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AN INVENTORY OF UNREINFORCED MASONRY CHURCHES IN NEW ZEALAND

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ABSTRACT

Churches are an important part of New Zealand's historical and architectural heritage. Various earthquakes around the world have highlighted the significant seismic vulnerability of religious buildings, with the extensive damage that occurred to stone and clay-brick unreinforced masonry churches after the 2010-2011 Canterbury earthquakes emphasising the necessity to better understand this structural type. Consequently, a country-wide inventory of unreinforced masonry churches is here identified. After a bibliographic and archival investigation, and a 10 000 km field trip, it is estimated that currently 297 unreinforced masonry churches are present throughout New Zealand, excluding 12 churches demolished in Christchurch because of heavy damage sustained during the Canterbury earthquake sequence. The compiled database includes general information about the buildings, their architectural features and structural characteristics, and any architectural and structural transformations that have occurred in the past. Statistics about the occurrence of each feature are provided and preliminary interpretations of their role on seismic vulnerability are discussed. The list of identified churches is reported in annexes, supporting their identification and providing their address.

INTRODUCTION

Unreinforced masonry (URM) is one of the construction materials that was most frequently used in New Zealand's early built heritage and URM churches represent a significant proportion of the heritage building stock of New Zealand. Churches, aside from having relevant historical and architectural value, often assume a symbolic significance for the communities that they belong to. The 2010-2011 Canterbury earthquakes had a dramatic impact on the community: 185 people died and many thousands were injured [1], but also the extensive damage and collapse of churches deeply marked their communities, who placed a high value on these heritage religious buildings, seen as an important part of the region's character and history [2]. Therefore, the importance of preserving such buildings is a fundamental societal issue.

It is also widely known that URM churches frequently perform poorly even in moderate earthquakes, because of their intrinsic structural vulnerability [3]. URM churches are particularly vulnerable to earthquakes because of their open plan, large wall height-to-thickness and length-to-thickness ratios, and the use of thrusting horizontal structural elements for vaults and roofs. Their use of low strength materials often causes decay and damage due to poor maintenance, and the connections between the various structural components are often insufficient to resist loads generated during earthquakes [4-6]. Additionally, damage is related to architectural types and construction details, which may vary from country to country. The 2010-2011 Canterbury earthquakes caused widespread damage to stone and clay-brick URM churches (Figure 1) [7]. Hence, a research project was undertaken to identify the New Zealand stock of URM churches and to interpret the damage observed in the area affected by the Canterbury earthquakes [8]. An accurate documentation of architectural heritage is the first step in understanding the relevance of the damage observed and in the implementation of effective conservation strategies. Consequently, a national inventory of URM churches is presented, accounting for the geometry, construction details, building and transformation history, and the preservation state.

In the following section the inventory collection procedure is presented, and in the third section an outline of the history of URM churches in New Zealand is provided based on bibliographic and field research undertaken as part of this study. An overview of the characteristics of churches, with reference to geographical distribution, types, architectural features, and structural characteristics is given in the fourth section. Possible applications of the results of this research are given in the final notes. Almost three hundred URM churches are listed in the 16 annexes for each region of New Zealand.

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(a) St Peter's Church (1875), Christchurch

(b) St Joseph's Church (1921), Christchurch

Figure 1: Examples of damage caused by the 2010-2011 Canterbury earthquakes.

INVENTORY COLLECTION PROCEDURE

For the purpose of understanding the scale and nature of the seismic risk of existing URM churches in New Zealand it is useful to investigate their number and national distribution. In the absence of a complete list of churches present across the country, several reference sources were utilised, leading to the identification of 297 URM churches currently existing in New Zealand (Figure 2). This total does not account for 12 churches demolished in Christchurch because of heavy damage suffered during the Canterbury earthquake sequence.

The first identification source considered was the Heritage New Zealand (HNZ) List [9], formerly referred to as the Register. Approximately half of the identified churches are recorded therein (Figure 3). Some of the non-registered buildings were identified through the online inventories of the different religious denominations in New Zealand, archive documentation, architectural books [10-18] and reports. Such research led to acquiring knowledge of churches constructed of all types of structural materials. Hence, a subsequent filtering was performed by preliminary observation using Google Street View. Finally, additional churches were identified during the field survey along the 10 000 km itinerary that was planned based on the previously identified sites. This field survey aimed to acquire technical information for all URM churches, and to appropriately identify numerous non-registered buildings considered to be potentially significant examples of early New Zealand architecture. Despite the care and effort put into the definition of this inventory, the existence of other churches along routes not explored during the field trip cannot be excluded.

Figure 2: Distribution of URM churches in New Zealand.

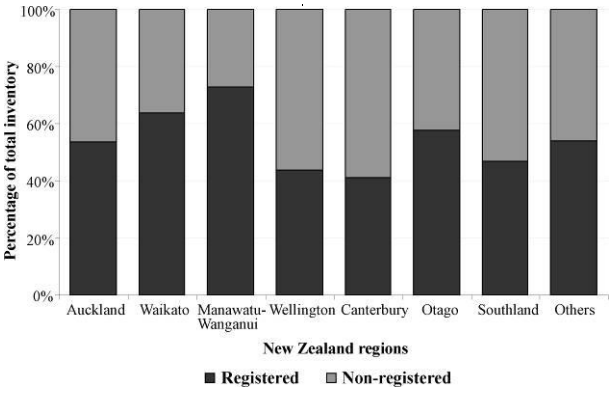


Figure 3: Percentage of existing URM churches registered within the New Zealand Heritage List (HNZ), grouped per region.

The inventory database is subdivided into geographical regions and the information is gathered into three groups: (i) general data; (ii) architectural features; and (iii) structural characteristics. *Table 1* shows the parameters considered for each main data group.

Table 1: Parameters considered in the inventory of New Zealand URM churches.

General Data
Name
Religious denomination
Location (region, city, suburb, street, #)
Former and current use
Construction date and architect
HNZ registered number
Phone contact and web-links
Architectural Features
Typological classification
Overall dimensions
Position (isolated or connected to other structures)
Plan and elevation regularity
Alterations / additions
Structural characteristics
Masonry type and quality
Wall texture and wall cross-section morphology
Type of roof
Presence of thrusting structures (e.g., arches, vaults, domes, roofs without bottom chord)
Additional vulnerability factors (e.g., soaring elements, large openings, heavy roof covers)
Additional strengthening factors (e.g., buttresses, tie-rods)
State of preservation

HISTORY OF UNREINFORCED MASONRY CHURCHES IN NEW ZEALAND

As soon as settlers became established in New Zealand they started to build churches because of their strong Christian faith [18]. The first churches were built mainly with timber, because of the ease of construction in terms of time and material availability [19]. The architecture was in accordance with Early English style, familiar to both clergy and architects [20]. Auckland and Wellington saw early examples of brick churches (respectively, St Paul's in 1841 and Wesley Chapel in 1844, the latter destroyed by the 1848 Marlborough earthquake (M_w 7.5)), both plastered to give an appearance of stone [21]. However, stone and clay-brick masonry buildings started being used largely from around 1880, when clay became readily available and prosperity increased. The 1931 Hawke's Bay earthquake (M_w 7.8) demonstrated the poor performance of URM and marked the beginning of the decline in use of URM [22-23]. After the destruction caused by the Hawke's Bay earthquake, the New Zealand Standards Institute was formed to regulate building practice, and URM constructions were prohibited in 1965 [23-25]. After this ban, the use of reinforced concrete became predominant. However, the bibliographic and field research undertaken as part of this study has shown that reinforced-concrete construction was applied starting as early as the first quarter of the 20th century, either alone or together with masonry (e.g., reinforced-concrete frame + clay-brick infill, or reinforced masonry).

The period of construction has been determined for 86% of the masonry churches in the inventory, and in Figure 4 the churches of known construction date are grouped according to decade of construction. The majority of this building stock was established between the 1870s and 1931 (84%), with a few cases (13%) built between 1931 and 1965. The trend in age shows that most of the construction activity occurred between 1910 and 1940, with a peak around 1930. The age statistic confirms that New Zealand ecclesiastic masonry-construction heritage was built over a short time span, compared to other countries worldwide.

In New Zealand the majority of religious buildings are Christian churches. The religious history of the country after the arrival of the Europeans was characterised by significant missionary activity. The Anglican Church of England brought Christianity to New Zealand through the Church Missionary Society, while Presbyterianism and Catholicism were respectively and largely brought by Scottish and French settlers [26]. Methodism arrived slightly later and the Baptist Church, which had grown rapidly in early 19th century in England, established its first congregations in New Zealand in about 1850 [27]. Later missionaries brought other religious denominations. With reference to the building inventory the four largest denominations are Anglican, Presbyterian, Catholic and Methodist (Figure 5a) and their churches can be found in all parts of the country. A much more limited number of buildings are, in decreasing order: Union parishes (grouping of Anglican, Presbyterian, Methodist and Congregationalist), Baptist, Congregationalist, Jewish, and Reformed.

Some of the ecclesiastic buildings are no longer used as was originally intended and are currently utilised for other functions, ranging from civic facilities to private usages. Both original and changed-use churches were included in the inventory. Figure 5b shows the proportion of URM buildings still used as originally intended (91%). The remainder of the inventory is made of buildings that have their use changed (7%), that are not in use (1%), or whose use could not be determined at the time of the survey (1%).

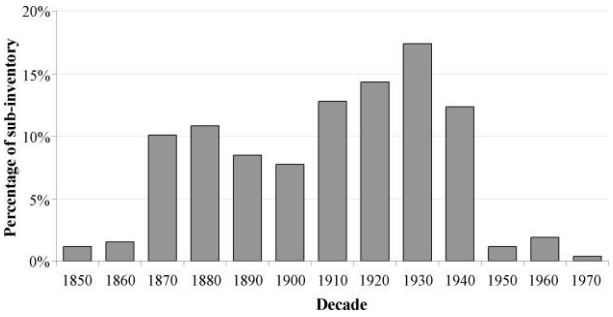
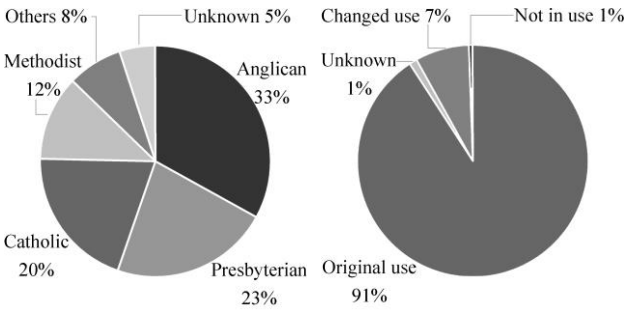


Figure 4: Percentage of URM churches according to construction period (for available date of construction).



(a) Religious denomination (b) Current use

Figure 5: URM church denomination and use.

CHURCHES CHARACTERISTICS

Geographical Distribution

For the purpose of understanding the history of URM churches in New Zealand it is useful to consider their distribution nationally. Almost 70% of the inventory is concentrated in the South Island, with a prevalence of churches located in the Otago (30%) and Canterbury regions (29%), as shown in Figure 6.

The comparatively low proportion of buildings in the Auckland region (14%), despite the region having always been the most populated of New Zealand [28], can be explained because of the larger use of timber in construction. There are at least two explanations for this fact. First, stone was less readily available in the area, whereas Kauri trees were common, especially on the Coromandel Peninsula and in northern areas [29]. Consequently most early constructions, including churches, were made with timber. For example, St Mary's in Parnell, Auckland, was originally designed in brick and stone masonry, but due to budget limitations was instead built in timber [19]. Second, at the time of the 1848 Marlborough and 1855 Wairarapa (M_w 8.2) earthquakes, it was observed that masonry buildings were susceptible to destruction while wooden buildings appeared more able to withstand such forces [30]. In some cases, even wind induced damage in masonry churches. For example, St. Stephen's Chapel in Parnell, Auckland, was originally constructed in stone in 1844, but after being destroyed by a hurricane three years later was replaced in 1857 by the current timber building [19]. Hence, timber ecclesiastic buildings became predominant in Auckland and acquired such a specific style as to be dubbed 'Selwyn churches', after the nation's first Anglican Bishop (1841-1867) George Augustus Selwyn [31, 32]. Wooden churches, sometimes intended as temporary buildings, are in general still standing today and in good condition [19]. This resilience was also proved by the Canterbury earthquakes, during which timber churches had the best overall performance, with no cases of structural damage [7]. However, over time there was a change in building practice after several severe fires affected timber structures, and because masonry construction conveyed a sense of permanency, which was deemed to be a fundamental attribute for any church establishment in a new colony [21, 33].

The Hawke's Bay region has a fairly low (1%) number of URM buildings, although many major churches were located in and around Napier up till 1931. In that year the M_w 7.8 Hawke's Bay earthquake and subsequent fire caused extensive damage and induced reconstruction with materials other than URM. The same reasoning can reliably be proposed for the Tasman, Nelson, and Marlborough regions, and for the upper portion of the West Coast region (combined 5%), which were strongly stricken by the 1929 Arthur's Pass (M_w 7.1) and 1929 Murchison (M_w 7.8) earthquakes [34]. Similarly, it is worth mentioning that the upper portion of the Canterbury region has almost no URM churches.

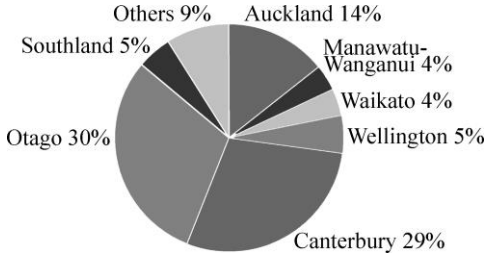


Figure 6: Estimated provincial percentage of existing URM churches.

The geographical distribution of URM churches was compared with the seismic hazard map of New Zealand, considering expected peak ground accelerations (PGAs) for a 475-year-return-period earthquake for shallow soils (Figure 7) [35]. The comparison was further explored by computation of the seismic hazard factor, *Z*, defined by New Zealand Standards [36], where the hazard factor has been derived as 0.5 times the magnitude-weighted 5% damped response spectrum acceleration for 0.5 s period for site class C (shallow soils) with a return period of 500 years. This factor is determined through the Initial Evaluation Procedure (IEP) spreadsheet provided by the New Zealand Society for Earthquake Engineering [37]. For church locations not listed in the IEP spreadsheet (about 20%), interpolation of the hazard factor was used. 27% of the inventory is located in zones with a hazard factor of $0.21 \leq Z \leq 0.30$, 10% in zones of $0.31 \leq Z \leq 0.40$ (Figure 8). A total of 13% of the inventory is located in high hazard areas, with a hazard factor greater than 0.30, being the current *Z* factor for Christchurch (raised from 0.22 by the Department of Building and Housing in May 2011 [38]). This outcome confirms the relationship between the geographical distribution of currently existing URM churches and the seismic history of the country, and suggests that those churches located in the highest hazard zones should be investigated and possibly strengthened ahead of the remainder.

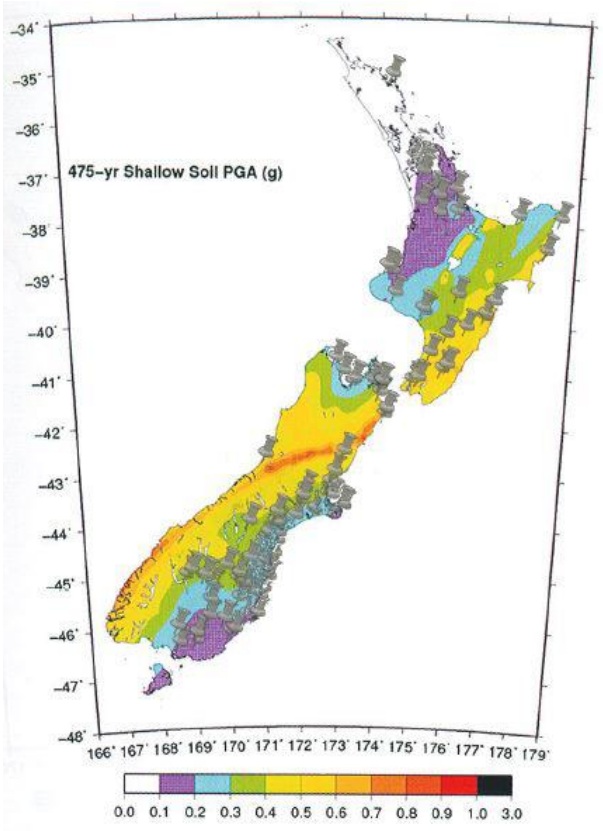


Figure 7: Distribution of URM churches compared with the New Zealand national seismic hazard model [35].

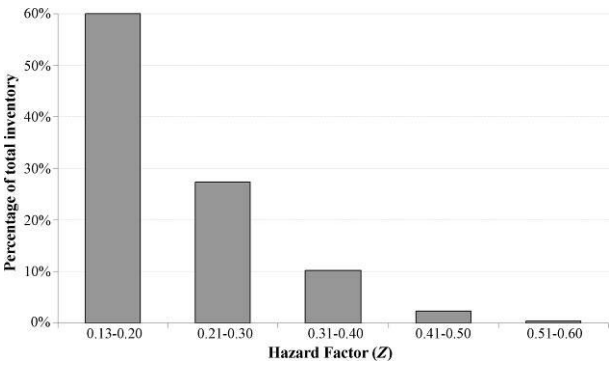


Figure 8: Percentage of URM churches according to hazard factor (Z).

Typological Classification

Within the characterisation of URM buildings, a very important classification is that concerning the overall building configuration. The seismic performance of a URM structure strongly depends on its general size and shape. Accordingly, a typological classification based on the plan and spatial features is developed, grouping structures that may display a similar seismic behaviour.

Six types are identified within the New Zealand URM church stock, as outlined in Figure 9 and *Table 2*. Photographic examples are given in Figure 11.

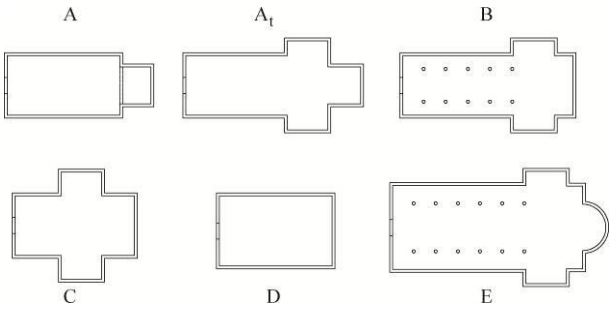


Figure 9: Typological classification of URM churches in New Zealand.

Table 2: Summary of typological classification of URM churches.

Type	Plan	No. of naves	Nave cover
A	Longitudinal	1	Roof
A_t*	Longitudinal	1	Roof
B	Longitudinal	3	Roof/Vaults
C	Central	1	Roof
D**	Central/ Longitudinal	1	Soffit
E***	Longitudinal	3 or more	Roof/Vaults

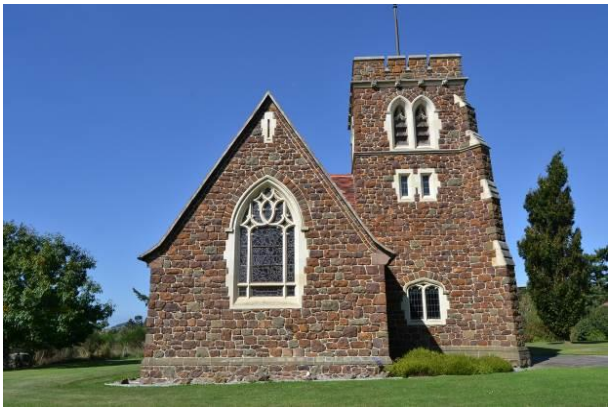
*A_t: one nave with transept;

**D: large hall without internal walls, with "box type" behaviour and exteriors as a building;

***E: Basilica, similar to B but much larger.

The graph in Figure 12 shows the frequency of the types for the entire stock. Note that the majority of churches (58%) are part of the A type, underlining the simplicity of the architecture of New Zealand churches. The A_t type includes the presence of the transept and reaches 21%, such that the combined percentage of A and A_t types covers almost 80% of the analysed stock.

Within the A type there is a group of small buildings, often officially denominated as chapels, that can be considered as votive churches, originally erected by wealthy families for devotion reasons or for celebrating a deceased. Generally, those churches are not part of a town centre, but are located in the countryside.



(a) St Andrew (1938), Maheno - A type

(b) All Saints' Church (1865), Dunedin - A_t type

(c) St Matthew's Church (1874), Dunedin - B type

Figure 10: Examples of types of URM churches, based on plan and spatial configuration.

(d) Trinity Church (now Fortune Theatre) (1869), Dunedin - C type

(e) Sacred Heart Cathedral (1899), Wellington - D type

(f) St Matthew in the City (1905), Auckland - E type

Figure 11 cont.: Examples of types of URM churches, based on plan and spatial configuration.

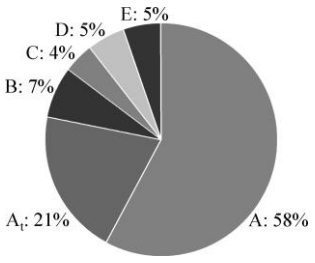


Figure 12: Recurring types of URM churches.

Architectural Features

New Zealand URM churches tend to have similar characteristics, in terms of both architectural features and construction details. This similarity occurs because most of the structures were built over a relatively short time span, and were often designed by the same architects.

Focusing on the architectural characteristics of the churches, it has already been observed that the religious heritage is mainly represented by longitudinal plan churches, with a long nave eventually crossed by a transept (technical terminology is explained in Figure 13). The body of the building is arranged in naves. The main nave is at times flanked by lower aisles, and rows of piers or columns separate them. The main nave can end with a circular or polygonal apse.

Churches were first analysed according to their overall dimensions, noting geometric irregularities in plan and elevation (e.g., whether they are isolated or attached/connected to other buildings). The foot-print area data was sorted into five value ranges: 31% have an area ranging from 50 to 200 m^2, being mostly chapels and countryside churches, and 53% have an area ranging from 201 to 500 m^2 (Figure 14).

For churches where it was possible to identify the wall thickness, the mean ratio between the peak height (h_f) of the façade and its thickness (t_f) is 23.8, with a coefficient of variation equal to 7.8 (Figure 15a). In addition to the vertical slenderness, the horizontal slenderness was computed, with the average ratio between the length (l_f) and the thickness of the façade being 24.3, whereas the coefficient of variation is equal to 8.5 (Figure 15b).

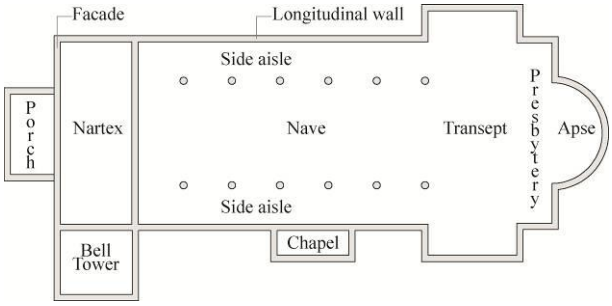


Figure 13: Schematic plan showing the common parts of a church.

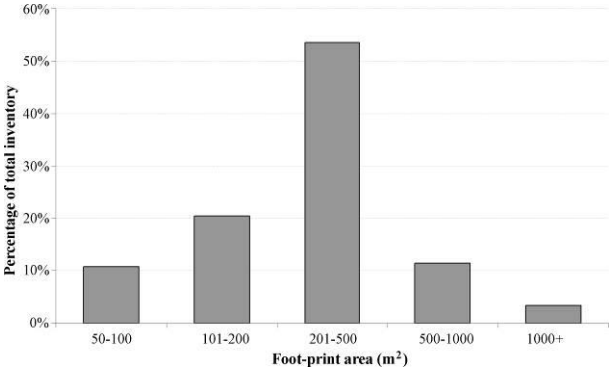
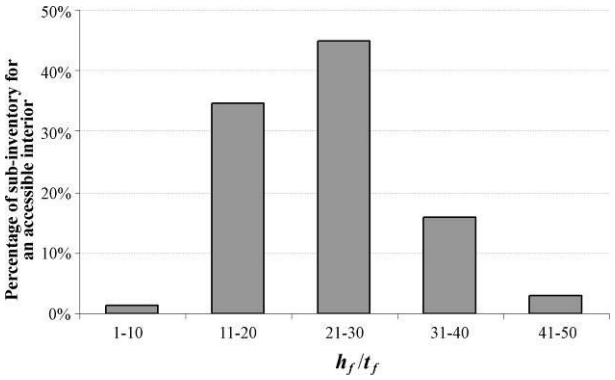
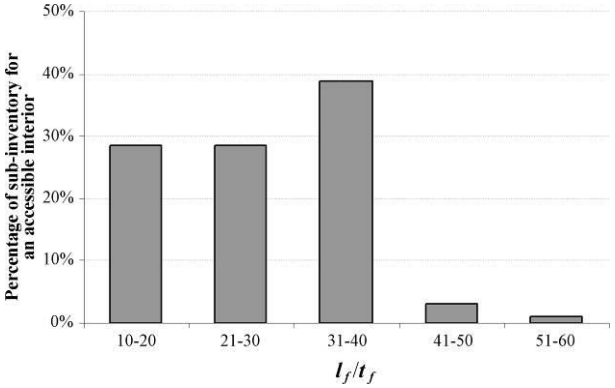


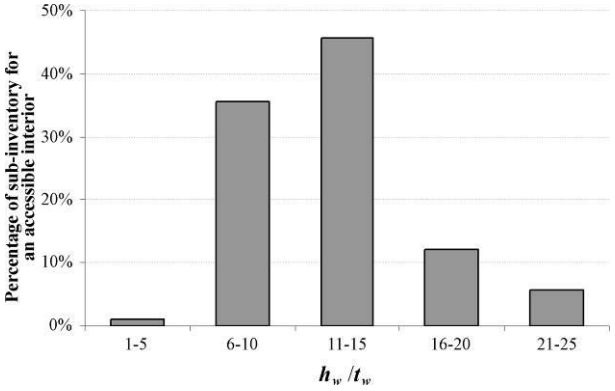
Figure 14: Approximate foot-print area.



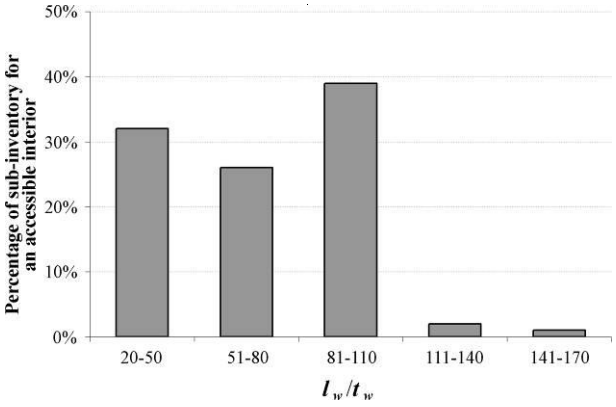
(a) Peak height/thickness ratio of the façade



(b) Length/thickness ratio of the façade



(c) Height/thickness ratio of longitudinal walls



(d) Length/thickness ratio of longitudinal walls

Figure 15: Wall geometric ratios.

(a) St Johns (1922), Auckland - Porch facing the façade

(b) St Patrick Basilica (1894), Oamaru - Nartex

(c) St Oswald's Church (1914), Westmere - Porch on a side

Figure 16: Examples of porch/nartex.

In the same way the ratio between the height (h_w) of the longitudinal walls and their thickness (t_w) was investigated (mean value and coefficient of variation equal to 12.3 and 4.3, Figure 15c), as well as the ratio between their length (l_w) and thickness (mean value and coefficient of variation equal to 58.2 and 24.3, Figure 15d).

These ratios can guide a preliminary vulnerability assessment, especially for those cases that show extreme values. Moreover, it would be interesting to compare New Zealand ratios with those from churches in other countries of both high and low seismic hazards, because existing data are limited and mostly restricted to ordinary buildings [39].

The presence of a porch/nartex (55%) is fairly widespread, being the church entrance. The porch/nartex is usually located facing the façade and opposite the church altar (37%), but sometimes is located on a side of the building, close to the corner of the façade (18%) (Figure 16).

A presbytery (refer to Figure 13) is also generally present (46%), while the apse is rarer (20%) and frequently polygonal (17%) rather than circular (3%). The apse is mainly present in three-nave churches and Basilicas.

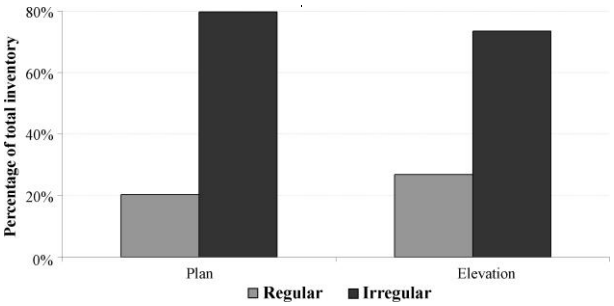


Figure 17: Regularity of URM churches, both in plan and in elevation.

(a) Holy Trinity (1898), Auckland - Extension in plan

(b) Wesley Broadway Methodist Church (1911), Palmerston North - Presence of adjacent buildings and raised element

Figure 18: Example of geometric irregularities in plan and elevation and position with respect to other buildings.

Plan and elevation symmetry and regularity were also recorded. It can be observed that nearly 20% of churches are symmetrical and regular in both plan and elevation (Figure 17). Cases of asymmetry are often due to extensions in plan that occurred during the life of the building, or the presence of adjacent buildings and/or raised structural elements (Figure 18).

(a) St Mary's (1888), Pleasant Point - Bell tower included in the façade

(b) Sacred Heart (1926), Ranfurly - Bell tower flanked to the façade

(c) St Peter's (1932), Queenstown - Bell tower along the longitudinal walls

Figure 19: Examples of bell-tower included in the façade, flanked to the façade or along the longitudinal walls.

(a) Moray Place Congregational Church (1864), Dunedin - Residential apartments.

(b) Hanover Street Baptist Church (1912), Dunedin - Bar.

Figure 20: Examples of churches whose use has been changed.

Raised elements can be domes and bell-towers, although the former is rarely present, and was found in only two churches of the inventory. Bell-towers are observed in 34% of the inventory, are always connected to the nave and can be the cause of vulnerability due to their different dynamic properties. In the majority of cases the bell-tower is flanked to the façade or along the longitudinal walls (80%), although sometimes it is included in the façade (20%) as seen in Figure 19. In 66% of cases bell-towers present buttresses and 53% have large openings up their height.

Chapels are present in 43% of the inventory, often not spread along the whole nave wall, and sometimes in an asymmetrical position with respect to the plan configuration (33%).

Sometimes the change from original use (refer to Figure 5) caused alterations to the structure and/or configuration (Figure 20). These modifications could contribute to improve or worsen the earthquake performance of the building, e.g., depending on the addition of connections or the removal of structural elements and the increase of mass.

Structural Characteristics

As shown in Figure 21, 55% of the inventory is constructed of clay-brick URM (Figure 22a) and 39% is constructed of natural-stone URM (Figure 22b). In 3% of cases, building stones were limited to facings, basement walls, and the main façade, probably because stone was more expensive than clay brick. For the remainder of the inventory the presence of plaster hampered a positive identification of the masonry type, although the date of construction indicates a traditional building technique and response to simple percussion excludes the use of timber.

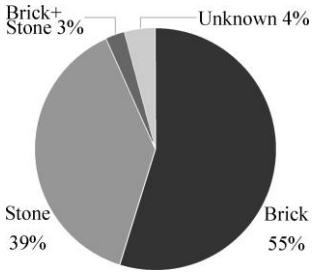


Figure 21: Masonry types of existing URM churches.

(a) St. Paul's church (1916), Auckland - Clay brick

(b) Caversham Church (1883), Dunedin - Natural stone

Figure 22: Examples of church construction materials.

The construction types were connected to local geology, with almost all stone URM buildings in New Zealand being constructed in areas where the material was available nearby from local quarries, fields and rivers (e.g., the volcanic rocks

of Auckland, New Plymouth, Christchurch, Timaru and Dunedin, the limestone in Oamaru, and the schist in central Otago) [40]. The natural-stone buildings are mostly concentrated in the South Island, in Canterbury and Otago regions (Figure 23), characterised by metamorphic rocks (such as schist, Figure 24a) and sedimentary rocks (such as limestone, Figure 24b), respectively. Igneous rocks are widely distributed throughout the country with a prevalence of basalt (Figure 24c) [41].

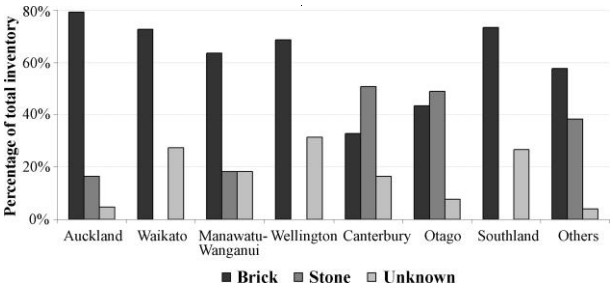


Figure 23: Masonry type distribution per region.

(a) St John's Church (1895), Middlemarch - Schist

(b) St Martin's Church (1901), Duntroon - Limestone

(c) St Paul's Church (1895), Auckland - Basalt

Figure 24: Examples of stone types in New Zealand.

St Cuthbert's Church (1860), Governors Bay

Figure 25: Example of bad masonry quality.

In the investigation of the wall cross-sections, 61% of the inventory (that was possible to survey) is made of single-material solid walls, while 39% of identifiable cases can be sorted into the following types showing:

- a cavity wall (presenting a continuous air gap separating wythes from one another), with either clay-brick (Figure 26a) or natural-stone (Figure 26b) leaves;
- a two-layer wall, with a stone external facing and one or two clay-brick leaves (Figure 26c).

Field observations have shown a rather high seismic vulnerability of non-solid walls, which are prone to failure of one or more leaves. Nonetheless, solid walls can also display inadequate performance, when the wythes are not properly connected and undressed units are used.

(a) St Joseph's Church (1921), Christchurch – Clay-brick cavity wall

(b) Trinity Congregational Church (1873), Christchurch – Natural-stone cavity wall

(c) St Peter's Church (1875), Christchurch (Photo courtesy of Joao Leite) - Two-layer wall

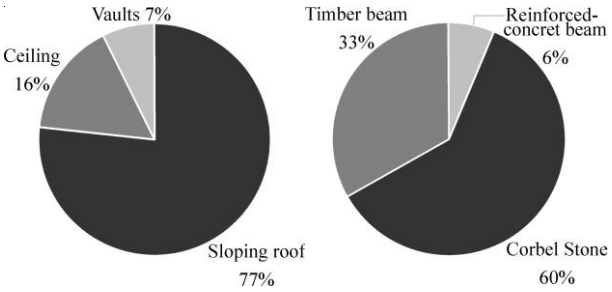
Figure 26: Examples of wall cross-sections.

Unlike other countries, in New Zealand the nave cover is rarely a URM vault. Considering only those churches where a survey of the interior was possible, stone vaults are present in 7% of the cases, being just two type B and five type E churches. A sloping roof, visible from the nave, is registered in 77% of the subset of the churches surveyed internally (Figure 27a). In the remainder of cases the roof is concealed by a ceiling.

In Britain and its colonies, trussed roofs started to be adopted in the 17th century and were developed up to the 19th century, initially hidden above the ceiling and later revealed as a visible feature of the buildings [43]. As shown in Figure 28, there are four main statical schemes of sloping roofs in New Zealand:

1. king-post trusses (28% of visible roofs), with a bottom chord in just one case and a raised tie in the remainder 24 cases (Figure 29a);
2. queen-post trusses (4%), with one metal bottom tie, one bottom chord, and two raised ties (Figure 29b);
3. an elegant elaboration of timber truss consisting of a scissors roof (23%), with or without a raised tie (19% vs. 81%) (Figure 29c);
4. a rafter roof (19%), with a timber arch below the rafters in 83% of cases, and with or without a horizontal top beam, also dubbed collar (66% vs. 34%) (Figure 29d).

Roofs without a chord at support level develop a thrust that can worsen earthquake performance of the building [44]. The remaining 9% of the visible sloping roofs are partially hidden by a ceiling that prevents an assured classification (Figure 29e). As shown in Figure 27b the roof support is a corbel stone (60%), a timber beam (33%), or a reinforced-concrete beam (7%).



(a) Nave cover (b) Type of roof support

Figure 27: Type of nave cover and roof support (related to the sub-inventory for an accessible interior).

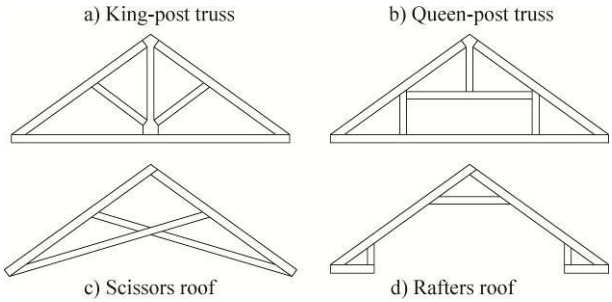


Figure 28: Statical schemes of New Zealand sloping roofs.

(a) St Gerard's Church (1908), Wellington - King-post truss

(b) St Joseph and St Joachim (1926), Auckland - Queen-post truss

(c) Sacred Heart (1918), Takaka - Scissors roof

(d) All Saints (1913), Palmerston North - Rafters roof

(e) St Andrew's Church (1914), Auckland - Roof partially hidden by ceiling

Figure 29: Examples of roof types.

The occurrence of additional structural details, such as soaring elements, large openings and heavy roof covers, which might increase the vulnerability of the building, was also investigated. Soaring elements are recurrently present in New Zealand churches and in 62% of cases a pinnacle, a parapet-belfry, or a crenellation was encountered (Figure 30). Large openings on the longitudinal walls and rose windows on the façade are respectively present in 21% and 61% of cases. A heavy roof cover (e.g., thin stones) is present in 36% of the inventory.

(a) Garin Memorial Chapel (Wakapuaka Cemetery) (1890), Nelson - Parapet-belfry (on the left side)

(b) St Joseph's (1879), Temuka - Pinnacles

Figure 30: Examples of soaring elements.

Different strengthening elements have been surveyed in the churches, with URM lateral buttresses observed in 82% of cases, whereas façade buttresses are present in 26% of the inventory. Tie rods are more rare, being used to eliminate the thrust of the roof in 24% of the surveyed cases (Figure 31a), or laid transversally and/or longitudinally in 18% of the sample (Figure 31b). Ring beams were detected in just two cases, but elsewhere they may be concealed by plaster or masonry facing.

A good state of preservation was encountered for 54% of the surveyed buildings in the inventory. However, the few churches not in use show some lack of maintenance in plaster and roof, and 27% show a limited number of small cracks or no more than two larger cracks induced by soil settlement and lack of connections (17 churches in Auckland, 10 in Dunedin, 5 in Wellington). Some churches (5%) show more relevant problems, presenting more than two large cracks, but the overall condition is still acceptable. Another 14% fall within Christchurch and have been damaged by the 2010-2011 Canterbury earthquakes.

(a) St Luke's (1908), Wellington - Tie rods in the roof

(b) St Magnus (1897), Duntroon - Tie rods connecting walls

Figure 31: Examples of presence of tie rods.

FINAL NOTES

The 2010-2011 Canterbury earthquakes have again demonstrated the unsatisfactory earthquake performance of unstrengthened URM churches, with approximately 15% of the affected buildings demolished due to the heavy damage suffered. Due to the high seismicity of New Zealand, the large concentration of people that may occur in religious buildings, and the societal relevance of these structures for historical and symbolical reasons, assessment and mitigation of the earthquake vulnerability of URM churches is of paramount importance. Despite such prominence, a comprehensive list of New Zealand URM churches was not present at the beginning of this research. Hence, a detailed inventory of URM churches throughout New Zealand was compiled, with a total of 297 buildings being located, excluding 12 buildings that were demolished after the Canterbury earthquakes. It is possible that additional churches are located across the country, along routes not explored during the 10 000 km field trip.

The analysis of the collected data led to the following considerations on the URM religious heritage buildings in existence in New Zealand:

- The buildings were constructed mainly between 1870 and 1940 and now approximately half of the entire inventory is registered with HNZ.
- The main religious denominations are: Anglican (33%), Presbyterian (23%), Catholic (20%) and Methodist (12%). Approximately ninety percent of churches are still used for their original function.
- The existing stock is concentrated in the Otago (30%), Canterbury (29%) and Auckland (14%) regions.
- A limited number of unreinforced masonry churches (13%) are located in high seismic hazard zones (*Z* hazard factor greater than 0.30).
- New Zealand churches usually have a simple layout when compared to European standards. 58% of the sampled buildings have a single nave, and in 21% of cases a transept is added to the nave. The most frequent gross foot-print area is larger than 200 m^2 and smaller than 500 m^2. Most of the buildings are not regular in plan or in elevation, due to the presence of added parts and connected bell-towers.
- In more than half of the inventory clay-brick masonry is used, while natural stone is slightly less common. Lime mortars are typically used. Masonry quality can vary significantly throughout New Zealand and it appears that the quality of construction improved over time. Cross-sections frequently show multiple leaves that are inadequately connected or even separated by cavities.
- The roof is usually sloping and has a raised tie in most cases, instead of a bottom chord. This detail can increase the vulnerability of the building due to exerted thrust. Vaults are rather seldom. In contrast, soaring elements (such as pinnacles, parapet-belfries and crenellations) are frequent.
- Buttresses are very frequent in New Zealand churches. In contrast, strengthening details such as tie rods are present in less than 20% of the cases. This absence of securing may be the result of the application of British construction practices, with a low awareness of detailing to safeguard against earthquakes.
- The state of preservation is usually good, although cracks can affect the buildings to a limited (27%) or moderate (5%) extent. The churches affected by the 2010-2011 Canterbury earthquakes, with varying degree of severity, are about 14% of the stock.

Further development of the project presented here will include in-depth analysis of the earthquake performance of the buildings affected by the 2010-2011 Canterbury earthquakes. Such analysis will address both the overall performance of the buildings and the response of their main elements (such as the façade, nave, apse, and transept). Knowledge of the behaviour of buildings with different structural features and geometric characteristics, as well as exposure to varying severity of shaking, will be helpful for the future seismic assessment of the national stock. The inventory reported in the annexes will

support the identification of buildings and provide their specific location. Moreover, it could be used for updating the HNZ Register. The overarching goal of this project was to support the conservation and protection of the religious heritage of New Zealand and the safety of people in and around these buildings.

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ANNEX 1 – UNREINFORCED MASONRY CHURCHES IN NORTHLAND

Name	Address	HNZ no.
PAIHIA		
Williams Memorial Church of St Paul	36 Marsden Rd	3824

ANNEX 2 – UNREINFORCED MASONRY CHURCHES IN AUCKLAND

Name	Address	HNZ no.
AUCKLAND		
St Patrick's Cathedral	1 St Patricks Square	97
St Andrew's First Presbyterian Church	Corner of Symonds St and Alten Rd	20
St Matthew in the City	Corner of Hobson St and Wellesley St	99
Pitt street Methodist Church	78 Pitt St	626
Congregational Church Of Jesus	3 East St	/
Baptist Tabernacle	429 Queen St	7357
St Paul's Church	28 Symonds St	650
Wesleyan Chapel	8A Pitt St	7752
St James' Church	39 Church Rd	689
Church of the Melanesian Mission Building	40-44 Tamaki Drive	111
Dominion Road Methodist Church	426 Dominion Rd	2607
St Alban the Martyr	443 Dominion Rd	511
St Barnabas	283 Mt Eden Rd	516
Holy Trinity	437 Parnell Rd	/
Holy Trinity	18 Mason Ave	2320
St Augustine's Church	95 Calliope Rd	4529
St Francis de Sales, All Souls	2A Albert Rd	/
St Paul's	Corner of Albert and Victoria Rds	/
St Benedict's Church	1 St Benedicts St	640
St Michaels Church	6 Beatrice Rd	118
Church of Our Lady of the Assumption	130 Church St	523
St Columba Church	100 Surrey Crescent	2644
King's College Chapel	41 Golf Ave	90
St Paul's Church	14 St Vincent Ave	651
St Saviour's Chapel	80 Wyllie Road	7169
All Hallows	218 Beach Road	/
Calvary Tamil Methodist Church	587 Manukau Road	/
St Vincent de Paul Church	Corner Fenwick Avenue and Shakespeare Rd,	/
St Joseph and St Joachim	118 Church St,	/
St John's	328 East Tamaki Rd	/
St Thomas	2 Islington Avenue	/
Waikumete Cemetery Chapel	Glenview Rd	2605
St David	70 Khyber Pass Rd	/
Neligan House Chapel	12 St Stephens Ave	/
St Andrews	18 Station Rd	/
New Zealand Chinese Mission Church	161 Trafalgar St	/
St Aidans	90 Onewa Rd	/
?	39 Margan Ave	/
?	40 Margan Ave	/
Selwyn Chapel	105 Great South Rd	693
First Presbyterian Church Papakura	2 Coles Crescent	/
St Johns	120 Great South Rd	/
PUKEKOHE		
St Andrew's	37 Queen Street	/

ANNEX 3 – UNREINFORCED MASONRY CHURCHES IN WAIKATO

Name	Address	HNZ no.
GORDONTON		
St Mary's Church	974 Gordonton Rd	4303
HAMILTON		
St Mary's Convent Chapel	47 Clyde St	5460
St Andrews	Cnr River Rd and Te Aroha St	/
HUNTLY		
St Paul's Church	Corner of William St and Glasgow St	4165
HYDE		
?	9071 Eton St	/
NGARUAWAHIA		
St Paul's Church	128 Thermal Explorer Highway	4246
RAGLAN		
Raglan District Union Church	3 Stewart St	/
TE AROHA		
St David's Union Church	8 Church St	4288
St Mark's Church	7 Kenrick St	4290
TE AWAMUTU		
Te Awamutu Church	261 Bank St	4295
TIRAU		
Tirau Co-Operating Church	67 Main Rd	/

ANNEX 4 – UNREINFORCED MASONRY CHURCHES IN BAY OF PLENTY

Name	Address	HNZ no.
OPOTIKI		
Former Methodist Church	?	/

ANNEX 5 – UNREINFORCED MASONRY CHURCHES IN GISBORNE

Name	Address	HNZ no.
GISBORNE		
Holy Trinity Church	79 Derby St	3526
St Andrew's Church	176 Cobden St	3525
WAIPIRO		
St Abraham's Memorial Church	12 Marae Rd	3490

ANNEX 6 – UNREINFORCED MASONRY CHURCHES IN HAWKE'S BAY

Name	Address	HNZ no.
PAKIPAKI		
Pakipaki War Memorial church	63 Old Main Rd	/
WAIPAWA		
St Peter's Church	57 Kenilworth St	4872
WAIPUKURAU		
St Mary's	11 St Mary's Rd	/

ANNEX 7 – UNREINFORCED MASONRY CHURCHES IN TARANAKI

Name	Address	HNZ no.
HAWERA		
St Mary's Church	206 Princes St	861
INGLEWOOD		
St Andrew's Church	104 Rata Rd	875
NEW PLYMOUTH		
Taranaki Cathedral (St Mary's Church)	37 Vivian St	148

ANNEX 8 – UNREINFORCED MASONRY CHURCHES IN MANAWATU-WANGANUI

Name	Address	HNZ no.
CARTERTON		
St Mary	2 King St	/
DANNEVIRKE		
St John the Baptist	174 High St	4551
LEVIN		
St John's Church	90 Cambridge St	4091
MANAKAU		
Methodist Church (Former)	1104 State Highway 1	4051
MASTERTON		
St. Luke's Union Church	Cnr Worksop Rd and Queen St	/
MOAWHANGO		
Batley Memorial Chapel	32 Wherewhere Rd	3308
PALMERSTON NORTH		
Wesley Broadway	264 Broadway Ave	
All Saints' Church	338 Church St	191
WANGANUI		
Wanganui Collegiate School Chapel	128 Liverpool St	999
WESTMERE		
St Oswald's Church	State highway 3	956
Westmere Memorial Church	110 State Highway 3	2738

ANNEX 9 – UNREINFORCED MASONRY CHURCHES IN WELLINGTON

Name	Address	HNZ no.
LOWER HUTT		
Epuni Baptist Church	304 Waiwhetu Rd	/
Methodist church	Laings Rd	/
WELLINGTON		
All Saints Church	1 Abbot St	/
St Luke's Parish	34 Pitt St	/
St Michael and All Angels	Corner St Michael's Crescent and Upland Rd	/
Karori Crematorium Chapel	Old Karori Road	1399
Congregational Church	45 Cambridge Terrace	/
Miramar Uniting Church	56 Hobart St	/
Our Lady Star of the Sea Convent Chapel	16 Fettes Crescent	1413
St Jude's	68 Freyberg St	/
St Hilda's	311 The Parade	/
Sacred Heart Cathedral	40 Hill St	214
All Saints Church	94 Hamilton Rd	1331
St Gerard's Church	75 Hawker St	226
St Anne's Church (Former)	77 Northland Rd	3603
Missions to Seamen Building (Former)	7 Stout St	3611

ANNEX 10 – UNREINFORCED MASONRY CHURCHES IN TASMAN

Name	Address	HNZ no.
MOTUEKA		
St Peter Chanel (Former)	31 High St	1671
Former church	207 High St	/
TAKAKA		
Sacred Heart	94 Commercial St	/

ANNEX 11 – UNREINFORCED MASONRY CHURCHES IN NELSON

Name	Address	HNZ no.
NELSON		
Garin Memorial Chapel (Wakapuaka Cemetery)	272 Atawhai Drive	1637
All Saints	30 Vanguard St	/
Christ Church Cathedral	Trafalgar Square	/
STOKE		
St Barnabas'	523 Main Rd	3025

ANNEX 12 – UNREINFORCED MASONRY CHURCHES IN MARLBOROUGH

Name	Address	HNZ no.
BLENHEIM		
The Church of the Nativity	76 Alfred St	/
HAVELOCK		
St Peter's Church	30 Lawrence St	1496
Sacred Heart Church	15 Lawrence St	/
PICTON		
St Joseph's	119 Wellington Rd	/
WARD		
St Peter's Chanel	7298 SH1	/
WHARANUI		
St Oswald's Church	8817 State Highway 1	/

ANNEX 13 – UNREINFORCED MASONRY CHURCHES IN WEST COAST

Name	Address	HNZ no.
HOKITIKA		
St Mary's	71 Sewell St	1705
St Andrew's United Church	66 Hampden St	5013

ANNEX 14 – UNREINFORCED MASONRY CHURCHES IN CANTERBURY

Name	Address	HNZ no.
AKAROA PENINSULA		
St Paul's Church	850 Old Tai Tapu Rd	4395
St Kentigern	396 Kaituna Valley Rd	/
Church of St John the Evangelist	1131 Okains Bay Rd	1715
St Luke	1280 Chorlton Rd	7094
St Cuthbert's Church	8 Governors Bay Teddington Rd	281
ASHBURTON		
Church of the Holy Name	58 Sealy St	284
St Andrew's Presbyterian Church	130 Havelock St	1809
St Andrew's Presbyterian Church (Former)	130 Havelock St	1804
Ashburton Baptist Church	Corner Havelock St and Cass St	/
CAVE		
St Monica	6 Anne St	/
All Saint's Cave	30 Elizabeth St	/
St David's Memorial Church	Burnetts Rd	312
CHRISTCHURCH		
St Joseph's Parish	133 Main North Rd	/
Christchurch North Methodist	61 Harewood Rd	/
Our Lady of Perpetual Help Church	58 Somme St	/
St John's Church	49 Bryndwr Rd	/
St Barnabas' Church	145 Fendalton Rd	3681
St Ninians' Church	9 Puriri St	/
St Peter's Church	24 Main South Rd	1792
St Brendan's Church	47 Kirk Rd	/
St John of God Chapel	12 Nash Rd	4393
Cashmere Hills Church	2 Macmillan Ave	1842
St Mark's Church	101 Opawa Rd	/
Opawa Community Church	158 Opawa Rd	/
Church of the All Saints	48 Wakefield Ave	/
St Mary's Parish	112 Lonsdale St	/
St Faith's	46 Hawke St	/
Synagogue	Gloucester St	/
The Rose Historic Chapel	866 Colombo St	7239
Trinity Congregational Church	124 Worcester St	306
Cathedral Church of Christ	100 Cathedral Square	46
Christ`s College Chapel	33 Rolleston Ave	3277
Nurses Memorial Chapel	2 Riccarton Ave	1851
Cathedral of the Blessed Sacrament	136 Barbadoes St	47
St James the Great Riccarton	69 Riccarton Rd	/
St John The Evangelist Church	Christchurch Akaroa Rd	5293
St Mark's Marshland	338 Prestons Rd	/
St John The Evangelist Church	10 St Johns St	/
Prebbleton Community	641 Springs Rd	/
Nazareth House Chapel	220 Brougham St	/
Knox Church	28 Bealey Ave	/
St Columba	88 Petrie St	/
St Andrew's College	347 Papanui Rd	/
Shirley Church	Shirley Rd	/
Ex-St James	?	/
DUNTROON		
St Magnus Presbyterian Church	11 Rees St	3255
St Martin's Church	3487 Kurow - Duntroon Rd	2429
FAIRLIE		
St Patrick and All Saints	7 Gall St	/
GERALDINE		
St Andrew the Apostle	10 Cox St	/
Immaculate Conception	19 Hislop St	/
Church of the Holy Innocents	Rangitata Gorge Rd	1976
HORORATA		
St John's Hororata	224 Hororata Rd	/
KAIAPOI		
Methodist Church	52 Fuller St	3760
KUROW		
St Alban Chapel	5636 Kurow-Duntroon Rd	/
St Stephen	83 Provincial Highway	2435
LAKE TEKAPO		
Church of the Good Shepherd	Pioneer Drive	311
LEESTON		
St John's The Evangelist	158 High St	/
MAKIKIHI		
St. Mary's Star of the Sea	1686 Waimate	/

Name	Address	HNZ no.
	Highway	
MAUNGATI		
St James' Maungati	143 Timaunga Rd	/
OTIPUA		
St Marks	High St	/
PLEASANT POINT		
St Mary's Church	29 Afghan St	7697
St Alban's Pleasant Point	20 Harris St	/
SAINT ANDREWS		
St Andrews	8 Thackeray St	/
SEFTON		
St Luke's	Upper Sefton Rd	/
SHEFFIELD		
St Ambrose Sheffield	46 Railway Tce East	/
SOUTHBRIDGE		
St James'	2 Hastings St	/
SOUTHBURN		
Southburn Church	994 Pareora River Rd	/
TEMUKA		
St Peter's Temuka	192 King St	/
St Josephs Catholic Church	28 Wilkin St	2033
Holy Trinity Arowhenua	3 Huirapa St	/
TIMARU		
St Paul	28 Seddon St	/
St Joseph's Church	42 Douglas St	/
Woodlands Road Methodist Church	Corner Woodlands Rd and North St	/
Bank Street Methodist Church	38 Bank St	3155
St Mary's Church	24 Church St	328
Chalmers Church	4 Elizabeth St	7107
TOTARA VALLEY		
St Paul's Presbyterian Church (Former)	856 Cleland Rd	1995
WAIAU		
All Saints' Church	35 Parnassus St	3690
WAIHAO DOWNS		
St Michael's Church	1115 State Highway 82	/
WAIMATE		
St Pauls Waimate	11 Glasgow St	/
Knox Church	58 Shearman St	/
St Patrick's Church	2 Timaru Rd	7343
WAIPARA		
St Paul's Church	173 Church Rd	7111
WOODBURY		
St Thomas' Church	6 Church St	/
WOODEND		
Methodist Church	86 Main North Rd	3795

ANNEX 15 – UNREINFORCED MASONRY CHURCHES IN OTAGO

Name	Address	HNZ no.
ALEXANDRA		
St Enoch's church	12 Centennial Ave	/
St Aidan's	42 Shannon St	/
ARROWTOWN		
St John's Church	26 Berkshire St	2119
St Patrick's	7 Hertford St	2117
AWAMOKO		
Awamoko Presbyterian Church	1783 Georgetown - Pukeuri Rd	/
BANNOCKBURN		
Bannockburn Presbyterian Church	33 Hall Rd	2385
CLYDE		
St Michael and All Angels Church	8 Matau St	2386
St Dunstan's Church	61 Sunderland St	2387
St Magnus'	60 Sunderland St	/
CROMWELL		
Goldfields Old Church	52 Erris St	/
Mary Immaculate and the Irish Martyrs	3 Sligo St	/
St John's Presbyterian Church	24 Inniscort St	2131
St Andrew's Anglican Church	41 Blyth St	2132
DUNEDIN		
St Davids Church	227 North Rd	4734
Glenaven Church	7 Chambers St	3371
Catholic Church of the Sacred Heart of Jesus	89 North Rd	2214
Opoho Presbyterian Church	50 Signal Hill Rd	/
Dundas Street Methodist Church (Former)	50 Dundas St	3367
All Saints' Church	786 Cumberland St	2136
Knox Church	463 George St	4372
Hanover Street Baptist Church	65 Hanover St	4792
St Paul's Cathedral and Belfry	36 The Octagon	376
Trinity Church (now Fortune Theatre)	231 Stuart St	3378
Moray Place Congregational Church (Former)	81 Moray Place	2218
Synagogue	29 Moray Place	9606
Cathedral Church of St Joseph	288 Rattray St	364
First Church of Otago	410 Moray Place	60
St Matthew's Church	28 Hope St	2212
St Andrew	64 Melville St	3185
Highgate Presbyterian Church	580 Highgate	/
Kaikorai Presbyterian Church	127 Taieri Rd	/
Roslyn Presbyterian Church	21 Highgate	3377
Caversham Baptist Church	10 Surrey St	/
Caversham Church	61 Thorn St	7319
St Peters Caversham	57 Baker St	9545
Wesley Church	333 Hillside Rd	/
St Patrick's Basilica	32 Macandrew Rd	2213
St James (South Presbyterian)	400 King Edward St	/
Holy Cross	12 Richardson St	/
St Kilda Tongan Fellowship	56 Queens Drive	/
Andersons Bay Presbyterian Church Deacons	76 Silverton St	/
North East Valley Baptist Church	270 North Rd	/
Halfway Bush Union Church	28 Balmain St	/
St Clair	51 Albert St	/
ENFIELD		
Enfield Presbyterian Church	805 Weston-Ngapara Rd	2417

Name	Address	HNZ no.
ESK VALLEY		
St Mary's Church	Church Hill Road	319
HAMPDEN		
Presbyterian Church	2 London St	3249
HERBERT		
St John's Presbyterian Church	1 Ord St	2416
HERIOT		
Heriot Community Church	17 Roxburgh St	/
HYDE		
Catholic Church of the Sacred Heart of Jesus	9137 Eton St	2253
KOKONGA		
?	Kyeburn-Hyde Rd	/
KUROW		
Sacred Heart Roman Catholic church	5634 Kurow-Duntroon Rd	/
LAWRENCE		
Lawrence Presbyterian Church (Former)	7 Colonsay St	2243
St Patrick	12 Colonsay St	2243
Holy Trinity Anglican Church	9 Whitehaven St	2245
Lawrence Methodist Church	Corner of Whitehaven St and Colonsay St	/
LOVELLS FLAT		
?	Station Rd	/
MACRAES FLAT		
St Patrick's Catholic Church (Former)	7 Hyde St	2397
?	1726 Macraes Rd	/
MAHENO		
St Andrew’s	4 Short St	/
MIDDLEMARCH		
St John's Church	4 Aberafon St	/
MILTON		
St John	167 Union St	/
Tokomairiro Church	30 Union St	2250
Immaculate Conception	24 Dryden St	/
MOSGIEL		
East Taieri Presbyterian Church	12A Cemetery Rd	2260
Gospel Hall	75 Gordon Rd	/
Mosgiel Presbyterian Church	11 Church St	/
NASEBY		
St George	46 Derwent St	/
NORTH TAIERI		
North Taieri Presbyterian Church	39 Wairongoa Rd	3234
OAMARU		
Rosary Chapel	70 Reed St	2301
St Patricks Basilica	64 Reed St	58
Reformed Church (Church of Christ)	6 Eden St	/
St Paul's Church	3 Coquet St	2300
St Luke's Anglican Church	2 Tees St	4365
Columba Presbyterian Church	33 Wansbeck St	7313
Wesley Church	22 Eden St	/
PALMERSTON		
St James' Church	80 Tiverton St	3247
St Mary's Church	8 Stromness St	2396
Blessed Sacrament	44 Ronaldsay St	/
PORT CHALMERS		
St Mary's Star of the Sea Church	34 Magnetic St	2328
Holy Trinity Church	1 Scotia St	2320
Iona Church	24 Mount St	7165
QUEENSTOWN		
St Peter's Church	6 Church St	2341
St Joseph's Church	41 Melbourne St	2340
RANFURLY		
Sacred Heart	4 Stuart Rd	/
ROXBURGH		
Teviot Union Parish Church	75 Scotland St	/
St James' Church	12 Ferry Rd	2345
Our Lady of Peace	5 Liddle St	/
SAINT BATHANS		
St Patrick's Church	Cross St	3210

ANNEX 16 – UNREINFORCED MASONRY CHURCHES IN SOUTHLAND

Name	Address	HNZ no.
CENTRE BUSH		
St Andrew's Presbyterian Church (Former)	1785 Dipton-Winton Highway	7427
GORE		
Holy Trinity	15 Traford Street	/
?	4 Irk St	/
INVERCARGILL		
First Church	151 Tay St	387
St John's Anglican Church Complex	108 Tay St	391
Central Methodist Church	82 Jed St	2449
St Paul's Church	178 Dee St	2517
Windsor Community Church	19 Windsor St	/
All Saints Anglican Church and Parish Hall	509 Dee St	2440
St Stephen's Church	284 North Rd	2518
Sacred Heart	449 North Rd	/
St Patrick’s	33 Rimu St	/
St Mary’s	54 Eye St	/
MATAURA		
St Savious	127 Main Rd	/
Mataura Presbyterian	?	/
WYNDHAM		
St Kevin’s	45 Inkermann St	/