Catholic Basilica
Catholic Diocese of Christchurch

Post Earthquake Structural Assessment Report

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1 Brief

1.1 Following the earthquake on 22 February 2011 Opus International Consultants (Opus) have been commissioned by the Catholic Diocese of Christchurch to undertake structural assessments of the Catholic Basilica, Christchurch. The building has suffered damage from the earthquakes of 4 September 2010 and 22 February 2011. As such the structural team at Opus have undertaken several inspections of the building prior to producing a structural report. The aim of this report is to:

(i) Describe the cumulative findings of structural inspections of the building.

(ii) Explain the structural behaviour of the building and problems arising.

(iii) Propose general recommendations to establish the structural stability of the building.

2 Authority

2.1 This report has been prepared in accordance with the engagement of Opus by the Catholic Diocese to assess and manage the structural stabilisation of the Basilica.

3 Limitations

3.1 The building is unsafe to enter and close access at ground level is prohibited, therefore the inspections have been external only.

3.2 This report is not an exhaustive list of all damage to the Basilica. It is intended to give a brief overview of the areas of significant structural damage and failure. Further in-depth analysis will be given to each structural issue in turn when they are more closely and specifically addressed for remedial measures.

3.3 The visual inspection of the building was undertaken from ground level and from a crane at high level around the north bell tower and the east dome.

3.4 No tests have been undertaken on the fabric of the building.

3.5 In the east dome structure some units of facing masonry have been removed from the frieze above the architrave.

3.6 This report is for the private and confidential use of the Catholic Diocese of Christchurch and its agents; it should not be reproduced in whole or in part or relied upon by a third party without the written authority of Opus International Consultants Ltd.

4 Brief History and General Description

4.1 The Basilica is situated on Barbadoes Street in the central area of Christchurch. It is aligned east-west in keeping with traditional church layout. The building is generally two storeys with the exception of the bell towers and the east rotunda and dome. There is a mezzanine floor which runs the internal perimeter of the building at first floor level. The nave sanctuary and altar areas are open to both storeys.

4.2 The church was designed by architect Francis W. Petre. Construction started in 1901 and was complete by 1905. It has been designed in the neo-classical style and is faced in Oamaru limestone, quarried 150 miles south of Christchurch.

4.3 The solid walls are constructed of reinforced concrete and faced in stone. The roofs to both bell towers and the east dome are timber framed with a copper finish. The nave roof is timber framed and finished in terracotta tiles. The flat roofs east of the nave around the base of the dome are reinforced concrete.

4.4 The church has a traditional plan form with nave, transept chapels and sanctuary.

4.5 The Basilica is heritage listed as category I and is an important landmark building within the city.

4.6 Previous structural work has been undertaken on the Basilica. A description of this is contained in a separate document.

4.7 The church has sustained significant damage, mainly from the February earthquake. This damage is mainly to the porch and gable at the east end of the building. The church is not currently in use.

5 The Survey

5.1 The structural survey was undertaken in various stages by Jamie Lester and Andrew Brown of Opus International Consultants (UK) Ltd.

5.2 A crane was used to survey the high levels of the bell towers and east dome. The building has not been entered to date since the earthquake. Close ground level access is not permitted as the building is unstable in many areas.

5.3 In the east rotunda structure some units of facing masonry have been removed from the frieze above the architrave in order to accurately determine the structural detail at the springer point of the east dome. The removed masonry elements have been catalogued and stored.

5.4 The terminology RHS and LHS refer to right hand side and left hand side respectively as viewed on the elevation under observation.

6 Survey Observations

West Elevation including Bell Towers

6.1 The bell towers are both 3 storey structures with timber framed copper domes. There are rooms to the ground and first floor and a belfry above.

6.2 The north bell tower on the LHS of the west elevation has suffered significant damage. The Belfry has collapsed down to the top of first floor level. A large amount of the fabric of the belfry remains in a precarious position having collapsed but no fallen to the ground. Large gaps have opened up on the north elevation at the head of the first floor window and diagonally between the first floor window and the east elevation. The bells are still visible at high level beneath the rubble.

6.3 Lower down on the north side of the bell tower there is significant vertical and diagonal cracking and displacement. A large gap has opened up on the north side above first floor level to the RHS of the window and the west face of the bell tower has moved outwards.

6.4 The majority of the south bell tower has collapsed. The belfry has completely collapsed completely and at ground and first floor levels the east wall and parts of the north and south walls remain.

6.5 The west front has suffered little damage in comparison. The pinnacle cross is still in place but leaning back towards the building and the balustrade at roof level in the furthest RHS bay over the west front has collapsed. There is significant cracking at the junction between the west front and the north bell tower, and some cracking to window arches.

South Nave Elevation

6.6 There is severe shear cracking on the south elevation behind the bell tower where the wall has been pulled laterally to the LHS due to the bell tower falling in the same direction. This cracking runs diagonally down the entire height of the building above and below the window positions.

6.7 On the outer elevation of the terrace, the architrave has failed and fallen in both of the end bays. On the inner elevation of the nave there is significant damage to the cornices and facework stone around the ground floor windows and doors with extensive displacement, cracking and localised collapsed of facework.

6.8 There is general minor cracking and damage to the inner south elevation at first floor level.

South Transept

6.9 Shear cracks have opened up around the junction between the nave elevation and the west wall of the south transept.

6.10 There is significant shear cracking around window head level at ground floor on the south elevation of the transept.

North Nave Elevation

6.11 There are severe shear cracks to the north elevation behind the bell tower. The cracking runs the entire height of the building down through the window positions.

6.12 In the outer terrace elevation there is a large diagonal crack in the entablature over the RHS end column.

6.13 On the inner north elevation there is significant cracking around the windows at ground and first floor in the end RHS bay. At ground floor level there is damage to the cornices and facework stone around the windows and doors with displacement, cracking and localised collapsed of facework.

North Transept

6.14 In the north elevation there is shear cracking around the ground floor RHS window head. Apart from this, the north transept does not appear to have sustained any major external damage.

East Rotunda and Dome

6.15 The east rotund is situated above the sanctuary. It comprises a large circular room within the rotunda lit by tall square headed windows around its entire circumference. The rotunda supports a large timber framed, copper clad dome and is supported on substantial solid walls and internal arches at roof level.

6.16 The rotunda has incurred severe damage from the earthquake. There is severe shear damage to the supporting north and south walls including large diagonal cracks, gaps and fallen masonry. The rotunda and dome above have moved significantly and are now noticeably leaning east.

6.17 In the south elevation there is extensive diagonal cracking running the full height of the supporting wall of the rotunda. There is a large area in the centre of the wall where the facing stone has fallen away and the concrete behind has suffered significant damage. There is very noticeable movement in the wall and many large gaps have opened up.

6.18 In the north elevation a large crack runs diagonally down the supporting wall from the top west edge down towards the east. A large area of facing stone has fallen away as has a significant amount of concrete behind, leaving a large gap in the side of the wall. There is significant movement between the two areas of wall divided by the diagonal crack.

6.19 The copper cladding has diagonal folds around its entire circumference indicating that racking has taken place. There is horizontal cracking in the frieze beneath the dome on the west and east sides and there is some displacement around these cracks.

6.20 In the east elevation there is horizontal and vertical cracking in the supporting wall beneath the rotunda and out of plane movement around the cracks.

6.21 In the west elevation there is a large crack in the base of the rotunda which extends from the northern side. Above the ridge line of the adjacent nave roof a facing stone has fallen away and there is cracking from the ridge up to the underside of plinth of the rotunda.

Sanctuary – South Elevation

6.22 There has been some shear cracking around the tops of the two windows in the lower arcade at the LHS end, the cracking also runs horizontally through the upper part of the pilaster between the two windows.

6.23 Most of the damage in the south elevation of the sanctuary as occurred at the RHS (eastern) end. In the upper arcade there is significant cracking above the window up to the balustrade in the end bay and from the RHS springer point of the same window diagonally down to the end pilaster.

6.24 In the lower arcade there is cracking above the windows in the two RHS end bays up through the entablature.

Sanctuary – North Elevation

6.25 In the two LHS bays on the upper arcade there is severe cracking through the window arches up through the entablature and the balustrade. Some of the masonry has fallen away and remaining masonry around the cracks has moved. The cracks have opened up significantly.

6.26 There is some cracking around the windows in the end bays of the lower arcade.

Sanctuary – East Elevation

6.27 The lower arcade of the east elevation appears to have suffered minor damage. There is, however, sever damage to the upper arcade.

6.28 The upper arcade is set back from the lower, as on the north and south sanctuary elevations, and has a central section which curves outwards behind around the apse.

6.29 The apse wall is severely damaged and leaning outwards. There is extensive horizontal, vertical and diagonal cracking across the apse wall and into the elevations on either side. Some of the facing stones have fallen from the wall of the apse, and there are large differential displacements in the masonry around the cracks. Large gaps have opened up at the junctions between the apse wall and the bays either side which taper towards the bottom. On the whole the apse wall is leaning severely outwards (east).

6.30 In the bays either side of the apse wall there are large horizontal cracks between the inner springer points of the window arches and the apse wall. The areas of wall above these cracks have been pushed outwards.

6.31 Parts of the balustrade above the east elevation have collapsed.

Internal Structure beneath Rotunda

6.32 Beneath the edges of the rotunda are four large arches which are parallel to the external elevations. Following an inspection undertaken from a crane it was possible to view inside through a broken window and it is clear that the south arch has collapsed and there is severe damage to the north arch.

Roofs

Nave and Transept Roofs

6.33 The roofs to the nave and transepts are timber framed and finished in terracotta tiles. On the whole most of the tiles have stayed in position but many are fractures and fragments are scattered over the roof. There are a number of tiles which have failed at the east end of the nave roof where it meets the base of the rotunda. There is localised damage around the bell towers where parts of the structure have fallen onto and through the tiles. On the roof of the south transept the pinnacle cross has fallen from the gable back onto the roof causing impact damage.

Bell Tower Roofs

6.34 Both dome roofs of the bell towers have completely collapsed.

Rotunda Dome Roof

6.35 The dome roof over the rotunda is still whole and in place. There is some damage to the internal timber structure and some of the internal timber struts have become dislodged. There are diagonal racking folds in the throughout the copper plates where the dome has twisted. The rotunda structure, including the dome, is leaning outwards towards the east elevation.

6.36 On the east side of the rotunda is the semi-conical roof of the apse, also clad in copper. There is evidence of previous repair to the copper and the flashings have been damaged. On the whole the roof finishes do not appear to have sustained any significant damage. The support for the roof has been severely compromised due to the damage incurred at the upper flat roof level.

East Flat Roofs

6.37 There are two levels of flat roof at the east end of the building. The lower level roof is at first floor level where the upper arcades of the sanctuary are stepped back from the lower arcades. The upper roof is at the eaves level of the nave roof and spans between the upper arcade walls of the sanctuary and the base of the rotunda and inner apse wall. All flat roofs are constructed in reinforced concrete.

6.38 There are some tension cracks to the lower roof running north-south at the east end of the north elevation. There is other cracking in the lower roof but no areas of collapse.

6.39 There has been a significant area of collapse to the upper flat roof at the north east corner. At this location the roof has fallen in between the external wall and the base of the rotunda and apse roof. This collapse has exposed internal areas of the sanctuary showing severe damage to the structure in this area. Elsewhere there is significant cracking in the upper flat roof.

7 Discussion

7.1 The basilica has been very severely damaged by the earthquake, particularly around the rotunda and bell tower areas. There is a large amount of unstable fabric which is at risk of falling, particularly around the bell towers. The east end of the building is also at risk of collapse due to the instability of the rotunda and the supporting structure beneath.

7.2 The collapse of the north bell tower has severely damaged the structure beneath. The cracking and displacement in the north elevation indicates that there is significant movement outwards of the west wall and risk of further collapse. Shear cracking in the north elevation behind the bell tower and the outer elevation of the terrace indicates that these areas are also vulnerable to the lateral loads acting in the direction of movement of the bell tower.

7.3 The collapse to the south bell tower is more severe than the north. The whole of the west elevation has been lost as have significant parts of the north and south walls. The south elevation behind the bell tower has cracked up its entire height under tension as the bell tower walls have pulled away from those behind.

7.4 On the outer south terrace elevation the architrave has fallen at both ends where they have lost support in the return walls and failed in shear. There is also significant damage from shaking and shear effects to the inner elevation at ground floor. There is significant shear damage and displacement at the springer points of the window arch which is the weak point in the elevation. The internal mezzanine floor acts as a diaphragm distributing the lateral loads to the external walls in the relevant direction. This diaphragm does not extend to the outer elevation of the terrace, hence the greater damage to the inner elevation. This principle applies to both elevations of the nave.

7.5 The south transept has tension cracking to its western elevation at the junction with the nave wall. The pattern of damage shows that the transept has rotated on plan towards the east end of the building. There is also shear cracking around the outer sides of the south elevation windows at ground floor. This is due to there being no continuity of resistance at the ends of the wall and therefore the masonry has failed.

7.6 The pattern of damage to the north nave elevation is similar to that on the south but less severe. The most severe damage has occurred at the weak point at the springer level of the window arches. There is a similar pattern to the south elevation of tension cracking in the north elevation behind the bell tower where the walls have been pulled forward by the collapse and movement in the tower. The architrave has not failed but there is cracking at the west end of the entablature in a similar position to where the failure occurred in the south elevation.

7.7 In the north transept there is shear cracking around the outer sides of the north elevation windows to the ground floor of the transept. As in the south elevation, the lack of continuous restraint has resulted in the failure of the masonry.

7.8 The damage to the structure within the footprint of the sanctuary is the cumulative effect of the structural behaviour of different elements in this area. The damage has followed the load path from the rotunda down to the supporting arches and then to the external walls which have moved outwards as a result. As one element has failed it has removed the support for another, which moves further and increases loading on the failed or damaged element. This cyclic pattern of damage has resulted in the sanctuary area being in a very precarious and unstable condition. The complete failure of one of the four principle internal arches beneath the rotunda has caused a critical situation. With the load paths now changed and made a lot more complex the structure is unable to behave as it was designed to do.

7.9 In addition to the failure of one of the internal arches, it is clear from what can be seen through the collapsed flat roof that several of the internal load carrying elements have also been badly damaged. This adds to the precarious condition of the structure. At present it is not possible to enter the building to assess the internal elements, making it difficult to predict structural behaviour.

7.10 At the top of the load path is the dome and rotunda. As a result of imposed loading, out-of-plane loads caused by the leaning of the structure and the damage and partial failure of the supports, it is in a precarious situation, whilst continuing to impose loading on the damaged structure beneath. However, it is also the imposition of loading which provides stability for arches, enabling them to be in a constant state of compression. Whilst the removal of the rotunda loading may relieve the detrimental loads on the walls, it would also remove the beneficial loads from the arches which could result in further collapse.

7.11 The pattern of damage is coincident with the direction of the lean in the rotunda. The loads are acting through the archest to push the east walls outwards. This is particularly noticeable in the apse wall and at the east ends of the upper north and south arcade walls where the structure has been visibly pushed eastwards. The direction of failure is also in the direction of least resistance; to the west of the rotunda is a much greater body of resistance in the nave structure.

7.12 The line of failure in the base of the rotunda is clear even from ground level. The large diagonal cracks and masonry failures up the north and south walls of the rotunda base clearly define the line of failure and movement.

7.13 The reinforced concrete flat roofs act as diaphragms to evenly spread lateral loads at roof level. With the collapse of a large area of the roof, the lateral loads have been concentrated at the edge positions of the lines of failure, and therefore altering the load paths and exacerbating the stresses in these positions.

7.14 The dome has clearly been subject to torsion by the visible diagonal folds which are around its entire circumference. The internal damage to the timber frame of the dome has compromised its ability to withstand further high loads and, as with the structure below, has altered the load paths putting it at increased risk of further damage.

8 Recommendations

Immediate/ Short Term

8.1 Given the condition of the building priority must be given to issues of health and safety and structural stability.

8.2 Working inside or close to the building cannot be permitted, including clearing of rubble around the building. Close working can only be undertaken from above by a crane whose base is sufficiently far enough away from the building to ensure it would not be affected by a full or partial collapse.

8.3 The areas at greatest risk of collapse and causing further severe damage are the structure in the area of the sanctuary and rotunda, and the upper level of the north bell tower. Whilst undertaking securing work and developing schemes for stabilising the building, it is essential that sufficient consideration be given to the heritage aspects of the building. This will undoubtedly mean working at a steady pace to carefully handle and document elements of the building.

8.4 The unstable collapsed material should be removed from the top of the north bell tower and documented. Salvageable material should be carefully stored for re-use.

8.5 The timber framed dome over the rotunda should be carefully removed as it would be severely damaged in the event of the structure beneath collapsing. As the dome is lightweight compared to the structure beneath its removal should not adversely affect the remaining stability of the internal arches. Any proposal for its removal should include a strategy to weatherproof the rotunda post removal and a proposal to ensure that the top of the rotunda walls continue to be adequately restrained.

Medium/ Long Term

8.6 Following the removal of the dome and the collapsed material from the north tower, the building should be re-assessed for any changes in structural condition and areas requiring attention listed in order of priority. The east area around the sanctuary will undoubtedly remain the focus of greatest attention due to the precarious condition and heritage value of the architecture in the most elaborate and ornate part of the building.

8.7 Work should be done with the ultimate aim of gaining safe access into the building. However, given the continued dangerous condition of the building and its heritage value, it should be understood by all parties involved that the whole process should be steady and carefully thought through at all levels and stages.

8.8 As access to more areas is made possible, regular inspections should be made and proposals and schemes regularly re-evaluated.

8.9 No work should be undertaken without the relevant statutory consents, if needed.

8.10 Reconstruction work should incorporate a structural solution designed to so that the building can withstand seismic loading in line with building code requirements.

9 Conclusions

9.1 The Basilica has sustained severe damage, mainly to the west and east parts of the building.

9.2 Priority should be given to the health and safety aspects of working around the building and making the building structurally secure with due regard to its heritage value and status.

9.3 The ultimate aim should be to stabilise the structure with a view to rebuilding the Basilica with a structural frame to withstand future seismic loading.

9.4 It is important that as much of the architectural fabric of the building is saved as possible so that the Basilica can be rebuilt faithful to the original design, with the added provision of adequate seismic resistance. This will ensure that the architectural heritage and significance of this important landmark building can be enjoyed and appreciated by future generations.