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International Journal of Architectural Heritage
Conservation, Analysis, and Restoration

ISSN: 1558-3058 (Print) 1558-3066 (Online) Journal homepage: http://www.tandfonline.com/loi/uarc20

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To cite this article: Stacy Vallis, Francisco Gálvez, Moustafa Swidan, Caroline Orchiston & Jason Ingham (2018): Classical Temples and Industrial Stores: Survey Analysis of Historic Unreinforced Masonry (URM) Precincts to Inform Urban Seismic Risk Mitigation, International Journal of Architectural Heritage, DOI: 10.1080/15583058.2018.1503372

To link to this article: https://doi.org/10.1080/15583058.2018.1503372

Published online: 15 Aug 2018.

INTERNATIONAL JOURNAL OF ARCHITECTURAL HERITAGE
https://doi.org/10.1080/15583058.2018.1503372

Classical Temples and Industrial Stores: Survey Analysis of Historic Unreinforced Masonry (URM) Precincts to Inform Urban Seismic Risk Mitigation

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ABSTRACT

Oamaru, Winton, and Invercargill feature some of New Zealand's most intact heritage precincts that are confronted by ongoing threats of seismic activity. The 2010/2011 Canterbury earthquake sequence and Canterbury Earthquakes Royal Commission of 2012, identified a nationwide trend through the proportion of deaths that occurred in public places as a result of the prevalent historic unreinforced masonry (URM) building stock. The reported study was undertaken to address urban safety and seismic risk mitigation through the lens of heritage conservation. The range of classically designed public buildings and industrial warehouses in the South Island of New Zealand were often produced by singular architectural practices, using locally sourced materials and construction techniques. It is vital to incorporate an examination of unique architectural qualities within urban seismic risk assessment and mitigation. Historic urban layout, architectural deployment of masonry, and extent of retrofits were recorded through onsite visual surveys via Geographical Information Systems and three-dimensional representation technologies. Extending the scope of information collected for engineering seismic risk assessment by focusing on the historical architectural context informs the selection of future mitigation measures. Oamaru, Winton, and Invercargill present intriguing case studies for multidisciplinary analysis, prior to testing urban-scale survey approaches within comparable historic centers across New Zealand.

ARTICLE HISTORY
Received 27 November 2017
Accepted 15 March 2018

KEYWORDS
Architectural conservation; Alpine Fault; Invercargill; New Zealand; Oamaru; photogrammetry; precinct; seismic risk mitigation; unreinforced masonry; Winton

Introduction

The case study precincts comprising of the Oamaru Historic Area, the Winton Historic Area, and Invercargill's Historic Areas are situated within the Otago and Southland regions of New Zealand (Figure 1a) and present a rich and varied sample of New Zealand's historic unreinforced masonry (URM) building stock. Local patterns of socio-historic development are reflected by the respective architectural identities of these regions and present specific challenges for the retention of their URM buildings. The three chosen historic area precincts face seismic hazard posed by the Alpine Fault (Figure 1b and c). The reported study focused on specific architectural and urban characteristics by using a range of data-collection and data-management technologies. Furthermore, this study was undertaken following two major New Zealand earthquake sequences. First, the Canterbury earthquake sequence of 2010/2011 (M_w 7.1 Darfield earthquake and M_w 6.3 Christchurch earthquake) highlighted the risk posed by the common, historic URM building typology to both building occupants and nearby pedestrians (Moon et al. 2014). More recently, the M_w 7.8 Kaikōura earthquake that occurred in November 2016 served as a successor to a series of strong earthquakes dating back to the mid-19th century that have been experienced by the upper South Island (Dizhur, Giaretton, and Ingham 2017).

Local and national seismic risk management and the associated need for seismic retrofitting schemes to be implemented within earthquake vulnerable buildings has recently been redefined in New Zealand. The "Building (Earthquake-prone Buildings) Amendment Act 2016" (hereafter referred to as the "Building Act") came into effect on 1st July 2017, bringing with it various changes to national and local policies governing the risk management of all earthquake-prone buildings (Ministry of Business Innovation and Employment 2017). Of especial relevance to this study are the designations of low-, medium-, and high-risk seismic zones across New Zealand (Figure 1d), along with prioritisation of local buildings depending on the results of upcoming and ongoing seismic assessment. Furthermore, the implementation of specific timeframes for the seismic assessment

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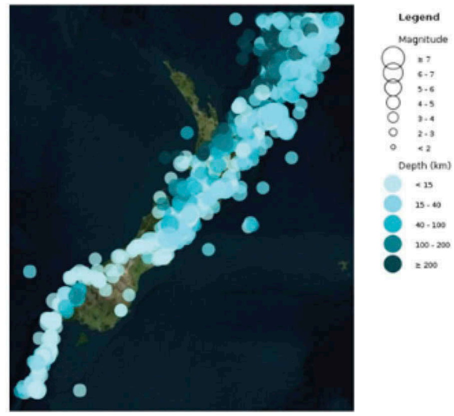
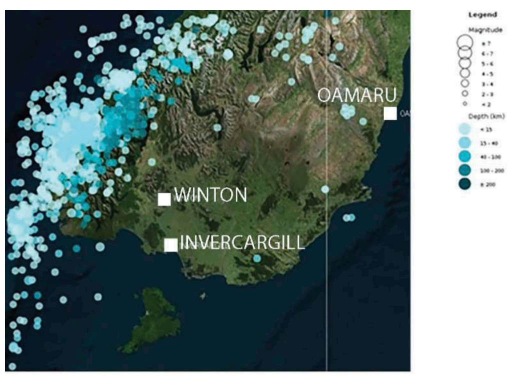
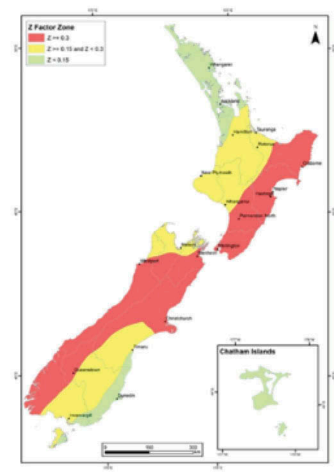
(a) Locations of Otago and Southland regions in relation to New Zealand's Alpine Fault



(b) New Zealand earthquakes greater than magnitude 4, 1987-2017



(c) Seismicity of lower South Island and proximity to case study historic areas in Oamaru, Winton, and Invercargill



(d) Seismic risk areas in New Zealand MBIE (2016)

Figure 1. New Zealand seismicity (Data extracted from quakesearch.geonet.co.nz).

and strengthening works to take place has widespread ramifications for building owners and occupiers, territorial authorities, and designers such as engineers and architects. Variation of geographic and seismic risk zones results in differing policies for heritage impact management across New Zealand, and this variation is evident across the case study historic precincts of Oamaru, Invercargill and Winton. The path to completion of seismic strengthening involves using updated methodologies of vulnerability assessment and the identification of earthquake-prone buildings by local councils and engineers. Consideration and selection of retrofitting solutions by building owners and engineers or architects, for example, will be undertaken with respect to the territorial authority regulations or recommendations based on local or national listing as a designated "historic area".

Comparison of the architectural composition of the Oamaru, Winton, and Invercargill precincts, in conjunction with the relevant heritage management, urban planning, and seismic risk management controls, offered insight into the primary factors that underpin the design, selection, and implementation of future mitigation solutions. Post-site survey analysis revealed variation in the prevalent historic architectural and urban planning trends. Therefore, the precincts of Oamaru, Winton, and Invercargill offered valuable lessons in identifying the benefits and challenges of urban-scale surveys of historic areas, along with opportunities for the development of a research framework for future undertakings.

The subject of urban-scale seismic risk assessment and retrofit of historical centers has received attention across the international research context in recent years. Broadscope literature review revealed the predominance of two overarching themes/applications of this approach, including heritage-led urban revitalisation and urban/provincial natural hazard risk management. Heritage conservation through structural upgrading may form one part of a wider overall economic revitalisation scheme for historic centers, as demonstrated by a range of international initiatives such as Main Street Approach (North America) (Smith and Washington, D.C. 2000), Regeneration through Heritage (United Kingdom) (Taggart, Thorpe, and Wilson 2006), Main Street and Precinct Enhancement (Australia) (Vines 1996), and UNESCO's Historic Urban Landscape (HUL) through the city of Liverpool (Rodwell 2008). An initial step toward achieving heritage-led urban revitalization may lie in undertaking the specific task of urban-scale heritage and seismic assessment. Urban-scale seismic assessment has been traversed within the European research context and encompasses data-collection methodologies for individual buildings and town centers, with the objective of generating heritage conservation guidelines for such centers (Giuffrè 1994; Binda et al. 1999; Binda 2004; Carocci 2001, 2012). Specific focus on assessing aggregates or interconnected clusters of masonry buildings has been explored by considering the conservation state and wall morphology conditions of shared masonry walls, compiled as datasets as reference for future conservation works (Ramos and Lourenço 2004; Vicente et al. 2010; Formisano et al. 2010; Da Porto et al. 2013). The reported study called for similar datasets featuring both individual building characteristics within whole urban blocks and was therefore undertaken using a range of survey methodologies. One approach was the use of Unmanned Aerial Vehicle (UAV)/drone technology, in addition to walking building inspection, discussed below.

Research methodology

The research methodology used for this study consisted of three stages of pre-site research, onsite visual surveys, and post-site data processing. These phases culminated in a qualitative comparative analysis of the selected Historic Area precincts, aided by the use of various survey methodologies for large-scale data collection, from the perspective of heritage conservation via seismic risk mitigation. Therefore, the study highlights both relevant heritage, urban planning, and seismic risk management controls, and relevant architectural and urban characteristics that constitute the historic precincts, via onsite documentation. A key objective was to compare these factors across all three precincts, in order to understand the context of present and future decision-making for seismic risk mitigation. It is noted that detailed examination of specific retrofitting solutions constitutes the next phase of the wider project, but lies outside the scope of the reported study.

Historic architectural significance of Southland and Otago

A literature review was undertaken to understand the socio-historical context of the chosen historic precincts prior to conducting onsite visual surveys using various data-collection technologies. Existing literature in the form of academic surveys of New Zealand architecture, heritage assessment reports or district plans published by local and national authorities, and engineering research reveal recurring themes shared by the three selected URM precincts. Therefore, existing literature assisted in the identification of significant architectural and urban characteristics embodied by each precinct along with insight into the historical development of the Otago and Southland regions, and highlighted inconsistencies or gaps in the knowledge pertaining to the existing building stock that required verification via onsite survey.

Studies of local architectural history, such as the account provided by historian John Stacpoole, suggest that New Zealand's "*street facades of the decades at the turn of the century are living museums of European culture, exuberant and eclectic, casting aside any earlier notions of simplicity to create strident effects of instant sophistication. Colonial functionalism, spiritually unsatisfactory in a remote country, was no longer felt to be sufficient*" (Stacpoole 1972). Peter Shaw supports this view, by pointing out that the turn of the century saw a solid consolidation and employment of European-derived architectural styles within New Zealand's colonial context (Shaw 2003). Governments, banks and commercial organizations substantially invested in producing impressive architectural monuments reflecting recovery from a long depression dating from 1879 (Shaw 2003) (Figure 2a,b,c). Adaptations of international architectural influences were determined by economic situation, more so than by local climate or geography (Stacpoole 1972). Nevertheless, the historic source and supply of various durable building stones such as Canterbury Halswell stone, Dunedin bluestone, Port Chalmers breccia, Central Otago schist, and the characteristic Oamaru limestone has been traced, whereas discussion of material properties lies outside the scope of the study (Porter 1983).

A review of national and local government heritage assessment reports revealed insights into the designation and potential seismic risk management of the three case study precincts (Figure 3a, b, c). The Oamaru Historic

(a) Intersection of Harbour and Tyne Streets, Oamaru (Burton Brothers studio; 1880s, Te Papa)

(b) Winton, Great North Road circa 1905 (Muir & Moodie studio. Te Papa)

(c) Tay Street, Invercargill (William Ross, active 1864-1902. Alexander Turnbull Library)

Figure 2. Oamaru, Winton, and Invercargill streetscapes.

Area (Heritage New Zealand List Number 7064) and the Winton Great North Road Historic Area (Heritage New Zealand List Number 7527) feature precincts recognized by the national heritage conservation organisation, Heritage New Zealand (Heritage New Zealand Pouhere Taonga 2017) (Figure 3a, b). In contrast, Invercargill is characterized by small groups of multiple buildings that are designated as "historic areas" by the local territorial authority, Invercargill City Council (Figure 3c) (Origin Consultants 2016). A nationally defined 'historic area' such as those in Oamaru or Winton includes "groups of related historic places such as a geographical area with a number of properties or sites, a heritage precinct or a historical and cultural area" (Heritage New Zealand Pouhere Taonga 2017) whereas Invercargill City Council does not offer a specific definition of its "historic areas", although the assessment criteria for designation are based on those advocated within the Heritage New Zealand Pouwhere Taonga Act 2014 (New Zealand Government 2014). All three precincts host individual buildings that are listed as heritage items on the national Heritage New Zealand List and/or on the local territorial authority heritage inventories. If listed with Heritage New Zealand, properties may be classified as "Category 1" ("historic places are of special or outstanding historical or cultural significance or value") or "Category 2" ("historic places are of historical or cultural significance or value") (New Zealand Government 2014).

The aforementioned heritage assessment reports and territorial authority District Plan documents also collectively reveal specific heritage and urban planning controls, which have an impact on the implementation of seismic risk mitigation. Modifications to historic URM building fabric, and the result of these alterations on the historic streetscapes, may in part be determined by the scope of permitted change. The degree and type of permitted change derives from local or national heritage listings and the density of listed historic structures along a given streetscape (Figure 3a,b,c), as highlighted within the Waitaki District Plan rules and Oamaru Central Area Design Guidelines, for example Waitaki District Council (2016). No statutory protection against changes or even demolition is offered to buildings unless they are listed in local authority District Plan heritage inventories (New Zealand Government 1991). Local listings generally reflect Heritage New Zealand recognition. However, the application of such policies to the specific heritage conservation objective of seismic strengthening lies outside the scope of the documents. For these reasons, the spatial composition of the designated historic areas warranted closer onsite examination, in order to better understand possible impacts of structural intervention to townscape heritage value.

It is interesting to consider the ever-evolving management policies across the selected precincts. Two

(a) The 'Oamaru Historic Area'

(b) Winton Great North Road Historic Area' (shaded)

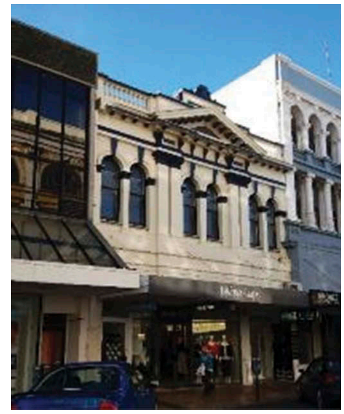
(c) Existing 'Invercargill Historic Areas' (shaded)

Figure 3. Distribution of heritage listed properties (thin blue outlines) and building story number within selected case study precincts: Oamaru Historic Area, Winton Great North Road Historic Area, and Invercargill Historic Areas (thick blue outlines). Produced using maptitude mapping software.

examples include the Oamaru Historic Area and Invercargill Historic Areas. The former recently underwent expansion from the Oamaru Whitestone Civic Trust's Victorian Precinct, which originally consisted of only sixteen Trust-owned historic buildings, to now encompassing the arterial Thames Street route for its assortment of significant buildings, interspersed with some newer structures (Bauchop 2016) (Figures 3a and 4a). The Invercargill City Council has proposed the expansion of Invercargill's historic areas from the Tay and Dee Street Historic Areas to include small clusters of buildings along Esk and Kelvin Streets (Figure 3c). Such changes reflect a shift in attitude toward the different types of structures comprising such precincts. Appreciation or protection of the more modest commercial buildings that line New Zealand's provincial and urban centers is becoming increasingly important, in addition to other grandiose and closely spaced historic structures.

Reviewing heritage assessment reports highlighted varying scales of the aforementioned precincts. The Oamaru Historic Area covers the Central Business District across approximately six urban blocks, in contrast to the Winton Great North Road Historic Area, which stretches only across four blocks (Figure 3a,b). However, the Invercargill Historic Areas consist of various building groups dispersed along the main Tay and Dee Streets (Figure 3c). The concentration of listed historic structures also offers clues to distinct patterns of historic urban development, warranting further research. While the Oamaru Historic Area features a dense concentration of nationally listed structures evident on both sides of the Thames, Harbour, and Tyne streetscapes, Winton's Great North Road Historic Area

(a) Oamaru



(b) Invercargill

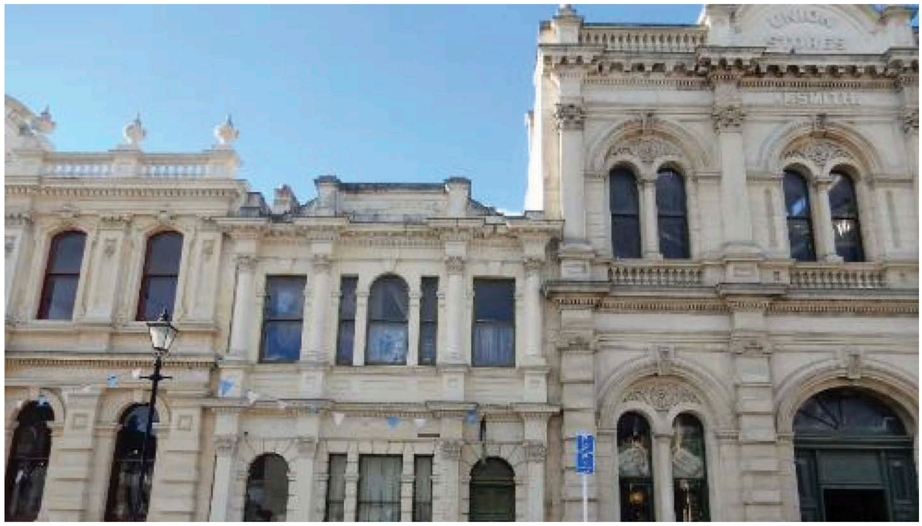
Figure 4. Interspersed historic and new building stock.

is confined to one side of the Great North Road thoroughfare (Figure 3a, b). As such, the highly gridded urban plan of Invercargill contrasts with the more organic patterns of development along the arterial Thames Street (Oamaru) and Great North Road (Winton) thoroughfares which also contributes to the dense clustering of the latter two precincts and the consequential structural behavior during an earthquake (Figure 3a,b,c).

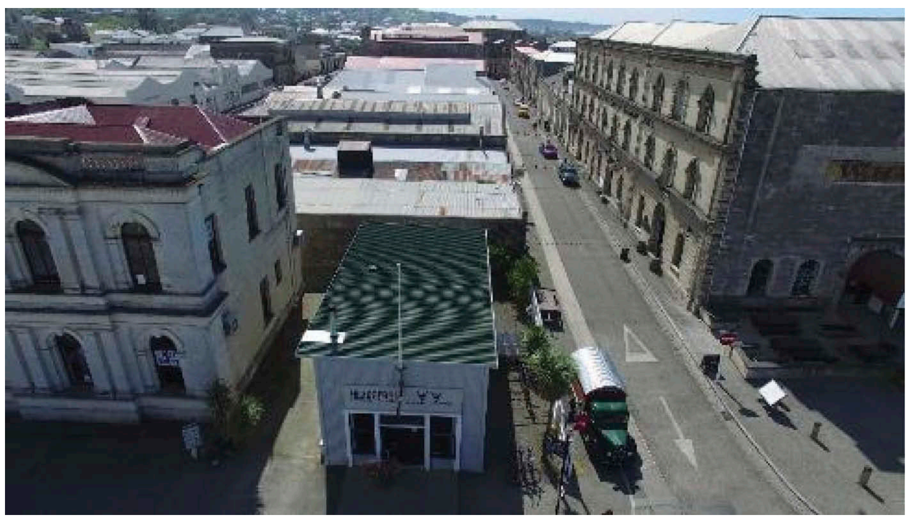
Specific thematic identification of cultural heritage value of the Oamaru, Winton, and Invercargill townships was identified within heritage assessment reports produced by territorial authorities and Heritage New Zealand. Categories of historic significance, architectural design, technology, and representativeness comprise the key themes for analysis and the design and implementation of seismic retrofitting solutions (Heritage New Zealand 2007a). Significance is generally attributed to agricultural or farming origins and is reflected by the respective historic URM building stocks. Strategic geographic locations, geological endowments of workable building materials, and the associated patterns of community development resulted in distinctive architectural identities (Figure 5). For example, the location of Winton is approximately 32 km north of Invercargill, resulting in its development as the largest service town in Central Southland due to servicing of the sawmilling supply route (Heritage New Zealand 2003). Conversely, Oamaru's distinct architectural assemblage is due to its locally sourced limestone, proficient designers, and agricultural prosperity (Heritage New Zealand 2017).

Another factor contributing to historic significance is the prevalence of a few historic architectural firms, responsible for designing significant portions of the associated townships. The Oamaru Historic Area's assortment of substantial masonry commercial, agricultural, and industrial structures designed in the Victorian Classicism style can claim an architectural lineage to the partnership of Forrester & Lemon, later adopted by Forrester's son to form the practice of Forrester & Steenson (Bauchop 2016). Further architectural significance can be found in the adaptation of this style to the colonial context, displayed via the smaller scale and reduced detailing, as compared with European counterparts. Paralleling the burgeoning Oamaru township, the development of Invercargill also took place over the 1870s and 1880s, with the firm of F.W. Burwell (1846–1915) responsible for the prominent design within Dee Street and the Crescent, featuring two-/three-story high Renaissance buildings (Origin Consultants 2016) (Figure 6). Moreover, it is significant that Burwell, along with Invercargill's three primary architectural firms, are represented within the Winton Street Historic Area, including E.R. Wilson (1871–1941), C.J. Broderick (1867–1946), and E.H. Smith (Heritage New Zealand 2003). One may argue that despite the often small scale or sometimes humble restrained architectural design, the significance of the three URM historic areas is derived from the collective value as a cohesive group, designed by a single firm.

On the subject of representativeness, the streetscapes of Winton and Oamaru (Figure 3a,b) illustrate a nationwide trend as both towns saw an architectural transition from timber to masonry during the early years of the 20th century, partly due to the threat posed by fire and the wealth acquired from farming and other industrial activity. Nevertheless, it is in the diversity of stone versus brick masonry deployment that significant qualities lie for consideration and retention during the risk mitigation decision-making process. The visual cohesion and sense of grandiosity



(a) Ornamental street frontages with irregularity of floor level



(b) Variation in building scale and use of Oamaru limestone, Harbour Street Warehouse buildings

Figure 5. Publicly showcasing the architectural manifestation of Oamaru's prosperity and development.

achieved by the gleaming Oamaru limestone within the central township is without parallel in New Zealand (Figure 5). However, historic legislation also posed specific influences on architectural design such as building form and internal spatial layout. A prime example is the 1881 Licensing Act and associated community concerns. For example, the Licensing Act required hotel buildings to have six rooms for accommodation, billiards/family rooms, various means of fire egress, conveniences, and stabling (Heritage New Zealand 2003). As such, Winton displayed an infrastructure typical of other staging post towns and included buildings such as the Railway Hotel (opened 1861) (Figure 7) along with the Commercial Hotel (opened 1870) and the Winton Hotel (opened 1876), all still in operation, though in different buildings (Heritage New Zealand 2003).

Complementing the heritage assessments, the significance of the respective historic construction technologies has been recently examined within the scientific and engineering research contexts. Giaretton et al. (2015) extracted structural mortar and natural stone samples from New Zealand's extant 670 stone URM buildings. The relationship between factors such as extraction site location, crystal grain size and mineral composition, and the resultant compressive strength, was examined in order to determine the likely behavior and performance during earthquakes (Giaretton et al. 2015). Oamaru's quarried limestone buildings can be dated to a period of nearly 100 years between

Figure 6. The Crescent, Invercargill, New Zealand, by Muir & Moodie studio. Te Papa (C.015188).

Figure 7. Photogrammetric Elevations of Great North Rd. Winton illustrating the Railway Hotel (now a tavern).

1860–1950, and as such these buildings illustrate the material's versatility as executed across a range of architectural styles and eras (Figure 8). The surviving building stock offers evidence of historical stone construction technologies, in addition to the use of modern heritage conservation practices or the integration of

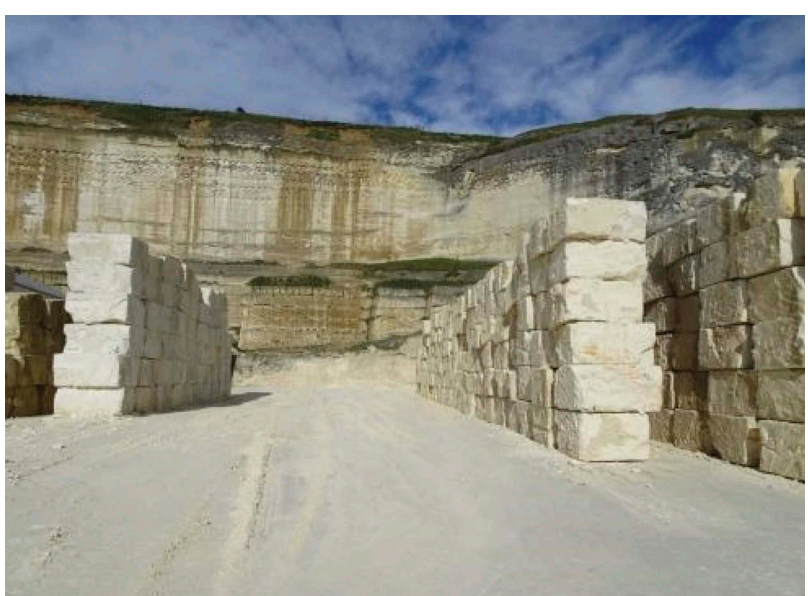


Figure 8. 2017 view of Oamaru's Parkside Quarries Limited.

structural upgrading systems. Despite the fact that most towns such as Winton or Invercargill would have their own brickworks from the late 1860s onward, there appears to be a scarcity of literature exploring the exact source or supply of these bricks (Porter 1983).

Recurring themes that are evident across the three selected case study precincts of Oamaru, Winton, and Invercargill derive from the historical adaptation of popular European architectural styles to the Antipodean context. This colonial design philosophy manifested itself in historical construction characteristics such as densely concentrated urban blocks, common motifs/types of Victorian Classical architectural ornamentation, and predominant two-/three-story building scale that may result in specific seismic behaviors during an earthquake. Across all three precincts such characteristics are recognized by local and national authorities, with this recognition being reflective of their significance in embodying the development of a New Zealand architectural identity from early colonial origins. Despite the fact that architectural studies have been previously undertaken to varying degrees, the threat posed by a possible Alpine Fault rupture suggested the need for renewed examination, specifically from the perspective of heritage conservation via seismic risk mitigation. A key aim of the reported literature review was to highlight the overall historic significance of these regions, in conjunction with specific factors or spread peculiarities potentially contributing to seismic vulnerability and the eventual adoption of mitigation measures.

Case study surveys

The Alpine Fault extends for more than 500 km from the Puysegur Trench, located within the south-western corner of the South Island until it branches into a group of faults north of Arthur's Pass (Zachariasen et al. 2006) (Figure 1). The Alpine Fault is a source of major earthquakes of moment magnitude larger than eight and recurring intervals ranging between 100–280 years (Wells et al. 1999), with the most recent earthquake having occurred in 1717. Today, a major earthquake occurring along the Alpine Fault is a plausible scenario. Attention is also being paid to the Waitaki Fault system that includes the Waitaki, Waitangi, Dryburgh, Clarkesfield, Stonewall, and Fern Gully faults, for example, that have active traces and present the possibility of generating seismic activity as close as 20 km from Oamaru (Forsyth 2001). The three townships of Oamaru, Winton, and Invercargill face the risk of seismic activity as a result of their geographical location with respect to the Alpine Fault (Figure 1a). Urban-scale seismic assessment of historical centers ideally requires detailed datasets to address combined interests in building damage, debris, and cordoning, along with the impact on building occupants and longer-term effects on trade and tourism (Boştenaru, Armas, and Goretti 2014). In an effort to obtain such information, the aforementioned townships were recorded via drone and geocoded photography, prior to producing three dimensional representations for post-site analysis.

Unmanned aerial vehicle (UAV) operation preparation

Emerging data collection technologies such as the use of Unmanned Aerial Vehicles (UAV) assist surveyors in gathering data within a short period of time (Saganeiti et al. 2017; Saffarzadeh et al. 2017). The reported study featured the use of a drone DJI Phantom 3 with a stabilized 4 K camera for recording the historical centers of Oamaru and Winton. UAV flights are often subjected to various restrictions such as to avoid air traffic zones (Figure 9) (Guillot 2016). Consequently, the Invercargill Historic Areas were not documented via drone due to proximity to Invercargill Airport and requirements imposed by civil aviation authorities. In addition, land owners permissions are needed to operate within private properties and some public spaces (CAA 2017). The Oamaru Historic Area also imposed a limitation to the height of flights which is reflected in the missing information from the top of the buildings and behind the front elevations. Additionally, cars, people, or vegetation are natural barriers that represent obstacles which will result in missing information. Hence, the restrictions to the aerial space where the UAV can operate result in limitations to the scope of collected information (Figure 9).

Prior to the UAV operation, the flightpath was strategically planned to cover all angles around the buildings for successful image processing, and to account for other related restrictions affecting flying time. These limitations include battery life that may be insufficient to cover large-scale areas within a single operation. Pre-programming the flightpath using the autopilot option guarantees a successful flight if the proposed site is sufficiently known in advance, but unfortunately a lack of knowledge of possible obstacles along the intended flight path meant that it was necessary to manually control the UAV for the selected case study precincts. Wind speed poses another factor for consideration when conducting drone flights. Nevertheless, the dataset captured by the UAV was used to build photogrammetric models of the building stock and

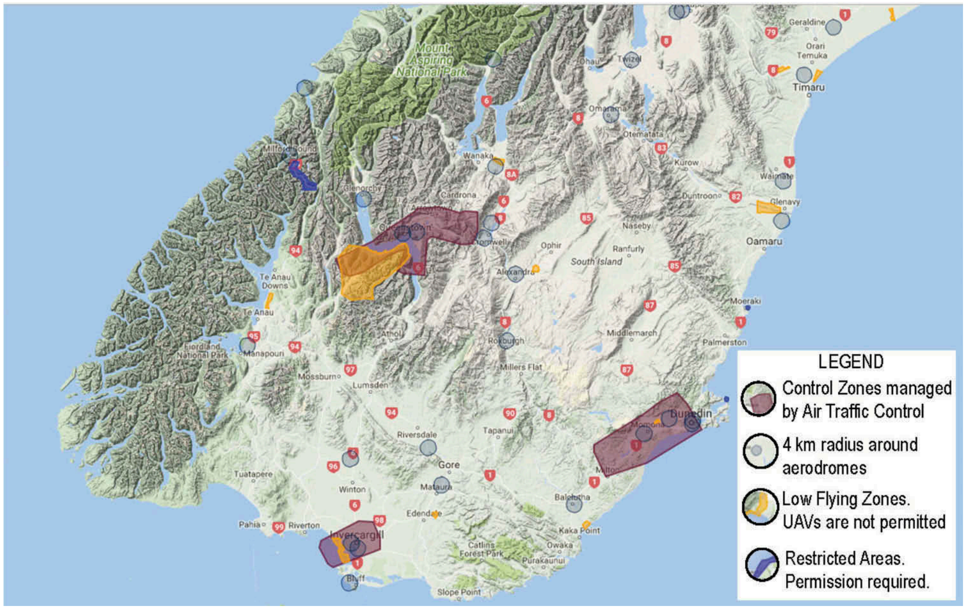


Figure 9. Drone use for site surveys in Oamaru, Winton, and Invercargill (amended map from https://www.airshare.co.nz/maps).

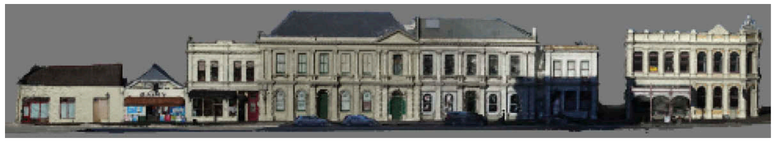
offered valuable information to the precinct assessment. A combination of UAV and photogrammetry offers a non-invasive, inexpensive, and efficient way to obtain a large amount of detailed information.

Onsite documentation

As Geographic Information System (GIS) documentation or existing building inventories were not consistently accurate or publicly accessible for some townships, the information gained from published reports required further verification using on-site visual surveys. It is noted that many local authorities or councils are in the process of compiling or updating existing building inventories, as a result of the updated mandates presented by the Building Act (Ministry of Business Innovation and Employment 2017). The visual surveys assisted in verifying the data gained from existing reports. The selected technologies supported the three stages of the study research, from pre-site literature review, through onsite surveys and post-site processing, in order to help inform further multidisciplinary analysis. Post-site processing involved production of photogrammetric models and also utilized mapping software (Maptitude GIS and Mapping Software).

The processes of data-collection and analysis were derived from the best-practice principles advocated by the *ICOMOS New Zealand Charter* (ICOMOS New Zealand 2010). Understanding and conserving cultural heritage value may be achieved by systematic documentation, physical investigation, and recording of the historic place, avoiding invasive investigation or disturbance to historic fabric as far as is possible. The Charter suggests that data for documentation may concern history, building fabric, physical changes or interventions, and recording of the rationale underpinning such conservation decisions. Recording enables the creation of documents specifically focusing on setting and building fabric, configuration, condition, use, and changes over time for future reference. These principles lend support to the Charter's Article 24: Risk Mitigation, which foregrounds the threats posed by natural disasters to cultural heritage. Study of the chosen heritage precincts is of significance, in order to collect and compare information prior to earthquakes, which will in turn enable post-earthquake analyses of impact and the selection of recovery solutions.

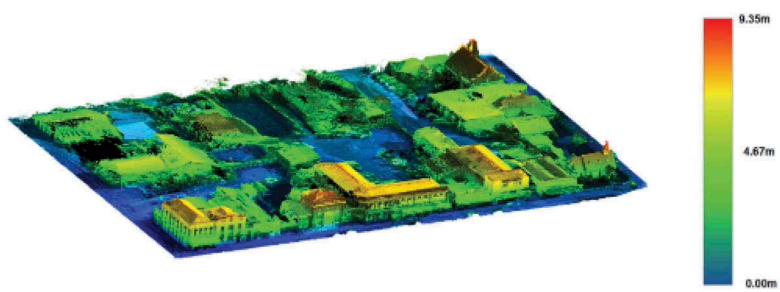
A key aspect of the post-site processing phase entailed a discussion of the architectural characteristics integral to each of the chosen historic precincts (Figure 10a–d). The combination of photography, mapping, and 3D modeling assisted in the analysis of the three defined historic precincts, to potentially allow the selection and implementation of seismic retrofitting measures that are appropriate to the identified heritage context. Data collection focused on urban and architectural characteristics. Whereas the former category targeted the streetscape scale (e.g., scale, lot size, roofscapes, relationship between buildings, and open spaces), the latter theme highlighted the individual building scale (e.g., number of stories, architectural style, treatment of openings, interior configuration, construction materials) (Heritage New Zealand 2007b). Other categories of data pertaining to both of the above themes included evidence of any historic or existing retrofitting interventions. Overall, the value of photogrammetry



(a) Itchen Street Elevations, Oamaru

(b) Intersection Thames and Itchen Streets, Oamaru

(c) Great North Road, Winton



(d) Approximation of building heights using photogrammetry

Figure 10. Photogrammetry models produced during post-site processing phase.

applied to architectural analysis may be summarized as the production of archival records, building fabric analysis, structural analysis, and town scape analysis, within the pre-disaster and post-disaster environments (Feilden 1987).

Processing via photogrammetry

The technique chosen to produce the 3D representation was Structure from Motion (SfM) (Westoby et al. 2012). SfM utilizes pixel information in a given photograph to locate the homologous point in a second photograph, to estimate the three dimensional geometry of objects (Buonamassa et al. 2017). The photogrammetric images were automatically obtained by processing UAV footage, that required a minimum of 60% of overlapping area between adjacent images of the selected region for reproduction (Luhmann et al. 2006) (Mikhail 2001). Combinations of UAV and SfM applied to heritage structures can be found in Murtiyoso and Grussenmeyer (2017), Chaiyasarn et al. (2017), and Chiabrandoa. and Teppati Losèa (2017).

Agisoft Photoscan™ software was used for the alignment of cameras, mesh point cloud reconstruction, and application of textures required for the final model. The model produced for Oamaru was composed of 602 photographs or “cameras”, 1,348,807 faces and 683,861 points. In contrast, the model for Winton used 1197 cameras and was composed of 3,109,046 faces and 1,556.974 points. A balance between resolution, scale and computational power in regard to the scope of the project should be achieved, e.g., if the information required from the model is related to the whole scale of the block, then a medium quality dense point cloud could be adequate. However, if the focus is on architectural details, then a high quality dense point cloud, mesh and texture should be used. Within this last option, it is possible to limit the processing to the specific portions of the model required for study, such as architectural details, hence minimising computation time. Nevertheless, special attention was paid to capturing as many details as possible for historic URM buildings. The rest of the building stock was also recorded, although in some cases only the scale of the building footprint in the block was included in order to reduce the number of photographs to process and therefore the computational time.

Targets were used as Ground Control Points (GCP) to provide a means of scaling the digital model, by measuring physical distances between the targets. Distances between targets were measured with a laser meter, noted on the digital model and scaled. Excluding missing areas due to drone flight restrictions and the density of the point cloud, the global error obtained was 7.1 cm for the precinct model and 1.5 cm for the detailed model.

Overall, the combination of the above data-collection and processing methodologies served as means of recording and preserving architectural details for future restoration or reproduction for study via 3D printing, for example. In case of an earthquake, studies of volume loss and damage in buildings in pre-earthquake conditions and post-earthquake situations are other valuable applications. Once fully processed and compiled, the future database will contain both written and visual material, across photography and video footage formats, for subsequent access by architectural or engineering researchers and practitioners. The potential of expanding the methodology to include LiDAR technology is a further option providing another means of non-invasive survey and inspection.

Informing the implementation of seismic risk reduction policies and mitigation measures

Heritage conservation via selection and implementation of seismic risk mitigation measures demands analysis of each precinct based on the historical architectural use of masonry construction, streetscape/urban characteristics, and evidence of existing seismic retrofits. Best-practice guidance offered by Heritage New Zealand and ICOMOS New Zealand pertaining to the modification of historic buildings addresses internal and external impacts on heritage building fabric (Heritage New Zealand 2007b). Analyzing these impacts requires consideration of the aforementioned architectural characteristics such as conserving the original roof form; materials or features (e.g., chimneys); retaining the internal spatial composition (e.g., plan); dimensions or detailing of historic walls; building cladding; retaining historical patterns of openings such as windows or doors, especially along principal elevations; and the conservation of fixtures. Additionally, conservation of historic streetscape character encompasses consideration of construction material, scale, mass, color or surface configuration, in relation to the adjoining and/or surrounding buildings (Heritage New Zealand 2007b). The concept of '"setting" as described within Article 9 of the ICOMOS New Zealand Charter encapsulates the above considerations using the following definition.

"Setting includes the structures, outbuildings, features, gardens, curtilage, airspace and accessways forming the spatial context of the place or used in association with the place. Setting also includes cultural landscapes, townscapes, and streetscapes; perspectives, views, and viewshafts to and from a place."(ICOMOS New Zealand 2010)

Site-survey methods using drone, geocoded photography, and the subsequent post-site processing revealed the scope of information gathered relating to the above considerations, along with the challenges associated with these data-collection methodologies. Bearing these factors in mind, comparative analysis for the Oamaru, Winton, and Invercargill precincts was undertaken as follows below, using the themes of historical architectural use of masonry, urban composition, and evidence of existing retrofit measures. Several data categories such as "current building use" and "number of floors (one, two, three, four story)" are summarized in Table 1, as a step toward more quantitative analysis, enabling comparison across the Oamaru, Winton, and Invercargill historic precincts. Whereas the initial focus of the reported study was data-collection methodology and urban site survey, full compilation of the dataset comprises the following phase of post-site processing.

Urban characteristics

Key urban characteristics which contribute to the historic streetscape character include building lot size, variation of row vs. stand-alone buildings, building height (number of floor levels), and setback from the street. As this project also furthers a wider study examining the causes and mitigation of pounding for New Zealand URM buildings,

Table 1. Proposed format and data categories for assets inventory of historic URM precincts in New Zealand, using Oamaru, Winton, and Invercargill as examples.

OAMARU *(Locally/Nationally Designated URM Buildings)*		
Current Building Use	Industrial (warehouses):	10
	Public/Civic (theaters, libraries, churches, banks):	16
	Commercial (retail):	56
	Total:	**82**
Number of Floors	One Story:	31
	Two Story:	46
	Three Story:	4
	Four Story:	1
	Total:	**82**
Presence of Parapets (processing)	**Parapets Present:**	**72**
Number of Retrofitted buildings (processing)	**Visible Retrofit/Total:**	-
Visible Retrofit Typologies (processing)	Parapet/Chimney Restraint:	-
	Steel/Wrought Iron Wall Ties:	-
	Sealed Openings:	-
	Gable/Roof Connection:	-
	Total:	-
WINTON *(Locally/Nationally Designated URM Buildings)*		
Current Building Use	Industrial (warehouses):	0
	Public/Civic (theaters, libraries, churches, banks):	5
	Commercial (retail):	9
	Total:	**16**
Number of Floors	One Story:	1
	Two Story:	15
	Three Story:	0
	Four Story:	0
	Total:	**16**
Presence of Parapets (processing)	**Parapets Present:**	15
Number of Retrofitted buildings (processing)	**Visible Retrofit/Total:**	**3**
Visible Retrofit Typologies (processing)	Parapet/Chimney Restraint:	0
	Steel/Wrought Iron Wall Ties:	3
	Sealed Openings:	0
	Gable/Roof Connection:	0
	Total:	**3**
INVERCARGILL *(Locally/Nationally Designated URM Buildings)*		
Current Building Use	Industrial (warehouses):	-
	Public/Civic (theaters, libraries, churches, banks):	-
	Commercial (retail):	-
	Total:	-
Number of Floors	One Story:	-
	Two Story:	-
	Three Story:	-
	Four Story:	0
	Total:	**50**
Presence of Parapets (processing)	**Parapets Present:**	-
Number of Retrofitted buildings (processing)	**Visible Retrofit/Total:**	-
Visible Retrofit Typologies (processing)	Parapet/Chimney Restraint:	-
	Steel/Wrought Iron Wall Ties:	-
	Sealed Openings:	-
	Gable/Roof Connection:	-
	Total:	-

the onsite survey included photographic documentation of specific building characteristics contributing to overall seismic vulnerability. Pounding is defined as "the collision of adjacent buildings because of their out of phase response, which can occur during an earthquake" (Cole, Dhakal, and Turner 2012). The authors cite specific characteristics increasing the vulnerability to pounding as irregularity of floor levels, adjacent buildings with differing mass or total heights, lack of separation gap, and the use of brittle materials such as masonry (Cole, Dhakal, and Turner 2012). Evidence of concrete floor beams was also acknowledged. The topic of pounding has received little attention within the local research sphere and onsite recording of these characteristics was an initial step toward generating a more embodied discussion. In conjunction with "pounding", the collection of historic building characteristics are based on established hierarchies of hazard to individual or standalone URM buildings. Such hierarchies begin with addressing falling hazards such as parapets chimneys and ornament, followed by out-of-plane failure mechanisms (e.g., out-of-plane façade failure) and in-plane failure (e.g., in-plane wall failure, bed joint sliding and rocking) (Canterbury Earthquakes Royal Commission 2012). International scholarly contributors offering perspectives on both structural assessment or remediation as well as heritage conservation, identify a range of actions potentially affecting a building such as direct and indirect actions, dynamic actions, and physio-chemical actions (Croci 1998; Beckmann and Bowles 2004; Forsyth 2007). Attention may be paid to masonry as a material versus masonry as a structures (Croci 1998). Retrofit may address substitution or reintegration of material, improvement of tensile, or shear resistance via structural connections, and repair of secondary elements such as gables or cornices. Local interventions may focus on enhancing masonry quality or repair to secondary elements, but other retrofit strategies can also reduce the damage or collapses due to out-of-plane overturning mechanisms, in addition to improving global structural response. The effect of retrofit interventions on adjacent structures, such as clustered or row buildings within urban blocks, is another consideration. Drone footage and survey via walking inspection highlighted and verified variations in urban spatial qualities across the three case study precincts.

Invercargill's Historic Areas are located across urban blocks characterized by gridded subdivision into individual building lots, most of which are similar in scale and densely composed within each block (Figure 3c). In contrast, the Oamaru Historic Area displays a more organic pattern of urban development across its recently extended precinct (Figure 3a). Whereas there is uniformity in building setback and approach from the main streets, buildings along Thames, Harbour, and Tyne Streets in Oamaru are less consistent in building scale (Figure 5b) and lot size, for example (Figure 3a). Historical patterns of circulation or approach, along with existing accessways between the buildings, were highlighted via drone footage and walking inspection.

Therefore, the survey revealed a larger number of monumental standalone buildings within the Oamaru Historic Area, as compared with the greater proliferation of small-scale row buildings distinguishing its Invercargill counterparts.

An overall similarity in scale was displayed by the predominantly two- and three-story structures characterising the streetscapes within the various Historic Area precincts (Table 1). Site observations reveal that irregularity/misalignment of floor level is evident, despite adjacent buildings having a similar/same number of floor levels, hence contributing to vulnerability to potential damage from pounding (Figure 5a). Variations in building scale and floor levels may be related to the represented historical architectural typologies ranging from civic monuments or public architecture (e.g., banks or theaters), to commercial buildings (e.g., shops or hotels) and industrial structures (e.g., warehouses, freezing works). Consideration of historic building typology and its associated existing use is another important factor for the design, selection, and implementation of retrofitting or mitigation measures (Table 1). The Oamaru Historic Area is significant in showcasing all three above typologies whereas the precincts in Invercargill and Winton are dominated by commercial and public buildings such as shops, banks, and theaters. Nevertheless, Winton's Great North Road Historic Area offered a point of difference through the prevalence of its larger-scale staging-post hotel structures that constitute large portions of the urban blocks. As one example, the Railway Hotel (Figure 7) is located at 232–234 Great North Road, Winton and occupies a substantial urban footprint and portion of the main historic street frontage. Similarly, Oamaru's grainstore warehouses offered variation as these buildings often feature four stories, catering to their varied industrial uses (Figure 5b).

Gauging the presence and extent of separation gaps between adjacent buildings in order to further understand the possible extent of pounding damage proved challenging during onsite documentation and inspection. Conversely, documenting the building rear elevations using geocoded photography proved productive due to the absence of exterior lining/claddings which characterized street-facing or principal elevations. Geocoded photography therefore assured the exact location of the images, and allowed comparisons and conclusions to be drawn (Figure 11). The alternative option was to undertake additional interior building inspection although these were outside the scope of the reported survey.

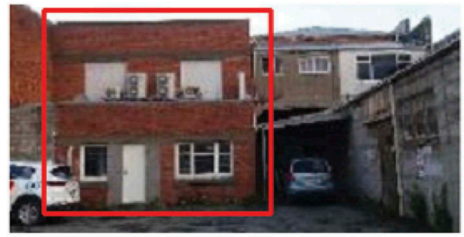
Historical use of masonry

The historical deployment of stone versus brick masonry across the three precincts is another source of architectural diversity. Drone footage and photography revealed trends relating to material properties (e.g., color, texture) in addition to confirming the extent or consistency of historical streetscape visual cohesion based on ornamentation along a whole streetscape for example, and verifying information which may be otherwise inaccessible due to building height or location. Recording similarities and differences in these historic architectural characteristics assists the future implementation of seismic mitigation measures.

Despite the streetscape variation of building scale and typology, the predominance of Oamaru limestone lends visual cohesion to the Historic Area. Masonry detailing adorns the Classical facades illustrating exposed masonry block construction. Therefore, the architects' use of masonry implies that significance lies within the natural color and texture of the worked limestone as the finished surfaces are left exposed and unpainted (Figure 5). Onsite survey also highlighted that it is more common for the stone to be used in isolation, than in combination with other materials. As such, this architectural practice reflects the accessible local supply of stone and ease of workmanship by stonemasons (Figure 12). The use of stone is also evident in the building's rear and side walls as rather to being constructed in more humble building materials. Therefore, the evident historical significance embodied by the architectural use of Oamaru stone should be reflected in the selection of future retrofitting or seismic risk mitigation measures, to avoid compromising the building fabric.

Converse to the argument articulated above, the Invercargill Historic Areas display a more varied architectural use of brick masonry across the historic building stock. Brick is used in load-bearing and non-load-bearing capacities, and especially to ornamental effect. Principal elevations such as those along Tay and Dee Streets (Invercargill CBD) are painted or feature the use of other materials in conjunction with brick (Figure 13). The streets are therefore characterized by an eclectic collection of facades, which vary in scale, color, and composition of building materials. The use of exposed, polychromatic brick masonry lend further variation, although there are fewer examples of this architectural use (Figure 14). In contrast to the Oamaru Historic Area, the streetscape of Invercargill presents ambivalent attitudes to the architectural use of brick masonry construction. Whereas Oamaru limestone was prized for its natural color and texture,

(a) Evidence of vertical separation gap, Invercargill



(b) Evidence of concrete structural elements, Invercargill

(c) Verification of brick masonry construction, compared with painted street elevation

Figure 11. Capturing exposed brick masonry construction at rear of buildings and verification of location via geocoded photography.

brick is both concealed and expressed, used in isolation or in conjunction with other construction materials. This architectural practice is evident along Winton's Great North Road, where brick masonry is exposed, painted, or plastered for example. Permission to conduct drone flight within Winton-enabled documentation and verification of detailing, particularly at parapet or building cornice height (Figure 15).

Further comparison can be made concerning selection and execution of architectural styles chosen by the respective designers, for the Oamaru, Winton, and Invercargill historic areas. Overall, Oamaru showcases a high degree of consistency in this regard, as Victorian Classicism pervades the streetscape facades. Primary characteristics of the style include symmetrical and regular composition of architectural elements and detailing evident in the *aedicules*, stringcourses and door/window surrounds. A commonality across all three townships are the highly ornamental parapets, comprised of balustrade pilasters or ornamental finials, for example (Figures 13 and 16). Similarly, Invercargill and Winton display elaborate facades and principal street frontages, albeit featuring characteristics, of the Edwardian Baroque architectural style (e.g., ornamental keystones). Drone photography therefore enables the examination of masonry condition for this usually inaccessible ornamentation and offered special value for the highly ornamental Oamaru building stock.

Evidence of existing retrofitting

The extent or effects of historic and/or existing seismic risk mitigation measures or retrofitting schemes specifically required verification via onsite inspection in addition to drone photography. Therefore, use of drone footage and geocoded photography as the primary survey methodologies for large-scale data collection proved valuable in identifying certain trends in the use of specific retrofitting solutions/seismic risk mitigation measures. Structural interventions may range from the removal, reproduction, and replacement of historic architectural ornamentation through to full seismic upgrading. The application of the aforementioned

(a) Union Building, 7 Tyne Street, Oamaru

(b) Connell and Clowes, 5 Tyne Street, Oamaru

(c) AMP Building, 18 Itchen Street, Oamaru

(d) Star and Garter Hotel, 8 ItchenStreet, Oamaru

Figure 12. Four distinct ornamental parapet forms, comprised of finials, pediments, balustrade, and stringcourse (Tyne and Itchen Streets).

technologies to the documentation of retrofitting evidence also bore several advantages and facilitated ease of recording of various building features. Instead of presenting a full inventory of all observed damage characteristics and retrofitting solutions, the following discussion reports a sample comparison of results from Oamaru and Winton (drone use) and Invercargill (no drone use). A tabulated summary of visible retrofit techniques is offered in Table 1, to aid further inter-disciplinary qualitative and quantitative analysis. Present data categories pending development include "number of retrofitted buildings", "presence of parapets" along with a breakdown of retrofit typologies (parapet/chimney restraint, steel/wrought iron wall ties, sealed openings, gable/roof connections). The undertaken survey collected data based on exterior observation and building condition only. A full assessment and documentation of retrofitting solutions would also include interior inspection, which lies outside the scope of this study.

Oamaru/Winton retrofitting solutions

The inspected listed historic buildings totalled 119 (Oamaru Historic Area) and 20 (Winton Great North Road Historic Area) and revealed a number of common retrofitting technologies across various buildings. Visible examples included sealed openings, wall ties, and parapet restraints (Figure 15). Drone footage also suggested the presence of concealed retrofitting solutions as a result of observed variations of Oamaru stone color, hence implying the introduction of newer materials (Figure 15e). Possibly the most useful application of the survey via drone was enabling accessibility in verifying parapet condition and securing methods. A question raised by rapid visual survey via drone flight was concerning the extent to which historic architectural elements have been removed, replaced or reproduced, within the Oamaru Historic Area (Figure 15). While confirmation of such conservation works cannot be verified by visual inspection alone, there are a number of

(a) Variation of painted masonry along streetscape

(b) Exposed and painted brick masonry

(c) Exposed brick masonry with timber detailing

(d) Exposed and painted brick masonry door/window surrounds

(e) Italo-Byzantine brick masonry

Figure 13. Varied architectural deployment of brick masonry, Invercargill CBD.

implications for further investigation. Any loss or compromise of historic building fabric may be gauged, in conjunction with internal inspection.

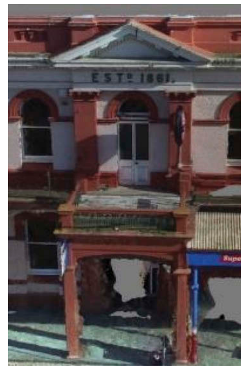
Employing concealed seismic strengthening measures also suggests a design approach based on augmenting the buildings' intrinsic resistance to earthquakes, by integrating structural elements within the historic structural matrix vs. unnecessary addition of elements which may not utilize the building's existing structural properties (Robinson 2000). As such, the illustrated examples display improvement of primary interconnections (e.g., floors and roofs to walls), restraint of falling hazards such as parapets and wall stiffness. Overall, observed measures to improve structural behavior are confined to either strengthening specific structural elements versus addressing the building as a whole. Approximations of age and period of the undertaken retrofitting may also be gauged by the varying wall tie mechanisms and materials (e.g., wrought iron vs. steel) (Figure 15b, d).

Invercargill retrofitting solutions

Of the surveyed buildings within the designated Invercargill Historic Areas using geocoded photography alone, there proved to be little external evidence of existing seismic mitigation measures (Figure 16). Common solutions included the use of steel wall ties and sealing of openings such as windows as well as parapet balustrades (Figure 16). Location within an area of low seismic risk (Figure 1) may serve as the primary reason for previously relaxed attitudes to potential damage by earthquake.

Conclusion

The reported study comprised a qualitative comparative analysis of Historic Area precincts across the three townships of Oamaru, Winton, and Invercargill, enabled by the use of various survey methodologies for large-scale data collection and with the primary objective of heritage conservation through seismic risk mitigation. These



(a) Painted brick masonry, Railway Hotel, Winton

(b) Exposed brick masonry, Bank of New Zealand, Winton

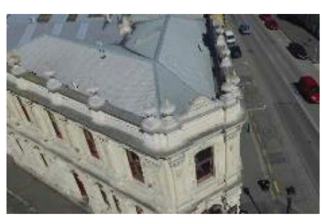
Figure 14. Capturing parapet ornamentation via photogrammetric modeling, Winton.

(a) Sealed openings (Oamaru)

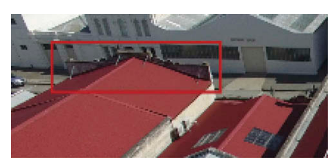
(b) Steel/wrought iron wall ties (Oamaru)

(c) Verification of no parapet restraints (Winton)

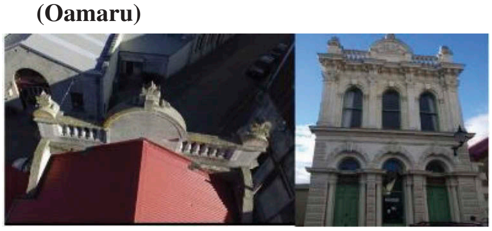
(d) Steel/wrought iron wall ties (Oamaru)



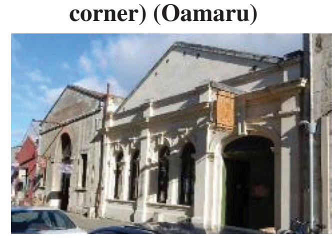
(e) Evidence of parapet modification (Oamaru)



(f) Steel parapet restraints (visible in upper left hand corner) (Oamaru)

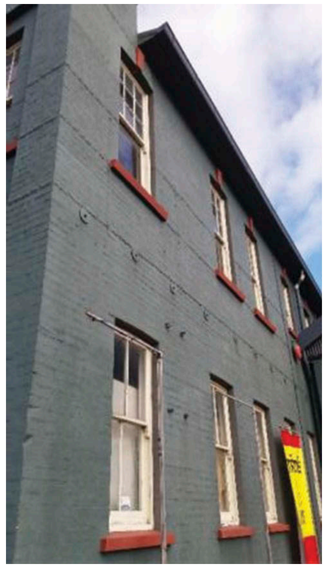


(g) Verification of no parapet restraints (Oamaru)

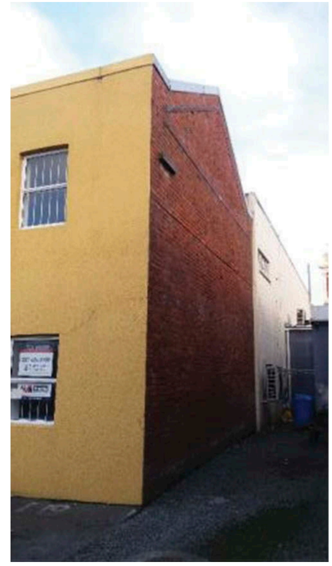


(h) Metallic connection between gable and roof (Oamaru)

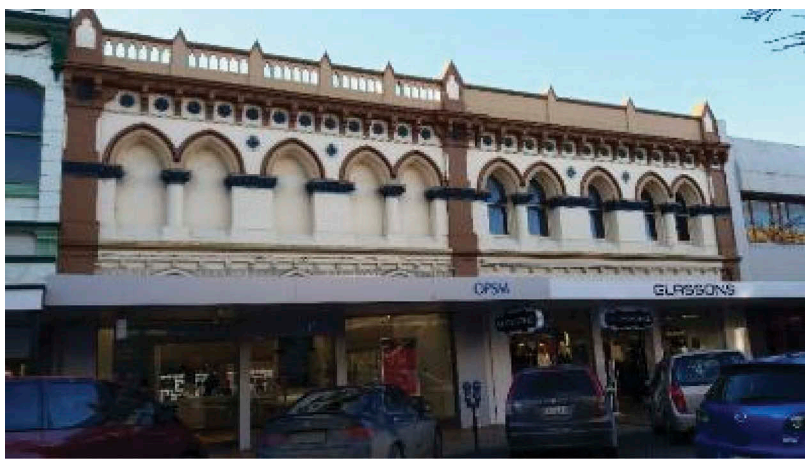
Figure 15. Verifying evidence of existing retrofitting via drone and geocoded photography, Oamaru and Winton.



(a) Steel/wrought iron wall ties



(b) Steel strapping along gable



(c) Sealed openings and parapet balustrade

Figure 16. Evidence of existing retrofitting via geocoded photography, Invercargill.

precincts were selected as early case studies underpinning research concerning New Zealand's Alpine Fault and as such, offered lessons in the use of data-collection and processing technologies for future application. Key objectives are summarized as trialling onsite documentation and visualization techniques that have previously received little local attention and therefore extending the scope of existing or traditional datasets, also through the compilation of historic building inventories. A unique value of such methods of data collection is the vast scope of information gathered during a single fieldwork session, and therefore the accompanying range of applications across both qualitative and quantitative study. Whereas architectural research may entail examination of shifts in the local heritage conservation attitudes and practices, such as the appraisal or design of sensitive retrofit strategies, a parallel quantitative study may entail exploring seismic assessment for historic Oamaru stone buildings versus clay brick counterparts for example, as one of New Zealand's distinctive historic structural/construction typologies. It is also acknowledged that raw drone footage or photography of the present townscapes can serve as invaluable archival material in its own right, prior to post-site processing for a given purpose. Existing literature highlighted recent changes to legislation and heritage management, while identifying specific historic urban and architectural townscape qualities for consideration during the seismic retrofitting process. Whereas the selected precincts have been documented to varying degrees, it was important to verify specific characteristics, in the wake of the aforementioned changes in their seismic risk and heritage management. Onsite documentation via inspection, drone and geo-coded photography confirmed shared trends and variations across urban characteristics, historical use of masonry, and evidence of existing seismic risk mitigation measures. An improved format for adopting the articulated methodology for other towns will involve adaptation to precinct scale (e.g., conducting shorter or slower drone flights). Potentially combining drone flight/photography with internal inspection can generate complete datasets that may be of use in the pre-disaster or post-disaster contexts, for researchers as well as rescue teams. As it is important to avoid invasive investigation for the purposes for heritage conservation, other non-invasive methods include 3D scanning or LiDAR technologies, depending on the scale and time restraints of the required historic precincts.

Acknowledgments

This project was supported by QuakeCoRE, a New Zealand Tertiary Education Commission-funded Centre. Associate Professor Julia Gatley is thanked for her suggestions and advice. Gye Simkin is thanked for his advice with the GeoNet maps.

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