SESOC CONFERENCE 2021
A New Beginning
CLAUDELANDS, HAMILTON | 5 – 6 JULY 2021

A SIMPLER APPROACH TO STRENGTHENING UNREINFORCED BRICK MASONRY BUILDINGS IN NEW ZEALAND

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SUMMARY

COSTS FOR THE SEISMIC ASSESSMENT AND STRENGTHENING OF EARTHQUAKE-PRONE BRICK BUILDINGS IN REGIONAL NEW ZEALAND ARE HIGH RELATIVE TO ASSET VALUES AND APPEAR LIKELY TO LEAD TO EXTENSIVE DEMOLITION OR ABANDONMENT. WE INVESTIGATE AN ALTERNATIVE APPROACH USING PRE-APPROVED TYPICAL DETAILS.

Note the views expressed in this paper are the authors' alone and do not necessarily express the views of Holmes Consulting.

ABSTRACT

New Zealand's current seismic assessment framework, introduced as the Earthquake-prone Buildings Amendment Act (EPB Act) in 2016, requires building-specific performance assessment and fully-quantified strengthening of earthquake-prone buildings to occur within set timeframes. For many earthquake-prone unreinforced brick masonry (URM) buildings the cost of assessment and strengthening is disproportionate to their asset value and rental return. It seems likely that EPB Act deadlines will arrive without widespread strengthening having taken place, especially in regional New Zealand. Extensive demolition or abandonment of small town centres could be the long-term result – and in the interim, building improvements that increase public safety are not being made. While bespoke assessment is prescribed by the EPB Act, in practice strengthening schemes for URM buildings almost always include common measures. These measures, termed "simple strengthening" in this paper, provide the majority of the performance improvement gained in a retrofit and reduce the hazard that URM buildings present to passers-by. This paper proposes that, for some buildings conforming to certain parameters, owners could be permitted to implement the simple strengthening measures, using pre-approved details, but without specific assessment, design, or quantification of performance. URM buildings meeting the criteria, with simple strengthening applied, could then be exempted from the requirements of the EPB Act by local authorities. Parallels are drawn to Bolts Plus strengthening programmes implemented in areas of the USA.

INTRODUCTION

The 2011 Christchurch Earthquake, in which 185 people were killed, highlighted deficiencies in the seismic resilience of New Zealand's building stock. In response, the New Zealand Government introduced the EPB Act, requiring the owners of existing buildings to undertake seismic assessment and strengthening within set time frames. In addition to the legislative requirements of the EPB Act, owners of earthquake-prone buildings also face other legal and market-related drivers to strengthen earthquake-prone buildings. These include the availability and cost of earthquake insurance for earthquake-prone buildings, the market demand for earthquake-prone buildings, and legislative commitments such as those related to the Health and Safety at Work Act 2015.

URM buildings are a common building typology throughout New Zealand and are often found to be earthquake-prone (Russell and Ingham 2010). For specific URM buildings, Martin Jenkins (2012), Auckland Council (2017) and others have provided guidance around expected costs of seismic assessment and strengthening under the EPB Act. Such costs might be in the order of $\$200/m^2$ - $\$450/m^2$ for strengthening to 33%NBS, and $\$300/m^2$ - $\$1250/m^2$ for strengthening to 67%NBS. It is widely understood that such costs tend to be challenging for small New Zealand towns, where URM buildings are commonly found along main street frontages. In small towns, property values and rental demands are generally lower than in New Zealand's large urban centres. It consequently becomes less likely that building owners are able or willing to finance seismic assessment and strengthening.

Nahkies (2014) investigated at the perspective of URM building owners in the Canterbury town of Waimate. In a case study on 85 small commercial URM buildings, Nahkies estimated that the average rateable building value was around $75,000 per building (approximate, as of 2014), whereas the strengthening costs were estimated at $120,000 per building. As the seismic strengthening costs exceeded the building value, the costs were found to give the buildings a hypothetical negative value. Demolition was found to be a more financially viable option for building owners than carrying out the strengthening. The resulting social and economic impacts on small New Zealand towns were predicted to be "severe". Further commentary on the feasibility of seismic strengthening for building owners was provided in Nahkies (2015). That study reinforced Nahkies' view that seismic strengthening is financially infeasible for many small town New Zealand URM buildings, and that the imposition of mandatory seismic strengthening was likely to lead to widespread demolition or abandonment of such buildings. Filippova and Noy (2020) made a similar prediction, noting that "*the financial barriers to retrofitting* [in small New Zealand towns] *are formidable, and that without public financial support, most buildings – including heritage ones – will not be retrofitted by their respective owners"*. That study looked at Whanganui by way of two URM building case studies. In one of the case studies, the authors noted that a building owner spent around $800,000 to seismically strengthen and refurbish a $370m^2$ URM building (of which approximately one-third of the cost was associated with the strengthening and two-thirds with architectural upgrades and refurbishment). This cost was estimated to be approximately equal to the building's value. Returns on the investment were less than 2% per year. According to Aigwi et al. (2019a), "*because owners of earthquake-prone historical buildings may be unsure of the returns on investment in the strengthening and redevelopment process, they tend to abandon these buildings for demolition and relocate….* [This] *could eventually result in changing previously vibrant provincial city centres into unattractive places….*" Aigwi et al. (2019b) went on to argue that, while not being the only influencing factor, the EPB Act had already contributed to socio-economic decline in Whanganui and Invercargill.

Various efforts have been made to assist owners of earthquake-prone buildings in small New Zealand towns. Grants and incentive schemes are available, for example, to assist owners of earthquake-prone URM buildings with significant heritage value. However, while such measures may be of assistance for some buildings, they are not currently not sufficient to address all issues (Filippova and Noy 2020).

Costs associated with the EPB Act thus appear likely to have negative economic and social impacts, in particular for New Zealand's small towns. This provides a strong moral impetus to identify innovative ways of improving seismic safety while minimizing the social and economic burdens. Filippova and Noy (2020) investigated this problem from a financial and legislative standpoint. In this paper, we investigate possibilities from an engineering standpoint, specifically around a simplified approach to seismic strengthening of URM buildings that we refer to here as “simple strengthening”. The proposal should be seen in the light of attempting to reduce the seismic risks from URM buildings while retaining some of the social, cultural, and historic value that they offer.

SIMPLE STRENGTHENING PROPOSAL

This paper investigates a simplified approach to seismic strengthening of URM buildings termed “simplified strengthening”. Under this approach, URM buildings meeting certain criteria would be strengthened using standard details without specific engineering input and be otherwise exempted from the requirements of the EPB Act.

Typology A building – one storey isolated.

Typology B building – one storey row.

Typology C building – two storey isolated.

Typology D building – two storey row.

Figure 1: Eligible buildings. Reproduced from Ingham & Russell (2010) with permission.

Eligible buildings

The buildings that this proposal targets are the one- and two-storey commercial/residential structures which line the main streets of regional New Zealand. These buildings fit within Typologies A-D as defined in Russell and Ingham (2010) (see Figure 1). Larger, more structurally complex URM buildings like churches and multi-storey masonry buildings in urban centres would not be included. URM buildings eligible for standard detail strengthening would be defined by a specific set of criteria, such as:

- Lateral load resisting system constructed of unreinforced clay brick masonry (i.e., not RC frame buildings with brick infill) with a minimum length of wall in each direction
- Located in an area with hazard factor (Z) per NZS1170.5:2004 not greater than a threshold value around 0.40 - 0.45
- No more than two storeys tall (basement not included)
- Inter-storey heights and diaphragm spans not to exceeding given threshold values
- Capital value not greater than a given threshold value[1]

These criteria have been set as a starting point to capture buildings within the target group. It is noted that further work would be needed to refine these if a "simple strengthening" scheme were to be implemented.

<u>Simple strengthening</u>

The standard strengthening to be applied to all eligible buildings under this proposal consists of the following measures:

- Parapets and ornaments to be restrained or removed.
- Roof structure to be connected to walls at each rafter and at regular centres along gables and walls parallel to rafters.
- Floors to be connected to walls at each joist and at regular centres along end joists parallel to walls.
- Cavity walls to be strengthened with cavity ties at regular centres.
- Canopy connections (and/or local zones around canopy connections) to be reviewed and strengthened.

For some buildings, the following additional measures should also be applied (see the Structural Effectiveness section for further detail):

- Timber strongbacks to be added to masonry walls for out-of-plane restraint (on the basis of lookup tables with input variables, for example, height, wall thickness, wall length between significant return walls and hazard factor).
- Diaphragm strengthening by adding plywood and nailing (on the basis of lookup tables with input variables, for example, aspect ratio and hazard factor)
- Chimneys to be removed or strengthened (on the basis of lookup tables with variables, for example maximum height above the roof plane, minimum width and hazard factor).

A starting point for the set of standard details could simply be the details as contained in the MBIE document *Securing Parapets and Facades on Unreinforced Masonry Buildings* (MBIE, 2018). It is intended that such details would be simple enough to be understood and implemented by local tradespeople, in a manner not dissimilar to the non-specific timber and masonry standards (NZS3604 and NZS4229). Once strengthened with these details, eligible buildings could be exempted from further requirements under the EPB Act. It would not be necessary to then attempt to quantify building-specific performance using the %NBS metric.

Note that this paper does not suggest that a standard-detail seismic strengthening scheme would perform "better" than a building-specific strengthening schemes (the relative seismic performance would depend entirely on how the standard-detail seismic strengthening scheme was implemented). The authors contend only that simple strengthening would make URM

[1] Capital value is used as a broad proxy for the asset value of the building and the consequent ability to generate revenue to fund strengthening or replacement. While it does not capture the financial resources of individual owners, it acts as a coarse sorting measure to distinguish buildings which should be expect to fund bespoke strengthening from those which cannot realistically be expected to do so.

buildings significantly safer, and that carrying out good-quality standard-detail strengthening is better than no strengthening at all.

STRUCTURAL EFFECTIVENESS

This section provides a brief overview of the measures which make up the proposed simple strengthening for eligible buildings. The measures have been chosen on the basis that they frequently form part of bespoke strengthening schemes, that they address the common weaknesses of eligible buildings, and that they have been shown to be effective by research, testing, and engineering practice. It is considered likely that such measures would be prescribed as part of the strengthening of a typical URM building if bespoke design was to be carried out. An example showing how the measures would be applied to a typical eligible building is given in Figure 2.

Parapets, canopies, ornaments and chimneys

Intent: parapets, chimneys and ornaments always braced or removed; canopy connections strengthened.

Parapets and ornaments on URM buildings almost always require strengthening, regardless of the location of the building. This necessity has been recognised in a number of ways, notably by the Hurunui/Kaikōura Earthquakes Recovery (Unreinforced Masonry Buildings) Order 2017 (NZ Govt, 2017) and its associated Securing Fund, which mandated parapet and façade securing works for URM buildings in certain locations in the immediate aftermath of the Kaikōura earthquakes. MBIE's guidance around allowable heights for unbraced parapets shows that most require bracing (MBIE, 2018). For the purposes of simple strengthening, we propose that any parapet more than two courses above the roof line should be braced.

From an analysis perspective, chimney stacks are somewhat similar to parapets in that they are cantilevering structures supported at the upper level of the building. The requirement to strengthen them could be simplified into a lookup table.

Wall-to-floor and wall-to-roof connections

Intent: connect all perpendicular joists and rafters to walls; connect all parallel joists and rafters to end walls at the same spacing as the perpendicular joists/rafters.

Connecting floors and roofs to walls is the essential portion of the strengthening described in this paper. The Guidelines for Seismic Assessment of Existing Buildings Section C8.2.7 (MBIE, 2017) provides a description of the state of connections in unreinforced brick masonry buildings: "URM buildings are characterised by absent or weak connections between various structural components." The Guidelines also note, "often, walls parallel to the joists and rafters are not tied to the floors and roof." Connections where joists and rafters are perpendicular to walls exhibit a range of typologies, though as noted in Auckland Council's *Earthquake Prone Buildings–Guidance and Approaches* document (Auckland Council, 2018), these connections are often friction-only, with joists and rafters pocketed into voids in the masonry or seated on "steps" where the wall thickness reduces. The authors' experience of assessing friction-only connections suggests that they are typically insufficient for restraining walls and transferring loads, even in regions of low seismicity. While friction-only connections can be shown to be effective in lower-storey walls where there is ample top load, engineering judgement and the identification of load paths is required to make this determination. The simplest approach, where standard details are being used without engineering input, is therefore to strengthen all floor-to-wall and roof-to-wall connections.

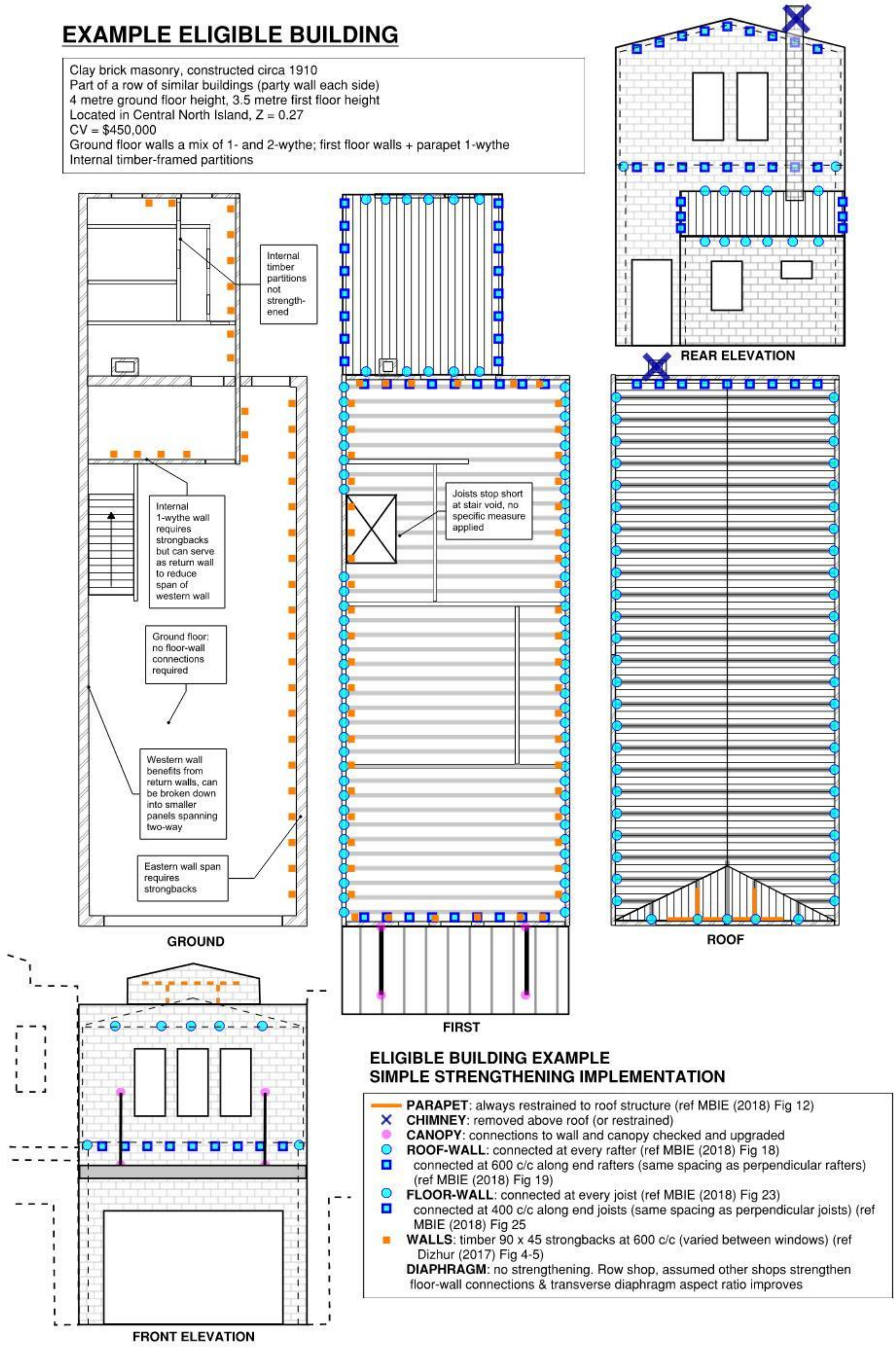

Figure 2: Example strengthening of an eligible building

Cavity walls

Intent: strengthen all cavity walls with horizontal ties

Around 40% of New Zealand's URM buildings contain cavity walls (Dizhur and Ingham 2015). These walls have a gap between the inner and outer skins, which serves as a moisture and temperature control barrier. Cavity walls have been shown to be vulnerable to earthquake loading (Dizhur and Ingham 2015), and their failure modes often result in masonry being projected outward from the structure, potentially falling into public space. A programme of research and testing by the University of Auckland has shown that rigid steel cavity ties are effective in securing outer leaves to inner leaves, increasing the out-of-plane displacement capacity of the wall (Giaretton et al. 2016). It is therefore proposed that cavity ties should be used as a standard detail for buildings undergoing simple strengthening.

Out-of-plane walls and timber strongbacks

Intent: slender and long masonry walls strengthened with strongbacks, especially in regions with higher demand

Experimental testing of URM walls with timber strongbacks by Dizhur et al (2017) has shown that the strongbacks "allowed flexural behaviour with a significant reduction in displacement and an increased PGA of three times the as-built condition for both cavity- and solid-walls." The strongbacks tested were standard 90 x 45mm timbers, suggesting that existing timber wall linings (where present) may be able to be converted to strongbacks with the aid of timber to masonry ties. Simple strengthening requirements around out-of-plane strengthening could be simply expressed by way of a lookup table, with input variables being wall height, wall thickness, wall length between significant return walls and hazard factor Z. It is intended that this table would be calibrated to include the beneficial effect of two-way span, which tends not to be accounted for in current practice due to the requirement for special study per the NZSEE Assessment Guidelines Section C8.8.5.3 (MBIE 2017).

Diaphragms

Intent: strengthened where aspect ratio is greater than a threshold for any direction

URM buildings generally require roof and floor diaphragms in order for face loads to be transferred to in-plane walls and to limit the displacement of face-loaded walls. The existing diaphragms of URM buildings have inherent capacity, as is recognised by the Assessment Guidelines and the research supporting the analysis methods they contain (MBIE 2017). As-built diaphragm capacity is often limited by connection capacity, which has been dealt with above. When diaphragms become overly slender, displacements increase, affecting the stability of face-loaded walls. The simple strengthening proposal is therefore that diaphragms with an aspect ratio of greater than roughly 2.5:1 measured between supporting in-plane walls in either orthogonal direction, should be strengthened with a plywood overlay. The authors recognise that diaphragm strengthening can increase costs of strengthening markedly. For this reason, it is proposed that where neighbouring buildings are being strengthened, the diaphragm aspect ratio could be considered across the row (see Figure 3).

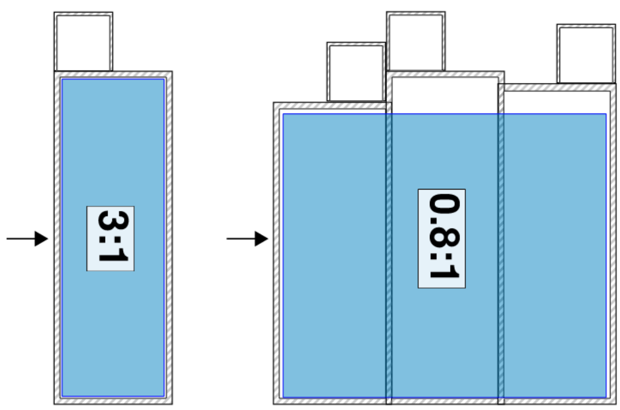

Figure 3: Diaphragm aspect ratio considered for a single building and a building within a row

In-plane walls
Intent: not included

In-plane strengthening has been excluded from the simple strengthening proposal, noting that URM buildings in high hazard areas with small masonry wall lengths are not considered eligible for simple strengthening. The authors' experience of assessment and strengthening of URM buildings suggests that considerable engineering time can be spent on determining the in-plane capacity of the walls. However, assessment is often strength-based only and the use of more detailed assessment approaches (such as the capacity-spectrum approach or nonlinear time-history analysis that allows for the effect of return walls) can show that in-plane walls are more resilient than might otherwise be expected. We also note that diaphragm and connection enhancements provided as part of seismic strengthening are likely also to provide additional in-plane robustness to open-fronted buildings through torsional restraint, especially in row buildings.

RISK, COSTS AND BENEFITS

The cost to implement the proposed simple strengthening is expected to be lower than the current approach. Reasons include: (a) simple strengthening would not require building-specific assessment and strengthening design; (b) simple strengthening would make use of typical details that have been optimized for buildability and kept consistent over multiple projects; (c) simple strengthening could be managed by building owners and implemented by local tradespeople. A reduction in cost also appears likely in that simple strengthening is intended generally to be targeted toward primary life-safety issues for URM buildings, such as the tying in of floors to walls, restraint of parapets and restraint of walls out-of-plane (i.e., it is similar to the "Bolts Plus" approach). The costs of a "Bolts Plus" type of intervention, in comparison to "full" strengthening including in-plane wall strengthening, have been investigated by Rutherford and Chekene (1990), Martin Jenkins (2012), Moore (2014), Paxton (2014) and others. It appears from these studies that cost savings associated with a simpler approach to strengthening could be as high as around 30% - 70% in some cases. However, it must be noted such cost reductions are highly variable and would depend strongly on how the simple strengthening scheme was implemented.

Simple strengthening would be targeted to mitigate key failure modes that are primarily responsible for fatality risks in URM buildings. Therefore, at high level, comparable risk reduction benefits are expected between bespoke and simple strengthening. Cost-benefit analyses undertaken by Paxton (2014) and Cutfield (2016) both point toward opportunities for significantly increased cost-effectiveness.

EXPERIENCE IN THE USA – BOLTS PLUS STRENGTHENING

Several mandatory seismic strengthening policies have been implemented in the United States that targeted URM buildings. A useful summary of these is provided by Paxton et al. (2015).

The San Francisco Building Code Ordinance 225-92, implemented in 1992, is of particular relevance to this paper. It included two possible retrofit alternatives. The first followed the specifications of the Uniform Code for Building Conservation (UCBC). However, for buildings fulfilling a certain set of criteria, a "Bolts Plus" level of seismic retrofit was also permitted. "Bolts Plus" strengthening included tying together of walls and floors, parapet strengthening, and out-of-plane strengthening for URM walls exceeding a given height-to-thickness ratio. For a URM buildings to be eligible for "Bolts Plus" strengthening, it had to fulfil a number of criteria, such as: (a) timber diaphragms at all levels; (b) maximum of 6 storeys; (c) no significant structural irregularities; (d) a minimum of two lines of lateral load-resisting walls in each direction (e.g. "open front" buildings were not eligible).

The “Bolts Plus” retrofit option was successful in reducing the proportion of URM buildings demolished in San Francisco (8%) relative to Los Angeles (30%), where more restrictive mandatory strengthening policy was implemented (Paxton et al. 2015). However, the “Bolts Plus” scheme only ended up being applicable to a relatively small subset of San Francisco’s URM buildings, which may have limited its impact. There is also the issue of engineering effectiveness, for which some concerns have been raised for example by Turner (2020). Such concerns highlight the need for a scheme like Simple Strengthening to have a carefully considered engineering basis.

LEGAL FRAMEWORK

This paper proposes an approach whereby eligible buildings that have had the simple strengthening measures applied to them should be exempted from the requirements of the EPB Act. It is noted that a possible mechanism for an exemption is already contained with the EPB Act. Section 401C(b) allows the Executive Council (all Ministers of the Crown) to determine “any … characteristics that a building or a part of a building must have for a territorial authority to grant an exemption [from the requirements of the Act] under section 133AN” (NZ Govt, 2016). Section 401C(b) therefore permits a list of characteristics like those given previously to be granted legal force as sorting criteria to define eligible buildings. This paper proposes that a further characteristic for the exemption to be granted could be the completion of simple strengthening. A precedent for the use of an Order-in-Council to make selective requirements for URM buildings is the Hurunui/Kaikōura Earthquakes Recovery (Unreinforced Masonry Buildings) Order (2017), which defined affected buildings by street name.

COMMENTS AROUND EARTHQUAKE INSURANCE

While owners of unstrengthened EPBs may find it difficult to afford insurance (or obtain it at all) (Fillipova and Noy 2020), strengthening a building is not always sufficient to reduce premiums to affordable levels. Egbelakin et al (2011) reported that “*the cost of insurance premiums does not reflect seismic mitigation actions implemented in a retrofitted EPB*”. The study also noted that “*28% of the owners interviewed complained they were unable to purchase insurance after retrofitting their EPBs to structural performance standard greater than 67%NBS*.” Recent comments from the Insurance Council tend to suggest that insurers view increased life-safety from strengthening as a separate issue from the likelihood of structural damage, meaning that premiums may not be significantly affected by strengthening (Norman, 2020). A building owner’s choice of simple strengthening vs bespoke strengthening may therefore not significantly affect a building’s insurability or the affordability of any available insurance.

Fillipova and Noy (2020) note that in New Zealand, the government already plays a significant role in providing earthquake insurance for private property, particularly residential property. While they point out that there is limited political will to provide government insurance for commercial property, they also suggest a number of ways in which government could extend the insurance cover it provides, in order to incentivise strengthening work to take place. An example given is insuring contractors against liability from the strengthening works they carry out, with the intention of lowering the cost of strengthening.

LIMITATIONS

The authors acknowledge a number of limitations which are inherent in the proposal to apply standard-detail strengthening to a subset of URM buildings. A non-exhaustive list of such limitations follows:

- **Removal of specific engineering input**. A scheme like simple strengthening would be set up so as to capture the key vulnerabilities expected to drive the overall performance of URM buildings. However, without building-specific engineering input, there would be risk of more minor building-specific vulnerabilities being missed. It could also lead to a situation where strengthened URM buildings in big cities have different performance expectations relative to strengthened URM buildings in smaller towns.
- **An exemption for URM EPBs which does not apply to other building types**. The similarities in the construction of URM buildings, and the research which has been carried out into their failure modes, has allowed the creation of a set of standard details which cover the limited construction typologies of eligible URM buildings. The same cannot necessarily be said for other earthquake-prone building types. If the proposal in this paper were to be adopted, owners of URM buildings would have an escape route from the EPB Act which would not be afforded to owners of other building types.
- **Liability and quality assurance**. An important factor in the cost of assessment of URM buildings is the necessity for an engineer to assume liability for rating the performance of the building, which in turn necessitates the engineer to perform analysis until they are satisfied that building response can be sufficiently well understood and performance goals can be met. Under this proposal, engineers are not involved and do not assume liability. Liability would therefore rest between the owner of the building, the contractor who carries out the standard details, and the TLA building inspector who verifies that the work has been done according to the details.

CONCLUSION

This paper summarises current research into the outcomes of the EPB Act for earthquake-prone URM buildings in regional New Zealand. It finds that owners face high costs for assessment and strengthening of their buildings. The resulting prediction is that many buildings, concentrated in regional centres, will be demolished or abandoned at the EPB Act deadlines, with consequent negative impacts on local communities. In the interim before the deadlines, safety improvements are not being made to guard against possible earthquakes.

The paper demonstrates that for common types of URM buildings, standard-detail solutions exist, which could be applied without specific engineering assistance (simple strengthening). The intent is that costs associated with assessment and bespoke engineering are removed, and a pathway is provided for owners to continue to operate their buildings. While the performance improvement from simple strengthening would not be precisely quantified, engineering judgement and experience shows that the implementation of these measures will make the earthquake-prone URM buildings safer and more robust. Standard-detail simple strengthening may be the only seismic improvement that can reasonably be afforded by many owners in regional centres without additional financial assistance. A parallel is drawn to the Bolts Plus standard-detail retrofit programme which was run in several cities in the USA.

The EPB Act legislation contains the flexibility needed to provide strengthening requirements tailored to the needs and capabilities of communities. The next steps required would be refine the engineering parameters, to test the willingness of local communities to engage with a standard-detail strengthening programme, as well as working on the support that would need to be provided to TLAs to help them administer such a scheme. The decision to proceed with a simple strengthening programme ultimately rests with the Executive Council and would require political will. However, the “do-nothing” alternative could be catastrophic for regional New Zealand. Under current settings, significant abandonment or demolition is expected along the streets that have formed the backdrop of our small towns for the last century.

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