

Christchurch Cathedral Structural Engineering Review

Prepared by an Independent Panel of Structural Engineers:

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Summary

The Church Property Trustees (CPT) have recently initiated a project to deconstruct the Christchurch Cathedral down to window sill height, with building fabric from above that level removed and stored for possible re-use. This methodology has been adopted as a means of addressing the requirements of the CERA Section 38 notice for the site in an affordable way, and the necessary (de)construction activities are deemed acceptably safe, by CERA. This methodology is intended to leave open the future options of partial or full reconstruction, stabilisation of the deconstructed ruins as a memorial, or construction of a new building or part-building on the same site. The de-construction methodology was one of a number of options proposed by CPT's project design team. Other options allowed for the retention, in-situ of significant portions of the existing structure.

At the request of the Great Christchurch Buildings Trust [GCBT], an independent panel of structural engineers [the Panel] have undertaken a limited review of both the de-construct option [DCO] and a maximum retention option [MRO].

The Panel considers that a maximum retention option is feasible in structural engineering terms and could be implemented without compromising acceptable construction safety standards. The alternative MRO methodology would stabilise the Cathedral safely in its current state, with repairs and strengthening undertaken following stabilisation. The Panel notes that similar maximum retention approaches have been adopted overseas with the stabilisation and repair of heritage church buildings following earthquake. (Recent examples followed the L'Aquila earthquake in April 2009.)

For either the de-construct or maximum retention options, the end results could, potentially, provide a repaired/reconstructed cathedral that complies with or exceeds Building Act structural requirements and which effectively matches the appearance of the Cathedral before it suffered earthquake damage. Both might incorporate similar modern strengthening techniques, and achieve a balance between heritage values and seismic performance.

In this brief report the Panel has considered:

- Comparison, in general terms, between the de-construct option and a maximum retention option
- A response to the specific questions raised by the Great Christchurch Buildings Trust
- For a maximum retention option
 - An Access and Securing Methodology
 - Specific Hazard Mitigation
 - A Conceptual Strengthening Solution

The Panel have based their findings on the following:

- A visit to the Cathedral site on Wednesday 30 May.
- Meetings with representatives from the Church Property Trustees (CPT), RCP (Project Managers for CPT), Holmes Consulting (Structural Engineers) and CERA.
- A brief review of engineering reports and deconstruction methodologies prepared for CPT and CERA.

The rationale for this report was to identify the key engineering options for the Cathedral without reference to the main stakeholder and financial requirements i.e. an engineering point of view.

Commission

This commission arose from a request by the Great Christchurch Buildings Trust for an independent structural engineering review of the decision to proceed with deconstruction of Christchurch Cathedral down to window sill height.

The review has been undertaken by a panel of independent, senior structural/seismic engineers: Adam Thornton of Dunning Thornton Consultants, Stefano Pampanin of the University of Canterbury and Robert Davey of Opus International Consultants. Various reports on the matter have been reviewed. The review has been assisted by discussion with representatives from RCP, Holmes Consulting Group and CERA.

Scope

The initial review scope was summarised in the questions below, and this report addresses those questions. During the review an alternative methodology was identified and the report also comments on this alternative.

Response to the key questions

1. Does the proposed deconstruction method allow for a future reinstatement of the Cathedral in its current form?

Yes, although risks of instability during the staged process of deconstruction, may result in a change of the methodology and as a consequence reduce the potential to retrieve heritage fabric and artefacts. The Panel notes that the term reinstatement is open to interpretation but has taken it to mean re-building the Cathedral so that it essentially appears the same as it did before the September 2010 earthquake, using original materials for the exterior and the interior fabric, even if the hidden, structural materials are different/new.

2. From an engineering point of view, does the Cathedral have to be deconstructed as proposed?

No, other options have already been proposed by the CPT's design team and/or could be envisaged that would significantly reduce the extent of deconstruction and allow for initial stabilization followed by permanent repairs/strengthening. Such options draw upon international experience.

3. What other options exist for retaining all or part of the existing structure?

As noted in response to question 2, CPTs consultants have previously developed options for retaining and strengthening the existing structure. The Panel believes that a MRO could be further developed from these previous options.

4. Could the Cathedral be left as is?

No, in practical terms it could not be left as a ruin without either a wide exclusion zone or significant stabilisation/strengthening. It is very vulnerable to further deterioration from continuing aftershocks and the effects of weather, in its present condition.

5. What are the key health and safety issues?

- *Life safety of construction workers*
- *Protection of passers-by and adjacent property*
- *Establishment of a strengthened/replacement structure, compliant with the NZ Building Code*

Refer also to separate notes.

6. Are the engineering and construction skills available in New Zealand to reinstate the Cathedral, either with the current option or with an MRO option?

Yes, although it is common on complex engineering projects to reference best available International experience and practice.

7. Would a potential reinstatement or MRO involve proven construction methods and technologies?

Yes, however it is likely that innovative application of technologies and construction methodologies would be required. All aspects of reconstruction and or strengthening would be subjected to rigorous checking, review and quality assurance.

8. Could a Cathedral reinstatement or MRO meet the standard for new public buildings?

Yes. The design could meet or exceed NZ Building Code requirements i.e 100% of current code at Importance Level 3.

Additional Response

Financial

The Panel have not reviewed the costings for the Cathedral deconstruction and/or rebuild. It acknowledges that stabilisation phase costs for the MRO option may be greater than for the proposed deconstruction. However if the long term plan is to reinstate the Cathedral to its pre-damaged form, the Panel believes that it is likely to be more cost effective to pursue the Maximum Retention Option.

Programme

The proposed deconstruction plan has been developed by the CPT project team and is scheduled to be implemented over the next 12 months. If a MRO was to be pursued, additional engineering work (with contractor input) would be necessary to further develop the work completed to date. This would take in the order of 8 weeks to develop in sufficient detail for a cost estimate to be prepared. It would also then be in a form suitable for CERA to check compliance with the requirements of the Section 38 notice.

Church Property Trustees

The Panel fully understands that the owner of a property will generally decide on chosen course or action based on a wide variety of considerations. This report was commissioned to only address the engineering perspective.

Comparison of Options

Merits/Issues relating to the De-Construct Option [DCO] include:

- It addresses the immediate requirements of the CERA Section 38 notice to effectively remove the danger posed by the damaged building.
- It does not commit the Church Property Trustees to the expense of a full reinstatement and strengthening but does not preclude this as a possible outcome.
- Possible outcomes other than full reconstruction are possible.
- Health and Safety methodology has already gained approval but will still require close monitoring.
- Some significant heritage items within the Cathedral can be protected remotely quite quickly to minimise risk of damage from further collapses caused by aftershocks.
- A careful, piecemeal deconstruct is likely to take a long time and will not remove the danger of further aftershock damage, in the short term.
- The danger of further aftershock damage, in the short term, will exist during the deconstruction process.
- Instability arising during deconstruction may necessitate demolition methodologies that are not sympathetic to maximum heritage fabric retention.
- The below window-sill structure will not, in itself, necessarily provide a satisfactory base/foundation for reconstruction

Merits/Issues relating to a Maximum Retention Option [MRO] include:

- It would address the concerns of CERA, in relation to the requirements of Section 38, by addressing the securing and strengthening necessary to remove the current safety hazards and strengthening to code requirements.
- It would mean a commitment to keeping the form and fabric of the current building largely intact
- Health and Safety methodology would need approval from CERA
- Some significant heritage items within the Cathedral could be protected remotely quite quickly to minimise risk of damage from further collapses caused by aftershocks.
- The potential for removing internal heritage artefacts undamaged by demolition is improved.
- The danger of further aftershock damage, in the short term, will exist until securing/stabilization is complete.
- The structure will retain seismic risk, higher than for fully compliant buildings, until the strengthening is complete.
- Possible instability arising during deconstruction is avoided.
- Greater retention of heritage fabric in-situ would be achieved.
- Faster overall programme to a full repair/reconstruction outcome would be possible.

A Maximum Retention Option

This section addresses, at a conceptual/strategic level, a methodology for retaining significant portions of the Christchurch Cathedral superstructure in-situ. It will not necessarily be the optimum methodology but is one that the Panel believes is structurally feasible. This section covers, in bullet-point form; 1) short-term access and stability, 2) Health & Safety hazard mitigation and 3) Seismic Strengthening Concepts.

1. Short-Term Access and Stability

The purpose of this phase would be to:

- Reduce the collapse hazard to an acceptable level
- Independently support the roof
- Brace damaged walls against out-of-plane loads & displacements
- Stabilise walls in-plane to prevent further movement in future aftershocks
- Utilize a “building-in building” approach to address the aims listed above and to also create a construction safe-haven within the entire interior.

This safe-haven approach would enable the progressive retrieval/protection of artefacts and would provide a stabilised structure ready for in-situ strengthening either immediately or at some time in the future. In simple terms the process would follow underground mining or tunnelling methodology whereby a shaft is shored and strengthened as progress is made into the mine/tunnel and the workers do not have to venture beyond an already constructed safe-haven.

A conceptual sequence of this phase is as follows (refer to sketches):

- Relocate the west-wall steel bracing frame to the southern side, adjacent to the western end. Secure to aisle wall and main roof eaves. The purpose of this is to provide a transverse buttress at the western end of the building.
- Temporarily remove the west end porch and the nave western gable wall (already largely collapsed), down to floor level.
- Form large level ramp, at floor level, from the square into the new western access void.
- Robotically remove nave pews
- Introduce and propel forward, into the church, a prefabricated steel shoring-shield. This primary shield would be sized to fit closely between the nave columns and would extend up to the underside of the main roof trusses. It would be transversely and longitudinally braced and would provide protection against falling debris. It would be a minimum of two nave bays long.
- Once the primary shield frame is in place, workers can advance into the nave with aisle frames and nave column frames.
- The aisle frames could be driven into position using a tracked moving-platform or dolly. Once in position they would independently support the aisle roof trusses and brace the aisle walls. These frames would be braced transversely and longitudinally and would provide protection from falling

masonry. As soon as an aisle frame is in location, artefacts within that bay could be removed or protected.

- Nave column frames would be erected beside each column and would extend up past the clerestory to support the nave roof trusses. They would also be used to support/brace the nave columns and the clerestory walls. The nave columns would be progressively linked together longitudinally and transversely to provide bracing and overall structural stability.
- Once a bay is completed the primary shield would be jacked forward to provide access and protection to the next transverse bay. This process could continue through the transepts to the apse.
- External bracing to the transepts gable mullions, the apse buttresses and some of the south wall buttresses could be carried out at the same time as the internal work.
- External application of ratchet-straps/turfers should be installed across existing cracks wherever and whenever possible.

2. Construction Hazard Mitigation

An essential requirement of any methodology for the Christchurch Cathedral is to ensure that life-safety hazards during the construction work are not at a higher level than on a typical construction site and fully in compliance with the Health and Safety in Employment Act. All potential hazards must be identified and mitigated through a comprehensive Health and Safety plan. Some of the potential hazards and conceptual mitigation measures are as follows:

- Individual falling stones
 - *Vertical and horizontal shields*
 - *Removal/securing of loose stones*
 - *Safe havens*
 - *Personal Protective Equipment (eg. hard hats)*
- Wall Collapse
 - *Out-of-plane bracing to aisle frames*
 - *Vertical and horizontal shields*
 - *Safe havens*
- Loss of support to roof
 - *Independent support to roof trusses*
- On-going aftershocks increase displacements to point of localised collapse
 - *Close monitoring of all displacement planes*
 - *Application of ratchet-straps/turfers across existing cracks.*
 - *Controlled local demolition where applicable*
- Controlled demolition leads to local instability
 - *All work subject to detailed work-plans with independent review*

3. Seismic Strengthening Concepts

The existing cathedral structure is complex and to bring it to a state of dependable compliance with the NZ Building Code will require significant analysis and physical work. Relevant strengthening concepts include the following (the Panel notes that many of these concepts are implied in the options already prepared by the CPT's design team):

- Design for Ultimate Limit State to exceed the code required performance (e.g. design for damage limitation as well as life safety) in a 1000 year return period motion (corresponding to Importance Level 3 design).
- Design for repairable damage in a 2500 year seismic event.
- Grout injection into rock-fill voids
- Hydraulic revelling and re-positioning displaced stonework.
- Reinforcing through known cracks.
- New concrete aisle-wall columns (buttresses) and foundations. (similarly for apse buttresses)
- Temporary removal of internal (ashlar) masonry to allow some or all of the following:
 - Carbon (or Glass) Fibre Reinforced Polymer (CFRP or GFRP) sheets and/or net grids
 - CFRP near-surface-mounted strips
 - Sprayed concrete walls
 - Vertical post tensioning
 - Grout injection
 - Through wall ties (Stainless Steel or carbon fibre)
- Reinforced concrete tower to provide permanent west-end transverse buttress
- Strengthening of nave and transept columns by one or more of the following:
 - CFRP near-surface-mounted strips
 - CFRP wrapping
 - Vertical post tensioning
 - Through column ties (carbon fibre)
- Replacement of slender mullions with precast concrete
- Pinning of interior and exterior stonework
- Improving wall-diaphragm connections
- Improving roof diaphragms