STRENGTHENING AND HERITAGE RESTORATION OF THE ARTS CENTRE OF CHRISTCHURCH

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ABSTRACT: *The strengthening and restoration of the Arts Centre of Christchurch city block of 22 heritage buildings is a significant project of national importance. Over a period of 30 years, Holmes Consulting Group has delivered a range of securing and strengthening solutions to the campus. Currently a site based team of 6 provide a dedicated resource to the site leading this complex and intricate project following the earthquake activity of 2010 – 2011.*

KEYWORDS: heritage restoration

1 INTRODUCTION

The Arts Centre of Christchurch is a heritage site of both local and national significance. The Canterbury earthquakes devastated the Arts Centre site as it did the rest of the city. All of the 22 Category 1 heritage buildings were damaged and their usability compromised. Following the Trust Board's determination and insurance negotiations, the Arts Centre embarked on a strengthening and restoration project that is currently the largest of its type being undertaken in the world. Holmes Consulting Group (HCG) is providing structural engineering and multi-discipline coordination for the project.

The relationship between HCG and the Arts Centre, which extends over a 30 year period, underlies the unique approach to project delivery. In addition to providing specialised and bespoke structural solutions, the site based team of six plays a key role in leadership and management of the restoration project alongside the Arts Centre management team. Now three years into the $290 million project, HCG has completed one building, with a further nine in construction, of which the majority will be completed during 2015. This will see over half of the available floor area on site open. Analysis of a further three has been completed with the site's largest floor plate, the Engineering Extension, due to start construction in April 2014. A continued design and construction programme will see partial opening of the site in 2015 with a further five to six years of activity ahead of the team.

This paper provides a summary and introduction to the site, the effects of the Canterbury earthquakes, and an insight into the work that has been undertaken to date.

2 THE ARTS CENTRE, THEN AND NOW

Established as a seat of learning in the early stages of European settlement, what is now known as the Arts Centre represents both the aspirational intentions of the settlers and a tangible reminder of the qualities and values that characterised their homeland. Modelled on Oxford and Cambridge, the campus is unique as an example of Victorian gothic revival architecture. The heritage values of these buildings and their setting are of local and national significance. It is one of the best examples of adaptive re-use of a heritage site in the country.

The 22 Category 1 heritage buildings, together with the 2.2 hectare central city block of land that they occupy, comprise one of the most significant heritage sites in New Zealand.

The NZ Historic Places Trust states, Category 1 status is given to places of 'special or outstanding historical or cultural heritage significance or value.'

The Arts Centre also carries a Group 1 rating under the Christchurch City Council city plan heritage listings.

Built over a fifty-year period from 1877, the buildings originally housed Christchurch Girls' and Christchurch Boys' high schools, the School of Art, and Canterbury College (later to become the University of Canterbury). Construction began with the building of the Clock Tower block—the first building in New Zealand to be designed specifically for a university.

The Girls' High School building opened the following year, with the Boys' High School building

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following three years later. Both schools moved off site in 1881 and 1926, respectively. Other buildings were added as the university expanded.

In the late 1970s, following the university's relocation to Ilam, the city campus was gifted, via the government of the day, to the people of Christchurch and New Zealand, to be held in Trust as a cultural centre.

Under the requirements of its trust deed, the Board is to maintain, conserve and promote the heritage integrity of the land and buildings as well as foster, promote and facilitate the interests of art, culture and education.

Prior to the seismic activity in 2010 and 2011, the site was occupied by more than 100 tenants, including galleries, theatres, cinemas, teaching studios, offices, workshops, speciality shops, bars, cafes and restaurants, 100 market stallholders, and was visited by close to 1.3 million visitors annually.

3 CANTERBURY EATHQUAKE SEQUENCE

The magnitude and duration of ground accelerations are well documented. The underlying ground strata across the site behaved relatively well during the earthquakes of 2010 and 2011 with no presentable liquefaction having occurred. Damage due to differential settlement was limited to isolated areas where some creep had already occurred.

The collection of buildings on site, built over a period of 50 years, are typically founded on shallow mass concrete foundations. However, few of the 22 individually categorised buildings stand-alone (see Figure 1 below). The interconnected nature of the site and lack of separation between buildings had a significant influence on their structural behaviour.

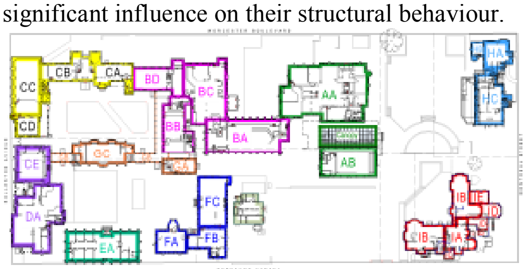

Figure 1: *The Christchurch Arts Centre Site Plan*

Following the September 2010 event, damage across the site was limited to the buildings' towers, turrets, chimneys, and finials, and at locations of building interaction. Following a number of securing measures, the majority of the site was able to be reopened in a relatively short period of time.

The February 2011 event had a significantly different outcome. Building stability across the entire site was severely reduced with a number of building elements suffering partial collapse, most notably the Observatory Tower (see Photograph 1 below). Following initial assessments and reactive securing to the most critical elements (done primarily to prevent further deterioration), it was apparent that all buildings would require significant works and the Arts Centre site was closed.

Photograph1: *Collapse of the Observatory building*

3.1 DAMAGE SUMMARY

As noted above, none of the buildings were left unscathed. In many instances the full extent of deformation and subsequent reduction in stability was not immediately apparent. A prime example is found with gable end walls that were able to flex and return to their original position leaving only hairline cracks. The extent of hinging undergone by these elements was not fully recognized until the action was actually observed during aftershocks or secondary damage discovered.

Beyond the obvious collapse failures the predominant mechanisms affecting building fabric were either out-of-plane deformations or interaction with adjacent buildings. In-plane shear failure of wall panels was limited.

3.2 PRIOR WORKS

The relationship between Holmes Consulting Group and The Christchurch Arts Centre extends over a 30-year period. During this time numerous seismic strengthening and securing works have been completed across the majority of the campus. These works fall under two basic categories: strengthening and securing. For the purpose of this paper, strengthening works take into consideration global building performance, while securing focusses on discrete load path resolution.

The scope and performance objectives of previous upgrades were driven by budget considerations and the preservation of heritage fabric.

These works ranged from simple gable restraints through to more complex post-tensioning solutions. Whilst some minor failures of these elements occurred, the majority satisfied their objective, limiting the extent of damage and collapse across the site.

3.2.1 Post-tensioning

Completed to varying degrees across College Hall, Engineering Extensions, and, notably, The Chemistry building, these works were completed circa 1985. They are predominantly considered under the category of strengthening works.

College Hall used vertical strands to restrain rocking and add flexural capacity to the 10-metre high, 30-metre long west elevation. Mounted both externally and internally at each side of the five primary buttresses, the strands were anchored between paired PFCs at the top of wall and strip foundations along its base.

Engineering Extensions used horizontal post-tensioning at both first floor and eave-level to provide longitudinal restraint (effectively a clamping force) to assist in global stability.

The Chemistry building used both vertical and horizontal strands primarily to add flexural capacity to the buttress (column) and spandrel (beam) arrangement along the north and south elevations. Anchored externally, as shown in Photograph 2 below, paired strands run from below the elevated ground floor to above first floor levels at the re-entrant corner of the buttress and spandrel panels. The horizontal strands at each floor plate are paired internally and externally.

Photograph 2: *External post-tensioning to Chemistry building*

Throughout the Canterbury earthquakes these elements performed well and significantly limited the extent of damage sustained by the building. Notable for both the Chemistry and College Hall projects, the final design solution is a mimic or refinement in detail of their respective post-tensioned systems.

3.2.2 Supplementary bracing and trussing

The implemented measures under this category predominately fall within securing works and are spread across the majority of the buildings on campus.

Boxed and portal frames were mounted to the internal faces of discrete areas of the Arts Centre buildings. These added flexural capacity and restricted rocking behaviour of elements with unstable aspect ratios. Frames were typically anchored to existing floor plates and wall or buttress elements below to resolve shear and overturning reactions.

Discrete tension braces were extensively used at roof level to connect trusses to eaves. Steel trusses were used to provide out-of-plane support at wide gables where access was available.

3.2.3 Diaphragms, ties and discrete restraints

Aside from the more recent works associated with the School of Arts and Registry buildings, diaphragm works were limited to nominal floor overlays supplementing existing floor capacities. Never to be underestimated, the addition of robust connections between existing tongue-and-groove or sarked substrates and surrounding walls improved the out-of-plane performance of connected walls, and the building globally. These were as simple as external wall "rosettes" (150 millimetre diameter cast-iron washers with through-bolts to purlins or joists) resulting in a significant reduction of collapse.

4 ANALYSIS AND DESIGN

The analysis and design of the buildings comprising the Arts Centre campus was undertaken using a combination of Equivalent Static Analysis (ESA) and Non-Linear Time History Analysis (NLTHA). Due to the Category 1 heritage designation of the Arts Centre campus, the buildings were strengthened to 67% Importance Level 3 (87% IL2) National Building Standard loads.

ESA was used for the principal assessment and design method for small and regular freestanding buildings such as the Gymnasium and Old Registry; NLTHA was used in conjunction with ESA for larger and more complicated structures such as the Boys' High and College Hall/Clock Tower buildings.

NLTHA modelling was a two-stage process. Initially, seismic records for the September and February events from the adjacent Botanic Gardens recording station were processed, allowing predicted building behaviour to be compared with actual damage observed. This process provided verification of the model performance with regard to global load paths and the material properties utilised.

The second stage of the NLTHA process was to assess the global performance of a building's strengthening scheme using earthquake records satisfying the requirements of NZS1170.5.

Strengthening schemes developed using NLTHA were iterative in nature to ensure local element strengthening did not induce damage in adjacent elements. Localised strengthening such as chimney bracing or out-of-plane gable support designed using ESA was incorporated into the NLTHA model to ensure compatibility with the buildings' global performance.

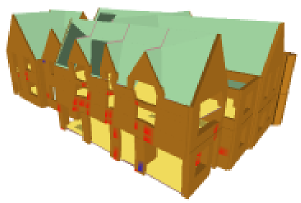

Figure 3: *Existing Boys High building during a NLTHA of a 67% IL3 NBS EQ record*

Throughout the campus, each building is largely unique and has required bespoke solutions governed by a number of potentially conflicting drivers, balanced throughout the design phase. Particular consideration was required when balancing heritage constraints with the cost of implementing strengthening works required to provide the necessary resilience at design load levels.

Solutions chosen for areas of high heritage value, such as the College Hall and Clock Tower buildings, were designed to be largely hidden within the existing building matrix and to have negligible visual impact. These solutions included:

- Vertical post-tensioned bars cored through existing walls, anchored at top and bottom to increase panel shear and rocking capacity.
- New reinforced concrete walls constructed within the original wall matrix. Typically, these were implemented by deconstructing the inner heritage fabric and wall core, casting against external stonework, and reinstating the inner heritage layer.
- Horizontal bars cored into an existing wall matrix to provide additional shear capacity and transfer of forces to adjacent strengthened elements.

Buildings with plaster finishes of lower heritage value, such as the Old Registry building, allowed for a slightly more intrusive strengthening approach. Solutions included the application of glass fibre-reinforced polymer (GFRP) overlays to masonry walls and embedded steel vertical straps to provide additional rocking capacity. Following installation of these solutions, plaster finishes were reinstated with no visible evidence of the underlying strengthening works.

The damage sustained and the structural form of several buildings required a more intrusive approach to the strengthening undertaken. For example, the Boys' High building sustained significant out-of-plane hinging of its numerous gables and, as a result of the subsequent collapse hazard, these were deconstructed early in 2012. The complex configuration of the Boys' High building's roofs did not allow for sufficient diaphragm strengthening to support the full reinstatement of the gables throughout the building.

In order to provide building stability, the strengthening scheme provided a network of exposed, internal steel cross-braces at eave-level. Gables will be reinstated with a lightweight stone façade, supported on a steel and timber frame with bracing struts to the eave-level bracing. It is intended that intrusive cross-bracing can be reversed in the future if so desired.

The most intrusive and permanent strengthening solution adopted is the use of reinforced concrete overlays on the internal faces of certain buildings. This level of intrusiveness is only adopted in buildings, such as the Engineering Extension, that have no feasible alternatives to providing the required capacity.

Each of the solutions developed was driven by the need to provide the necessary global capacity within the heritage and commercial constraints while:

- Balancing the stiffness of strengthening works with the original heritage fabric.
- Collecting and transferring loads to strengthened elements.
- Providing strengthened floor and roof diaphragms to transfer out-of-plane loads to in-plane walls.
- Providing connectivity of all elements to ensure direct load paths exist throughout the buildings.
- Ensuring global performance and stability of the buildings.

5 PROJECT DELIVERY

Presently, five strengthening and repair projects are underway at the Arts Centre, with works being carried out by four separate lead contractors. These include the Gymnasium/Canopy, Boys' High, Chemistry, College Hall/Clock Tower, and Library-Common Room. A fifth project, the Old Registry, was the first building to undergo strengthening works, and was completed in July 2013. Holmes Consulting Group's role in the delivery of these projects, and prior stabilisation works, has varied from that of typical construction observation to outright project management.

Regardless of role, structural design, or the contractor involved, HCG's part in project delivery

has proved to be extremely reactionary due to the high level of discoverability involved with site works. Given practical constraints during the design stage, only a limited amount of a building's as-built condition can be observed and taken into account, with historic drawings and a designer's assumptions providing a "best guess" for the remainder. This has necessitated an intensive observation role on HCG's part with frequent modification of structural details due to the discovery of as-built conditions that differ from structural drawings.

The following sections outline key features and decisions made on three projects within the Arts Centre site.

5.1 REGISTRY BUILDING

The Registry building was the first strengthening and repair project undertaken at the Arts Centre following the Canterbury earthquakes of 2010-2011. Opened in July 2013, the Registry is a stand-alone building with a minimal footprint relative to other buildings on site, making it a logical starting point for construction works.

From an engineering perspective, the project was beneficial as it trialled several structural systems (steel strap rocking restraints, GFRP, and reinforced concrete walls hidden within the building's fabric) that have since been specified elsewhere on site. Additionally, the building underwent prior strengthening works in 2004 that required augmentation as opposed to outright replacement.

Completion of the Registry provided the Arts Centre with a revenue source due to its use as a commercial space. Determination and reinstatement of the building's various finishes also provided a costing and scheduling baseline for future commercial spaces on site.

5.2 COLLEGE HALL AND CLOCK TOWER BUILDINGS (BLOCK C)

A top priority for the Arts Centre Trust, and listed as Category 1 heritage buildings by the New Zealand Heritage Places Trust, the Block C buildings were designed by Benjamin Mountfort and constructed between 1876 and 1882. Strengthening and repair works began in early 2012 and follow a design completed to 67% of NZS1170.5 prescribed loads for an Importance Level 3 building. Additionally, the Arts Centre tasked HCG with providing a structural solution that would leave the buildings geometrically unchanged with nearly all of the strengthening and repair works hidden within building fabric. As shown in photographs 3 and 4.

Photograph 3: *Clock Tower internal concrete skin wall within existing geometry*

Photograph 4: *College Hall downhill core drilling for post-tensioned bars*

The Block C buildings best demonstrate the close involvement of HCG during construction works. Given the Arts Centre's imposed design constraints and the continuous discovery of as-built conditions

that differ from design drawings, regular re-design of structural systems is required. Additionally, close collaboration between HCG and the lead contractor is necessary to ensure solutions that are practically achievable, structurally sound, and durable enough to meet the buildings' 100-year design life requirement.

5.3 BOYS' HIGH

Slated for completion in mid-2015, the Boys' High building underwent extensive deconstruction prior to the commencement of strengthening and repair works. Nearly all of the building's 14 gable end walls experienced significant hinging, with several partial collapses, during the Canterbury earthquakes. Thus, HCG recommended controlled deconstruction of the walls to avoid further collapse and reduce the building's seismic mass while considering a permanent strengthening solution.

A key consideration for the Boys' High structural repair scheme came with the building's inherent geometric complexity. This is due to the building containing nine gable roofs of differing orientation, making a typical plywood roof diaphragm costly and impractical. Instead, HCG designed a ceiling-level steel cross-braced diaphragm that allows for a permanent reduction in the building's seismic mass through the use of reinstated lightweight gable end walls.

6 CONCLUSIONS

Conclusions are drawn on a very general nature given the broad topics discussed in this paper. Key lessons from our experiences to date are to never underestimate the inherent resilience that does exist within masonry fabric, the ability of even minor securing measures to provide an overarching increase in a building's performance and stability.

Most significantly, however it should be noted that work of this nature whether for individual buildings or a larger site can be incredibly complex and very intensive throughout the investigation analysis design and most significantly the observation phases of these projects.

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