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STRENGTHENING AND HERITAGE RESTORATION – THE ARTS CENTRE OF CHRISTCHURCH

JOHN TROWSDALE, PETER CARNEY, ALISTAIR BOYS

Holmes Consulting Group LP

SUMMARY

The restoration and strengthening of the Arts Centre of Christchurch is reviewed and discussed, including how the campus of Gothic Revival buildings behaved during the 2010-11 Canterbury earthquakes and the performance of prior strengthening and securing works. The use of concrete and cement materials in both the original construction and the current restoration project is also discussed.

INTRODUCTION

The Christchurch Arts Centre is a significant heritage site of both national and local significance. Like many of the buildings in Christchurch the devastating effects of the Canterbury earthquakes left the site with severe damage and compromise to all of the 23 Category 1 heritage buildings. Following the determination of the board of trustees and insurance negotiations the Arts Centre has embarked on a strengthening and restoration project that is currently the largest of this type being undertaken in the world.

The relationship between Holmes Consulting Group (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 6 play key roles in leadership and management of the restoration project beside the Arts Centre management team.

Now 4 ½ years into the $290 million project we have completed 2 buildings, with a further 9 in construction, of which, the majority of these will be completed during 2016. Analysis of a further 5 has been completed with the intention to start construction on 2 further buildings this year, with all analysis and design being completed by 2017.

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.

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 23 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 CCC 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 or 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, followed by the Boys' High School 3 years' later, and other buildings were added as the University expanded. Both schools would move off-site in 1881 and 1926, respectively.

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 as a cultural centre for their benefit by the owners, the Arts Centre Trust Board. Under the requirements of its trust deed, among other responsibilities, 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 again in 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 each year.

THE CANTERBURY EARTHQUAKE SEQUENCE

The information and statistics around peak ground and vertical accelerations, durational data, etc. is well documented. The underlying ground strata across the site behaved relatively well during the earthquakes of 2010 and 2011. No presentable liquefaction occurred with differential settlement damage limited to minor acceleration of pre-existing creep deformation in some isolated areas.

The collection of buildings built over the fifty year period are founded on typical mass concrete shallow foundations. However very few of the 23 individually categorised buildings stand alone as shown in Figure 1. The interconnected nature of the site, and lack of positive connection between buildings had a significant influence on building behaviour.

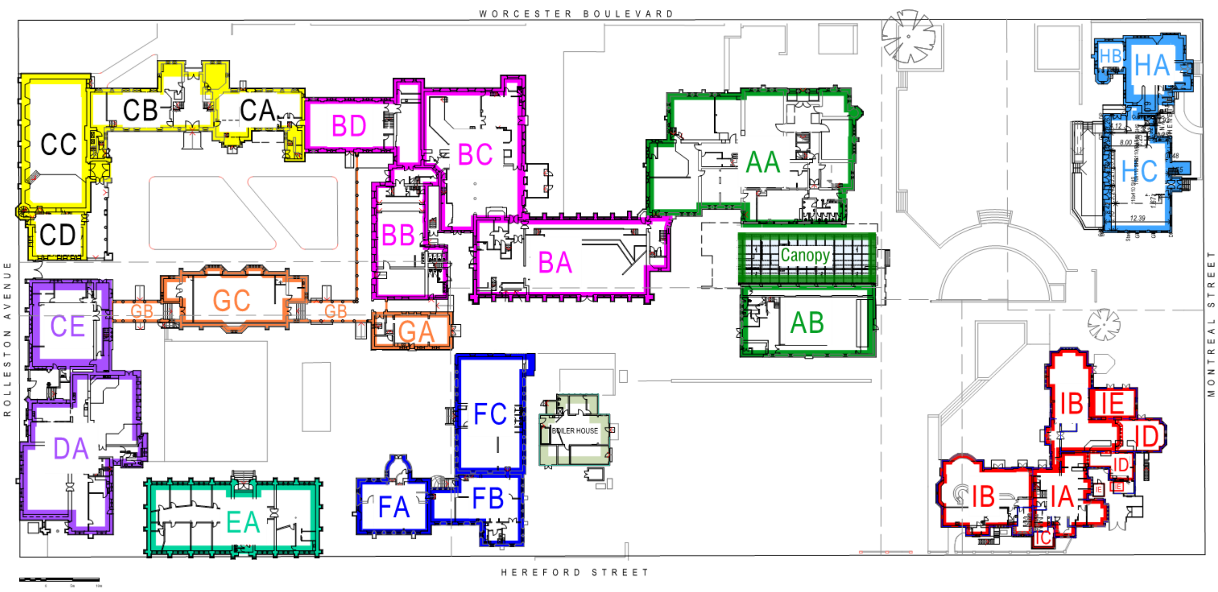

Figure 1. The Arts Centre of Christchurch Site Plan

Following the September 2010 event, damage across the site was predominately limited to the buildings' towers, turrets, chimneys, and finials, with minor damage also occurring as a result of building interaction. Following a number of securing measures the majority of the site was able to be re-opened in a relatively short period of time.

The result of the February 2010 event had a significantly different outcome. Building resilience across the entire site was severally reduced with a number of building elements suffering partial collapse; most notably the Observatory tower shown below in Figure 2. Following initial assessments and reactive securing to the most critical elements (primarily to prevent further deterioration) it was apparent that all buildings would require significant works and the site was closed.

Figure 2. Photograph Showing the Damage to the Observatory Tower Incurred from the February 2011 Earthquake

<u>Damage Summary</u>

As noted above none of the buildings were left unscathed, in many instances the full extent of the deformation and subsequent reduction in resilience was not immediately presentable. The ability for some elements (gables, in particular) to self-centre leaving only hairline cracks is a prime example. In many instances the extent of hinging to these elements was only determined during significant after shock activity via a combination of witnessing it occur during the shock sequence and the measurement of secondary damage associated with a hinging element above.

Beyond the obvious collapse failures predominate mechanisms affecting the buildings' fabric were either out-of-plane deformations or building interaction related. In-plane failure of wall panels was limited to a couple of key exceptions.

Prior Works

The relationship between HCG 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 2 basic categories; strengthening or securing. Generally considered for the purpose of this paper, strengthening adds and takes into consideration global building performance whilst securing focusses on discrete load path resolution.

Predominate restraints to the extent of scope and robustness of design (completeness of load resolution, hence securing works) were primarily financially and heritage-intrusiveness driven. These works range from simple gable restraints through to more complex post tensioning solutions. Whilst some minor failures of these inclusions occurred, the majority performed incredibly well in limiting the extent of damage and potential collapse across the site.

Prior Works: Post Tensioning

Engineering Extensions buildings and notably the Chemistry building; these works were completed circa 1985 and are predominately considered under the category of strengthening works.

College Hall used vertical strands to strengthen (providing rocking restraint and adding flexural capacity) the 10m high, 30m long western elevation. Mounted both internally and externally each side of the 5 buttresses the strands were anchored between paired PFCs at the top and strip foundations at the base.

Engineering Extensions used horizontal post tensioning at both first floor and eaves 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 to the north and south elevations. Anchored externally as shown in Figure 3, 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 equally internally and externally at each floor plate.

Figure 3. Photograph Showing Post Tensioning to the Chemistry Building

In each instance these elements performed incredibly well with behaviour significantly limiting the extent of damage sustained to the building. Notably for both Chemistry and College Hall, the final design solution is a mimic or refinement in detail of the original installation.

Prior Works: 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 frames and portal frames, face-mounted to the internal faces of discrete parts of the buildings. These added flexural capacity and restricted rocking behaviour to susceptible geometries. Anchorage was typically provided to existing floor plates and wall or buttress elements below to resolve shear and overturning reactions.

Extensive use of discrete (predominately tension-only) braces focused primarily at the roof truss to eaves connections; these elements added continuity to the wall to roof-plane diaphragm interface.

Where suitable access allowed, steel trusses bridged some of the wider end elevations at eaves height providing significant additional out-of-plane capacity to a number of the larger gables.

Prior Works: 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 T&G or sarked substrates and the walls added significant additional resilience to both elevation out-of-plane behaviour and global building performance. These were as simple as external wall “roses” 150mm cast washer anchored through gables and walls via threaded rods with bracketed connections to purlins or joists via 2-3 bolts resulted in a significant reduction of collapse failure.

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% IL3 (87% IL2) NBS loads.

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

NLTHA modelling was a two stage process. Initially, seismic records for the September 2010 and February 2011 events from the adjacent Botanic Gardens recording station were processed allowing the predicted behaviour of the building to be compared to the actual damage observed. This process provides verification of the model performance with regard to global load paths and the material properties utilised. The second stage of the NLTHA process is assessing the global performance of the building’s strengthening scheme using earthquake records satisfying the NZS1170.5 requirements.

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 were incorporated into the NLTHA model to ensure compatibility with the global performance of the buildings.

Each building throughout the campus is largely unique and has required bespoke solutions governed by a number of potentially conflicting drivers; these were 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-tension bars cored through the existing wall, anchored top and bottom to increase shear and rocking capacities of the panels.

- New reinforced concrete walls constructed within the original wall matrix. Typically, these were implemented by deconstructing the inner heritage fabric and the wall core, casting against the external fabric and then reinstating the inner heritage layer.

- Horizontal bars cored into the 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 Registry building, allowed for a slightly more intrusive strengthening approach. Solutions included the application of Glass Fibre Reinforced Polymer (GFRP) to the masonry surface and embedded steel vertical straps to provide additional capacity. Following installation of these solutions, plaster finishes were reinstated with no visible evidence of the underlying strengthening provided.

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 stability of the building, the scheme adopted provided a network of exposed internal steel cross-braces at eaves level. Gables are being reinstated with a lightweight stone facade, supported on a steel and timber frame with bracing struts to the eaves level bracing. It is intended that the intrusive bracing provided 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 face of some buildings. This level of intrusiveness is only adopted in buildings, such as the Engineering Extension building, that has no feasible alternative 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 the strengthening 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.

PROJECT DELIVERY

Presently, 5 strengthening and repair projects are underway at the Arts Centre, with works being carried out by 3 separate lead contractors. These include the Boys' High, Engineering Extensions, C block, Chemistry, and G block (comprising the Library, Common Room, and Arcades).

Completed projects to date include the Old Registry and the Gymnasium. HCG'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, our 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 with frequent modification of structural details due to the discovery of as-built conditions that differ from structural drawings. The following paragraphs outline key features and decisions made on 3 projects within the Arts Centre site:

<u>Registry Building</u>

This was the first strengthening and repair project undertaken at the Arts Centre following the Canterbury earthquakes of 2010/2011. Opened in July 2013, the Old 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 campus. Additionally, the building underwent prior strengthening works in 2004 that required augmentation as opposed to outright replacement.

Completion of the Old 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.

<u>College Hall and Clock Tower Buildings (C Block)</u>

A top priority for the Arts Centre Trust, and listed as Category 1 heritage buildings by the New Zealand Heritage Places Trust, the C block 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 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.

Of real interest in the C block buildings is the original construction methodologies employed in the construction of the arched ceiling panels; an original 1876 drawing associated with the Canterbury College's specification is shown in Figure 4. Whilst traditionally we would have assumed these to be formed in plaster, they were found to be formed in 50mm thick pre-fabricated pieces of concrete. Given these would have been fabricated in 1877 these are one of New Zealand's earliest examples of pre-cast concrete construction.

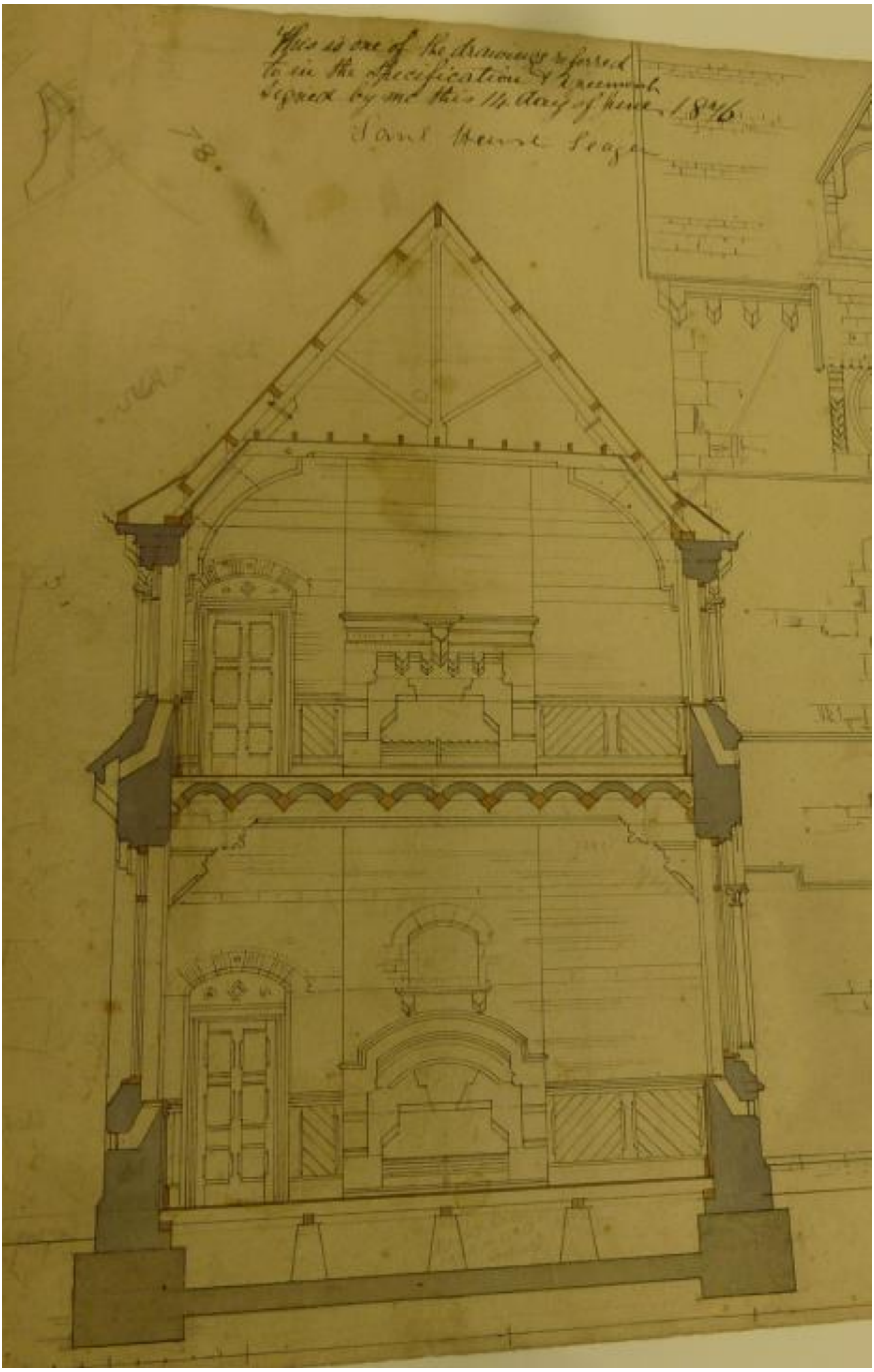

Figure 4. An original 1876 drawing of Canterbury College showing the arched ceiling panels made from 50mm pre-fabricated concrete

The C block buildings best demonstrate the close involvement of HCG during construction works. Given the heritage preservation focus of the Arts Centre's design brief 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 us 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.

<u>Boys High</u>

Slated for completion this year, 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, we recommended controlled deconstruction of the walls to avoid further collapse and to 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 9 gable-end roofs of differing orientation, making a typical plywood roof diaphragm costly and impractical. Instead, we designed a ceiling-level steel x-braced diaphragm that allows for a permanent reduction in the building's seismic mass through the use of reinstated lightweight gable-end walls.

The use of modern materials in the restoration has enabled the use of unique solutions with greater levels of performance over historic construction methods. Nonetheless, the performance levels of original construction materials, whilst not comparable today's, have been shown to be greater than we had previously assumed. Figure 5 is an excerpt from the 1879 handwritten specification for Boys' High which was consulted during the analysis and design of the building, post-earthquakes. This clearly shows extensive use of Portland cement for both foundation concrete and mortar mixes.

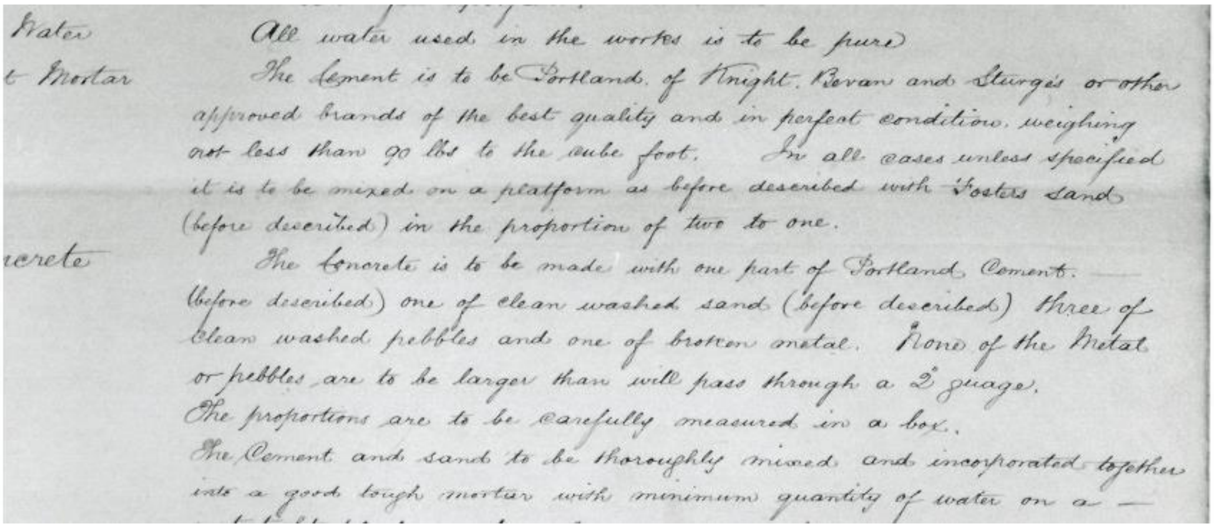
Water — All water used in the works is to be pure
Mortar — The Cement is to be Portland of Knight, Bevan and Sturge's or other approved brands of the best quality and in perfect condition, weighing not less than 90 lbs to the cube foot. In all cases unless specified it is to be mixed on a platform as before described with Fosters sand (before described) in the proportion of two to one.
Concrete — The Concrete is to be made with one part of Portland Cement (before described) one of clean washed sand (before described) three of clean washed pebbles and one of broken metal. None of the Metal or pebbles are to be larger than will pass through a 2" guage. The proportions are to be carefully measured in a box.
The Cement and sand to be thoroughly mixed and incorporated together into a good tough mortar with minimum quantity of water on a —

Figure 5. Excerpt from the 1879 handwritten specification for Boys' High showing the use of Portland cement

CONCLUSIONS

Key lessons from our experiences to date are to never underestimate the inherent resilience that does exist within masonry fabric, and the ability of even minor securing measures to provide an overarching increase in a building's performance and stability. It should be noted that work of this nature – whether for individual buildings or a larger suite – can be incredibly complex and very intensive throughout the investigation analysis, design, and most significantly the observation phases of these types of projects.

ACKNOWLEDGEMENT

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