Provisional Seismic Assessment and Improvement of Napier’s Art Deco Buildings

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K.Q. Walsh

University of Auckland

J.M. Ingham

University of Auckland

ABSTRACT: Following the 1931 Hawke’s Bay earthquake, buildings in Napier and surrounding areas were rebuilt in a comparatively homogenous structural and architectural style comprising the region’s famous Art Deco stock. These ‘interwar buildings’ are most often composed of reinforced concrete frames and, while detailed in a fairly ductile fashion for the time, often register as earthquake-prone in preliminary seismic assessments, causing concern to owners, tenants, city officials, and all of those who value the heritage and future use of these iconic structures.

The study reported here will address aspects of the seismic hazard, assessment, and potential retrofit solutions for Napier’s Art Deco buildings. The study concluded with provisional recommendations developed in collaboration with the Napier Art Deco Trust and other interested parties regarding a pathway to alleviate the hazard posed by Napier’s Art Deco buildings.

1 INTRODUCTION AND BACKGROUND TO RISKS AND VULNERABILITIES

At 10:47 am on 3 February 1931, the infamous Hawke’s Bay earthquake shook Napier, Hastings, and the surrounding areas. The collapsing structures, landslides, and subsequent fires killed 256 people (Lee et al. 2011) including 157 people in Napier (McGregor 2012). The people of Napier rebuilt most of their city in the ensuing two years, and many of the reconstructed buildings were erected as reinforced concrete frames in the Art Deco architectural style.

The policies regarding “earthquake-prone” buildings in the Building Act (NZ Parliament 2004) and findings from the Canterbury Earthquakes Royal Commission (Cooper et al. 2012) have caused local Councils, building owners, and tenants alike to consider more keenly the implications of seismic risk and retrofit costs associated with Hawke’s Bay’s heritage buildings, especially Napier’s famous Art Deco buildings constructed during the “interwar” years of 1920-1940, with the majority built in the few years immediately following the 1931 Hawke’s Bay earthquake.

Two major active fault lines exist just west of Hawke’s Bay (the Mohaka Fault and Ruahine Fault) and numerous other faults exist in the southern portion of the region. Hence, the hazard factor, Z, for Napier is 0.38, which is amongst the higher values in the country’s major cities when considering Z=0.13 applies in Auckland and Z=0.40 applies in Wellington (NZS 1170.5:2004). The design basis earthquake (DBE) for Napier’s buildings (assuming an importance level of 2 and design working life of 50 years) is expected to occur every 500 years on average with an intensity of ~MM 9.1 (Stirling et al. 2002).

Napier, Hastings, and Havelock North are located in a physiographic region known as the Heretaunga Plains and are situated on Quaternary sediments (Dravid and Brown 1997). These surface soils could be at risk of liquefaction when saturated and subjected to seismic waves. However, one sample taken from the foundation of one of the case study buildings in Napier City Centre showed visibly higher cohesion, consolidation, and grain-size heterogeneity than is typically associated with soils having high liquefaction potential. Nonetheless, alluvial soils such as these can vary largely in grain size and consolidation across even a relatively small geographic area such as the region in discussion (Lee et al. 2011).

2 THE ART DECO REBUILD

The few buildings that survived the 1931 Hawke's Bay earthquake were usually newer structures built within the 10 years preceding 1931. Hence, the current Napier City building population includes 140 buildings that were constructed between 1920 and 1940 (McGregor 2012). Given the confined time period in which so much of Napier and Hasting's city centres were constructed, the structural and architectural consistency of this unique building population is prominent. Reinforced concrete (RC) frames were the dominant structural form in the rebuild, as evidenced in plans and photographs available from historical records and from personal inspection.

Economically, tourism stemming largely from Napier's Art Deco attractions contributes greatly to the Hawke's Bay region's revenue. Furthermore, Hawke's Bay's climate and soils provide for one of the best agricultural regions in the country, especially for vineyards which have made the area famous for wines (Stewart 2009). The Art Deco buildings of Napier and Hastings help define the uniqueness of the region, not only in terms of architectural appeal, but also as a representation of the courage and dedication that the people of the region exhibited in rebuilding so quickly and elegantly after a catastrophe like the 1931 Hawke's Bay earthquake.

3 DAMAGE OBSERVATIONS OF SIMILAR STRUCTURES IN CHRISTCHURCH

The Canterbury region of New Zealand experienced a swarm of earthquakes in 2010 and 2011, with the two most prominent events occurring on 4 September 2010 (Darfield/Canterbury earthquake, moment magnitude M_w 7.1) and 22 February 2011 (Christchurch/Lyttelton earthquake, M_w 6.2). Teams from multiple universities and engineering consulting firms scoured Christchurch after these events, assessing structural health and documenting failure modes. Typical structural deficiencies noted in pre-1970s RC buildings most associated with undesirable structural behaviour and/or failure included the following (Kam et al. 2011):

- Inadequate steel reinforcement in general providing little ductility, especially in the lack of confining stirrups in walls, joints, and columns, the use of plain reinforcing bars, and inadequate lap splice lengths;
- Inadequate anchorage details, especially at floor/beam to column/wall connections;
- Poor concrete material properties including smooth and/or inadequately sized aggregates, chloride infiltration, and low compression strength; and
- Irregular plan and elevation configurations including cantilevered beams and discontinued columns and walls at lower storeys.

Christchurch City Council lists 29 non-ductile reinforced concrete heritage buildings in its City Plan, including 21 buildings erected between 1920 and 1939 (Hare 2009). Ten of these buildings were identified. All ten building are between two and four storeys in height and constructed of RC frames, and some have brick infill (Pampanin et al. 2012). Other interwar buildings in Christchurch not included in this consideration were disregarded for dissimilarities such as having more than four storeys.

Despite the prominence of shear cracking in exterior columns (some severe) as well as damage to masonry infill walls and even the partial collapse of an infill wall in one building, none of the ten buildings experienced complete collapse during the earthquake, despite the unusually high earthquake intensity and unique vertical motions (much higher than the design basis earthquake) experienced during the Christchurch/Lyttelton earthquake after the buildings had already been weakened by the preceding Darfield/Canterbury earthquake. These findings increase confidence regarding the probable non-collapse of Napier's Art Deco buildings during a design basis earthquake (DBE).

4 DAMAGE OBSERVATIONS OF SIMILAR STRUCTURES INTERNATIONALLY

Figures 1-5 illustrate some of the common causes of failure and failure modes of reinforced concrete frame buildings in Padang, Sumatra, Indonesia following the 2009 Padang earthquake. While the building standards in much of Indonesia have been quite different from those in New Zealand over the course of the countries’ histories, some observations of damage in Padang are relevant to the consideration of Napier’s Art Deco buildings. Inadequate detailing of steel reinforcement and concrete cover caused columns, in particular, to be damaged excessively during the earthquake. Plastic hinges were observed at the tops of some columns resulting in the formation of non-ductile column-sway mechanisms.

Figure 1. Poor quality concrete material is vulnerable to crushing and shearing.

Figure 2. Poor reinforcement detailing with a lack of transverse reinforcement and insufficient longitudinal reinforcement.

Figure 3. Plastic hinge formed in non-ductile column-sway mechanism.

Figure 4. Soft-storey deformation.

Figure 5. Shear cracking in infill wall material.

The observations of failure mechanisms from Christchurch and Padang are consistent with those published internationally regarding the 1994 Northridge (Islam 1996, Moehle 2000), 1995 Kobe (Otani 1999), and 1999 Chi-Chi (Wu et al. 2009) earthquakes, amongst others (Taciroglua and Khalili-Tehrani 2008). In general, the most consistently noted concern is that some form of a strong-beam/weak-column mechanism exists, and columns with inadequate ductile reinforcement detailing located at a soft-storey level sustain heavy cracking, weakening, and, sometimes, destabilisation as a result. Given the similarities in configuration and detailing to the buildings in these international studies, brittle system failure mechanisms could be expected to occur in many Napier Art Deco buildings during a large earthquake.

However, most international publications on non-ductile RC buildings do not focus largely on “interwar” (1920-1940) RC buildings such as those in Napier. In fact, RC buildings from the period of 1960-1980 are of generally greater concern to engineers and emergency managers. NZSEE (2006) summarises why this is the case:

> *Reinforced concrete buildings from the 1940s and the 1950s are typically low-rise with regular and substantial wall elements. Many of these structures would be capable of close to an elastic level of response, with local detailing exceptions. Reinforced concrete buildings from the 1960s and early 1970s are, however, generally taller, less generously proportioned, with less redundancy and greater irregularity often in evidence in frame structures.*

These concerns were, unfortunately, validated in Christchurch as four RC buildings constructed between 1960-1990 collapsed or experienced partial collapse, whereas interwar RC buildings performed more admirably, as described above. Observations of RC building damage from major earthquakes around the world are consistent with this notion. Citing data accrued by the Architectural Institute of Japan from the sites of four of the more significant earthquakes of the past thirty years, Wu et al. (2009) note that "the probability of structural collapse in older-type concrete buildings was relatively low (1.9-6.6%) even in such damaging earthquake events." Damage observation data from these same four earthquakes were compiled by Otani (1999), and that data have been sorted in Table 1 to illustrate the relatively low risk associated with RC buildings with no more than three storeys, which is the height range associated with Napier's Art Deco building stock.

Table 1. Damage observation data from Architectural Institute of Japan from four major earthquakes sorted by storey height ranges

Earthquake	Location	Total # Bldgs Surveyed	Heavy Damage		Collapse		Building Type
			1-3 Storeys	4+ storeys	1-3 Storeys	4+ storeys	
1985 Mexico	Old Lakebed of Mexico City	4532	3.0%	7.8%	0.9%	4.8%	RC, 1-18 storeys
1985 Mexico	Lazaro Cardenas, Mexico	164	10.9%	52.9%	1.4%	0.0%	RC, 1-9 storeys
1990 Luzon	Baguio City, Philippines	181	18.6%	19.0%	2.0%	8.9%	RC, 1-9 storeys
1992 Erzincan	Erzincan, Turkey	415	11.3%	29.8%	0.0%	16.7%	RC, 1-5 storeys
1995 Hyogo-ken Nanbu	Kobe, Japan	2017	3.3%	10.2%	3.9%	10.6%	Pre-1981 RC, 1-10 storeys

Table 1 indicates that low-rise buildings (one to three storeys) are generally less likely to sustain heavy damage and collapse during major earthquakes than their taller counterparts. Building height and corresponding period of vibration may be the most critical factors contributing to these discrepancies. However, it is worth noting that, while these data are not sorted for age of construction (other than the Kobe earthquake as noted), the average age of the low-rise buildings is likely older than that of the higher-rise buildings.

5 STOCK ASSESSMENT OF NAPIER'S EXISTING ART DECO BUILDINGS

According to McGregor (2012), 164 non-residential buildings were erected in Napier between 1920 and 1940, and 140 of these buildings remained at the end of 2012. The majority of these buildings were identified (155/164 total and 125/140 existing as of 2012) by amalgamating information from a number of literary sources (McGregor 1998, 2003, 2012; City of Napier 2001, 2011; Shaw and Hallett 2002; Bilman et al. 2004; Stewart 2009; New Zealand Historic Places Trust 2012) along with consulting with representatives of the Napier Art Deco Trust, the Napier City Council, and local

Napier business owners. Of the 125 existing structures remaining and identified, 105 (84% of the 125) were constructed or reconstructed soon after the 1931 Hawke's Bay earthquake, between 1931 and 1936. Of these buildings, 93% are constructed primarily of reinforced concrete, 95% are one or two-storey in height (none are taller than three storeys), 46% are primarily and formally Art Deco in style, and 77% are primarily designed by four architecture firms. Hence, the smaller number of buildings considered at more refined levels of analysis should ideally have traits common to the majority or plurality of this larger stock.

Concrete slabs (cast in place with the concrete frames) likely dominate the stock's structural diaphragms (lateral-force resisting floors and roofs), although there appears to be some notable variation in roof diaphragm construction (timber versus concrete) as well as the inclusion of steel framing (partial framing, retrofitting, composite with concrete, etc.) supplementary to the RC framing in some buildings. Wall infill materials such as unreinforced brick masonry seem common and may also represent significant hazard-causing components in seismic risk assessments.

6 INITIAL EVALUATION PROCEDURE

Of the 111 existing buildings with enough data to be considered for a preliminary Initial Evaluation Procedure (IEP) as developed in NZSEE 2006 (disregarding configuration components that alter the performance achievement ratio), most are moment-resisting reinforced concrete frames; some have brick infill walls, floors of concrete or timber, roofs of timber, iron, concrete slab and/or corrugated galvanised iron (CGI), and/or high parapets; all are 1 to 3 storeys (avg. 1.7), and the year of construction (or reconstruction if applicable) falls within 1926-1955 (avg. 1933). These traits are consistent with the general traits determined in the previous level of analysis. The importance level of these buildings is assumed to be 2 (AS/NZS 1170.0:2002). For purposes of this preliminary IEP, the ductility is assumed to be maximized at 2.0. For type D soils, the IEP %NBS range is 13.2 - 17.5% (avg. 13.7%). For type C soils, the IEP %NBS range is 17.0 - 25.0% (avg. 17.8%). Based on the preliminary IEP alone, all of these buildings are considered "earthquake-prone" per the Napier City Policy (2012). Most of these buildings will likely remain as such even with a full IEP being performed; hence, a more detailed engineering assessment will be needed to prove that they are not "earthquake-prone".

7 FORENSIC ASSESSMENT

The next level of analysis involved a forensic investigation of six buildings considered to be representative of the entire Napier Art Deco building stock, including on-site inspections as well as a review of available construction documents. The initial years of construction (or reconstruction if applicable) of all six buildings fall within 1931-1932. The structural systems are moment-resisting reinforced concrete frames (although some have partial steel framing components). Some buildings have brick infill walls, floors of concrete or timber, roofs of timber or iron framing, and high parapets. All buildings considered in the forensic analysis are two storeys in height. The architects for these six buildings are all amongst the four most prominent architects listed previously, and the primary architectural styles include three Art Deco, with the other buildings being primarily in the Renaissance and Chicago School/Prairie styles. Complete or partial original plans were available for all six buildings, and building specifications were available for one.

7.1 Configuration irregularities

Relatively speaking, the vertical irregularities in Napier's Art Deco building stock are fairly minimal, although a few examples do exist, especially in buildings that have had annexed portions constructed. The most significant potential structural weakness of some individual Napier buildings appears to be pounding potential. The two types of pounding are illustrated in Figures 6 and 7 along with corresponding photographed examples from Napier.

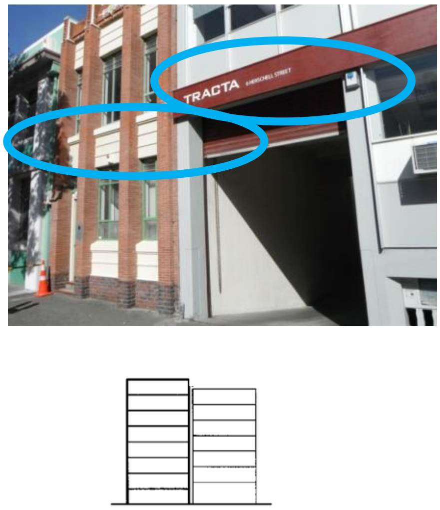

Figure 6: Floor mis-alignment between buildings in Napier could possibly lead to "pounding effect" during an earthquake (bottom row image from NZSEE 2006).

Figure 7: Example of possible "height difference effect" in Napier (bottom row image from NZSEE 2006).

One building in Napier serves as a clear example of potential plan irregularities. This building is constructed of an RC frame with exterior and interior columns and concrete and timber diaphragms on one end and a potentially more flexible arched steel truss diaphragm with no interior columns on the other end, as illustrated in Figure 8. An earthquake with strong motions acting parallel to the boundary between the two systems may cause a torsional reaction. Other potential plan irregularities observed in Napier included large portions of diaphragms missing for open lobbies, light wells, and courtyards. Stairwells that are large, oddly shaped, or eccentrically placed within a building may also pose as plan irregularities if they are expected to greatly affect the building's response to lateral forces. In some of the smaller buildings inspected in Napier, stairwells made up large portions of the building footprints. In corner buildings in Napier, the two walls facing the streets are often constructed with lighter non-structural materials than the non-structural materials used for the other two backside (i.e., not visible from the main roads) walls, which often include heavy masonry infill.

Figure 8. Example of plan irregularity in a Napier Art Deco building based on different construction materials, configurations, and placement of interior columns at one end (architect withheld to help keep building anonymous).

While the concept of plan irregularities generally applies to the "global" effects of building response during an earthquake, other components observed in Napier's Art Deco buildings may affect the building locally. As exhibited in Figures 9-11, some beam and column centerlines observed in Napier that do not align, possibly resulting in the beam transferring a torsional load into the column during an earthquake. Irregularly shaped columns were observed that may resist lateral loads torsionally with resulting higher stresses, as well as an elevated floor space in a building that is irregularly shaped and connected to the surrounding structure eccentrically, possibly resulting in this floor twisting during an earthquake and increasing the loads on some localised portions of the surrounding structure.

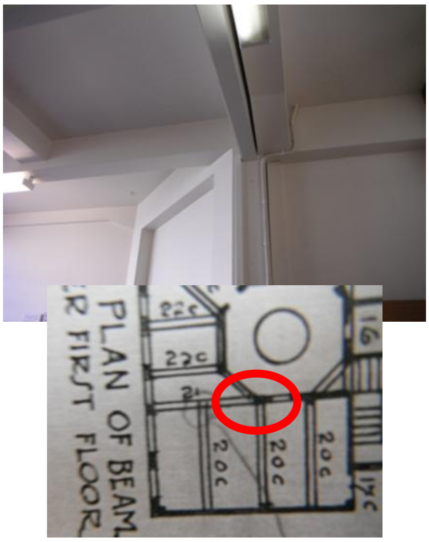

Figure 9. Beam and column centerlines do not align.

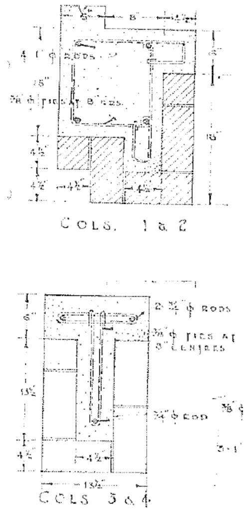

Figure 10. Irregularly shaped columns (architect withheld to help keep building anonymous).

Figure 11. An elevated floor space in a building is irregularly shaped and connected to the surrounding structure eccentrically.

7.2 **Falling hazards**

In some cases, the most significant hazards to people during an earthquake may not be the failures of load-bearing structural components, but rather the collapse of non-structural elements. While Napier's Art Deco stock has few tall chimneys and gable end walls, unreinforced masonry infill walls and parapets are fairly prominent in Napier. These components can be especially dangerous to people just outside a building.

It is often unclear from the available plans whether appropriate anchorage was provided for the tall parapet walls on the buildings inspected in Napier. Unreinforced brick masonry infill walls were especially prominent on the backsides of the buildings inspected. Research performed on unreinforced masonry buildings in Christchurch after the 22 February 2011 earthquake suggests that passers-by who were outside unreinforced masonry (URM) buildings were at greater risk than occupants within those buildings during an earthquake (Ingham and Griffith 2011). The traits of URM buildings most responsible for this risk are common to the Napier Art Deco building stock – namely, unsecured parapets and unreinforced masonry walls.

7.3 **Summary of Forensic Analysis**

In summary, forensic investigations were performed on six representative buildings of Napier's Art Deco building population. Comparative investigations internationally and in Christchurch led to the identification of issues with inadequate ductile reinforcement detailing, geometric irregularities, and pounding, which are causes for concern given similar observations of traits in Napier's Art Deco stock. However, similar buildings in Christchurch exhibited good life-safety performance under exceptional earthquake demands; no RC frame building in Christchurch less than five storeys in height experienced full collapse during the powerful 22 February 2011 earthquake. Hence, good life-safety performance should be expected in Napier Art Deco buildings for the design-basis earthquake (DBE), even though partial collapses of infill walls, parapets, chimneys, and other exterior ornamentation is much more likely. It is emphasised that falling building appendages do represent a significant life-safety hazard that merits specific attention, as promulgated in Volume 4 of the CERC final report (Cooper et al. 2012).

8 RETROFIT PRIORITISATION, SOLUTIONS, AND ECONOMICS

Table 2 summarises the primary considerations related to retrofit solutions available to RC buildings.

Table 2. Summary of retrofit solution considerations for RC framed buildings.

Retrofit Solution / Benefits	Increase Strength	Increase Ductility	Increase Period	Reduce Forces	Reduce Falling Hazards	Reduce Heritage Value	Typical 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	High
Additional concrete shear walls or frames	Yes	Maybe	No	No	No	High	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, infills, etc.)	No	No	No	No	Yes	Low-Med.	Low-Med.

9 FURTHER INVESTIGATIONS

The authors expect that further efforts will provide greater clarity on the seismic risks associated with the Art Deco building stock in Napier. These efforts will likely include performing a more detailed inspection of reinforcement detailing as provided in the plans and compared to modern standards and acceptance criteria (such as Boys and Bull 2012), performing a detailed computer-aided analysis and comparing the results to those from the IEP and forensic investigations, and accruing more soils reports across Napier's CBD, especially those that address liquefaction potential. With enough data, criteria could be suggested that may be incorporated into fragility curve functions particular to Napier's Art Deco building stock in order to enhance the accuracy of New Zealand seismic hazard models such as RiskScape and international models such as GEM and HAZUS.

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