Seismic Upgrade of Heritage Masonry – A Case Study of St Peter's Cathedral in Adelaide

J. Vaculik[1], M.C. Griffith[2], A. Klenke[3], and P. McBean[4]

1. Corresponding Author. Research Associate, School of Civil, Environmental and Mining Engineering, University of Adelaide. Email: jaroslav.vaculik@adelaide.edu.du

2. Professor, School of Civil, Environmental and Mining Engineering, University of Adelaide. Email: michael.griffith@adelaide.edu.du

3. Associate Director, Swanbury Penglase Architects. Email: andrew.k@swanburypenglase.com

4. Joint MD, Wallbridge Gilbert Aztec. Email: pmcbean@wga.com.au

Abstract

The main Anglican church in Adelaide, St Peter's Cathedral, is prominent on the city's skyline as it sits adjacent to the Adelaide oval and just across the Torrens river from the central business district. In late 2017, the church decided to undertake remedial work of its roof structure in order to stop water ingress problems through several leaks. Fortuitously, the church committee tasked with fixing the roof included Peter McBean who, from his experience in Christchurch, had intimate knowledge of what earthquakes can do to heritage stone masonry cathedrals. With this knowledge and in recognition of Adelaide's earthquake hazard, the committee agreed to allow access to the roof structure wherever work was being undertaken to fix the leaks in order for the authors to assess the feasibility of incorporating works to improve the cathedral's seismic resistance. This paper presents the solutions developed in partnership with the contractor and architect to improve the seismic resilience of this iconic structure for the Church and the City of Adelaide.

Keywords: Heritage construction; seismic retrofit; historical stone masonry

INTRODUCTION

St Peter's Cathedral (Figure 1) is the main Anglican cathedral in South Australia and one of the most significant architectural landmarks among Adelaide's built heritage. The cathedral was built in multiple stages as shown in Figures 2 and 3. Its construction began over 1868-76 with the construction of the sanctuary, choir and transepts, followed by the second phase over 1890-95 which incorporated the extension of the nave and construction of the main entrance at the south-east end (refer Figure 2). The final phase, over 1901-05, involved construction of the two bell towers above the main entrance and the Lady Chapel extension at the north-west end. The walls of the original portion were built of bluestone (a locally used umbrella term in South Australia for a dark, hard stone related to shale, schist and gneiss; Young, 1993) faced externally by high quality quartzite (Tea Tree Gully sandstone), while the bluestone was replaced with clay brickwork in the later additions.

Figure 1: St Peter's Cathedral as it stands in the present day (south-east elevation).

Recent water ingress through the slate roof in several locations was causing sufficient water damage to the interior that a church committee was formed to direct/oversee the repairs to the roof together with the ongoing conservation of the Cathedral. Luckily, Mr Peter McBean was one of the committee members and with his emergency search and rescue experience in Christchurch New Zealand after the February 2011 earthquake he was able to see the project scope extended to include, where practical, seismic performance improvements. This was seen as an issue of importance given that Adelaide has the highest earthquake hazard of any of the capital cities in Australia and simple calculations indicate that any masonry element at the top of the church with a height-to-thickness slenderness ratio greater than three will be prone to out-of-plane rocking/bending failure. Hence, given the difficulty and expense involved associated with accessing the high level areas, the philosophy adopted by the project team was to improve the seismic resilience of the cathedral wherever and whenever access was made possible by the roof repair project and where relatively straightforward and inexpensive solutions were viable. This paper describes some of this work to date.

(a) (b)

Figure 2: Staged construction of St Peter's Cathedral, including: (a) the original 1868-1876 build with gantry in place to begin extension of the nave (circa 1894); (b) front entrance before construction of the bell towers (circa 1900). Photos provided by State Library of South Australia (photographs SRG 94/A1/26/3 and SRG 94/A1/26/7).

SEISMIC VULERABILITIES

The main seismic vulnerabilities of most unreinforced masonry buildings are associated with out-of-plane loaded walls (Moon et al, 2014; Penna et al, 2014) and free-standing toppling hazards and St Peter's Cathedral is no exception. Preliminary assessment of the cathedral identified the main seismic vulnerabilities to be those indicated in Figure 3, that is, the gable end walls, the two front entrance belltowers, the relatively tall and long spans of the nave walls, the free-standing ornaments and spires on the roof of the Lady Chapel, and the lantern tower due to its tall height and large proportion of window perforations. Parapets at the top of the nave walls are relatively stocky and therefore not considered to pose a major threat by comparison to the other items.

As noted earlier, access to the structure was dictated by the roof repair work being conducted to stop water ingress. Hence, to date, the seismic strengthening work has only focussed on items to which access was available as a consequence of the other works. This includes stabilisation of two of the gable end walls adjacent to the lantern on the south-west face of the cathedral and stiffening of the Lady Chapel roof structure to improve horizontal diaphragm action for improved out-of-plane stability of the side walls (refer Figure 3). These are discussed in more detail below.

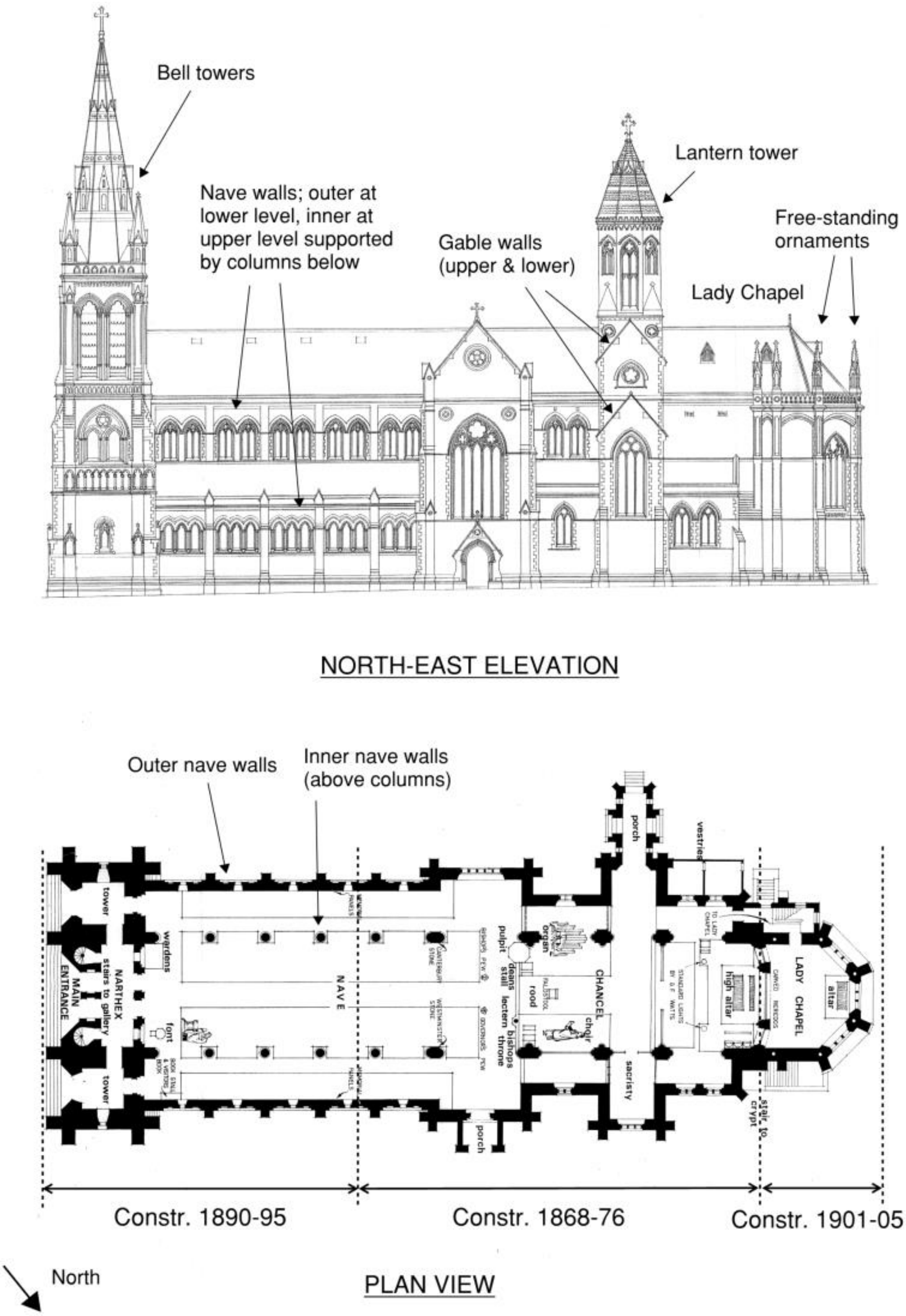


Figure 3: Plan and longitudinal elevation of St Peter's Cathedral

GABLE END WALL STRENGTHENING

The two gable end walls strengthened thus far are located on the south-west face of the cathedral adjacent to the lantern (one at the upper and one at the lower level) as shown in Figure 4. The walls each contain a rose glass window above which approximately 2m of vertical spanning gable wall was situated. Each gable wall has a width of about 6m at the eave level and 3m at the ceiling level (above which the strengthening was implemented), height of 3.5 m above the eave level, and thickness of nearly 1 metre. Given this height-to-thickness ratio, each wall should be capable of resisting a peak ground acceleration of approx. 0.1g (assumes height amplification factor of 3). Nonetheless, while the walls are relatively stout they were poorly connected along their edges back to the roof structure. The retrofit/strengthening object was therefore aimed at improving the connection of the gable wall to the pitched roof structure so that any out-of-plane movement of the gable wall would engage the full stabilising force provided by the roof structure. Figures 5 and 6 show the triangular backing woodwork that was tied to the gable wall with long adhesively anchored bolts. These bolts served the dual purpose of anchoring the timber frame to the gable whilst also ensuring that the inner bluestone and outer sandstone masonry layers of the gable were adequately pinned together. The backing timber frame was then connected to the gable roof structure with diagonal bracing to engage the full roof structure. Timber was chosen as the preferred material owing to its ease of procurement and installation. This resulted in a solution that was able to improve the out-of-plane resistance of the gable wall without being visible from the outside. This approach was used for both gable walls that have been strengthened to date.

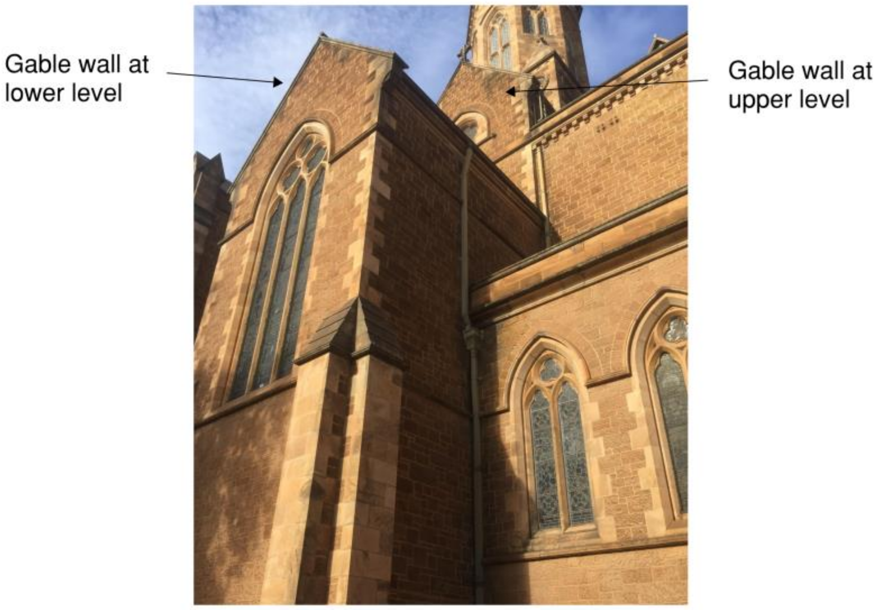


Figure 4: Gable end walls adjacent to the lantern, shown on north-west side.

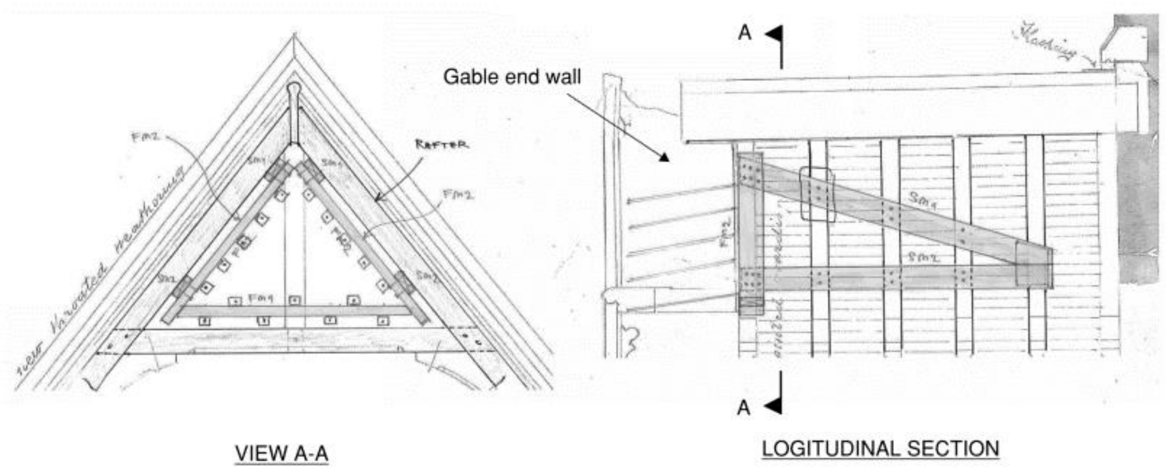


Figure 5: Strengthening concept for gable end walls.

Figure 6: Internal view of gable wall strengthening. (Image courtesy of Chris Oaten, Insight Visuals)

LADY CHAPEL ROOF STRUCTURE

The Lady Chapel is located at the north-west end of the cathedral as shown in Figure 3. The main object of this strengthening work was to increase the horizontal diaphragm stiffness of the roof structure at this location in order to reduce the potential for large out-of-plane deflections in the longitudinal external side walls by engaging the stiffness of the transverse internal and external cross-walls. The work was complicated due to the vaulted ceiling of the Lady Chapel (refer transverse section in Figure 7) which meant that it was not possible to provide the ideal stiffening solution which would have been to fully bridge between the external walls to maximise the resulting diaphragm stiffness.

As a pragmatic compromise to accommodate these limitations, a series of timber diagonal braces were installed at the upper level above the arched ceiling as shown in Figures 7 and 8. Each brace spanned across individual vertical roof 'rafter trusses' to increase the horizontal stiffness of the overall roof diaphragm through horizontal truss action. Vertical timber struts were also installed to deal with the vertical component of force generated from the inclination of the remedial bracing with respect to the horizontal plane. This solution meant that the retrofit remained concealed within the roof space thus providing no visible impact outside of the ceiling space.

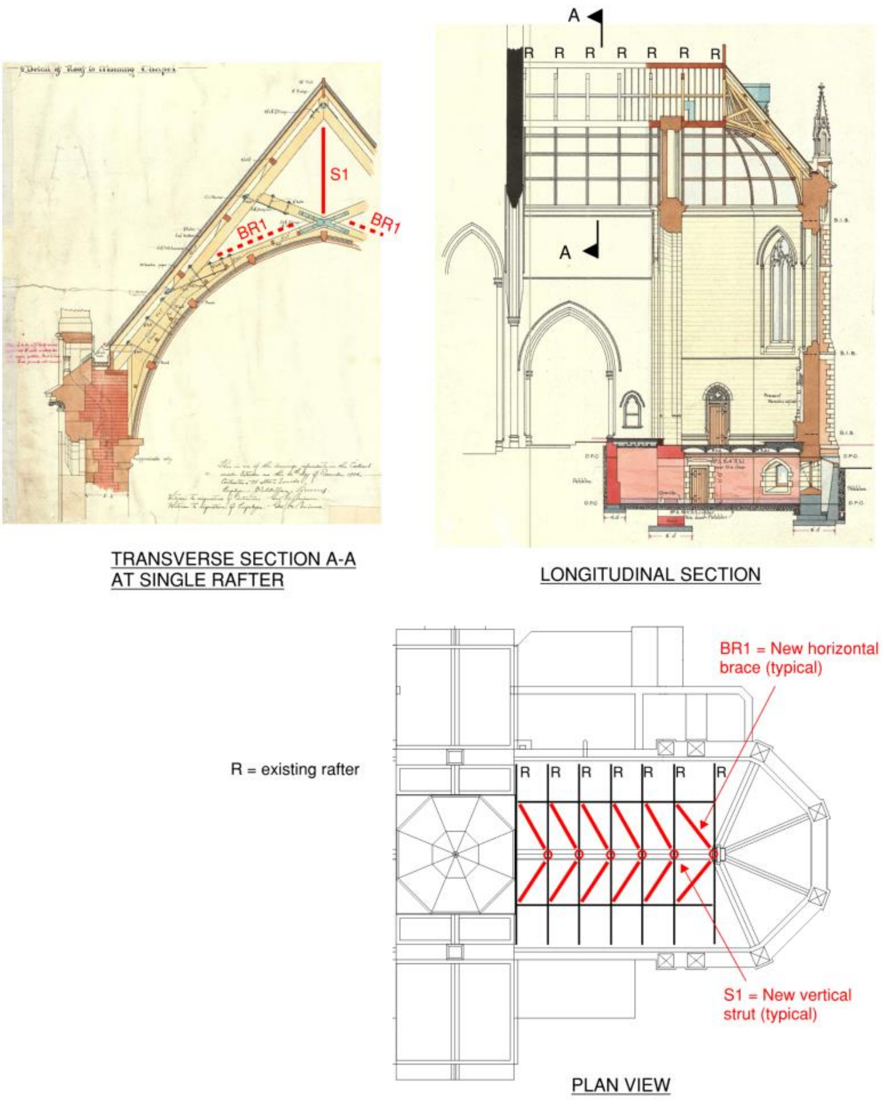
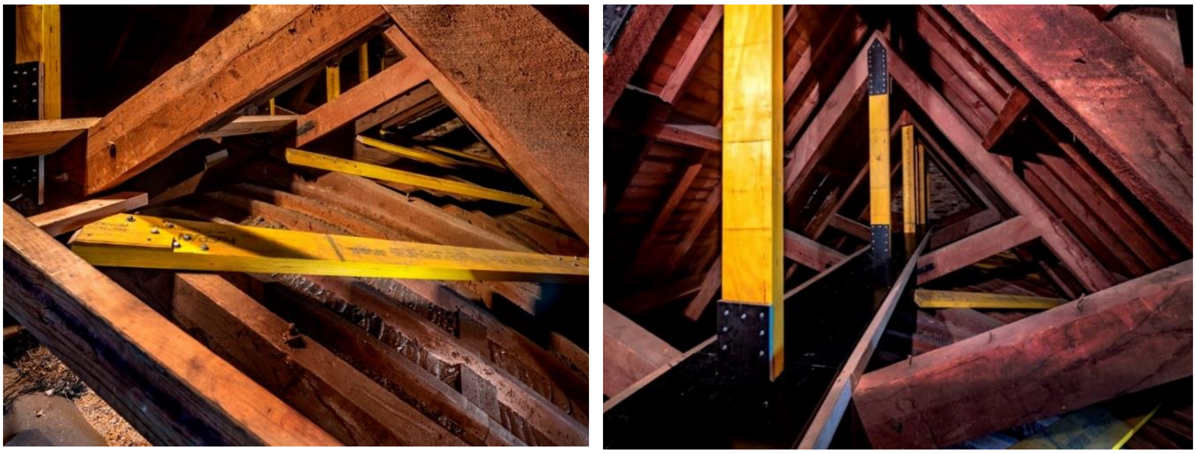


Figure 7: Scheme for stiffening of the Lady Chapel roof diaphragm.



(a) Diagonal braces (b) vertical struts

Figure 8: Lady Chapel roof strengthening details. (Image courtesy of Chris Oaten, Insight Visuals)

SUMMARY AND CLOSING REMARKS

To summarise, the seismic retrofit work undertaken on St Peter's Cathedral has been focussed on improving the resistance against local out-of-plane wall failure mechanisms. These mechanisms constitute the main seismic vulnerabilities of unreinforced masonry buildings (heritage or otherwise) and hence it can be argued that in projects with tight budget constraints, improvement of capacity against these modes of failure should be among the priority items for retrofit. The seismic strengthening work undertaken on the cathedral followed a simple philosophy of using straightforward measures to improve seismic resistance wherever possible and convenient within the limitations of the project. Because the work was able to piggy-back on the roof maintenance work, the incremental cost to incorporate seismic strengthening was relatively small. Among the main lessons demonstrated is that through a considered and pragmatic approach that takes advantage of available opportunity, it is possible to significantly improve the seismic resilience of existing buildings with low additional cost to a project.

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