A CHANGE OF SCENE: HOW THE CANTERBURY EARTHQUAKE SEQUENCE LED TO A DEPARTURE FROM CONCRETE TECHNOLOGIES

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Over time, nature can expose even the slightest weakness. This became very clear following a sequence of unexpected earthquakes that struck in Christchurch, New Zealand earlier this decade. At the time the quakes struck, research and development with concrete building technology Canterbury had gained an international reputation and contributed significantly to the region's development. Structural and architectural innovation helped make concrete the material of choice for new commercial buildings. The paper outlines some of the key architectural and structural innovations evident in the buildings of the city. The earthquake sequence exposed several shortcomings in the design, construction and maintenance of buildings, including to several buildings that represent key moments along the innovation pathway. Now that the rebuild is well under way it is becoming clear with every building that is completed that the city's visual character will be significantly different. The emerging character appears to be developing around the global materials of steel and glass, with concrete no longer featuring in the ways it had. The paper discusses the background to this departure and how it signals the end of a productive period of innovation with this local material.

Keywords: Christchurch earthquakes, performance, concrete, disaster, innovation

INTRODUCTION

Throughout its brief history of post-colonial settlement, and prior to the widespread losses arising from the 2010-12 seismic sequence, Christchurch had gained a well-deserved reputation for the quality of its built environment. With the city situated on the flat and expansive Canterbury Plain, those who created the city were untroubled by the landscapes that challenged the builders of New Zealand's other major cities. The flip side to this is that designers have not been able to rely on natural features to frame their work and that the city's visual character is derived almost completely through its buildings, gardens and infrastructure. Buildings in Canterbury are seen against a largely man-made context rather than in relation to nature. There are no distant views to celebrate, no natural landscapes to relate to; instead the outlook from every building and public space has been constructed (Mitchell and Chaplin, 1984).

During the Victorian period of colonisation and growth, architectural sensibilities could be traced back to the English buildings that were familiar to the early settlers. These traditions were often modified by material availability and environmental conditions. The immigrant architect Benjamin Mountfort was one who helped transform Christchurch

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from a village of crude timber buildings into a magnificent city of Gothic Revival buildings by the end of the century (Lochead, 1999). The strong and angular basalt and volcanic stone materials found in the area around Christchurch lent themselves to a style of building that quickly became associated with the city and with its public buildings in particular. Public and expert opinions also agreed that this architectural character was attractive (Fowler, 1984; Terrence Hodgson, 1990).

A factor in the development of a distinctive Canterbury architectural character has been a willingness on the part of architects and engineers to challenge prevailing conventions. For example, Mountfort pursued a different vision for Gothic Revival than did his contemporaries working in Britain and America. The freedom that Mountfort and his colleagues enjoyed by working in a still emerging colony in an isolated part of the world led to opportunities that would have been unlikely had he remained in Europe (Lochead, 1999). Over time, and as architectural theories and practices change, new opportunities emerge for local designers to adapt these to local conditions. In response to such opportunities, concrete materials and technology came to be adapted for use in the Canterbury region by local architects and structural engineers. Over a particularly interesting 40-year period of development last century, this made significant contributions to local architectural and cultural character.

The paper traces the lineage of concrete usage, noting the contribution it made to Christchurch's architectural character, particularly in buildings built between 1950 and 1990. Many of these buildings represented points along a path of innovative architectural and technological development. A sequence of earthquakes in 2010-12 led to widespread demolition of damaged buildings and with it, the city's architectural character. As the city is rebuilt from the ground up, material preferences have shifted to glass and steel. The paper pursues the question of why designers have departed so markedly from the materials and technologies they were working with before the quakes. The analysis is based on published sources, supported by structured interviews with representatives of the design and property management professions. The interruption to the long and productive period of development is contextualised through literature.

A CONCRETE HERITAGE

The conditions throughout the Canterbury region are ideally suited to the manufacture of concrete. The Southern Alps are the backbone of the South Island and continue to grow as a consequence of the ongoing collision between the Australian and Pacific tectonic plates. With each passing year the process spills crushed stone to either side, a continual source of aggregate. Until recently, Portland cement was also manufactured on the west coast of the island, providing a dependable source of concrete's active ingredient. With an abundant and accessible supply of the raw materials needed for concrete manufacture, concrete is without doubt one of the country's indigenous construction materials.

Early settlers were able to build with concrete as early as 1843, using casks of Portland cement imported from England by boat (Reed, Schoonees, and Salmond, 2008). Over the following century their skills and techniques developed and the material was used extensively for infrastructure projects as well as in agricultural and industrial buildings. Somewhat surprisingly at the time, concrete found its way into several residential and civic buildings under the sponsorship of architects such as William Clayton, Frederick de Jersey Clere and Thomas Douce. These early adopters all saw opportunities to enhance construction efficiencies and performance with the still relatively new material (Thornton, 1996).

It was not until the arrival of two European architects in the late 1930s that the architectural potential for concrete began to be realised more widely. In the wake of World War II, the government's ambitious housing programme identified concrete as the principal material in medium and high density housing developments. Immigrant architect Frederick Newman felt that local architects were wasting timber and recognised that concrete would provide better structural performance and durability in social housing projects (Newman and Leach 2003). Even so, in the context of the prevailing Modernist design philosophies, architects considered the material as a means to an end; when it could be plastered and painted white it was an effective medium with which to create geometrically clear architectural form and space. The task of reflecting New Zealand culture and conditions through architecture would fall to the next generation of architects, and concrete became a material of choice.

The period following the war is widely acknowledged as a rich period in New Zealand's cultural and architectural history. From the late 1940s there was widespread interest among architects to develop appropriate design responses, working with the country's unique cultural and social characteristics, responding to the environmental conditions and making use of local materials (Clark and Walker 2000). It was during this time that designers began to recognise the potential of concrete as an architectural medium beyond its previous manifestations.

At this time, New Zealand was riding a wave of international modernity. Participation in the war effort had brought them closer to their European and American allies. However, "international architectural culture began attending to the specificity of particular locations. The conjunction of the local and the modern is a fundamental issue in New Zealand architecture." (Clark and Walker 2000). In these ways, critical regionalism could be distinguished from simple, nostalgic vernacular design. This would drive the search for appropriate architectural forms, embedded in local culture and expressive of the national identity.

These efforts were particularly productive in the South Island, where development was taking place at a great rate to make up for a generation of minimal construction activity. The architects whose work would contribute to the quality of this period were well acquainted with New Zealand's architectural history and also able to draw on their experiences of other places. Accordingly, their work reflected a mix of inherited architectural traditions animated by their own personalities and thoughtful reflection about key architectural concerns of the day (van Raat 2005). The quality of work being produced in Christchurch at that time was particularly high. Walker (2005) suggested that this was in part due to the willingness of clients to commission young designers and in part to the wide variety of projects that were being commissioned. Beaven (1967) also attributed it to the amount of time architects were able to lavish on their work. In his mind architecture enjoyed higher social stature in the city than elsewhere and by the 1960s Christchurch architecture had attained a mythical status (Walker 2005).

A strong lineage of Canterbury designers experimented and worked innovatively with concrete as an architectural material in the latter half of the 20th century. None were as successful as two young architects who set up separate practices in the 1950s. Miles Warren had worked in London where he witnessed the emergence of the Brutalist movement in architecture. Mitchell and Chaplin (1984) noted that Warren was influenced by the aesthetic approach taken by the Brutalist architects, who sought to express the way a building was made. As much as Warren was a rationalist, the architect Peter Beaven was committed to romanticism. He drew his architectural inspiration from

Mountfort, Ruskin and everything Gothic. Having grown up around the family engineering business, he was also comfortable with the honest reality of the grain stores and freezing works built by his grandfather (Beaven 1967, 2002). Beaven (1962) also wrote to educate his colleagues on the exciting aesthetic possibilities that he could see emerging with concrete construction techniques. He was particularly taken with prestressed, precast concrete elements. Earlier construction methods and materials had proven inappropriate for use in the ruthless New Zealand climate and he expressed dissatisfaction with 30 years of depression and wartime standard building. Architecture, he wrote, has a role of excitement and fitness for purpose that must come with more flexible and expressive methods of building. Over the course of their parallel careers, the expressive use of precast concrete elements would be another area their architectural sensibilities would overlap.

The work of these two designers helped redefine the character of the city toward the end of the century. Perhaps the country's most famous 20th century building, the Christchurch Town Hall has been discussed widely since the winning entry to a national architectural competition was first announced. Concrete elements feature throughout the building and the structural proportions are elegant (Gatley 2008). Also around this time, Peter Beaven was given the opportunity to build a new administration building for the Lyttelton Tunnel Authority. The proportions of space and structure are grand, expressive of the widespread pride felt by Cantabrians with the completion of the vehicle tunnel linking the port to the city (Hodgson 1990). The confident use of materials and formal expression also signalled a new maturity in New Zealand's modern architecture (Gatley 2008).

Although it can be difficult to appreciate this now with the central area largely empty, Christchurch earned a well-deserved reputation for the quality of its office buildings. Many of those that were most highly respected were built for those who would be working in them (Warren 2008). Organisations such as Canterbury Frozen Meats and Colonial Mutual commissioned buildings that they planned to own, that needed to provide for their ways of working and that would often go on to represent the company in the eyes of the public. Three important projects from this era were those undertaken for SIMU, Manchester Unity and General Accident. Only the latter remains standing today.

These projects are all linked by their facades, where precast concrete was used with great effect. The buildings predated widespread use of air-conditioning and the architects each realised that overheating could be the main cause of discomfort in large office buildings. While three-dimensional modelling of the façade panels helped provide all-important shading it did much more than that in architectural terms. These buildings have a generosity of depth and high levels of visual interest generated by the repeating patterns that is unmatched in this country or elsewhere. The façade designs and construction materials were important elements in the development of an architectural language that became synonymous with the Canterbury region.

In 1964 Peter Beaven broke new ground on several fronts when designing the Manchester Unity building on the corner of Worcester and Manchester Streets (figure 1). He conceded that it was the first time he had consciously addressed the local context and in this case his design referenced Mountfort's Trinity Congregational Church on the opposite corner. The project was built using the lift-slab method, innovative at the time in Canterbury although its use was short-lived (Gatley 2008). The key design feature developed by Beaven to link this building with the Trinity Church were the articulated precast concrete mullions, which extend the full height of the street facades. The depth of the mullions allowed the architect to manipulate the alignment of the glazing and the floor structure over the height of the façade. This articulated façade contrasted with thin curtainwall systems being used elsewhere at the time.

With a generous, largely glazed ground floor and copper clad roof the building adopted the classical tripartite composition. Along the shopfronts the design revealed 'Y' shaped columns, which were used by Beaven to 'collect' adjoining pairs of mullions from the upper levels, and running them to the ground. With this building Beaven provided punctuation to an important corner of this gridded city. He also brought a sense of European elegance to Christchurch (van Raat 2005) but tempered this through references to local buildings and by using his beloved precast concrete innovatively.

The structural solution for the SIMU building, designed for a site facing onto an important public square in the city, adopted Lyall Holmes's technique of concentrating lateral support into a stiff core - in this case two cores - allowing the outer columns to be relatively light as they were only required to support gravity loads (Warren 2008). Spanning between floors, the precast concrete cladding panels used at SIMU had an exposed aggregate finish and adopted tight rhythmic spacing. While Warren remained committed to the expressive potential of roofs in the Canterbury landscape, SIMU was given a light, almost ethereal conclusion. The vertical mullions of the panels below stretch upward causing the building to literally merge with the sky.

Figure 1: The Manchester Unity building by the architect Peter Beaven

Figure 2: The SIMU building by the architect Miles Warren

The buildings from this period stood as a testament to effective collaborations between architect and structural engineer in the concrete medium. Moving from structures designed to rigidly resist lateral forces, where shear walls could limit interior space planning freedom, engineers adopted more open solutions that were designed to flex. Virtually all new commercial buildings in Christchurch from the early 1980s utilised moment resistant frame structural designs (Hare 2013). In principle, these structures were designed to flex under load and this brought new challenges to designers as façade claddings and other architectural elements needed to be able to accommodate this movement. Construction solutions were developed in close consultation with the building industry and engineering schools. At the University of Canterbury, Professors Tom Paulay and Robert Park had a profound worldwide influence on the design of structures to resist earthquakes. A book they published in 1975, *Reinforced Concrete Structures*, became the seminal work on capacity design internationally. Engineering academics, supported by a steady stream of PhD candidates, were able to undertake full scale testing of structural design innovations. In most cases the design development has followed an evolutionary track, such as taking on contemporary industry issues like the seating details of hollow-core flooring units. However, in a few cases the research has been revolutionary, such as the programme to develop Damage Avoidance Design solutions.

A CHANGE OF SCENE

The circumstances surrounding the Christchurch earthquakes are now well rehearsed in several academic and media outlets. For example, see Brownlee (2011), Bennett, Dann *et al*., (2014), Brand and Nicholson (2016). The knockout punch was delivered in the form of a 6.3 magnitude earthquake on the 22nd of February 2011, taking 185 lives and reducing many parts of the city to rubble (Brownlee 2011). This was the defining event, with ground accelerations recorded at one and a half times that of gravity leading to structural loadings of up to twice the levels specified in the New Zealand Building Code (NZBC). With some 1,350 buildings in the central business district alone having been demolished, the architectural character of the city has unquestionably changed forever.

While the older unreinforced masonry (URM) buildings were the most vulnerable to damage, due largely to their age and lack of comprehensive reinforcement, there was also considerable damage to concrete buildings (Ingham and Griffith 2011, Hare 2013). The two most catastrophic failures, which together led to the deaths of 133 people, occurred in concrete structures. The Canterbury Television (CTV) Building was built during the heady boom period of the mid 1980s, when a great number of older buildings were demolished to make way for new commercial buildings that were commissioned in response to unprecedented financial growth. Many of the structural innovations that took place during the 1980s, such as those employed in the CTV project, challenged the prevailing concrete performance limits of the day in the name of innovation (Hare 2013). Like the CTV building, the Pyne Gould Corporation (PGC) Building had an offset services/structural core but was older, having been originally built for local government in the early 1960s. The innovative plan configurations for these two buildings were driven by space planning objectives, which the structural design for each was required to support. The failures of the two buildings were a reminder that those with irregular plan configurations do not perform as well as those more rationally configured. The seismic forces exposed the tendencies toward torsional twisting, which the concrete load bearing columns around the perimeter of the plan were unable to cope with (Canterbury Earthquakes Royal Commission 2013). The two Achilles heels of concrete are its inability to resist tensile forces and its tendency toward inelastic (crumbling) failure. Both were exposed under the duress of the shaking and the consequences were fatal.

The CTV building represented the only failure of a building designed after building regulations changed in 1976. Hare (2013) confirmed that all others performed above the bottom line required by the NZBC, which is to provide for the safety of those within them. However, after people had a chance to reflect and speak to others, their opinions of building performance was diminished significantly. Although many had initially taken comfort that the city had come through the earthquakes surprisingly well, their attitudes changed to alarm once they came to understand how many buildings would have to be demolished (Matthews 2012). The fact that most of these had a concrete structure led building owners and the public to form negative associations with the material and structural design approaches that had been used. As some experts were looking backward, interested in learning more about how concrete buildings had behaved, others were looking forward to suggest how buildings could be designed to be more resilient to seismic events such as this. Other competing structural systems such as timber and steel, which had not been part of the landscape before the earthquakes, were suddenly being considered. Neither material would have to overcome the negative associations that concrete had with building failure.

It is clear now that the lineage of concrete technology that could be traced through buildings dating to different eras has been abruptly stopped though the invisible hand of the market. As the rebuild has taken shape it is now obvious that building owners and designers have been almost universally attracted to glass and steel (Marshall, Sheppard *et al*., 2016). While this attraction has undoubtedly been fuelled by global fashion, the manner and consistency with which braced steel frames are celebrated in the new building facades suggests that architects seek to send a not-too-subtle message to potential occupants: "This building's structural design has been given top priority". The emerging Christchurch style can be attributed to what urban designer Hugh Nicholson calls corporate urbanism, where the goal of attracting tenants in the current market leads to the expression of seismic engineering features. See figures 3 and 4. This opinion was confirmed by property developers and owners, who are aware that safety and resilience are now much higher on the list of tenant needs than they were prior to the earthquakes. These demands are fuelled by tenant organisations aims of attracting and keeping high quality staff and enabled by the current competitiveness in the market as property owners seek to attract tenants. In this context, it is about perceptions as much as it is about demonstrated performance. Residual concerns about the performance of concrete have led the market away. Property owners' motivations toward steel structures complement those of the designers consulted in this research. They expressed strong preferences to explore lightness, crispness and transparency in new buildings, qualities that glass and steel make possible. The architects expressed low regard for the earlier character of the city, noting that with so much of it gone there is an opportunity to create a new visual environment.

Figure 3: Like many new buildings, the steel structure is clearly expressed in the facade design.

Figure 4: The glass facades of most new buildings lack the articulation and visual interest that was a hallmark of concrete facades in the city prior to the earthquake sequence.

DISCUSSION

The reasons for this departure are several. The two most dramatic building failures were to concrete buildings. Of these, it is perhaps most relevant to consider the CTV building as it was the one modern design that failed. While the project was developed in the post-1976 era it was also undertaken during a period of wholesale economic liberalisation. That socio-economic circumstance invited innovative practices that could enable designs to meet performance-based outcomes more efficiently. Hare (2013) noted that prescriptive, code-based approaches around the world are written in ways that provide for the required design performance AND higher performance to be achieved. Such “better than expected” performance derives from the factors-of-safety that have been allowed for in prescriptive engineering design solutions. However, where the engineer steps outside a code-based approach in order to pursue a more innovative solution “the onus must fall back on to the engineer to ensure they can meet this level of performance”.

Hare (2013) took a critical view of the performance of some of his structural engineering colleagues when he noted that ‘professional judgement’ is given as a justification for a solution far too often. The unfortunate truth in many cases has been that the engineer has neither the ability nor the energy to deliver an appropriately robust analysis. Although Hare’s opinions were expressed in connection with the on-going investigation of performance during the earthquake sequence, they extend past this circumstance and suggest that structural design practices would need to change. The evidence provided by the seismic sequence confirms that, during a period of economic liberalisation, concrete structural innovation processes was not appropriately reflexive.

While all but one modern concrete designs did meet the minimum life safety standard, many others failed to respond in a manner that would allow them to remain in service. The majority of the 1,350 buildings that were demolished could not be reinstated following the damage they had suffered. Two factors may help explain why so many concrete buildings were amongst those that were required to be demolished. The first, and most important, is that many failed to perform as expected. While many more buildings had been designed around empiric evidence than had been configured based on the professional judgement of the designer, the structural responses of these did not meet the performance of tests carried out in research laboratories. There was a lack of correlation between observed laboratory testing and actual structural behaviour (Canterbury Earthquakes Royal Commission 2013). Clearly such poor results against the predictions would cause property owners to think carefully when deciding on a replacement. A second factor affects the potential for concrete buildings to be rehabilitated following the event. While the concrete provides the compressive strength, in a seismic event it is likely that the tensile steel will be the most severely tested. With steel reinforcing buried deep inside the concrete and unable to be comprehensively inspected, it is also impractical to replace. Techniques for repairing and rehabilitating concrete structural elements is only in its infancy and the easy decision made by many building owners has been to avoid any attempts to repair buildings if there is a likelihood of real or perceived shortfall against seismic strength.

Through active exploration of the architectural and structural potentials of concrete, this locally sourced material became closely associated with Canterbury. The positive relationship was reflected in the testing laboratories at the University of Canterbury, in the concrete related businesses that had established and most visibly in the built environment. Those who developed new technologies and uses for concrete in the Canterbury region for over a century were driven to add value, a fundamental expectation for innovative practices (Orstavik and Dainty *et al*., 2015). Whether that value was conceived in aesthetic terms, thermal performance, economic cost or sustainable sourcing of materials, development followed rigorous processes of design, evaluation and refinement. Smith (2001) advised that innovation for seismic performance must be supported by rigorous evaluation and testing of new materials and processes in laboratory conditions. However, he also cautioned that further development and refinement must be made in conjunction with performance in the field. Ours is an applied science that learns from failures as well as from successes. It would seem that the reaction by designers and building owners to steer away from using concrete structural systems has interrupted processes of innovation at an important moment in time. Innovative practices depend of stock being taken following a failure such as this in order to base further development on what has been learned. No doubt, forensic assessment of failures will continue to inform improvements in the ways buildings and infrastructure can be designed to withstand seismic activity, but it is becoming more likely that those improvements will not be made in ways that will extend the lineage of concrete buildings and technology in the Christchurch built environment. On the evidence to date of the rebuilding effort and the views of those making decisions about the form and structural approaches of new buildings, concrete is no longer the structural and architectural material of choice.

CONCLUSIONS

Concrete has enjoyed considerable favour with local architects and engineers for over a century, being used creatively to enhance structural performance and building appearance. Over time concrete became closely associated with the Canterbury region and was increasingly utilised in important building projects. The paper has discussed the wholesale departure from a concrete-based building approach in Christchurch in the wake of the Canterbury earthquake sequence. As the city sets about to reconstruct its central area, the most prominent materials are glass, aluminium and steel, none of which are produced locally and all of which come with environmental costs.

In a positive sense, the change in approach has been influenced by an attraction to new, shiny materials by architects and their clients, informed by global fashion. However, the bigger factor seems to have been a negative reaction to concrete structural systems which could be attributed to poor performance during the earthquakes. While concrete systems have been progressively developed to meet anticipated structural loads through innovative thinking, they've never been severely tested, at least to the extent of this event. The building stock response has exposed several shortcomings in process and systems that have no doubt led the industry to look for alternatives. In some instances, concrete systems did not perform as predicted by laboratory testing. In others, while they remained intact and protected the lives of those inside, the ongoing viability of buildings was compromised. Not only did this lead to widespread demolition but it also gave cause for building owners to look for alternatives. Finally, some of the most devastating failures were attributed to a failure in process. Economic liberalisation, which provided opportunity for some professionals to innovate beyond sound judgement, was exposed in the process.

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