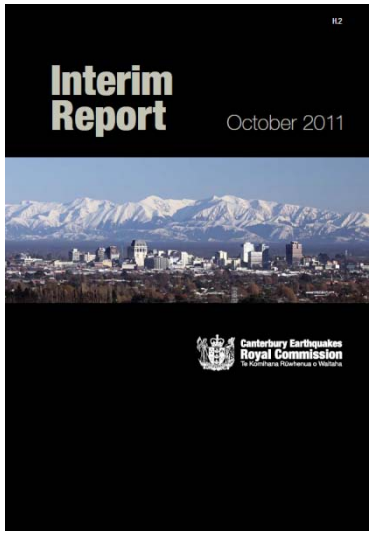
= Design Basis EQ (DBE)
(e.g., Napier's DBE ≈ MM 9.1)



(Duan and Pappin 2008)

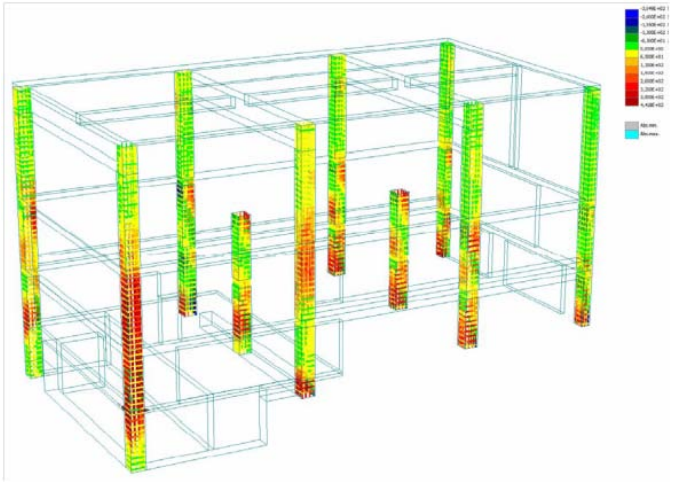
Canterbury EQ Royal Commission 2012

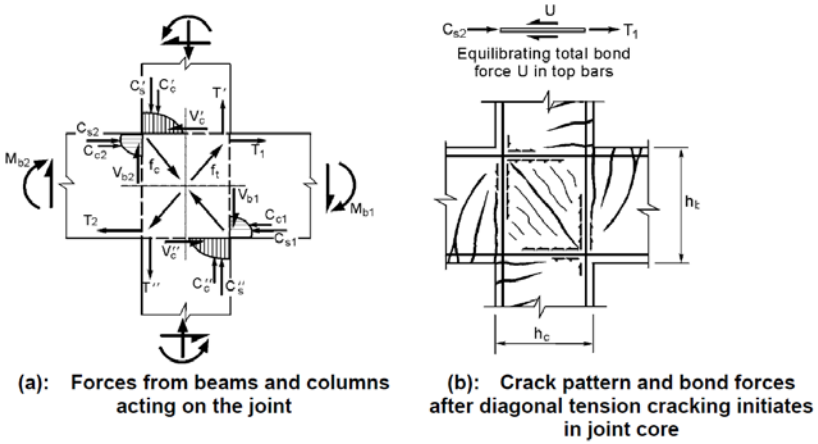
- Perform better soil investigations for structure foundations.
- Where soil has liquefaction potential, utilize deep foundations or shallow foundations on engineered soil (deep foundations preferred).
- Consider potential vulnerabilities of stairs in multi-storey buildings and of reinforcing mesh across lateral-load resisting joints.
- Response spectra, particular related to vertical accelerations, should be revised.
- Elongation of plastic hinges and rocking joints have notable implications in structural analyses.
- Compatibility in deformation (stiffness) amongst structural components should be considered.
- Unexpectedly high tensile strengths of concrete could effect undesirable failure modes.
- Non-structural elements that may pose as falling hazards (chimneys, parapets, ornaments, and gable ends) and/or block egress should be secured.



Level 4 – Detailed Assessment

- Can use simplified hand calculations or FEM model
- Will likely use representative prototypical Art Deco RC building rather than actual buildings
- Will compare results to IEP and forensic observations
- Concrete strengths
- Rebar characteristics
- Lit review to find typical behaviour characteristics for this type of construction
- Three dimensional nonlinear analysis





(a): Forces from beams and columns acting on the joint

(b): Crack pattern and bond forces after diagonal tension cracking initiates in joint core

Figure 7.2: Interior beam – column joint subjected to seismic loading

(NZSEE 2006)

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Seismic retrofit of older concrete buildings

Retrofit Solution / Benefits	Incr. Strength	Incr. Ductility	Incr. Period	Reduce Forces	Reduce Falling Hazards	Reduce Heritage Value	Typ. Cost
FRP fabric or strips (surface or near-surface)	**Yes**	Maybe	No	No	Maybe	Low-Med.	Med.
Steel bracing (concentric or eccentric)	**Yes**	Maybe	No	No	No	High	Very High
Additional concrete shear walls or frames	**Yes**	Maybe	No	No	No	High	Very High
Conversion of infill walls to concrete shear walls	**Yes**	Maybe	No	No	No	Medium	High
Post-tensioning (internal or external)	Maybe	**Yes**	No	No	No	Low-Medium	Med.
Base or mid-storey isolation (response modification)	No	Maybe	**Yes**	**Yes**	No	Medium	Very High
Selective weakening	No	**Yes**	**Yes**	Maybe	No	Medium	High
Mass reduction	No	Maybe	No	**Yes**	Maybe	Med.-High	High
Secure falling hazards (parapets, chimneys, ornaments, etc.)	No	No	No	No	**Yes**	Low-Med.	Low-Med.