Seismic Strengthening and Restoration of Cargill's Monument

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Abstract
Cargill's Monument was one of the first stone structures/monuments in Dunedin which required the skills of stonemasons and stone carvers capable of shaping complex neo-gothic forms. Built in 1864, it was designed by Otago's Provincial Engineer, Charles Swyer. Its level of execution far surpassed most of the basic houses and stone structures of the time. It is currently listed as having Category 1 historic place status with Heritage New Zealand Pouhere Taonga (formerly the New Zealand Historic Places Trust), meaning it has 'special or outstanding historical or cultural heritage significance or value'. This paper describes the process and methodology for the seismic strengthening design and construction, in conjunction with a full restoration of the now 150 year old historic monument. The main findings of this paper are that seismic strengthening of significant heritage structures requires early consultation with Heritage New Zealand to ensure consideration of conservation principles and requirements, allowing specific adaptation of strengthening methods to meet restoration and preservation objectives. This includes factors such as reversibility, resilience and minimal visual impact. It is also important and necessary to provide a higher level of input into construction methods and monitoring.

1. Introduction

The Cargill Monument was erected in the Octagon, Dunedin, in 1864. It commemorates Captain William Cargill, founder of the province of Otago. This paper describes and details the process and methodology behind the seismic strengthening design and construction of stone monuments in conjunction with restoration. The 150 year old Cargill's Monument is used as a case example. Historic stone monuments, by their very nature are potentially earthquake prone structures, relying mainly on mass and friction to resist sliding and overturning. In developing seismic strengthening solutions it is important to ensure the integrity of the structure and the visual impact of the works does not detract from the heritage and cultural values placed on the structure.

The Dunedin City Council (DCC) are to be acknowledged and commended for recognising the historic and cultural importance of Cargill's monument and in funding the seismic strengthening and restoration.

2. History

Cargill's Monument was one of the first stone structures/monuments in Dunedin that required the skills of stonemasons and stone carvers capable of shaping complex neo-gothic forms. Built in 1864, its level of execution far surpassed most of the basic houses and stone structures of the time.

It was designed by Otago's Provincial Engineer, Charles Swyer and is based on the larger Sir Walter Scott Memorial in Edinburgh, Scotland.

The monument was moved from its original site in the Octagon to its present site in the Exchange in 1886. [Figures 1 and 2].

Figure 1: Cargill's Monument on right c1900. (Photo: University of Otago Hocken Collections).

Figure 2: Intersection of Princes and Rattray Streets. Post 1910. (Photo: University of Otago Hocken Collection).

It is a very rare monument as it is built mainly out of solid sandstone blocks, unlike other large monuments that use a combination of brick, concrete and/or stone. It is listed as a Category 1 historic place (List no.4754) with Heritage New Zealand (known as the New Zealand Historic Places Trust prior to 2014), meaning it has 'special or outstanding historical or cultural heritage significance or value'.

3. Background

Initially this project started off as a maintenance and refurbishment project, as some of the stone elements had become loose or had fallen off due to weather erosion, vandalism and inappropriate maintenance (such as abrasive cleaning). Some stonework was also showing cracks and movement in and around the joints.

In 2008, the DCC decided it was prudent to do a seismic analysis of the structure which returned a result of around 14% of New Building Standard (NBS) which classed the monument as potentially earthquake prone. As a result, a decision was made by DCC to complete earthquake strengthening of the monument to a minimum 67% NBS in conjunction with the restoration and conservation of the monument. The strengthening design had to consider and meet the requirements of legislation relevant to the heritage and archaeological values of the site. These were the Historic Places Act 1993 (now the Heritage New Zealand Pouhere Taonga Act 2014 (HNZPTA)) and Resource Management Act 1991 (RMA).

Figure 3: Cargill's Monument before restoration.

Heritage New Zealand administers the HNZPTA. Of relevance were the criteria for the legal definitions of an archaeological site, the legal protection for such sites, and the process for gaining permission to destroy, damage or modify such sites. This act contains a consent (authority) process for any work affecting archaeological sites. Under the act an archaeological site is defined as

(a) Any place in New Zealand, including any building or a structure (or part of building or structure), that:

i) was associated with human activity that occurred before 1900 or is the site of the wreck of any vessel where the wreck occurred before 1900; and

ii) provides or may provide through investigation by archaeological methods, evidence relating to the history of New Zealand (HNZPTA section 6).

(b) Includes a site for which a declaration is made under section 43 (1).

Any person who intended to carry out work that could modify or destroy an archaeological site, or to investigate a site using invasive archaeological techniques, has to first obtain authority from the Heritage New Zealand.

To comply with the HNZPTA and follow conservation best practice advice, the DCC had commissioned; a Condition Report and Conservation Specification by conservator Ian Bowman 1992 [1]; a Condition and Specification report for repair and restoration by Marcus Wainwright 2009 [6]; and the Archaeological Assessment Report by Guy & Erin Williams dated November 2011 [7].

The Wainwright report [6] identified damage to stonework from abrasive cleaning and from water ingress through the joints, causing the original metal ties to corrode causing further damage especially around the upper flying buttresses and lower vault arches. The Williams report [7] made recommendations for repair and restoration works which included the systematic deconstruction of the upper part of the monument to enable removal of the faulted steel armature and damaged stones. It also revealed several archaeological features in the immediate vicinity of the structure, which needed to be considered if the ground was to be disturbed. In the event of disturbance below the monument it was possible that evidence of earlier subterranean public toilets (said to have been filled in with sand and broken toilets), remains of the former Mechanics' Institute, and pre-1900 use of the site by both Europeans and Maori, could be encountered.

Williams [7] made the following recommendations:

- As a first principle, every practical effort should be made to avoid damage to any

archaeological site, whether known or discovered during development.

- In the advent of site disturbance works being proposed, an archaeological authority under the [HNZTPA] for those site disturbance works should be applied for and obtained from [Heritage New Zealand].
- No site disturbance works should occur prior to the issue of an Archaeological Authority, and all works undertaken thereafter should be in accordance with the conditions of the authority that is granted.
- In the event of any site disturbance works being undertaken, this should be kept to an absolute minimum and be directed and monitored by a [Heritage New Zealand] approved archaeologist.
- All contractors engaged in site disturbance works should be briefed and familiar with the conditions of the authority, and be prepared to abide by those conditions.
- All contractors engaged in site disturbance works should be briefed on the nature and extent of the archaeological sites in the development area, as well as any others in the vicinity of the works site.
- In the advent of archaeological material being discovered, all works in the vicinity of the discovery should cease, the area of the discovery isolated by marker tapes or protective barriers, and the monitoring archaeologist arrange for actions to be undertaken that are appropriate to the significance of the discovery.
- If at any stage during the excavation or site works Maori material is discovered, local iwi should be consulted in the first instance. If any Maori material does exist in the area, damage to this should be minimized. Any pre-European artefacts will be, prima facie, property of the Crown, and should be submitted to Otago Museum.

The above conditions were followed but as there was minimal disturbance of the ground (four micro piles) no items of archaeological importance were discovered or disturbed.

Further design considerations required, were that the mortar and stone had to be assessed to determine material properties including density, compression and shear strengths.

A full topographic survey was carried out to accurately determine structural dimensions. The monument had two levels of stone arches and cross sections progressively narrowing to the intricate spire at the top. A variety of finials and grotesques [Figures 4 and 5] adorn the structure and these needed to be included in the strengthening design.

Figure 4: Grotesques and lower arch.

Throughout the project, consultation with Heritage New Zealand was maintained to ensure the integrity and reversibility of the proposed and eventual work, and to ensure strengthening measures and implementation was undertaken to an acceptable restorative standard.

Figure 5: Decorated finials and upper arch.

4. Challenge

The monument, approximately 12m in height, is highly ornate and decorative. These features do not allow for external strengthening. Therefore any strengthening had to be placed unobtrusively within or behind the stone. The structural strengthening was based on a specified design life of 100 years, so had to be durable and also reversible to facilitate future repairs or replacement.

The restoration part of the project required removal of the original steel cross ties that had varying states of corrosion and replacing these with highly protected metal (Thermal zinc spray and a high build epoxy coating).

The original stone needed to be sourced for the repair and replacement of sections and to determine the physical properties. The original stone was Tasmanian sandstone [7] and was unfortunately no longer available [2]. However the replacement stone was sourced from Australia and was the closest that could be matched to the original stone.

Collaboration with the restoration stone mason, Marcus Wainwright, was essential in planning the project to determine what strengthening system would be possible and acceptable within the conservation and restoration process. Advice was sought as to probable historic construction method and the internal stone size and configuration.

5. Design

Strengthening analysis of the structure was undertaken in accordance with New Zealand standards NZS 1170.0 and NZS1170.5 Structural Design Actions [5].
Design assumptions used were as follows;
Soil Type C – Shallow soil sites
Ductility = 1.5
Importance level 2
Hazard Factor, Z= 0.13
Design life = 100 years
ULS Annual Probability of exceedance = 1/1000
SLS Annual Probability of exceedance = 1/25
ULS Return Period Factor, Ru = 1.3
SLS Return Period Factor, Rs = 0.25
Near fault factor, N = 1.0
ULS Seismic co-efficient = 0.25
SLS Seismic co-efficient = 0.05

Material Properties
Sandstone density 2250 kg/m3
Sandstone Compressive Strength (~20MPa)
Natural Hydraulic Lime Mortar strength 8MPa
Macalloy bars yield strength 650MPa

The original monument stonework was structured around four main buttresses and pillars, reducing in size as they ascended, being connected at various levels through arches and metal cross ties.

Various strengthening options were considered and it was decided that the preferred solution was to provide corrosion resistant steel rods dowelled through the stone. The rods were bolted to cross plates or beams at various levels, clamping the structure in place. At the base the rods were bolted to a steel box beam placed through cored stone and held down with tension piles.

The monument's structure was analysed using Microstran computer analysis software to determine the expected design forces within each of the structural elements. This was conducted by modelling a frame structure that consisted of equivalent sized concrete members replicating the stone dimensions and properties in conjunction with the new central steel tie elements [Figure 6]. The analysis used the equivalent static method with the forces applied at the six levels throughout the monument where diaphragm action was expected to occur with the installation of the new steel plate members.

The tensile forces are transferred through the structure by the installation of the vertical steel tie members located within holes cored through the stone elements, with each of these tension ties restrained at the various levels by the cross braced plates. The tension ties were introduced throughout the height of the monument to provide a continuous load path within the stone all the way down to the base of the structure.

Four new micro-pile foundations were installed below the monument to resist any uplift forces that resulted from a significant seismic event where the self-weight of the monument alone was insufficient. The micro-piles were unable to be located directly below the lower level tension ties. Therefore, a steel box section cross beam was installed to transfer the tensile loads from the monument back into the newly installed micro-pile foundations through bending and shear. Shear forces within the structure are resisted by the shear strength of the lime mortar joints, tie rods and friction due to the mass of stone above.

Prior to the strengthening works the monument was assessed as having a nominal ductility of 1.0 (non-ductile). The strengthening design conservatively used a ductility factor of 1.5. This was based on the installation of the steel tie members that were de-bonded from the surrounding grout by wrapping them in Denso tape, thus allowing the potential to yield and elongate between the adjacent steel plates located within each level of the monument. Seismic energy will potentially also dissipate through the bending of the steel base box beams and individual steel plates located at each level as a result of the offsets between the steel tension ties within various sections of the monument.

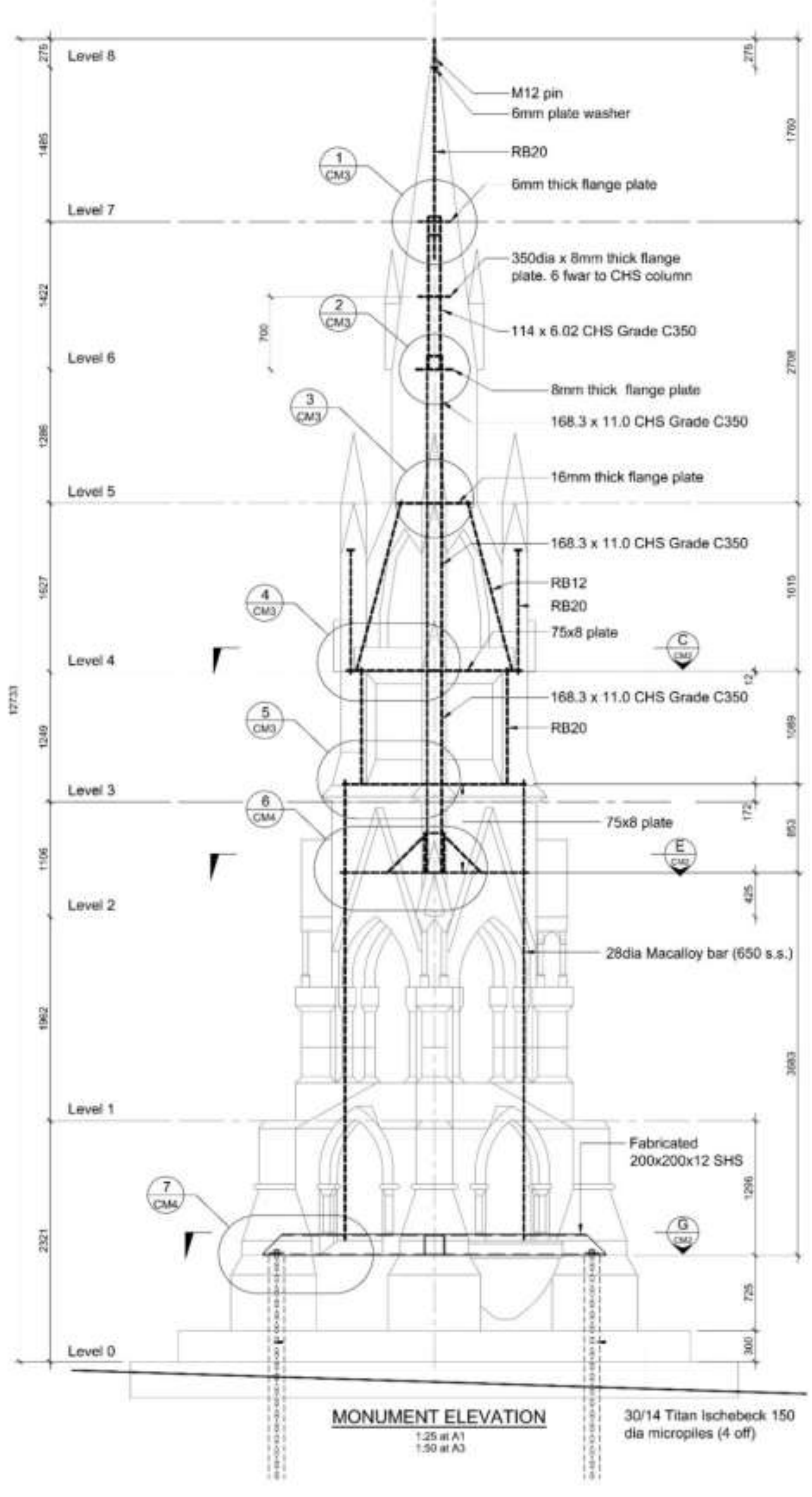

Figure 6: Seismic strengthening frame model.

After a Heritage New Zealand commissioned review of the initial design and subsequent comments by Heritage Engineer Win Clark, additional options were considered including the potential for the monument to rock under full seismic load allowing further energy dissipation. NZS1170.5:2004 [5] Section 6.6 addresses design of rocking structures by requiring that '…the actions of the structure shall be determined by a special study'

However the rocking design procedure we adopted followed simplified guidelines by Kelly [3] and Priestley et al [4]. In analysing this option it was found that the seismic force required to generate uplift was high; due to the structure geometry and the fact that the monument was located in a low seismic zone. Also to limit potential non-structural damage it was decided to limit rocking displacement by use of the un-bonded Macalloy rods combined with thick bearing pads between the base beams and the four Micro-piles.

The governing design factor was the shear strength of the mortar and steel bar system. The solution to the rod/stone interaction was achieved by using a natural hydraulic lime mortar around the tie rods. This enabled the rods and structure to move with a degree of separation and flexibility, allowing the rods to yield in a large seismic event. The lime based mortar also allowed the stone to breathe and move as original; reducing potential stress in the stone.

Above the lower arch there was sufficient internal void to enable a central steel column to provide lateral restraint from plates and rods at various levels [Figures 8 and 9].

The seismic resisting mechanism has been designed to exceed 67%NBS but also encompasses future resilience with almost all elements able to be repaired or replaced after a seismic event.

6. Execution

Figure 7: Dismantling revealing original corroded tie bars.

The monument was carefully dismantled in late 2011 to a low level just above the lower arches, removing all corroding steel. [Figure 7]. The stone elements removed were transported to a workshop for repair and for coring vertical holes to fit proposed rods.

The corner stones at the base of the monument were also temporarily removed to allow for the micro piling to be undertaken.

The reconstruction phase followed in 2012 to re-build the steel/stone framework structure with the restored stonework. The reconstruction team of specialist stonemasons and engineers were appointed and combined to achieve the high standards and care required. Whilst the concept was simple to visualise on paper, each section/level of steel had to be site measured and tailored to fit with templates during the monument's re-build.

Further limitations/alterations to the strengthening plan were:

- Thickness of stone to allow for the central coring, this reduced further up the monument especially in the location of the curved arches.
- The ability to cut the stone without damaging its integrity,
- The capability of the steel workers and stonemasons to actually lift, install and place the steel; and finally
- The requirement for reversibility, where natural hydraulic lime and bolting was used instead of cement, epoxy and welding.

Figure 8: Reconstruction.

Figure 9: Re-Construction plates and rods.

Due to variations in stone configuration from that assumed before dismantling, the internal design dimensions had to be amended as each section was exposed. Further design considerations that affected the final solution were:

- The seismic demand was reduced by removing the stone rubble mass located within the enclosed area above the first arch.
- Stainless steel Macalloy bars were used in the lower section for durability reasons, as well as the fact that they had a higher ductility than the alternative bars that were proposed.
- Originally all members were to be stainless steel but it was decided to use galvanised bars wrapped in Denso tape above the lower arch to provide an equivalent durability at reduced cost. The steel plates were protected with thermal zinc spray and a high build epoxy coating.
- Wrapping in Denso tape also ensured all bars were de-bonded from the surrounding grout, allowing them to yield if required.
- The cored voids within the stone were flooded with water before grouting to ensure that the surrounding stone was saturated. This ensured that the moisture within the grout did not transfer into the surrounding stone which reduced the potential for shrinkage within the grout surrounding the steel rods.

Figure 10: New carved stone Grotesques.

7. Conclusion

The structural strengthening of this important heritage monument is unique within the country. The restoration works and strengthening required the monument to be partially dismantled and rebuilt. The installation of the steel rods and sections within the stone posed on-going challenges mainly due to the fine tolerances required, but were competently solved on site with satisfying results.

This report has highlighted the fact that successful seismic strengthening of significant heritage structures requires early consultation and coordination with conservatory principles and requirements, and Heritage New Zealand. This allows site specific adaptation of existing strengthening methods to be developed which meet restoration and preservation objectives. These include factors such as reversibility, resilience and minimal visual impact. It is also important and necessary to provide a higher level of input into construction methods and monitoring.

In this way the Cargill's Monument seismic strengthening and restoration project has ensured a lasting legacy for many years to come.

Figure 11: Restored and Strengthened Monument.

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