Hadley & Robinson Ltd.
Consulting Civil & Structural Engineers

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Catholic Diocese of Dunedin
Rattray Street
DUNEDIN

Attention Bill Haydon by email: BillH@cdd.org.nz

Dear Bill,

PRELIMINARY REPORT ON LIKELY PERFORMANCE IN EARTHQUAKE
—St Joseph's Cathedral, Dunedin
—St Patrick's Basilica, Oamaru
—St Mary's Basilica, Invercargill

You have requested an assessment of the likely performance in earthquake of the following churches: St Joseph's Cathedral Dunedin; St Patrick's Basilica, Oamaru; and St Mary's Basilica, Invercargill.

We have previously reported on progress on the assessments. We reported that the buildings are not earthquake prone, but delayed reporting the actual performance levels until completion of the analyses. We also indicated that further analyses would be undertaken to extend the analyses performed to that time (see below). We have not yet undertaken those further analyses, so have not yet prepared the reports.

However, you have indicated urgency in getting indications of performance levels so that renewals or insurances can be completed. That we now do, but first discuss the legal background and policy issues.

Legal requirements
The provisions of the Building Act with respect to earthquake prone buildings are noted in Appendix A. In brief, a building is defined as being earthquake prone if it would collapse in a moderate earthquake. A moderate earthquake is defined as one that would produce shaking at the site one-third as great as would be assumed for the design of a new building at the site. This is often referred to as one-third new building standard (33%NBS), which is imprecise but useful in understanding earthquake proneness.

If a building is assessed as being earthquake prone, the Territorial Authority may require the danger presented by that condition to be removed by demolition or by improvement of performance in earthquake within a specified time. The standard of improvement required by legislation is such that the building would not be considered earthquake prone if the test for earthquake proneness were reapplied after the improvements were completed. That is, buildings need to be brought up to a level of performance such that they would not collapse in a moderate earthquake.

Territorial Authorities—policies
Territorial Authorities are required to prepare policies toward implementation of the requirements of the Act. Policies vary. For example, the Dunedin City Council Policy states that assessments would be required whenever the cost of alterations exceeds 25% of the capital value of the building or $200,000, whichever is greater, but within two years in any case if Council identifies a building as potentially earthquake prone. The time provided to complete improvement would vary from 15 years or more, depending on the level of assessment.

The Act and associated policy directives are presently under review, but it is clear that the threshold defining earthquake proneness and the time for completion of any required improvements to remove that state are unlikely to change. That is, if a building is assessed as earthquake prone then it would need to be improved

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to a level where it is not earthquake prone within a timeframe set by Council. The time for completion of this improvement might no longer be set by Council, but within the act. It seems that it would remain at least 15 years.

Target performance levels
Higher standards of improvement than just those sufficient to meet earthquake prone tests might well be set by owners, considering both the concerns for life safety and reflecting requirements of their financiers, their insurers of their tenants. Owners might also apply greater urgency to complete the improvements than Council might impose.

Where a higher level of upgrading is be considered, such as for a change of use, or just from considerations of additional safety or property protection, there is a question of what constitutes a "reasonably practicable" level of shaking to assume, taking into account heritage values of a building and how these might be jeopardised by inappropriate intervention into the existing fabric. It is often assumed that 67% is a reasonable level for this type of building. The NZSEE document referred to below recommends that as a minimum level.

Assessment methods
The assessment methods most commonly used are those outlined in the document "Assessment and Improvement of the Structural Performance of Buildings in Earthquakes", which the New Zealand Society for Earthquake Engineering prepared for the Department of Building and Housing (now within the Ministry of Business, Innovation and Employment). The document was published in 2006. It is intended primarily for the assessment of earthquake prone buildings and the improvement of performance of a building to the extent that it would not then be earthquake prone. However, the methods are also useful for other purposes, such as improving performance to higher standards. The document is presently under review.

Unreinforced masonry is commonly assessed using a modified Mohr-Coulomb failure criterion. For the implementation of finite element work, the Mohr-Coulomb criterion shows excess dilatancy. For that reason the Drucker-Prager criterion is often used.

In the studies that we are presently undertaking, the deficiencies in the standard Mohr-Coulomb model are remedied through using a modified flow potential[1].

This requires changes to the usual solution method[2], because otherwise the solution will show numerical instability and be slow to converge, in some cases so slow as to lead to premature abandonment of solution at particular load levels.

This will be more fully explained in the completed report.

That level of refinement is not completed, so the ratings given below are on the low side.

Preliminary results
We refer to our previous reports in which we stated that the buildings were not earthquake prone. We now report that the buildings would not collapse in an earthquake that generated shaking at the site the following percentages, X, of the levels that would be assumed for the design of new buildings on the same sites. To use the common notation, they are rated at least X%NBS.

[1] The flow potential, *G*, for the modified Mohr-Coulomb yield surface is chosen as a hyperbolic function in the meridional stress plane and the smooth elliptic function proposed by Menétrey and Willam (1995) in the deviatoric stress plane. That results in a nearly associative flow. The effect of the new criterion is to modify the traditional Mohr-Coulomb yield surface. For instance, the irregular hexagon that describes the Mohr-Coulomb criterion in the deviatoric plane (the π-plane) becomes an ellipse, in the limit matching the Drucker-Prager circle in that plane. The precise shape, such as the relative size of the ellipsoid axes, depends on the values selected for the eccentricities.

[2] Since the plastic flow is non-associated in general (that is, the strain tensor is not necessarily in a direction normal to the yield surface), the use of this modified Mohr-Coulomb model generally requires an unsymmetrical matrix storage and solution scheme. Such a solution strategy is required because the dilation angle should be smaller than the friction angle (thus making the inelastic stiffness matrix unsymmetrical); otherwise the solution will show numerical instability and be slow to converge. In some cases, solution using the same dilation and friction angles and a symmetric matrix will lead to solution paths that are so slow as to lead to premature abandonment of attempts at solution at particular load levels.

St Joseph's Cathedral, Dunedin	85%
St Patrick's Basilica, Oamaru	85%
St Mary's Basilica, Invercargill	70%

The reasons for the lower performance rating for St Mary's include the higher seismicity of Invercargill, and the condition of the ring beam supporting the dome. The latter feature may be improved at moderate cost and so improve the rating to a level similar to that of the other buildings.

As noted above, refinements of analyses are not complete, being interrupted for this report. The urgency in advising the status of the buildings means that we reverted to the customary strategy, with numerical difficulties encountered (as expected) at the stated level of earthquake. These will be avoided when we revert to the approach that was originally intended.

We are therefore confident that the preliminary levels stated above will be bettered.

Yours faithfully

L M Robinson
DIRECTOR

Appendix A: Earthquake Proneness

Legal Requirements—earthquake proneness
The test for earthquake prone buildings is defined in section 122 of the Building Act 2004, and in associated regulations.

122 Meaning of an earthquake-prone building

(1) A building is earthquake prone for the purposes of the Act if, having regard to its condition and the ground on which it is built, and because of its construction, the building—
- *(a) will have its ultimate capacity exceeded in a moderate earthquake (as defined in the regulations); and*
- *(b) would be likely to collapse causing—*
  - *(i) injury or death to persons in the building or to persons on any other property; or*
  - *(ii) damage to any other property.*

(2) Subsection (1) does not apply to a building that is used wholly or mainly for residential purposes unless the building—
- *(a) comprises 2 or more storeys; and*
- *(b) contains 3 or more household units.*

The regulations referred to in s122 were promulgated in 2005/32 on 21 February 2005. Regulation 7 defines a moderate earthquake.

7. Earthquake-prone buildings: moderate earthquake defined
For the purposes of section 122 (meaning of earthquake-prone building) of the Act, moderate earthquake means, in relation to a building, an earthquake that would generate shaking at the site of the building that is the same duration as, but is one-third as strong as, the earthquake shaking (determined by normal measures of acceleration, velocity, and displacement) that would be used for the design of a new building at that site.