Envisioning Earthquake Architecture in New Zealand

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ABSTRACT: Earthquake architecture is an approach to architectural design that draws upon earthquake engineering design issues as a significant source of inspiration. After explaining earthquake architecture and exploring its possible benefits, the paper considers the current status of earthquake architecture in New Zealand. Two theoretical seismic strengthening case studies are then presented. They illustrate how an earthquake architectural approach can apply to existing buildings and also demonstrate how an expression of seismic resisting structure can add architectural richness. Strategies for realizing the vision of a more widely accepted earthquake architectural approach inevitably focus on architects. Structural engineers need to be the catalyst for the vision to be caught and progressed.

SCOPING THE VISION

The phrase “earthquake architecture” describes the architectural expression of some aspect of earthquake action or resistance [Arnold, 1996]. The wide breadth of expressive possibilities ranges from metaphorical exploration of seismic issues, to the more straightforward exposure of seismic technology.

Of the former type, there are a number of ways metaphor and symbolism may be used in an architectural response to seismic design. Arnold cites an extreme example of the Nunosani Headquarters Building in Tokyo. Its disjointed and displaced façade elements are intended to “represent a metaphor for the waves of movement as earthquakes periodically compress and expand the plate structure of the region.” Another example is the Museum of New Zealand Te Papa Tongarewa, Wellington. According to the design architect “The need for direct connections ... in turn led to the introduction of the idea of geological power/Ruaumoko (the Maori god of earthquakes and volcanoes) expressed as a mighty Wall slicing diagonally through the building. This symbolic fault line (parallel to the actual earthquake fault line nearby, on the western side of the harbour) created a fissure of space which houses the newly created Entry from the city” [Bossley, 1998]. Although it is unlikely that building users make a mental connection between the physical architectural form, in this case two parallel granite panel clad moment resisting frames, with the underlying concept of a fault line, the fact remains that seismic issues have generated an innovative architectural design concept. Pete Bossley, architect for Te Papa Tongarewa has also introduced earthquake architecture into several house designs including the Heatley House which is cut by a ‘fault’ that has caused the two sections to slip relative to each other, and the Emirali House in which an upper storey is skewed relative to the floor below [Wallis, 1991].

Many aspects of seismic activity and resistance can become relevant when responding to the tectonics of a site. Apart from crustal compression and expansion, other aspects and metaphors used by architects include slicing, fragmenting (also acknowledged in the Te Papa design),
splitting, fracturing, sliding, folding and faulting. At a more conceptual level that does not address tectonic activity, architects explore other issues relevant to seismic behaviour, providing additional meaning to designs, enriching the architecture. Explorations of concepts like strength, or weakness or fragility can lead to different but potentially rich design possibilities. For example, while one concept, such as fragility to earthquake attack might be a major design concept, one or more contrasting ideas might also be included in a design: strong or dense structure may be concentrated in one area of a building plan and relatively fragile and lightweight structure elsewhere.

Finally, earthquake architecture can comprise the basic expression of seismic resisting technology. Primary lateral load resisting systems or members can be exposed, and seismic separation details or seismic hardware like dampers or isolators can be celebrated architecturally. As outlined in a previous study [Charleson and Taylor, 2000] many possibilities present themselves, ranging from major structural expression to the subtle detailing of a non-structural joint. Depending on the depth of earthquake engineering knowledge within the design team quite sophisticated levels of structural understanding may be drawn upon to achieve the desired architectural enrichment. Such an example would be where exterior steel banding to beams and or columns articulates potential plastic hinge zone confinement.

WHY ENVISION?
The previous discussion raises the question as to why one might engage in an earthquake architecture. One possibility is to openly acknowledge the necessity to safeguard against seismic danger. Others include the desire for an authentic expression of the structure necessary to protect against earthquakes, and the communication of intended seismic safety of a building through visible seismic resisting components. Such expression can be both structurally authentic and aesthetically satisfying. Further, the specifics of local tectonic activity fuels a regional architectural response; one that shuns international models in an environmentally responsive manner. When general awareness to seismic safety peaks in the period immediately following a damaging earthquake, an undamaged building with visible seismic resistant technology will act as a sign, a tangible reminder of physical resistance. Such upfront acknowledgement of seismic risk, a constant reminder of earthquake threat, indicates a level of seismic preparedness.

These approaches to architecture are not new. Architect David Farquhason who introduced innovative seismic resistant features in the South Hall, University of California at Berkeley in 1873, believed that safety features of a building should be revealed to passers-by in the form of art, and proposed a method that integrated reinforcement with decorated wrought iron work [Tobriner, 1998]. More recently Reitherman [1998] has urged Californian structural engineers to explore with architects the potential of earthquake architecture.

The final reason for encouraging earthquake architecture resides in the psyche and business sense of New Zealand structural engineers. Engineers like to see the outcome of their work. When designing in reinforced concrete, all the important details, the product of significant knowledge and experience, are encased. Similarly, the base-isolators and dampers in all but one New Zealand building are hidden from view. Exposed structure is very satisfying to engineers. Their expertise and effort are displayed. Inner satisfaction combines with promotion of their skill to the public. There may even be an opportunity to market New Zealand’s seismic design expertise to aware overseas visitors.

CURRENT STATE OF VISION IN NEW ZEALAND
Apart from a few notable exceptions, New Zealand buildings do not openly reveal the fact that they have been designed to resist seismic loads. There are few examples of earthquake architecture to be observed along the streets in Wellington’s CBD or in the pages of “Wellington’s New Buildings” [Kernohan, 1989] which catalogues 1970s and 1980s construction. Occasionally, seismic (and gravity/wind load) resisting members are expressed. In an architectural attempt to emphasis verticality, columns are often the only visible structural members. Sometimes beams are hinted at by opaque cladding panels, and frequently, as in the
case of reflective glass façades, all structure is concealed. Separation gaps between buildings and precast panels may be visible but no attempt is made to transform these necessities for aesthetic purposes.

Earthquake resistant technology is most apparent in seismically strengthened buildings. Our research indicates that highly visible diagonal steel braces, inserted as structural necessity, often conflict with building form and function. They do little to enhance the existing architecture.

VISIONARY EXAMPLES

This section reports on a theoretical research-by-design project where two earthquake prone buildings are strengthened according to tenets of earthquake architecture. The possibility of intentionally expressing strengthening structure to make new and positive architectural contributions by adding layers of physical and metaphorical richness is explored. It is not the intention to design a low cost solution.

A US National Park Publication [Look et al, 1999] suggests such a possibility in a discussion of the potential intrusiveness of seismic strengthening: “However, structural reinforcement can be introduced sensitively. In such cases, its design, placement, patterning, and detailing should respect the historic character of the building, even when the reinforcement itself is visible.” Some designers might interpret ‘respect’ as meaning to imitate or conform as closely as possible to historic character, but this research questions that approach. It proposes that exposed strengthening can offer a critical insight to the existing building in a way that contributes aesthetically.

In order to test an approach to retrofitting where strengthening structure is expressed, the authors chose two Wellington buildings as case studies. Although its lift-slab construction technique is most uncommon in New Zealand, the first building of eight storeys is representative of many pre-1976 multistorey reinforced concrete buildings constructed prior to modern ductile design and detailing requirements. The second building, Turnbull House, of unreinforced masonry construction was chosen for its historical value, public appeal and prominent location.

Pre-1976 Building

The building, named the Pre-1976 Building for the purposes of this paper, occupies a corner site in an area of the city where medium-rise office buildings of the Central Business District reduce in scale to two and three storey small office and retail buildings. The building is rectangular in plan and elevation. Apart from a high ground floor, the elevation is regular, and so is the plan, defined by two structural bays 6.9m wide, and by three 8.1m bays long (Figure 1). Reinforced concrete is the predominant construction material except for the ground and first floor columns that consist of concrete filled steel box sections. Cast-in-situ perimeter upstand beams post-tensioned between columns form earthquake and wind load moment resisting frames.

Like many buildings of the same era it was designed prior to enlightened yet demanding Standards Association of New Zealand 1976 seismic requirements. In the light of this Code and its subsequent revisions, the fragility of the building is exposed. It was designed for a relatively low seismic load level (0.06g) when compared with today’s standards, and several building configuration defects known to be problematic in damaging earthquakes are observed; a soft storey, short-columns caused by partial height infill walls, weak columns and strong beams, and torsional asymmetry. Detailed study of reinforcement
detailing might possibly reveal other problems expected in a building of this vintage. It is not our intention to claim the building will fail in an earthquake, but to use it as an example of a potentially vulnerable reinforced concrete building.

Design process
After assessing possible structural solutions, the authors looked to various sources for inspiration including unique New Zealand approaches to construction, the site and its history, the form of the building, its novel construction, its crudeness of detail and its apparent fragility. An idea of propping and shoring was used to transform the existing perceived fragility into resilience and strength.

Props connect to the building for load transfer only at their ends, at uppermost floor slabs and foundations. (Figure 2). As expected, linear elastic analysis confirmed that the most steeply inclined props were not very effective. Alternative schemes characterised by fan shaped prop configuration thatoptimised structural efficiency were deemed aesthetically unsuitable, given their visual links to the bygone handcrafts of string art and fan making. An unambiguous expression of the ruggedness and rawness of props against a building staggering from the punishment of a recently damaging earthquake was the essence of the final design concept.

Design description
Given the chosen structural form, all design aspects, including the lateral design load of 0.1g (appropriate for an equivalent new building) comply fully with relevant NZ Standards. Props are fully ductile in tension and compression in order to achieve maximum slenderness to minimise obstructions to views, and out of sensitivity to elevational aesthetics. Ductile ‘fuses’ are placed at the bottom ends of each brace. A 50mm maximum diameter mild steel bar within the 219mm dia. prop tube absorbs inelastic tension and compression strains over a maximum 3.4m length. Incompressible material that fills the annulus between bar and tube restrains the bar from buckling. Struts with high levels of ductility have been described before [Matthewson and Davey, 1979], and one technique is patented [Kalyanaraman et al, 1998]. The authors had hoped to express the fuse region, but its mechanical complexity and vulnerability to corrosion sees it ‘referenced’ by architectural detailing rather than being exposed to view. Bracing is proposed along the main street elevation and the two side elevations.

For the purpose of structural design the existing overall building lateral strength is neglected. However, some individual members are utilised where they contribute to the new bracing scheme. For example, corner column tension strength is mobilised, and in fact requires supplementing to resist tension forces arising from biaxial seismic attack. Some columns require fibre wrapping or equivalent treatment to enhance their shear and inelastic rotational capacity.

Existing foundations require significant upgrading, especially to resist tension uplift and resist prop loads.

Three architecturally significant structural details emerge: the shoe (ground level), the corner clamp and the prop lateral restraints. The shoe, consisting of steel encased concrete wedges and stainless steel pins speaks of the shunting of wooden stakes at the ends of traditional timber shoring props (Figure 3). This detail epitomises the temporary nature of traditional shoring and expresses its structural action.

Long slender steel props stretch from the shoes across the building face. They terminate at the outside corner of each floor slab where they are clamped and pinned.
The method of fixing accounts for the unique angles in three-dimensional space of each prop. It also speaks of temporary fixing of scaffolding and building construction, and responds to the ideal of structural reversibility.

Props are tied back to the building face along their lengths. As well as to prevent buckling, these lateral restraints carry an additional non-structural responsibility of stitching the external steel structure into the existing concrete frame. This detail grew out of an appreciation of New Zealanders’ use of number eight wire to string fences, and to bind and tie anything together (Figure 5).

**Turnbull House**

Turnbull House, a brick reviverist building completed in 1917, is an example of Edwardian architecture imported into New Zealand (Figure 6). Unreinforced brick masonry load bearing walls form the primary structural elements. They support a timber roof structure and two levels of timber floors, except in the former stackroom area in the south-western corner where reinforced concrete floors supported heavy book loads.

Some seismic securing work has been undertaken over the years to improve life safety but not to protect the building fabric in the event of a significant earthquake. Areas on the northern façade and other transverse walls are vulnerable to severe damage under seismic loads in the transverse direction considerably less than Code design loads. This proposal provides for a far higher level of seismic performance, primarily to protect the building fabric, and at the same time lower risk of injury to occupants.

Structural and architectural considerations indicated that seismic retrofitting was better served from inside rather than outside the building envelope. Proximity to site boundaries meant any exterior structure for transverse resistance affected views of the east façade, and the internal longitudinal spine wall provided an ideal opportunity for interior strengthening.
**Strengthening scheme**

In accordance with New Zealand National Society for Earthquake Engineering guidelines, the scheme adopts a strengthening level (0.4g) that is equivalent to 75% of Code requirements for a new building. At this load level the new structure, designed to resist all seismic load elastically, restricts the horizontal deflection of the building to 30mm at eaves level, 10m above ground, to minimise brickwork damage.

Earthquake resistance is provided by new structure in both orthogonal directions (Figure 7). In the transverse direction three lines of new structure are needed. The inside surface of the north façade bearing wall is lined with steel framed plywood that forms a two-bay moment resisting frame. Two new structural walls of similar construction are placed inside the former stack room. In the longitudinal direction, the existing masonry spine wall is strengthened in-plane by a perforated sheet steel wall (Figure 8). With similar aesthetic and structural properties to the web of a lattice truss, lateral loads are transferred through 50mm by 15mm diagonal steel compression and tension members. They are prevented from buckling by closely spaced bolts fixed into the face load restrained masonry walls behind.

New vertical steel mullions at 1.2m maximum centres are fixed to all existing masonry walls to resist face loads and transfer them to existing plywood floor and roof ceiling diaphragms. These, in turn, are connected to the new structural walls and frame. The steel mullions take three different architectural forms (Figure 9). First, a series of steel stressed skin panels, with pattern cut perforations and internal acoustic material line most exterior walls. Timber clad steel mullions are located inside the bay windows and the third mullion type is steel rib and timber panel lining to the Reception Room walls. The exterior brick veneer is pinned to face load supported inner load bearing masonry walls and marked by stainless steel bolt heads of 12mm diameter stainless steel veneer ties.

As with many retrofit schemes, new piled foundations are necessary to resist overturning moments and shear forces from the new structure. These foundations, hidden from view, will also prevent damage from predicted uneven settlement of the ground during a large earthquake.
REALIZING THE VISION

While it is one thing to envision, it is another matter entirely to have others share the vision, especially where they are from a different profession. Structural engineers may be keen to embrace the idea of earthquake architecture but architects are less enthusiastic. It is clear that engineers will need to take the initiative. Reitherman suggests that an engineering consultant should host a Friday afternoon charrette and discussion to explore earthquake architecture.

There is also opportunity for the Society to take a lead. Given that the first object of its constitution is to “Foster the advancement of the science and practice of earthquake engineering” [NZSEE, 1999], the sponsoring of a design competition may be strategic. It has the potential to stimulate discussion between architects and engineers and bring the concept of earthquake architecture before both professions. The impact and success of a competition would be enhanced by it being based on a live project. Architectural students, perhaps teamed up with willing and sympathetic consulting engineers, could have a similar competition of their own.

Collating and disseminating precedents of earthquake architecture internationally will also help promote the idea. The authors have already begun this through a request for case studies placed in Californian earthquake engineering newsletters. Whether acknowledged or not, precedent is a formative design technique for both professions.

The final suggestion for realizing the vision is for earthquake architecture ideas to be promulgated within Schools of Architecture. Support from the Society, financially or in kind, could facilitate selected design studio projects, as well as staff and student research projects.

REFERENCES

1 PAPER DETAILS

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