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TOWARDS AN EARTHQUAKE ARCHITECTURE

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SUMMARY

This paper explores the scope and potential for an earthquake architecture. It responds to a previous observation that there is little architectural expression of seismic design in earthquake prone regions. An earthquake architecture might be warranted for a number of reasons, including celebrating seismic technology to add to the aesthetic richness of a building. Architectural possibilities for developing such an architecture reside within a wide range of different architectural and structural issues, and spaces and elements that provide opportunity for visual expression. Some international and New Zealand examples illustrate progress to date.

While outcomes of an earthquake architecture can be very diverse in their physical manifestations, architectural expression of seismic principles can also take many forms and levels of sophistication. An analysis of the three most common primary seismic load resisting systems, moment resisting frames, structural walls or shear walls, and braced frames, illustrates how each system provides different opportunities to express seismic behaviour including sophisticated seismic design principles. This possibility represents a considerable challenge to designers= innovation and creativity. The paper concludes by expressing the hope that having outlined the potential to express seismic design architecturally, architects in collaboration with engineers might avail themselves of some of these opportunities in future designs.

INTRODUCTION

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

Of the former type, there are a number of ways metaphor and symbolism are used in an architectural response to seismic design. Arnold cites an extreme example of the Nunotani 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”. Once aware of the design idea, some seismic activity can be seen in the main elevation of the building, but most viewers would probably interpret the distortions as evidence of seismic damage itself or incompetent construction!

A less well known example of seismic issues informing the architecture of a building occurs in 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

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of space which houses the newly created Entry from the city" (Figure. 1.) [Bossley, 1998]. As with the first example, it is unlikely building users mentally link the physical architectural form, in this case a highly penetrated wall, with the underlying concept of a fault line. Interpretation is needed. However, the fact remains that seismic issues have generated an innovative architectural design concept.

Countless other metaphors are possible sources of inspiration for architects who desire to recognise to some degree at least, tectonic activity under or adjacent to the site and who are grappling with the development of building form. Apart from ideas of crustal compression and expansion, a fuller list would also include slicing, fragmentation (also acknowledged in the Te Papa design), splitting, fracturing, sliding, folding and faulting. Geological metaphors have been adopted by architects in non-seismic regions as well. These metaphors may be developed into a central design concept, or else find themselves combined with other design ideas.

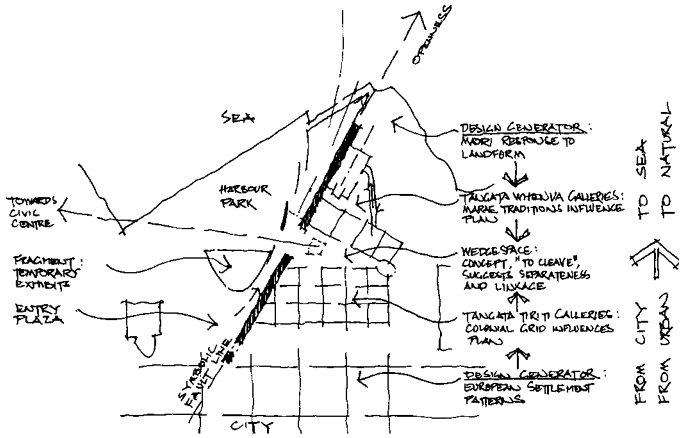

Figure 1: Conceptual plan of Te Papa showing the 'fault-line'

At a conceptual level, architects may wish to explore other issues relevant to seismic behaviour in order to give additional meaning to their designs and enrich their architecture. For example, concepts of strength, or weakness and fragility can lead to many different but potentially rich design possibilities. These ideas can be contrasted in a single design, as in the case of strong or dense structure concentrated in one area of a building plan and lightweight structure elsewhere.

This discussion raises the question as to why one might engage in an earthquake architecture. Some designers may wish to openly acknowledge the necessity to safeguard against seismic damage. For others, rather than adopt overseas architectural trends, they may try to generate a regional architectural response given the special geophysical setting of a region and site. Finally, some might wish to explore the potential for aesthetic richness through a celebration of seismic technology. This appeared to be the motivation of architect David Farquhason who introduced innovative seismic resistant features in the University of California at Berkeley, South Hall in 1873. He believed that safety features of a building should be revealed to passersby in the form of art, and proposed a method that integrated reinforcement with decorated wrought iron work [Tobriner, 1998]. This example shows that interest in an earthquake architecture is not new.

Arnold observes in his brief discussion of earthquake architecture that it has not become established as an architectural movement. He suggests that the reason "may be due to the psychological desire to deny the prevalence of earthquakes: building designs which remind the knowledgeable observer are striking a negative note". While this may be one reason, there are others as well. Certainly there is little architectural historical and theoretical development of these possibilities. Also, some architects possess relatively little seismic knowledge, and even interest in seismic issues. Architects have many other concerns on their design agendas as well. A more positive approach is to suggest that appropriate earthquake architecture might provide clients with increased status that could be linked to marketing opportunities. Owners could emphasis the seismic safety and security of their own building. After all, it is quite fashionable to drive a heavy and robust vehicle around city streets these days. Certainly in the period following a damaging earthquake when awareness to seismic safety peaks, an undamaged building whose seismic resistant technology is visible, is likely to be more acceptable than other similar buildings.

Ethical questions surface at this stage. To what extent do architects have a responsibility to inform building users of the vulnerability of their building in the event of a damaging earthquake? Do architects have a role or responsibility to remind people of their personal fragility in the context of building safety? Architects must take building safety seriously. Tadao Ando emphasised this repeatedly during his Royal Gold Medal Address [Ando, 1997]: "Returning to Kobe and visiting the site of the earthquake, the first thing that struck me was just how important a responsibility we architects have on the very basic level of providing safety and security for people." What about psychological security as well? It is common practice for architects to 'scale up' slender columns by bulking them out with non-structural material. In these cases they do not believe people perceive strength as 'striking a negative note', but rather they believe people will feel more secure, though in reality they are not!

EARTHQUAKE ARCHITECTURE: POTENTIAL OPPORTUNITIES

Opportunities for developing earthquake architecture exist in most aspects of architectural design. Metaphorical and symbolic examples and possibilities have been considered so now the paper focuses on visual and physical expression. This is discussed in relation to particular specialist aspects of architecture.

Urban planning

It is commonsense that land areas over active faults in urban areas be acknowledged by providing open park-like spaces. Open spaces provide for refuge and temporary storage of post-earthquake building debris. Wide streets provide greater assurance of maintaining traffic flows and quick response and rehabilitation following damage to city blocks. Landscape architectural elements can also enhance public safety. Frank Lloyd Wright, despite strong client pressure, provided a feature pool in front of the Imperial Hotel, Tokyo. He argued successfully that it would be a reservoir from which to fight fires following an earthquake. In the immediate aftermath of the 1923 Tokyo earthquake it was put to exactly that use [Wright, 1977].

At a more detailed level of urban design, seismic behaviour is acknowledged by building back from site boundaries and creating vertical separation gaps between buildings to avoid hammering. These gaps are usually hidden, but might they be expressed and even celebrated in an attempt to indicate their important safety function?

Figure 2: Cross-braced tower, Wool House, Wellington

Building form and massing

Possibilities exist to express earthquake architecture through building form. For example, pyramidal and squat building forms can suggest a sense of lateral stability. At a finer scale, it is possible to confront potential building configuration seismic problems, such as set-backs, or soft-storeys, with structural solutions that become important architectural elements.

Exterior elevations

Facades present opportunities to express seismic resisting systems. The degree of visual exposure of structural members can range from the subtle indication of structure to direct expression. Conventional cross-bracing, the most prevalent consciously exposed seismic structural system is probably overworked, but well designed variants can make a positive contribution to a city scape. The two reinforced concrete braced cores at each end of Wool House, Wellington, are examples of a refined reinforced concrete cross-braced aesthetic placed above a solid potential plastic hinge region (Figure 2).

Moment resisting frames are also exposed frequently, but their lateral load resisting function is not obvious. The relatively massive and separately colour coded wind and seismic frames of Castrol House, Wellington, articulate the lateral load resisting system by contrasting with the slender white gravity structure on either side (Figure 3).

Interiors

Exposed interior structure can contribute to spatial quality and aesthetic impact [Charleson, 1998]. Gravity load bearing elements such as columns and beams feature most commonly, but there is every reason for interior seismic resistant structure to be equally successful in architectural terms.

At a detailed level, floor, wall and ceiling seismic separation gaps also provide architectural design opportunities. Exposed sliding or rolling joints between the base of stairs and floors are another example of the aesthetic exploitation of seismic details (Figure 4).

Figure 3: Differentiation between seismic and gravity moment resisting frames, Castrol House, Wellington

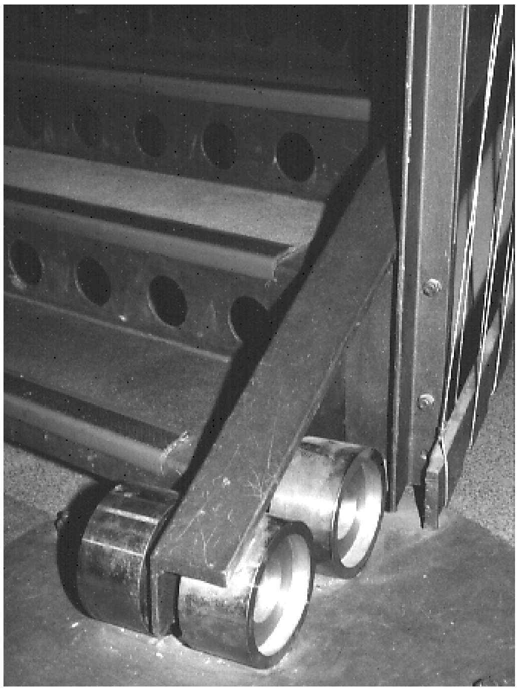

Figure 4: Roller staircase joint, IRD Building, Wellington

Non-structural elements

Heavy and strong elements such as precast concrete and masonry wall panels require special seismic separation details, especially if they are located within a relatively flexible structural system such as a moment resisting frame. Opportunities exist to express the separation gaps between structure and cladding panels, and between cladding panels themselves. Where cladding panel separation concepts are similar in principle to the action of flexible scaley reptilian skins, details that express that action might be worth investigation. Similarly, the provision for movement in seismic mullions may warrant design exploration. Even partition wall connections to structure, designed to accommodate interstorey drift, may provide opportunity for appropriate aesthetic expression.

Seismic restraint of building contents is another area ripe for architectural expression. In some cases, given care in both design and detailing, attractive and elegant restraints might even enhance an interior environment.

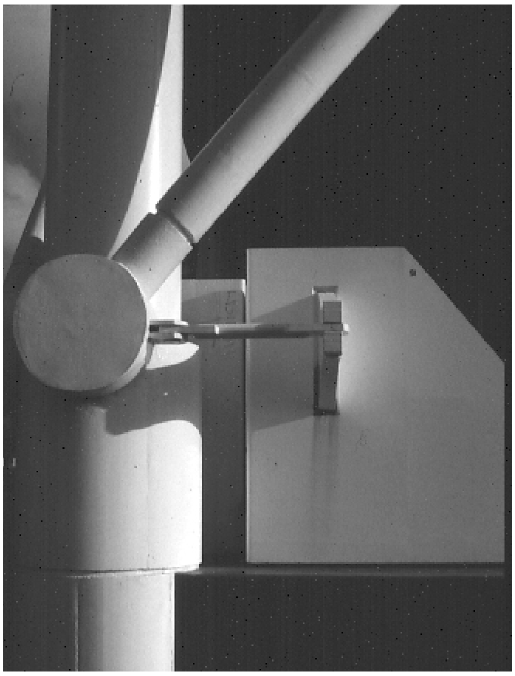

Figure 5 : Union House dampers, Auckland

Seismic equipment or hardware

There is an increasing use of base-isolators, fuses, dampers and bearings in modern buildings. At Union House, Auckland, mild steel cantilever dampers are exposed around the perimeter of the building (Figure 5). This is possibly the first time base-isolation has been articulated to any significant degree. Such a design approach is worthy of further development. In all the other nine New Zealand base-isolated buildings, exciting and innovative technology is concealed from public view. Expressive qualities of devices such as lead extrusion dampers are lost. Architects in seismic regions also have yet to make the connection between their commonly expressed wish to 'float a building', and the possibilities provided by base-isolating systems.

EXPRESSION OF SEISMIC STRUCTURAL PRINCIPLES AND ACTIONS

This section explores the potential for expressing seismic principles architecturally in the context of common structural forms. Depending on the degree of seismic knowledge within a design team of architects and engineers, ever deepening layers of understanding may be accessed to realise an expression of earthquake architecture. However, a high degree of structural and architectural integration and collaboration between architect and engineer is necessary to fully exploit these ideas.

Figure 6: Wrapped potential plastic hinge regions

Moment resisting frames

At the most basic level, structural actions such as axial load, bending moments and shear forces arising from seismic loads can be expressed in the detailing of structural members. Usually just one action, such as bending will provide enough architectural potential. If this were the chosen action, then one consequence for beam and column detailing is that members can be haunched from beam-column junctions to minimum cross-sectional depths at

member mid points.

Another level of sophistication involves expressing the concept of Capacity Design. In this case the fundamental requirement is for the expected seismic damage to occur in beams. Damage to columns that support the building

gravity load is suppressed. This concept of strong columns and weak beams can be expressed easily. Attention can also be paid to the expression of potential plastic hinges, usually at ends of beams. Here, engineers design for anticipated concentrated damage. Structural engineering attention to these regions, in reinforced concrete construction, results in confinement of the concrete beam core to prevent cracked concrete dislodging from the beam and resulting in longitudinal reinforcing bar buckling. Images of binding, strapping or bandaging illustrate the structural necessities of plastic hinge zones. The refurbishment of some existing earthquake risk structures in Wellington has involved wrapping these zones with high strength materials (Figure 6). The

Figure 7: Typical beam stubs

utilitarian nature of this solution does not preclude more elegant alternatives for new construction.

For glue-laminated timber frames, prefabricated mild steel and ductile beam-column joint zones articulate the structural goal of preventing damage to the brittle timber members [Buchanan and Fairweather, 1992].

There may be opportunity to integrate other specific reinforcement detailing solutions with architectural expression. For example, beam stubs projecting from corner columns were popular in many New Zealand multistorey frame buildings in the 1970s. Stubs solved the problem of adequately anchoring top and bottom beam longitudinal bars, and lessened reinforcement congestion in the beam-column core, easing concrete placement (Figure 7). Subsequent research has led to other satisfactory anchorage methods.

Braced steel frames

Apart from the active link region near the inclined braces, eccentrically braced frame members resist loads in tension or compression. Reduced axial load levels towards the top of a building can be expressed, as in Wool House.

Capacity Design considerations once again provide more profound detailing opportunities. An economical and reliable approach is for the areas in tension and/or compression members selected to yield, to be deliberately weakened. Other members and connections will therefore remain undamaged during an earthquake. There is considerable scope for such 'fuses' to be expressed architecturally, particularly if the detailing is elegant and refined and is positioned where it can be appreciated (Figure 8).

Figure 8: 'Fuses' in cross-bracing, Schools of Architecture and Design, Wellington

Structural walls

Bending moments and shear forces are the dominant seismic structural actions on walls. Possible expressive architectural strategies include differentiating between wall chords and webs, that is, between moments and shear forces. Chord dimensions and wall thickness can be varied. One approach for shear force articulation and the need for an unpenetrated potential plastic hinge zone at a wall base has been to decrease the amount of fenestration towards the base of a wall (Figure 9). A far more explicit example of a shear wall tapering towards the top occurs in the Tandy Center Building, Fort Worth, Texas [Arnold and Reitherman, 1982].

Figure 9: Reduced fenestration towards wall base, Wellington Central Telephone Exchange

Horizontal members

Diaphragms, together with other members that collect and transfer loads into vertical structure, are essential components of the lateral load resisting system of a building. Diaphragms resist shear forces and bending moments. Collecting members also known as drag bars, collectors and tie beams, act in tension and compression. They may be conveniently shaped as ribs or can be articulated separately. Usually, floor slabs double as diaphragms, but across large openings any special diaphragm structure such as steel cross-bracing that may be required can be expressed.

CONCLUSIONS

Earthquake architecture can encapsulate metaphorical references to seismic issues, or at a more practical level, express a design response to seismic loads. Depending on the seismic knowledge within a design team, the potential exists for various layers of structural technology and technique to be expressed architecturally. The primary motivation for such expression may be to enrich the aesthetic and other aspects of architecture, but other reasons are also possible. For an earthquake architecture to succeed, a high degree of integration of structure and architecture, and collaboration between architect and engineer is necessary.

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