TRENDS IN THE ARCHITECTURAL CHARACTERISATION OF UNREINFORCED MASONRY IN NEW ZEALAND

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SUMMARY

This paper identifies seven typologies for characterising New Zealand's unreinforced masonry (URM) building stock. This enables a better understanding of what typical properties to expect when assessing heritage URM buildings. Distinctions between typologies are drawn largely on the basis of building height and the geometry of the building's footprint.

INTRODUCTION

Unreinforced masonry (URM) buildings have been shown to perform poorly when subjected to the lateral forces in an earthquake. New Zealand is a seismically active country and lies in the boundary between the Australian tectonic plate to the west, and the Pacific tectonic plate to the east. Recently a programme has been undertaken in conjunction between The University of Auckland and The University of Canterbury to develop seismic retrofit solutions for New Zealand's earthquake risk buildings. Within this programme and elsewhere (NZSEE 2006) it has been recognised that buildings constructed of URM pose the greatest risk in terms of safety in an earthquake. Legislation has recently been introduced in New Zealand where earthquake risk buildings must be improved to meet a required standard (DBH 2007; NZSEE 2006). Within this legislative framework the option of demolition may be more attractive to the building owner when compared to the investment associated with seismic retrofit of the structure.

Very few URM buildings have been constructed since 1931 in New Zealand, when in the Napier earthquake of that year they were exposed as having poor seismic resistance. Hence the bulk of URM buildings are eighty years old or more. As many seismically at-risk buildings also form a significant part of New Zealand's heritage building stock, exploring options for retrofit are all the more important. Before economical and cost-effective retrofit solutions can be identified and developed for such buildings, it is first necessary to accurately assess the their structural and seismic performance. However, before the structural properties of URM buildings are ascertained and for a comprehensive understanding of the building stock, the architectural characteristics must be defined.

BACKGROUND OF BUILDING TYPOLOGIES

Within the architectural characterisation of URM buildings, the broadest and most important classification is that of the overall building configuration. The seismic performance of a URM structure depends on its general size and shape. A small, low-rise, square building will behave differently when subjected to seismic forces than a long, row-type, multi-storey building. In addition to this, retrofit interventions which may be appropriate for one type of building may not be appropriate for another, different type of building.

Magenes (2006) notes the importance of building configuration in the overall seismic performance of masonry buildings. He states "the main factor that produces the variation of the OSR is the geometric configuration (plan and number of storeys)." The OSR (overstrength ratio) is defined as OSR = F_y/F_{el}, and arises from the analysis of the inelastic cyclic deformation and energy dissipation capacity of a structural unreinforced masonry system. F_y is the ultimate strength capacity corresponding to an ideal bi-linear system, and F_{el} represents the base shear at which the first element in the structure would reach its strength capacity according to a linear elastic analysis.

From the point of view of assessing and upgrading heritage brick buildings, The New Zealand Historic Places Trust recognises the importance that the configuration of a building has on its behaviour during an earthquake. It states that the torsional resistance of small, almost square buildings is greater than that of buildings with a less uniform ground footprint, because their geometry allows for resistance in all horizontal directions. It also recognises that buildings up to three storeys high with many walls can generally withstand a reasonable amount of earthquake shaking, whereas buildings higher than three storeys with open-plan frame-type geometries are much more vulnerable (Robinson and Bowman 2000).

Binda (2006) suggests some building typologies to classify historic structures in the Italian building stock. These typologies are as follows:

- Type A: isolated houses and/or dwellings;
- Type B: row houses;
- Type C: palaces;
- Type D: bell towers;
- Type E: arenas;
- Type F: churches and cathedrals; and within this typology,
    - Type F1: churches, plan based on Latin cross scheme;
    - Type F2: churches, central plan.

The New Zealand building stock differs from that in Italy in a number of ways, in particular the age, the materials used and the typologies most frequently occurring. Tonks et al. (2007) began a preliminary identification of building typologies in New Zealand, based on those identified in Italy. Three typologies were identified, as follows:

- Stand alone isolated secular or religious buildings and chimneys;
- Row residential buildings;
- Row commercial and retail buildings.

NEW ZEALAND URM BUILDING TYPOLOGIES

It has been identified that the New Zealand building stock warrants seven typologies, which are outlined in Table 1. Buildings are separated according to storey height, and whether they are isolated, stand-alone buildings or a row building made up of multiple residences joined together in the same overall structure. A suggestion of the expected importance level of the structure is also given, according to AS/NZS 1170.0:2002 (Standards New Zealand 2002). The prevalence of URM structures according to the number of buildings in that typology which make up the overall building stock is also shown in Table 1.

Table 1. URM Building Typologies

Type	Description	Prevalence (rank)	Importance level (AS/NZS 1170.0)	Description
A	One storey, isolated buildings	4	II	One storey URM buildings. Examples include convenience stores in suburban areas, small offices in a rural town.
B	One storey, row buildings	3	II	One storey URM buildings with multiple occupancies, joined with common walls in a row. Typical in main commercial districts, especially along the main street in a small town.
C	Two storey, isolated buildings	2	II/III	Two storey URM buildings, often with an open front. Examples include small cinemas, a professional office in a rural town, post offices.
D	Two storey, row building	1	II	Two storey URM buildings with multiple occupancies, joined with common walls in a row. Typical in commercial districts.
E	Three + storey, isolated buildings	7	III/IV	Three + storey URM buildings, for example office buildings in older parts of Auckland and Wellington.
F	Three + storey, row buildings	6	III/IV	Three + storey URM buildings with multiple occupancies, joined with common walls in a row. Typical in industrial districts, especially close to a port (or historic port).
G	Monumental buildings	5	III/IV/V	Churches (with steeples, bell towers etc), water towers, chimneys, warehouses. Prevalent throughout New Zealand.

Within the above typologies, further distinctions can be made. For example, Type A buildings, can be divided into those which have a dividing wall down the centre (Type A1), and those which do not (Type A2). Type G buildings are generally monumental structures and those which do not fit easily into the other categories, and usually for such structures unique problems are presented, and unique analyses are necessary. Nevertheless there are useful sub-classifications which can also be made within this grouping. For example, Type G1 buildings are religious buildings in New Zealand, Type G2 are warehouses and factories with very large tall sides and large open spaces inside. Further detail on each typology is given in subsequent sections.

PARAMETERS FOR DIFFERENTIATING TYPOLOGIES

Storey Height

Typologies are separated according to whether the buildings are one storey, two storey or three or more storeys. Buildings taller than three storeys are not commonly occurring in New Zealand and occur almost exclusively in the central business districts (CBD) of the largest city, Auckland, and the capital, Wellington. While one and two storey buildings are approximately evenly distributed throughout the country, three and higher storey buildings are few in number and a single typology to classify all URM buildings three storeys or higher is sufficient. Moreover, the difference in expected seismic behaviour between a three and four storey building is significantly less than the difference between a one and two storey building, for example. This is particularly because three and higher storey buildings tend to be of masonry frame construction (on at least one face of the building, usually the front and back faces), in contrast to solid wall construction. As a broad generalisation, in masonry frames rocking of piers between windows and openings can be the expected in-plane behaviour when subjected to lateral seismic forces (Abrams 2000), and diagonal shear failure is less likely. For walls without openings (or with small openings), and depending on the axial load, the expected in-plane failure mode in an earthquake is likely to be either sliding shear failure, diagonal tension (shear) failure, or rocking of the wall itself.

Another reason buildings are distinguished according to storey height is because of the axial loads acting in the walls. One storey buildings with low axial loads are less likely to exhibit diagonal shear failure and are more likely to rock or slide. The bottom storey walls in a taller building are more likely to fail in shear because of the higher axial loads on them.

Building Footprint

The second primary characteristic for separating buildings into typologies is the building footprint. That is, whether the structure is considered a stand-alone, isolated, (almost) square building, or a row building made up of multiple residences joined together with common walls. This accounts for Typologies A – F, whereas those buildings with a non-uniform ground footprint (for example, many URM churches) will fit into the Typology G classification.

In row structures containing walls common between residences, pounding can be an issue during earthquake loading. This is especially likely when floor or ceiling diaphragms in neighbouring residences are at different levels. Different heights for the force transfer into the common wall can result in punching shear failure of the wall or diaphragm detachment and collapse. The effects of pounding are greater when concrete floor diaphragms are in the structure, compared with timber diaphragms. Conversely in the case of many residences within the structure with similar heights, the seismic resistance is greatly enhanced due to the increased stiffness in one direction.

Essentially square or round buildings with well distributed walls generally have a greater torsional resistance than buildings with less evenly distributed lateral force resisting walls (Robinson and Bowman 2000). Long row structures have different torsional properties than isolated buildings.

A significant difference between isolated and row buildings becomes evident at the time of upgrading the structure. An isolated structure usually contains few residences, perhaps two shops for example, or occasionally more. Row structures may contain many residents, even ten or more. An isolated structure is generally considered just that – a single structure. A row structure, despite behaving in an earthquake as a single interconnected structure, may be perceived as different buildings. It may be more difficult to perform remedial work on an entire row structure at one time compared with on an isolated structure. If retrofit interventions are implemented on only a part of a structure, such an intervention may be ineffective.

DETAILS OF NEW ZEALAND URM TYPOLOGIES

Typology A – One Storey Isolated Buildings

Type A buildings are one storey isolated structures, and are the fourth most prevalent in New Zealand. Equally common in both small towns and large centres, these structures are often today used as convenience stores, or small commercial premises. Typically they have a square ground footprint, but may have longer side walls making the building rectangular. Sometimes there is a dividing wall through the centre of the building, usually with no piercings. Typology A1 are buildings with a dividing wall, and Typology A2 are those buildings without a dividing wall. Generally the external side walls have no openings. The front may be largely open, with up to 90 % of the width of the front open, and the rear wall usually has openings in the form of doorways. The side walls usually have no openings. On top of the front wall is usually a parapet, and often the side walls slope from the top of this parapet to the top of the rear wall, meaning the sidewalls are of trapezoidal shape. The sidewalls are usually either two or three leaves thick, as are the front and back walls. The ceiling diaphragm is usually timber with a suspended ceiling underneath, and light cladding over the top, often either tiles or corrugated iron. Photographic examples are given in Figure 1.

Figure 1. Typology A Structures

Figure 2 and Table 2 show as an example typical dimensions of a Typology A1 structure. Upper and lower bound dimensions are shown, as well as those of a “typical” Typology A1 building. The mean dimensions of such a building can be used for finite element modelling, and will enable expected seismic behaviour patterns to be established for this Typology.

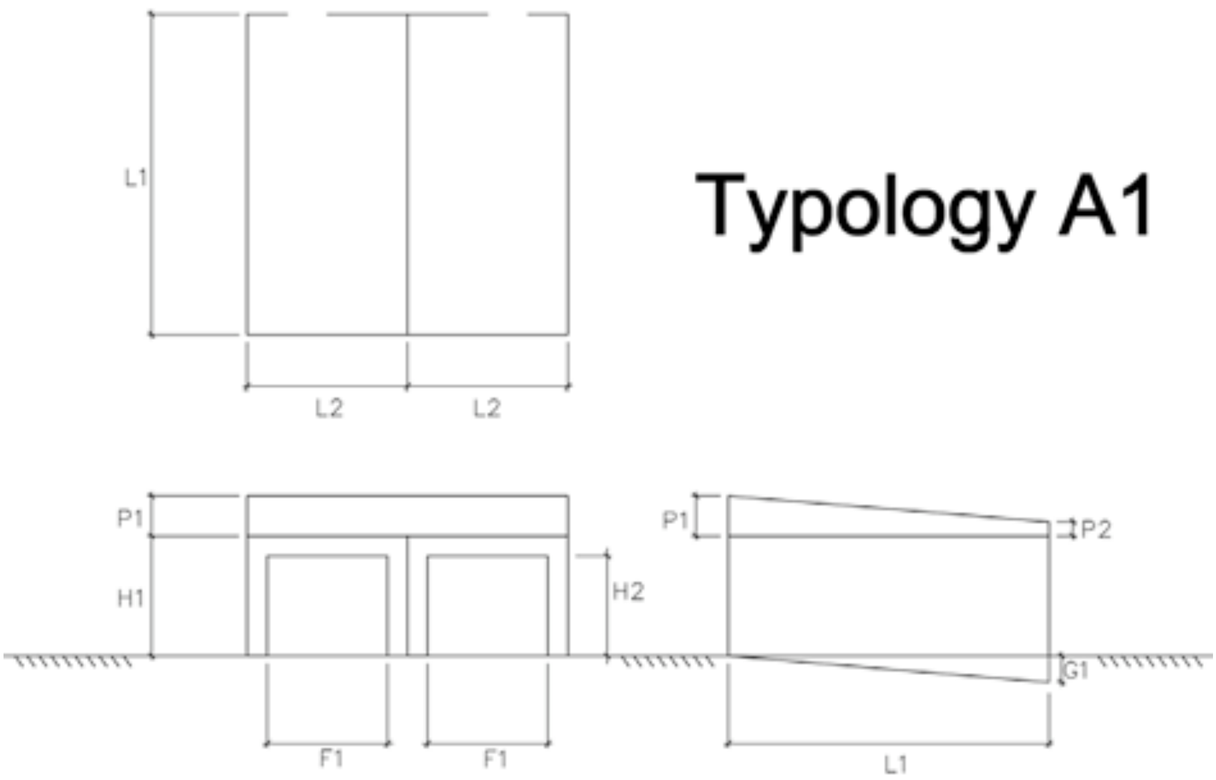

Figure 2. Overall Dimensions of a Typology A1 Building

Table 2. Overall Dimensions of a Typology A1 Building

Dimension		Lower bound structure (m)	"Mean" structure (m)	Upper bound structure (m)
L1	Overall length	6	8	16
L2	Width of residence	4	6	12
P1	Height of parapet at front	1	1.2	2
P2	Height of parapet at rear	0	0	1
H1	Height from ground to bottom of parapet	3	4	6
H2	Height of front opening	2	2.5	4
F1	Width of front opening	3	4	5
G1	Depth of rear wall below front street level	0	0.5	2

Overall dimensions for lower bound, upper bound and mean structures have been identified for the other typologies B – F. For space constraints they are not shown in this paper.

Typology B – One Storey Row Buildings

Type B buildings are one storey row structures, differentiated from type A structures in that they are essentially made up of multiple type A buildings joined together. They are slightly more prevalent throughout New Zealand (the third most prevalent out of the seven typologies identified) than type A structures, and often occur in small provincial towns, especially along the main street which is the commercial centre of the town. Generally there is a uniform front to the building which faces the street, but the location of the rear wall in each residence may vary depending on what extra rooms there are - a toilet and bathroom block for example. There are often individual parapets on the front of the building, and usually they are unique for each residence. There can be anywhere from three to ten or more residences joined together in the one overall structure. Similar to type A structures, the side walls are usually two or three leaves thick, , the frontages may be up to 90% open and there are suspended ceilings underneath roofs of either tiles or cast iron cladding. Typically type B structures are occupied by commercial tenants - retailers, hairdressers, cafes etc. Photographic examples are given in Figure 3.

Figure 3. Typology B Structures

Typology C – Two Storey Isolated Buildings

Type C buildings are two storey isolated structures, and buildings of this height are the most prevalent across the country – both isolated and row (type D). The most important feature of type C buildings is the floor and ceiling diaphragms and their connections to the walls. It is common for the bottom storey to be three leaves thick, and the upper to be two leaves thick. Timber bearers supporting the floor are often only simply supported on the resulting ledge, with no positive anchorage. In other instances the bearers may be embedded in the walls, but the depth of embedment is usually very small, providing little anchorage. Other features of these structures are that the side walls are generally not pierced, there are window openings on the top storey at the front and back and the front of the building on the ground floor may have large openings. These structures are usually square, but on occasions they may have a trapezoidal or triangular ground footprint, particularly when the building is situated at an intersection of two streets on an acute angle. Photographic examples are given in Figure 4.

Figure 4. Typology C Structures

Typology D – Two Storey Row Buildings

Two storey row structures are very prevalent and occur in similar locations to type B buildings, but are especially common in larger centres such as Auckland and Wellington. Some type D structures are mostly uniform, with consistent floor, roof and parapet levels resulting in a structure which is essentially homogeneous but divided into sections. Other structures are very much heterogeneous and have the appearance of individual and distinctive buildings simply joined together. There can be many variations between adjoining residences. For example the height of the first floor may be different between adjoining residences (which may contribute to the effects of pounding) and parapet heights and levels can also vary. Floor diaphragms may be concrete or timber (timber is more common) and the diaphragm seating issues identified for type C structures are also true for type D structures. Also openings are similar to those in Typology C. Photographic examples are given in Figure 5.

Figure 5. Typology D Structures

Typology E – Three + Storey Isolated Buildings

Type E structures are isolated buildings of three storeys or more. It was felt there were too few 4, 5, 6 or higher storey buildings in the country to warrant a separate class of building for each. These structures tend to be isolated to the larger centres, particularly Auckland and Wellington. They are situated mainly around older commercial areas and also close to the ports. The most important feature of these structures is that their front and back faces have multiple and consistently spaced window openings. This means that these faces tend to behave as masonry frames and the pillars between windows can rock when subjected to lateral displacements. The side walls tend not to have any openings. There can be step-ups in wall thickness from the bottom to the top of the structure. The ground storey walls may be up to seven or nine leaves thick, with each subsequent wall above decreasing in thickness. Again, the floor or ceiling diaphragms may be of timber or concrete construction, with the same seating issues as identified above. Photographic examples are given in Figure 6.

Figure 6. Typology E Structures

Typology F – Three + Storey Row Buildings

These structures are three and higher storey buildings, which similar to Typology B and D, are row structures. There can be a blurred distinction between Typology E and F, but generally type F structures are very long and may form a whole block of a street. Most characteristics of these buildings are similar to those of type E buildings. The main difference is that neighbouring (joined) residences may have different floor and overall heights resulting in pounding or lateral displacement incompatibility issues. Photographic examples are given in Figure 7.

Figure 7. Typology F Structures

Typology G – Monumental and Institutional Buildings

Type G structures are those URM buildings which do not have a simple or uniform ground footprint. Any monumental or unique structure which does not fit into Typologies A – F will be a Typology G structure. It is not the purpose of these classifications to define buildings by their use, but type G buildings tend to be churches, warehouses and factories, or civil buildings such as a town hall, ferry building or post office. Because of this Typology G has been further divided into G1 for religious buildings, G2 for warehouses and factories with large tall sides and large open spaces inside, and G3 for institutional buildings. For type G structures unique analyses are necessary on a case-by-case basis. Photographic examples are given in Figure 8.

Figure 8. Typology G Structures

CONCLUSIONS

The overall configuration of a building influences its performance in an earthquake. Seven typologies have been identified to categorise configurations in the New Zealand URM building stock. Separations between typologies are made on the basis of building height and the geometry of the building's ground footprint. Assessment and analysis of the structural performance of buildings within these typologies will enable targeted and cost-effective retrofit solutions to be implemented for the retention of New Zealand's heritage URM buildings.

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