A SURVEY OF STRUCTURAL MODELLING PRACTICE FOR UNREINFORCED MASONRY BUILDINGS IN AOTEAROA NEW ZEALAND

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ABSTRACT

Structural modelling is central to seismic assessment and retrofit efforts for unreinforced masonry (URM) buildings, yet limited information exists on how these buildings are modelled in industry practice in Aotearoa New Zealand. A nationwide survey of structural modelling practice in the context of URM seismic assessment and improvement was undertaken to investigate modelling approaches, factors influencing method selection, sources of material properties, modelling assumptions, technical challenges, confidence in model reliability, and perceptions of existing guidance. A total of 45 responses were obtained from practitioners having a wide range of experience. The results indicate that simplified static analysis methods are most commonly used, particularly for low-rise buildings with regular configurations that make up most of the national URM building stock. Advanced numerical analyses are applied less frequently and are generally reserved for complex structures or cases requiring more detailed analysis. Modelling decisions are driven primarily by building complexity, project constraints, performance objectives, and the availability of reliable data. Material properties are typically derived from code-recommended values, engineering judgement, and simple in-situ testing, and uncertainties are managed through conservative assumptions and sensitivity checks. Respondents identified modelling challenges, including building complexity, uncertain load paths and boundary conditions, software limitations, and the interaction between existing construction and retrofit works. Confidence in modelling results was generally moderate. Existing guidelines were considered adequate for typical buildings but less effective for complex cases. Respondents in general expressed strong support for harmonised modelling guidelines to improve the consistency of modelling results and reliability of URM seismic assessment practice in Aotearoa New Zealand.

Keywords: modelling practice, structural analysis, survey, unreinforced masonry.

1 INTRODUCTION

Unreinforced masonry buildings in Aotearoa New Zealand

Māori first arrived in Aotearoa New Zealand between approximately 1320 and 1350 CE. Early Māori construction traditions were derived from Polynesian building practices and were adapted to the colder climate of Aotearoa NZ, resulting in predominantly timber structures with smaller semi-subterranean forms, rectilinear plans, low walls, and gabled roofs (Brown, 2009). The first European to reach Aotearoa NZ was Abel Tasman in 1642, while British interest in Aotearoa NZ increased during the 1830s (Stubbs et al., 2023). Early colonial buildings were typically utilitarian, plain, and solid in character but Renaissance-influenced architectural styles became dominant in public and commercial buildings during the final three decades of the nineteenth century. By this time, unreinforced brick masonry was increasingly used because timber construction was considered vulnerable to fire (Shaw & Hallett, 1995). Construction of unreinforced masonry (URM) buildings continued until the 1931 Mw 7.8 Hawke's Bay earthquake that effectively ended widespread URM construction and led to the development of the first seismic design provisions in Aotearoa NZ (NZSS, 1935).

The existing URM building stock in Aotearoa NZ is dominated by low-rise structures that are typically about 100 years old and generally represent the oldest surviving commercial buildings in the country (Figure 1). In 2010 the total number of URM buildings in Aotearoa NZ was estimated to be approximately 3,750 (Russell & Ingham, 2010). These buildings are commonly used for mixed commercial and residential purposes and are often located along main streets at the centres of many provincial towns and community hubs in larger cities. The URM building stock features similarity in design across all of Aotearoa NZ, with approximately 90–95% comprising relatively simple structural geometry, while the remainder of the building stock serves as larger historic buildings and town landmarks such as town halls, railway stations, museums and public theatres (Goodwin et al., 2009; Russell & Ingham, 2010).

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Figure 1: Typical low-rise URM buildings

The poor seismic performance of URM buildings is well-known in Aotearoa NZ (Blaikie & Spurr, 1992; Ingham & Griffith, 2010; Dizhur et al., 2011; Moon et al., 2014). Both in-plane and out-of-plane failure mechanisms present significant hazards, particularly where buildings are located near public spaces (Derakhshan et al., 2014; Dizhur et al., 2013; Dizhur et al., 2017). As a result, the assessment and strengthening of URM buildings have become major engineering and policy concerns. Guidelines, including the Detailed Seismic Assessment Guidelines (commonly referred to as C8), NZS 1170.5, and related procedures (e.g. ASCE 41-23), provide recommended methods for evaluating seismic performance. These frameworks define analytical procedures, acceptance criteria, and performance objectives for existing URM buildings. Within this framework, structural modelling is a critical component for estimating seismic response and identifying governing failure mechanisms in URM structures.

Modelling of URM buildings

A wide range of methodologies have been developed for the seismic assessment and structural modelling of URM buildings. These methods are used to predict the complex behaviour of URM buildings and meet the different objectives of engineering analysis. They range from simplified calculation-based procedures to advanced numerical simulations. The choice of approach is usually governed by building characteristics, available information, required level of accuracy, and project constraints. Structural modelling has therefore become an essential tool in using methods beyond the basic procedures provided in codes and guidelines for existing URM buildings.

Lessons learned from blind prediction studies provide clear evidence of the challenges associated with URM modelling (Mendes et al., 2017; Cattari & Magenes, 2022; Calderini et al., 2024; Tomić et al., 2024). Results from these blind prediction studies were largely varied, not only across different modelling approaches but also across analyses conducted by different modellers using the same method. This variability demonstrates the strong influence of modelling assumptions and user decisions on the analysis results.

A notable example is a blind prediction exercise on a three-storey European masonry building reported in a Special Session of the European Conference on Earthquake Engineering. Participating teams used a variety of modelling strategies (Parisse et al., 2021). The predicted damage patterns and collapse mechanisms were generally similar, yet the type and extent of failure modes differed across analysis results obtained using different approaches. More importantly, the predicted capacity curves and peak ground accelerations (PGA) were significantly scattered. The variability was particularly pronounced in brick masonry buildings, meaning that clearer modelling procedures are needed to support consistent professional practice. Similar conclusions were drawn from the URM nonlinear modelling benchmark project funded by the ReLUIS consortium and the Italian Department of Civil Protection (Cannizzaro et al., 2022). In that study, the scatter of results was reduced by adopting consistent modelling assumptions. However, noticeable differences remained, especially in the ultimate displacement capacity of the pushover curve, which is a parameter that significantly affects the seismic assessment results. These blind prediction studies collectively indicate that reliable structural modelling requires expertise in the selected modelling approach, material representation, and software implementation. Developing such expertise typically demands considerable time and experience. In professional practice, however, engineers are often required to undertake complex analyses within tight timeframes dictated by project budgets and contractual obligations. At the same time, software developers aim to provide user-friendly interfaces and default parameters to facilitate wider use. While simpler software features improve accessibility, they may also enable inexperienced users to perform sophisticated analyses without fully understanding the assumptions or limitations associated with the selected method or the software that is used.

Despite the importance of modelling decisions, current building codes provide limited guidance on the selection and application of modelling approaches, and substantial reliance is placed on engineering judgement during model development. All these issues highlight the need for frameworks and recommendations to support the proper use of these modelling approaches and raise awareness among users about the reliability of the model outputs.

The results of a nationwide survey of practitioners involved in the seismic assessment of unreinforced masonry buildings in Aotearoa NZ are presented in this study. The modelling approaches, reasoning behind modelling choices, material assumptions, challenges encountered, and perceptions of reliability of the current modelling approaches and guidelines were investigated. The broader objective of this study was to identify areas where additional guidance, standardisation, or research may be beneficial.

2 SURVEY METHODOLOGY

Survey design

The survey was designed to investigate the current industry practice in the structural modelling of URM buildings in Aotearoa NZ. The questionnaire consisted of multiple sections covering respondent demographics, modelling approaches, sources of model properties and assumptions, modelling challenges, and the perceptions of practising engineers regarding the codes and guidelines available for the seismic assessment of URM buildings.

The questionnaire included a combination of closed-ended and open-ended questions. The closed-ended questions employed multiple-choice or Likert-type formats to enable quantitative analysis of modelling approaches, confidence levels, and influencing factors, with several questions allowing multiple selections when appropriate. The open-ended questions were designed to obtain qualitative insights into the reasoning behind the modelling choices, challenges encountered in practice, and suggested improvements to codes and guidelines. This mixed-methods approach captured both statistical trends and practitioner perspectives. Ethics approval for the study was obtained from the University of Auckland Human Participants Ethics Committee prior to data collection (Ref. UAHPEC28901). Participation was voluntary and anonymous, and no personally identifiable information was collected without consent.

Respondents and survey distribution

The inclusion criteria for respondents were structural engineers practising in Aotearoa NZ who have experience in the seismic assessment or modelling of URM buildings. The survey was distributed primarily through the Structural Engineering Society of New Zealand (SESOC) membership, which includes a large proportion of practising structural engineers in the country. Distribution channels utilised were professional mailing lists and networks associated with SESOC. Due to voluntary participation and self-identification of respondents as having relevant experience in URM modelling, the sample reflects practitioners actively engaged in this area of work rather than the broader engineering population.

A total of 45 valid responses were obtained and approximately 50% represented fully completed surveys. Among the 45 respondents, 60% identified themselves as Senior Structural Engineers with more than 10 years of industry experience, 24% identified themselves as Structural Engineers with less than 10 years of experience, and 16% identified themselves as Engineering Consultants (Figure 2a). In this context, a structural engineer refers to a specialist focusing specifically on the design, analysis, and safety of structures such as buildings and bridges, whereas an engineering consultant refers to a licensed expert providing strategic advice, design, and project management services across a range of engineering disciplines.

In terms of experience specifically related to the seismic assessment of unreinforced masonry (URM) buildings, 38% reported more than 10 years of experience, 31% reported 6 to 10 years of experience, 18% reported 2 to 5 years of experience, and 13% reported less than 2 years of experience. The majority of respondents indicated that their professional work and experience were based in Aotearoa NZ (75%), while the remaining 25% reported experience that also covered other regions, including Asia, Europe, Australia, and North America (Figure 2b).

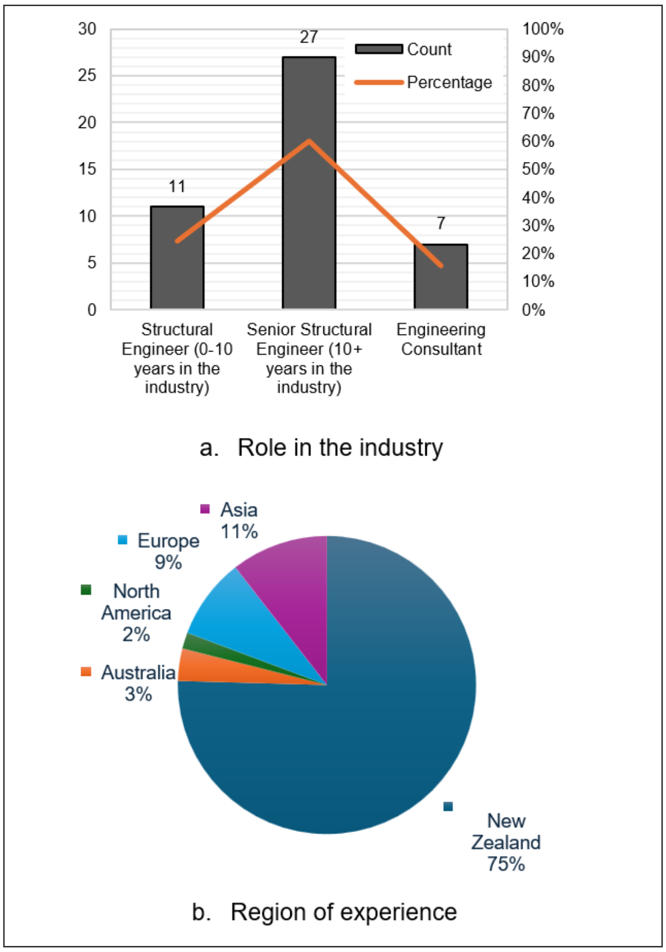


Figure 2: Respondent demographics

Data analysis

Responses were analysed using a combination of quantitative and qualitative methods. Quantitative analysis was applied to closed-ended responses to determine frequencies, distributions, and dominant trends. Qualitative responses to open-ended questions were analysed using thematic coding to identify recurring themes and common categories. This process involved grouping similar responses and identifying frequently occurring keywords through word-cloud illustration when appropriate to provide a structured interpretation of qualitative data.

3 SURVEY RESULTS AND ANALYSIS

Modelling strategies

Modelling efforts were most commonly undertaken to support retrofit design decisions, identify governing failure mechanisms, estimate building force capacity, understand load paths, obtain building displacement capacity, and obtain force resultant values for structural members. The distribution of the modelling objectives is presented in Figure 3.

Respondents reported a wide range of calculation and modelling approaches for URM buildings, and the results reflected both the diversity of building characteristics and the absence of a single standardised methodology for URM seismic assessment. As shown in Figure 4, a calculation-based simplified static method (e.g. force-based calculation, code-based calculation) was selected by 23% of respondents, software-aided linear static analysis was selected by 15% of respondents, a calculation-based equivalent frame method was chosen by 13% of respondents, and software-aided nonlinear static (pushover) analysis was selected by 12% of respondents. Other approaches mentioned by respondents included simplified lateral mechanism analysis (SLaMA) and a calculation-based macro-element method. These approaches appear to be favoured because they are relatively straightforward to implement, computationally efficient, and widely understood among practitioners. The practice trend is also consistent with the characteristics of the URM building stock in Aotearoa NZ, which consists largely of low-rise buildings with relatively regular configurations that allow simplification and generalised assumptions. More advanced techniques were used less frequently

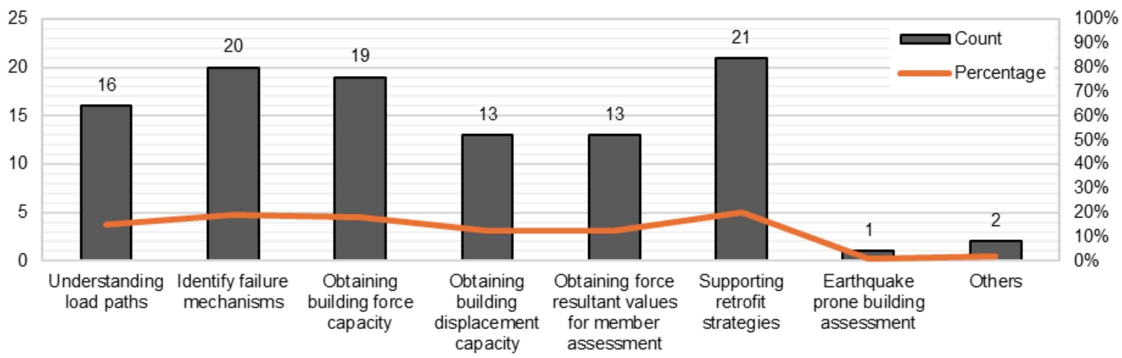


Figure 3: Modelling objectives

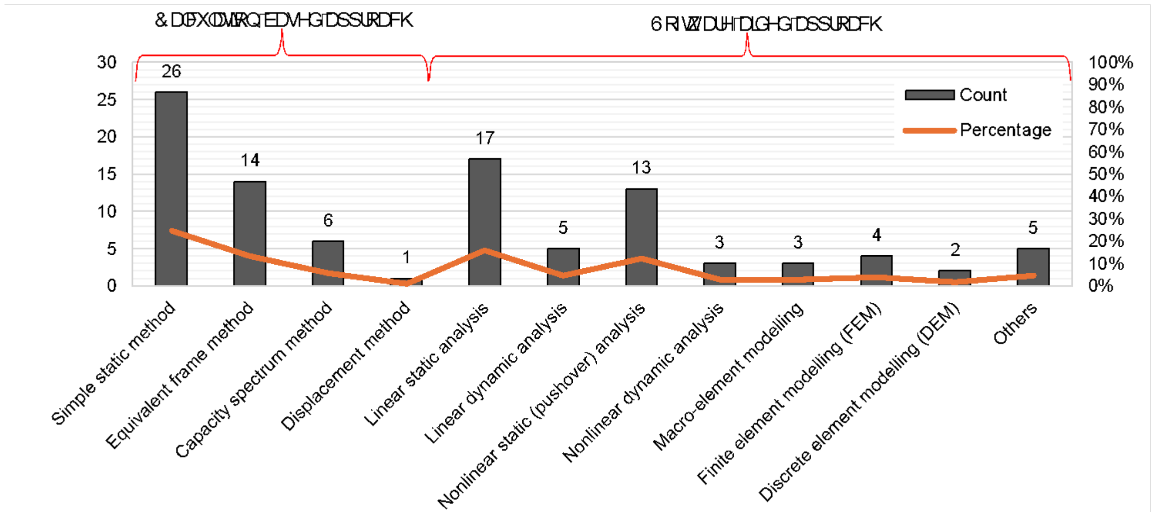


Figure 4: Modelling and analysis approach

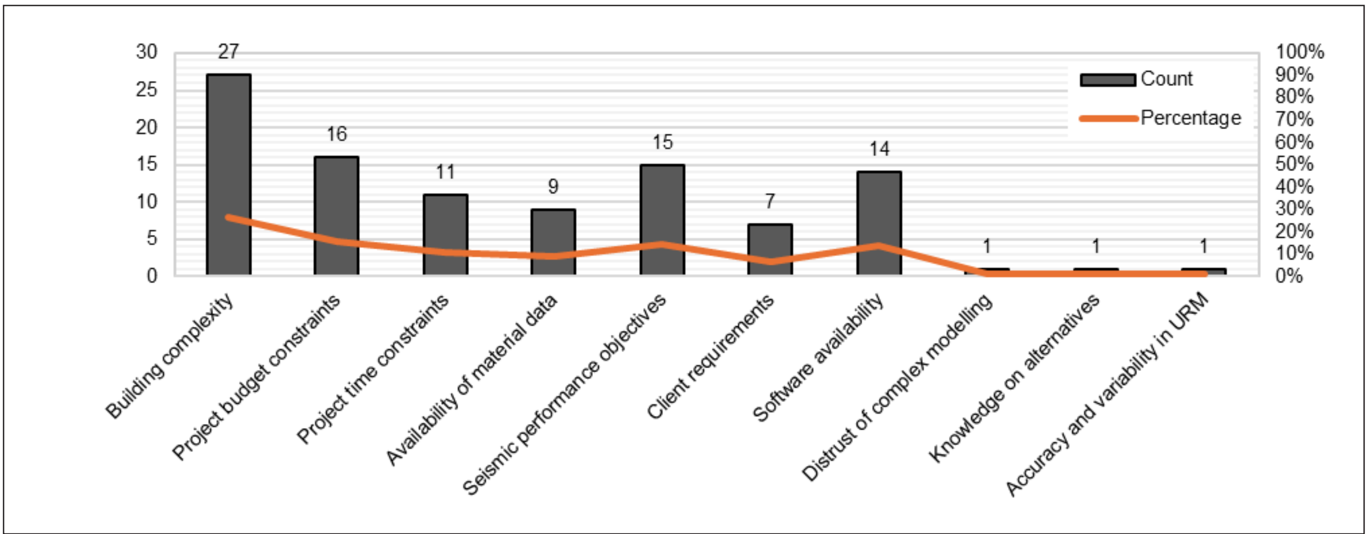


Figure 5: Reasoning behind modelling choices

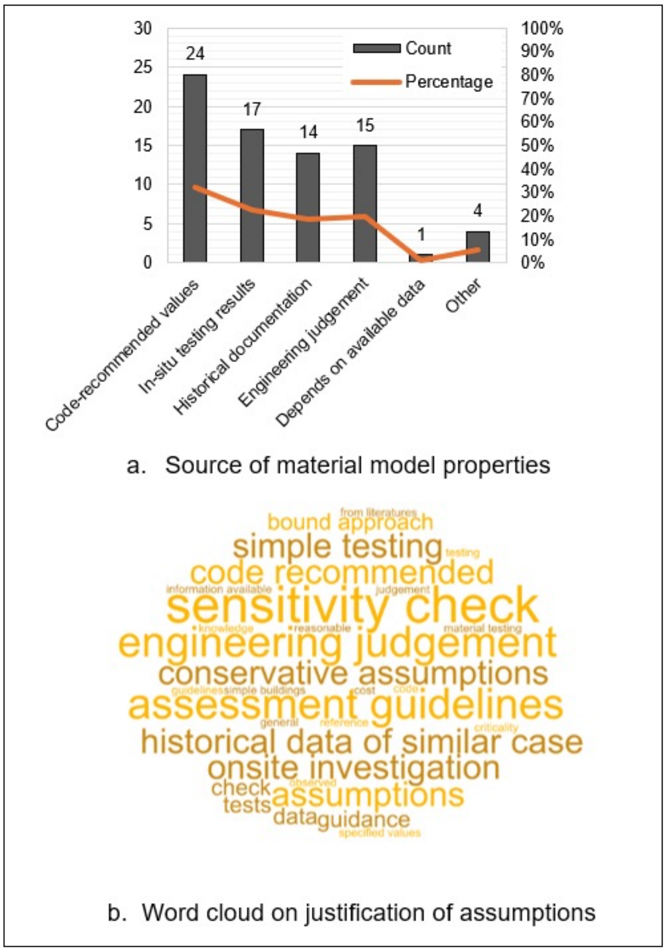
and were typically reserved for complex structures or situations requiring greater analytical detail. Nonlinear dynamic analysis, macro-element modelling, finite element modelling (FEM), and discrete element modelling (DEM) were reported by a smaller proportion of respondents, likely due to their computational cost and the need for specialised expertise.

The selection of modelling strategy was influenced by multiple factors, with building complexity identified as the dominant consideration (26%), as shown in Figure 5. Practical constraints, such as project budget limitations (16%), time constraints (11%), and availability of data (9%), also played a significant role, which accounted for over a third of responses and reflected the trade-offs between analytical rigour and project feasibility. Seismic performance objectives were another major reason (15%) as higher performance targets typically require more advanced modelling approaches. Software availability (14%) was also influential, indicating that modelling choices are partly shaped by access to suitable tools and familiarity with specific platforms. Client requirements that represent the role of stakeholder expectations in determining the level of analysis undertaken accounted for 7% of responses. Factors related to scepticism towards advanced modelling were scarcely mentioned as the reasoning behind the selection of approach. Distrust of complex modelling, lack of knowledge or guidance on alternative methods, and concerns regarding variability and uncertainty in URM behaviour each accounted for only 1% of responses. Overall, it is suggested from the results that modelling strategies in practice are driven primarily by technical demands and practical constraints rather than personal expertise and preferences. This observation is important because it may help the development of multi-level modelling guidelines that link the level of analytical complexity imposed by building characteristics, project constraints, and the consequences of modelling decisions.

Material modelling

Considerable variability was observed in how the material properties were determined and incorporated into the URM models. The sources of material model properties adopted in URM analysis and the rationale for material modelling assumptions in the absence of comprehensive data are presented in Figure 6. The code-recommended values were used most frequently as the source of material model properties (32%), which indicated a strong reliance on guidance and seismic provisions when detailed testing data are unavailable (Figure 6a). In-situ testing results (23%) were also used when feasible. The scale of testing mentioned varied considerably among respondents, ranging from simple scratch tests to full on-site investigations. In some responses, the extent of testing undertaken was not specified. Engineering judgement (20%) and historical documentation or published literature (19%) were also commonly used. This result suggests that practitioners rely on professional experience and previously documented information when first-hand data are limited. A small number of responses did not identify a specific source of material properties and instead indicated that modelling assumptions depended on the resources available for the project or on discrepancies between recommended values and observed building conditions.

Keywords of how assumptions are justified in practice are presented in Figure 6b. The prominence of terms such as engineering judgement, conservative assumptions, sensitivity check, code-recommended values, and on-site investigation indicates that engineers rely heavily on experience-based reasoning supported by the available references. Historical and similar case studies that were mentioned suggest that information from comparable buildings was used to supplement limited first-hand data. Practitioners also mentioned that adjustment of material property values during the modelling process is relatively common and is primarily undertaken to assess sensitivity and improve the realism of predicted behaviour. Sensitivity analyses were used to establish upper and lower bound capacities and to determine whether further investigation or testing was warranted. Overall, the results indicate that uncertainty in material properties is typically managed through conservative assumptions, verification/sanity checks, and iterative analysis.



a. Source of material model properties

b. Word cloud on justification of assumptions

Figure 6: Material modelling practices

Modelling challenges

Respondents identified numerous technical challenges associated with the modelling of URM buildings (Figure 7). The most frequently reported challenge was the overall complexity of modelling (26%) caused by difficulties associated with irregular geometry, mixed structural systems, heritage features, and uncertain construction details. Uncertainties in load paths (16%) and boundary conditions (16%) were also major concerns, particularly where diaphragm behaviour or connectivity between structural components was unclear. Software limitations and computational demands accounted for 12% of responses. Budget and time constraints were cited by 12% of respondents. Lack of reliable material data accounted for 10% of responses and was often compounded by deterioration and prior modifications.

Other challenges (9%) mentioned were a range of practical issues not captured by predefined categories. These challenges included difficulties in identifying the actual construction form from site investigations, limited confidence in complex numerical modelling or software results, concerns regarding diaphragm capacity and performance, and challenges in modelling systems beyond those explicitly covered by existing guidelines. Complex structural configurations, irregular geometry, and the presence of heritage features further increased modelling difficulty. Several dominant themes related to the challenges associated with modelling complex URM buildings are presented in Figure 8a. Terms such as computational time, software limitations, complex URM behaviour, and variability and inconsistencies indicate that advanced modelling is constrained not only by analytical difficulty but also by practical feasibility. URM structures generally exhibit non-homogeneous behaviour that is challenging to characterise, particularly when material properties and construction details are uncertain. The mention of hand calculation limitations suggests that simplified static methods may

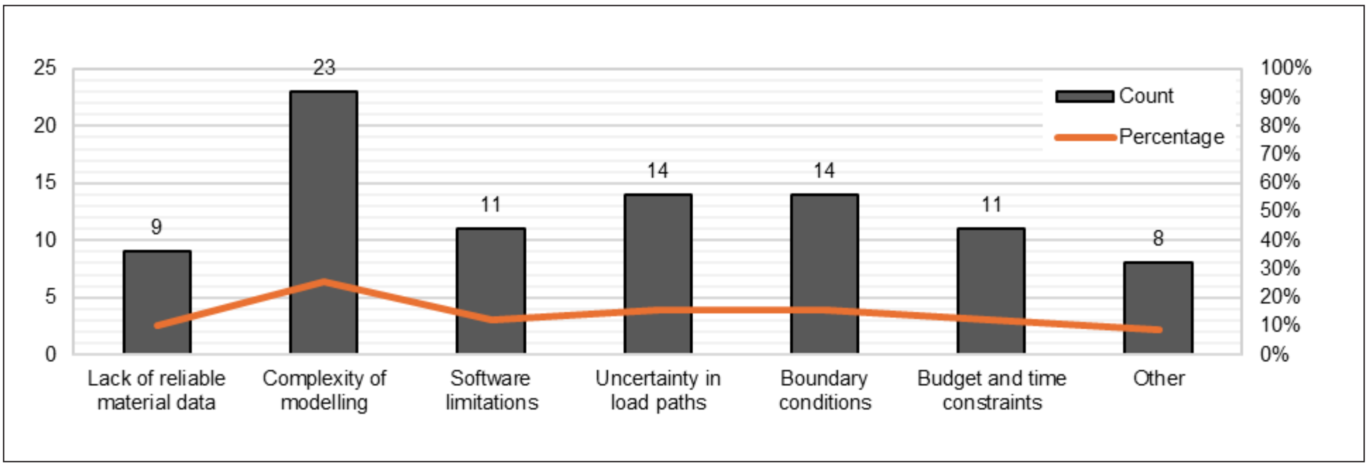


Figure 7: Challenges when modelling URM buildings

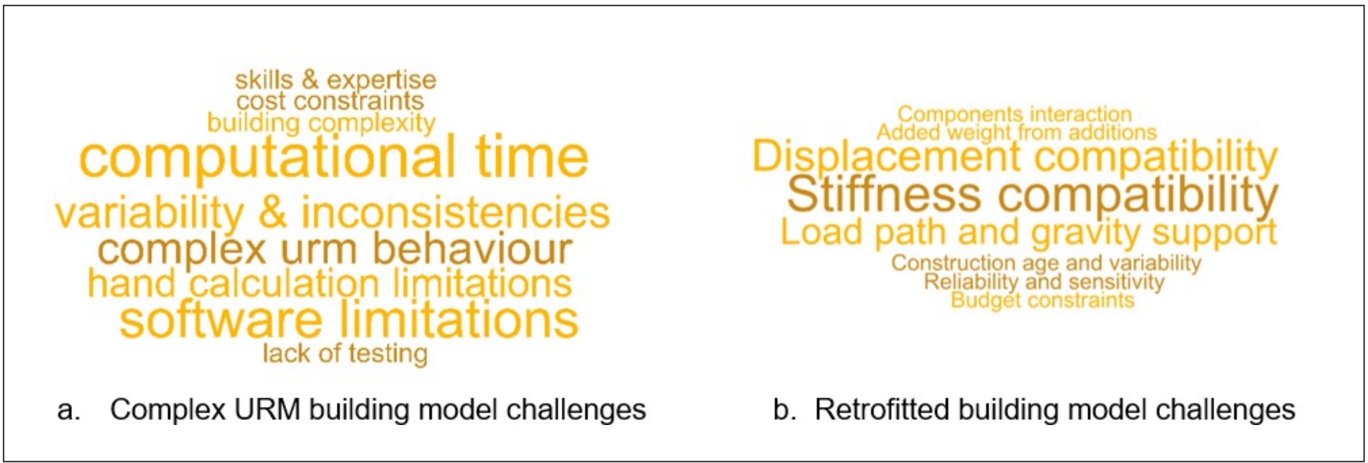


Figure 8: Challenges when modelling complex and retrofitted URM buildings

be insufficient for complex buildings, yet the required alternatives impose significant computational demands. The mention of cost constraints and expertise further indicates that advanced modelling approaches were not considered as pragmatic solutions. Specific technical difficulties faced by practitioners when modelling complex URM buildings included modelling out-of-plane wall behaviour, multi-leaf or cavity walls, irregular geometry, and buildings with unknown internal construction. To manage these challenges, engineers reported using a combination of conservative assumptions, simplified modelling techniques, targeted investigations, and engineering judgement.

Modelling of retrofitted URM buildings introduces additional complexity due to the interaction between existing materials and new strengthening systems. Respondents reported challenges related to stiffness compatibility, load redistribution, and displacement compatibility (Figure 8b). These compatibility issues arise from the difficulty of predicting how strengthening interventions interact with the original construction. Retrofitting often introduces new materials and structural systems with different stiffness and strength characteristics that can alter load distribution and deformation patterns. Additional concerns, such as added weight from additions, component interaction, and construction age and variability, emphasise the uncertainty associated with existing conditions and the potential for unintended consequences following the retrofitted works. The mention of reliability and sensitivity indicates that engineers must carefully evaluate the robustness of modelling assumptions, particularly when small changes in parameters may significantly influence the modelling results. In the context of complex retrofitted building models, some respondents also questioned the practical usefulness of highly detailed modelling when strengthening interventions are typically required regardless of the level of analytical precision achieved.

Confidence in the reliability of URM modelling results was generally moderate (Figure 9). Most respondents reported being somewhat confident (54%), while a substantial proportion expressed neutral views (34%). Only a small fraction of respondents indicated very high confidence (4%), and 8% of respondents reported low confidence. This distribution is further evidence that practitioners recognise both the usefulness and the limitations of commonly used modelling approaches. The predominance of simplified static analysis methods and the significant technical challenges associated with URM modelling likely contribute to this cautious confidence. While such approaches are practical and consistent with guideline procedures, the inherent uncertainties in URM modelling limit the level of confidence in detailed predictions.

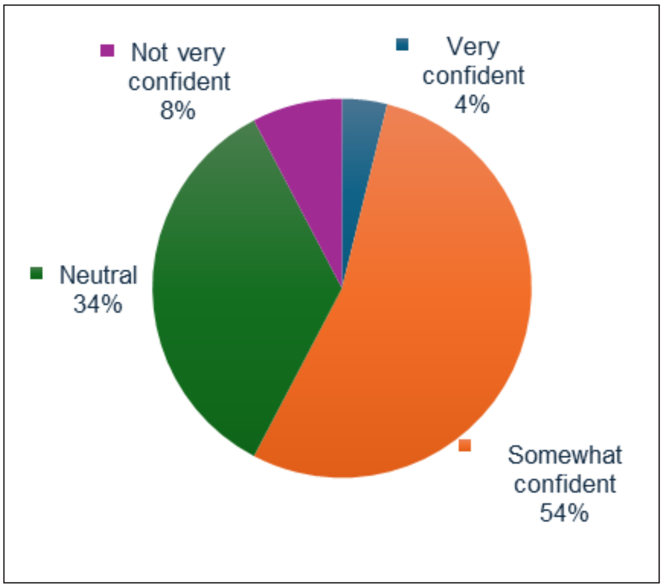
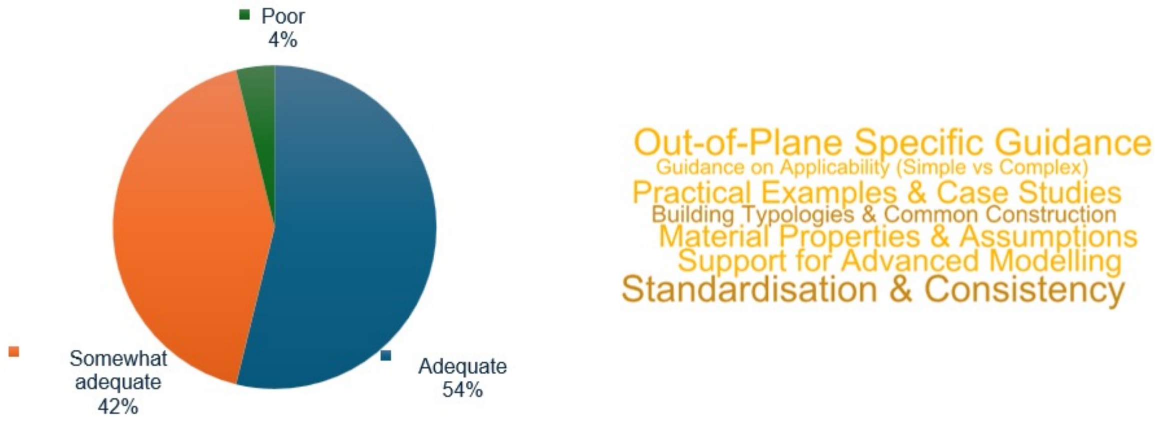


Figure 9: Confidence in the reliability of URM modelling



a. Adequacy of the current seismic guidelines for URM buildings

b. Aspects that should be better addressed in the guidelines

Figure 10: Respondent views on the seismic assessment guidelines for URM buildings

Code and guideline development

The majority of respondents indicated frequent use of established guidance documents for seismic assessment, particularly the Detailed Seismic Assessment Guidelines and NZS 1170.5. These documents were generally regarded as adequate for typical cases, with 54% of respondents rating them as adequate and 42% as somewhat adequate (Figure 10a). Only a small proportion of respondents (4%) considered the guidance to be poor. Despite this overall positive assessment, respondents noted that the guidelines are less effective for complex or unusual buildings.

Respondents also identified several aspects that should be better addressed or clarified in the Aotearoa NZ seismic assessment guidelines for URM buildings (Figure 10b). The most prominent themes relate to the need for improved guidance on out-of-plane behaviour as a critical failure mode for URM structures. Practitioners also highlighted the importance of clearer guidance on the applicability of different assessment methods for simple versus complex buildings, as well as the corresponding practical examples and case studies. Additional suggestions included better characterisation of material properties and assumptions, guidance on common building typologies and construction forms, and stronger support for advanced modelling approaches.

Strong support was expressed for the development of harmonised guidelines specifically addressing URM modelling in Aotearoa NZ. Respondents indicated that greater standardisation could improve consistency in assessment outcomes, reduce uncertainty associated with modelling assumptions, and enhance confidence in the reliability of results. Such guidance was seen as particularly valuable for well-supported and defensible engineering decisions across projects involving existing URM buildings.

4 CONCLUSION

A snapshot of the current industry practice regarding the structural modelling of URM buildings in Aotearoa NZ was presented based on a survey of structural engineers engaged in assessment and retrofit projects. Based on survey results, the following conclusions were drawn:

1. Structural modelling of older URM buildings is inherently complex, primarily due to uncertainties in material properties, construction details, boundary conditions, and the structural behaviour of ageing buildings.
2. A wide spectrum of modelling approaches is used in practice, ranging from simplified calculation-based methods to advanced numerical modelling. Engineers typically select methods based on building complexity, available data and resources, and project constraints.
3. The results from a survey of the adopted modelling strategies indicated a preference for the simpler static approach aligned with the existing guidelines for seismic assessment of URM buildings when this approach is adequate for decision-making, while reserving advanced modelling techniques for cases involving greater complexity or higher consequence.
4. Engineers reported cautious confidence in modelling results and recognised both the usefulness of the existing practical tools and the limitations imposed by uncertainty and variability. Verification through sanity checks and sensitivity analysis remains common practice.
5. Existing national guidelines were generally considered adequate for typical assessments but less effective for complex cases, particularly in relation to out-of-plane behaviour, boundary conditions, and advanced modelling approaches.

6. There was strong support within the professional community for the development of more harmonised guidelines to improve consistency and reliability in URM seismic assessment across Aotearoa NZ.

Overall, the results of the survey highlight the need for further development of practical modelling frameworks that covers multi-level objectives and complexity to support reliable and consistent seismic assessment of URM buildings in Aotearoa NZ. Several limitations of the survey results should be acknowledged. First, the sample size represents only a subset of structural engineers in Aotearoa NZ who were exposed to the survey, and therefore, the results may not fully capture the diversity of practice across all firms and regions. Second, participation was voluntary and thus introduced the potential for self-selection bias, as engineers with a strong interest or experience in URM assessment may have been more likely to respond. In addition, some questionnaires were incomplete, so not all responses were available for every question. Despite these limitations, the survey provided valuable insight into the current professional practices and trends in URM modelling in Aotearoa NZ.

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Brain Teasers

1. Cantilevered deck: An engineer came across a reinforced concrete cantilever deck (about 1.6m wide). The deck was lower on the outside edge due to creep and appeared to have corrosion stains on top, most likely due to corroding reinforcing steel. The engineer's solution was to prop the deck on the outside edge to prevent collapse. Was this a sensible solution?

2. Moving load: A beam with a span L = 10 m is crossed by a truck with two axle loads: Pb = 60 kN (rear, bigger) and Ps = 40 kN (front, smaller), separated by a distance d = 5 m. Find the maximum bending moment in the beam.

3. Intermediate timber partition: An engineer has designed a building with long span suspended concrete floors (precast with topping). The architect has indicated an intermediate line of timber framing at each level. Should this raise a red flag for the engineer?

Answers on page 114

Tips & Traps

Portal frame buildings

HERA has finalised Steel Portal Frame Design Guide – Volume 1, with release scheduled for April 2026. The technical development of the guide is complete, and the document is currently undergoing final formatting. The guide provides comprehensive, practice-focused guidance for the structural design of steel portal frame buildings, reflecting current New Zealand standards and industry best practice. It covers loading and load combinations, analytical modelling, structural analysis, and design of primary portal frame steelwork. A detailed worked portal frame design example is included to demonstrate the practical application of the recommended design methodology.