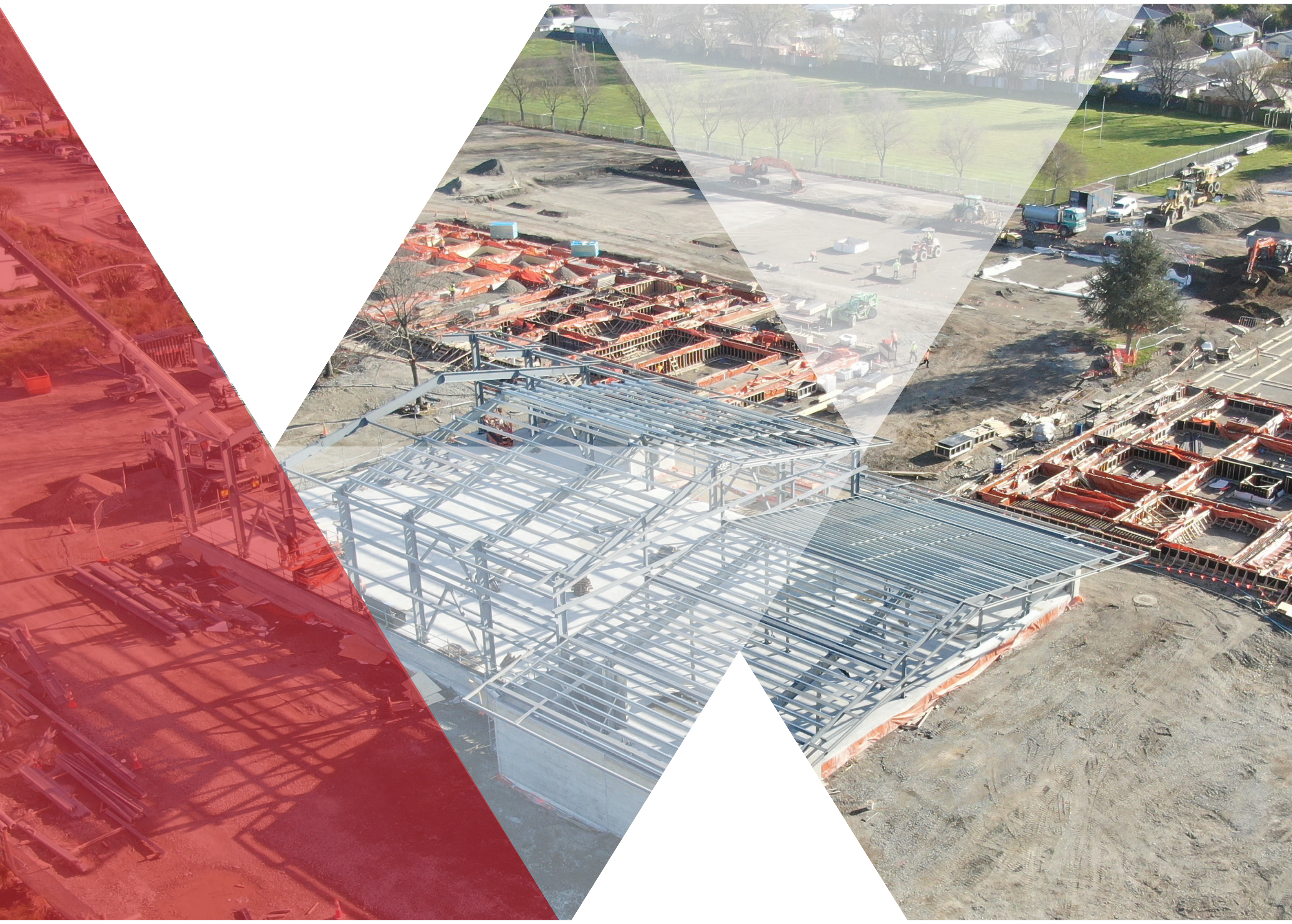
MINISTRY OF EDUCATION
TE TĀHUHU O TE MĀTAURANGA

Designing Schools in New Zealand

Structural and Geotechnical Requirements

Version 3.0, October 2020



BUILDING PERFORMANCE

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

New Zealand Government

Document History

The table below is a record of the changes that have been made to this document:

Version	Date	Summary of Changes
Version 1.0	09/03/2015	• First version for general issue
Version 1.1	29/06/2015	• Section 2.6 Masonry Veneer: the policy on the use of masonry veneer on new buildings has been amended to reflect a more risk-based approach. Figures have been added to illustrate the policy. • Section 3.5 Seismic Assessment of Existing Buildings: treatment of timber-framed school buildings with heavy roofs (or internal walls removed) has been clarified.
Version 2.0	30/03/2016	• General editing revision, including changes to reflect the latest design guidance documents issued by the Ministry. • Clarification of terminology relating to site and ground classification (e.g. deletion of previous Table 3). • Some re-ordering of sub-sections. • Deletion of previous Appendix A: Project and Site Constraints Table (which is now released as a standalone document, can be found from the Ministry's online Education Infrastructure Design Guidance Documents pages, and is included in the Project Brief document). • Deletion of previous Appendix B: Building Type and Foundation Selection. Further guidance on settlement-tolerant buildings is included in Part B 'Designing to Accommodate Settlement and for Usability Following Earthquakes'. • Deletion of previous Appendix C: Specific Information for the Christchurch Schools Rebuild Programme. This information is no longer considered necessary in national guidance. • Incorporation of a worked example for SLS2/ULS2 as Appendix B1.
Version 3.0	2/10/2020	• Change from Structural and Geotechnical *Guidelines* to Structural and Geotechnical *Requirements.* • Major re-ordering of all sections with the addition of a key summary points table to the start of each section. • Updates to reflect the updated school design Quality Assurance process and the Design Review framework. • Requirement for geotechnical engineering assessments to be prepared by, or under the direct supervision of, a suitably experienced CPEng Geotechnical Engineer. • New commentary on the suitability of NZS3604 and school buildings (section 2.5). • New section on demonstrating compliance with the NZBC and through construction, including the requirement for designers to confirm compliance with the SGR (section 2.5). • New section on construction monitoring and the requirement for specific elements to be inspected during construction (section 3.7). • Consolidation of previous tables A1 and A3 into Table 5.1. • The addition of a SLS2 return period for buildings of lightweight construction for secondary structural and non-structural elements (Table 5.1). • Extension of the requirement to detail for ductility for all significant concrete and steel load bearing elements (section 9.3). • Addition of an additional superimposed dead load for future flexibility of floors (section 9.8). • New section on the design of external decks (section 9.9). • Requirement for testing certification for Proprietary Products (section 9.10 and 10.7). • Clarification that it is the structural engineer's responsibility to circulate the non-structural requirements to the design team (section 10.1).

		• Update to the Seismic Assessment and Strengthening section to reflect the completion of the Ministry's assessment programmes, and to provide guidance on future assessment requirements as part of school upgrades and Master planning (section 12). • Revision of requirements for designers on the use of masonry veneer as a cladding system with the removal of previous height and location restrictions (section 10.2).

FOREWORD

The *Structural and Geotechnical Requirements* has been prepared by the Ministry of Education's Engineering Strategy Group, and is supported by the Ministry of Business, Innovation and Employment (MBIE), who are encouraging of all initiatives that deliver good practice.

This document was first released in March 2015 and became mandatory for state school buildings on 1 July 2015. Changes in this latest version have been made to reflect both technical and legislative changes, and feedback received since the release of version 2 in 2016.

While the Ministry has taken care in preparing this document, it does not relieve any person of the obligation to consider any matter to which that information relates, according to the circumstances of the particular case.

Background

The Ministry owns one of the largest property portfolios in New Zealand, with more than 18,000 buildings spread across more than 2,100 state schools. The engineering design and seismic assessment of state school buildings occur through various mechanisms – nationally via Ministry led programmes, regionally through the Ministry's Capital Works and Infrastructure Advisory Service divisions, and locally through schools' Boards of Trustees.

Following the Canterbury earthquakes, the Ministry put considerable engineering effort into understanding the seismic performance of its existing school buildings. Many technical issues and lessons have also emerged from the review of new school designs undertaken as part of the Ministry's Design Review process. Most of these issues are common to New Zealand buildings generally, and apply to both new building designs as well as the assessment and seismic strengthening of existing Ministry school buildings.

Engineering Strategy Group

The Ministry's Engineering Strategy Group (ESG) was established in 2012 and provides technical leadership on the Ministry's policies for the structural assessment and seismic strengthening of existing school buildings and the design for new school buildings. The ESG is currently comprised of the following members:

- Dave Brunsdon — Kestrel Group (Chair)
- John Hare — Holmes Consulting Group
- John Finnegan — Aurecon
- Nick Traylen — Geotech Consulting
- Mark Willard — Ministry of Education

Structural and Geotechnical Requirements

This document sets out the Ministry's specific requirements and expectations for the structural and geotechnical aspects of the design and assessment of state school buildings. This revision (3.0) adds to, and clarifies the content of version 2.0 and has been re-organised to allow easier navigation. The document is organised in sections to highlight where the Ministry's requirements are in excess of the New Zealand Building Code, with elaboration on how provisions of the Building Code that are particularly relevant to school building should be applied.

Emphasis is given to the establishment of clear and consistent overall design philosophies including more specific guidance on matters that are particularly important to the Ministry and the users of schools. The requirements cover both new school building designs and the assessment and strengthening of existing buildings.

These requirements form part of a set of documents for designing schools in New Zealand that structural and geotechnical engineers should use when undertaking work on school buildings. It is also important that those who lead and co-ordinate school design work, such as architects, project managers and Ministry property personnel, are familiar with the scope and purpose of this document.

This document is freely available for download from the Ministry's online Property pages.

Feedback and Future Amendments

The Ministry are constantly seeking to improve the content and usability of its documents. If anything in this document requires clarification or if you would like to provide feedback, please contact the Ministry through the School.Design@education.govt.nz mailbox. Your feedback will be reviewed and, where accepted, incorporated into future amendments.

Kim Shannon

Head of Education Infrastructure Service

Contents

STRUCTURAL AND GEOTECHNICAL REQUIREMENTS

1. INTRODUCTION

Key Summary Points

- The Ministry owns one of the largest property portfolios in New Zealand and has a unique approach to asset management (section 1.1).
- The *Structural and Geotechnical Requirements* provide an engineering basis for delivering school buildings that meet Ministry objectives (section 1.2).
- In addition to the protection of occupants, an appropriate balance is required between reduction of damage from a seismic event, the initial capital cost and the likely repair cost, as well as the likely disruption to the ongoing use of the school (section 1.2).
- The performance requirements for state school buildings are different to those associated with normal construction and designers must be familiar with them (section 1.3).
- Designers need to be familiar with a range of both Ministry and non-Ministry documents and guidelines (section 1.4).
- A robust and comprehensive assessment of the likely geotechnical and structural issues for a project is required in the very first stages of a school project (section 1.5).
- There are a number of mandatory requirements for Ministry of Education projects that the designers must be familiar with (section 1.6).

1.1 Context

The Ministry of Education (the Ministry) owns one of the largest property portfolios in New Zealand and accordingly has a unique approach to asset management. The Ministry, as the buildings' owner, is well informed about the risks and long-term costs of any design decisions that are made regarding expected building performance. As a long-term property holder, the Ministry is unlikely to on-sell significant amounts of school property, so there is little risk of a subsequent owner unknowingly taking on design decision consequences that may not align with their own performance expectations. For almost all buildings constructed with these requirements, the Ministry will retain responsibility for the maintenance and repair costs over the design life of the building.

The property portfolio has characteristics of near-perpetual ownership, large size, and a geographically diverse spread. This allows the Ministry to adopt a flexible approach in determining an appropriate balance regarding the level of design specification, asset maintenance requirements, refurbishment and upgrading, and the costs and speed of repair in response to a natural or other disaster (all within the overarching framework of the New Zealand Building Code).

The Ministry takes a whole-of-life approach to the way in which it manages its portfolio, based on achieving the Ministry's broader long-term strategic asset management objectives. These include supporting educational outcomes, flexible building designs that can respond to different teaching pedagogies, durable and weathertight buildings, and property protection. The presence of the Ministry's design review framework ensures that the design process is a robust one.

Most other building owners are not able to adopt the same strategies as the Ministry. For this reason, the Ministry's requirements are provided for use on state school buildings only. Conversely, any desired departure from these requirements must be approved by the Ministry, as part of the Design Review process.

1.2 Purpose and Objectives

The overall purpose of the *Structural and Geotechnical Requirements* (SGR) is to provide a basis for engineers and other designers to deliver cost-effective school buildings that meet the Ministry's expectations for safety, usability and whole-of-life costs (including capital and operating costs, future maintenance obligations and anticipated repairs). The objectives of this document include:

- To ensure efficient and economic design and construction practice is incorporated in the design of new state school buildings, and best practice is applied in the assessment and seismic strengthening of existing school buildings.
- To provide guidance on the preferred configuration of state school buildings to achieve more resilient outcomes in future natural disaster events.
- To communicate where departures are required from conventional design in order to satisfy specific Ministry performance requirements.
- To highlight particular aspects of the historic performance of state school buildings that designers should take into account in both the design and the seismic strengthening and refurbishment of existing school buildings.

1.3 Design Principles

In approaching the design of school buildings, designers should recognise the need to provide resilience. Resilience is a broad term, and can be defined as the ability of a community to survive, adapt and grow, no matter what the circumstances. A school is a central part of its community and has an important role to play in the aftermath of an event. The principal engineering objective is for school buildings to be operational as quickly as possible after a significant event, even if repairs are required, and to do so in a manner that makes the best use of available resources.

The principles that guide structural and geotechnical engineering design for state school buildings are:

- To ensure that all occupants are adequately protected from injury in the event of a significant natural hazard or man-made disaster event.
- To provide a design for a building that achieves an appropriate balance between a robust design (to reduce the damage from a significant natural hazard event), the initial capital cost and the likely repair and reinstatement cost.
- To provide a building that is likely to remain usable after a reasonably foreseeable natural or man-made disaster, with repairs being able to be carried out within reasonable timeframes using conventional techniques for smaller but infrequent events.
- To recognise that performance requirements for the portfolio of educational buildings owned by the Ministry are unique and may be different to those that are associated with typical residential or commercial construction.

1.4 Design Standards and Relevant Documents

All building work on school buildings must comply with legislative requirements, as well as the Ministry's requirements which may be above and beyond the New Zealand Building Code (Building Code).

Information on the Ministry's Design Requirements and Standards is publicly available from the Ministry's online Property pages. Other Ministry documents with structural and geotechnical implications are set out below:

- Ministry of Education, Designing Schools in New Zealand – Requirements and Guidelines (Version 1), October 2015.
- Ministry of Education, Weathertightness Design Requirements for New Schools, September 2020.

The Ministry for Business Innovation and Employment (MBIE) in conjunction with the New Zealand Geotechnical Society (NZGS) has released a series of guidelines titled 'Earthquake Geotechnical Engineering Practice'. The Ministry requires that the MBIE guidelines are followed for state school buildings. These guidelines are listed below:

- Module 1 - Overview of the Guidelines.
- Module 2 - Geotechnical Investigations for Earthquake Engineering.
- Module 3 - Identification, Assessment and Mitigation of Liquefaction Hazards.
- Module 4 - Earthquake Resistant Foundation Design.
- Module 5 - Ground Improvement of Soils Prone to Liquefaction.
- Module 6 - Earthquake Resistant Retaining Wall Design.

Further background material that may assist in understanding aspects of the *Structural and Geotechnical Requirements is listed below:*

- Ministry of Education, Earthquake Resilience Programme Contextual Report, September 2020.
- Greater Christchurch Earthquake Resilience Programme, Contextual Report for Detailed Engineering Evaluations, May 2014.
- Ministry of Education, Guidelines for the Seismic Evaluation of Timber Framed School Buildings (Version 2), June 2013.
- Ministry of Education, Catalogue of Standard School Building Types, August 2013.
- Ministry of Education, Report on Structural Testing of a Standard Classroom Block in Carterton in June 2013, October 2013.
- Ministry of Education, Report on Structural Testing of a Standard Classroom Block in Christchurch in December 2013, February 2014.
- D. Brunsdon, J. Finnegan, N. Evans, G. Beattie, D. Carradine, J. Sheppard & B. Lee, Establishing the Resilience of Timber Framed School Buildings in New Zealand, 2014 NZSEE conference, March 2014.

Where any contradictions with current Ministry policy are noted in these or other documents, the current version of the *Structural and Geotechnical Requirements* takes precedence.

1.5 Engineering Involvement

Geotechnical and structural engineers provide critical input to every school development from the early project stages, starting with geotechnical investigation and advice prior to site selection and acquisition.

Geotechnical reports for Ministry projects are expected to contain significant geotechnical engineering assessment and advice, and therefore must be prepared by, or under the direct supervision of, a suitably experienced Chartered Professional Geotechnical Engineer. Similarly, structural engineering assessment and design work must be carried out by, or under the direct supervision of, a suitably experienced Chartered Professional Structural Engineer.

Foundation systems are a relatively high cost item in any construction budget and they sit at the interface between geotechnical and structural engineering, thus requiring active collaboration between the two areas of expertise. Additionally, the highly variable cost implications of the selected superstructure system are such that early collaboration between the Master Planning architect and the structural engineer is important. It is therefore vital that structural and geotechnical engineers are engaged, are actively involved, and actively collaborate from early on in the life of a development.

The Ministry's Design Review framework requires staged reviews for every project at specific design stages, commencing with Master Planning[1] (and possibly earlier). These reviews require that structural and geotechnical information be provided with a sufficient level of detail that ensures a review can be effectively completed.

1.6 Key Mandatory Requirements

There are a number of mandatory requirements on Ministry projects. Key requirements are summarised as follows:

(a) All projects must comply with the New Zealand Building Code and the Ministry's additional requirements, including SLS2 considerations for both structural and non-structural elements, even where not required by the Building Code (section 4.1).

(b) A Project and Sites Constraints Table (PSCT) must be prepared for every stage of a project and used as a risk register (section 3.2).

(c) A Design Features Report (DFR) must be prepared from the Master Planning stage (even if information is 'high-level') and is to be updated and presented with all subsequent design stages (section 3.3).

(d) A Geotechnical Report must be prepared from the Master Planning stage onwards, or earlier if geotechnical investigations are carried out for other purposes (section 3.4).

(e) All geotechnical data (new and old) must be uploaded to the New Zealand Geotechnical Database (NZGD) (section 3.5).

(f) Construction records must be kept for the project, including as-built details for all below-ground components (section 3.8).

(g) Shallow foundation systems must be considered in the first instance in all cases, including foundation optioneering where shallow foundations are not suitable (section 7.2).

(h) Detailing for ductility is required for key structural elements, whether or not these elements are intended to be part of a fully ductile system (section 9.3).

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[1] Note that the scope of work for the Master Planning stage is specific to the Ministry. The project specific briefing and deliverables will be defined in the individual *Project Brief* document and/or by further Ministry guidance.

(i) The use of masonry veneer cladding systems must be in accordance with Ministry requirements (section 10.2.2).

(j) Engineers should be aware of the potential impact of the 2016 changes to the earthquake prone buildings provisions of the Building Act and the 2017 update of the national seismic assessment guidelines, and previous assessments of multi-storey buildings should not be relied upon without independent validation. At the time of school master planning or building refurbishment, all existing school buildings of two or more storeys and of heavy construction, should be subject to engineering review, and where necessary, further seismic assessment (section 12.4).

2. DESIGN METHODOLOGY, PHASING AND COMPLIANCE

Key Summary Points

- Design of foundation and primary structure should be carried out on a risk-based approach, following the broad strategies outlined in this section and Section 7 (section 2.2).
- Strategies and process flow charts are provided in this section for Master Planning, and Preliminary Design stages (section 2.3 and 2.4).
- An options analysis must be provided including demonstrating the overall cost-effectiveness of the favoured design solution (section 2.4).
- Clause B1.02 of B1/VM4 is not the only means available to comply with the Building Code, and should not necessarily limit design opportunities on state school buildings (section 2.5.1).
- Designers are to demonstrate compliance with the *Requirements* in the Design Features Report (section 2.5.2).

2.1 General

School projects should follow the conventional design methodology and phasing approach as typically used in industry and as outlined in the New Zealand Construction Industry Council (NZCIC) design and documentation guidelines, but as modified by the Ministry's brief specific to each project. The brief will identify major departures from this standard approach, which may include:

- The addition of a Master Planning design phase, for which the Ministry will supply its own requirements.
- The requirement for additional design and documentation to be undertaken during the Preliminary Design phase to ensure performance objectives will be met and to provide greater cost certainty.

2.2 Risk Based Approach

With regard to the consideration of soil-structure interaction and the selection of foundation and superstructure systems, the design methodology should reflect a risk-based approach, and be appropriate for both the nature of the hazard and the phase of the design development.

No unnecessarily detailed analysis should be undertaken where either the likelihood of the hazard is low, or conversely, where it is so high as to preclude any other solution than avoidance (e.g. significant ground deformation).

The risk assessment and design processes corresponding to the Master Planning and Preliminary Design phases are outlined below with further detail provided in section 7.3.

2.3 Master Planning Phase

The purpose of the Master Planning phase is, among other things, to provide a long-term vision of the school development and to provide a high-level cost estimate.

The Master Planning phase should include the consideration of site hazards and constraints, in order to develop design strategies that best meet Ministry requirements. Critical to developing the Master Plan is the consideration of the foundation system of buildings as this may affect siting, structural form and material selection. While Master Planning normally requires only a high-level structural concept to be prepared, greater structural consideration will be required where the geotechnical conditions do not readily support the use of shallow foundations.

From a geotechnical and structural engineering perspective, the focus should be to avoid, as far as practical, siting new buildings on areas with poor ground conditions (e.g. weak or liquefiable soil, areas subject to debris inundation, steeply sloping or unstable ground etc.). However, other site planning issues may preclude this, in which case the Ministry should be involved in discussion as to the relative merits and risks of the siting options (refer section 3.4). Where feasible, foundation solutions at the Master Planning phase should adopt the simplest practical shallow foundation assumption.

Although the Master Planning process is generally focused at a site-wide level, a more detailed design approach may be required to select foundation systems for individual buildings, where site planning dictates that buildings are sited on poor ground.

The outline of a Master Planning process is provided in in Figure 2.1. It should be noted that the red shaded boxes represent the only significant quantitative analysis during this phase. Further notes are provided for the numbers in the grey circles.

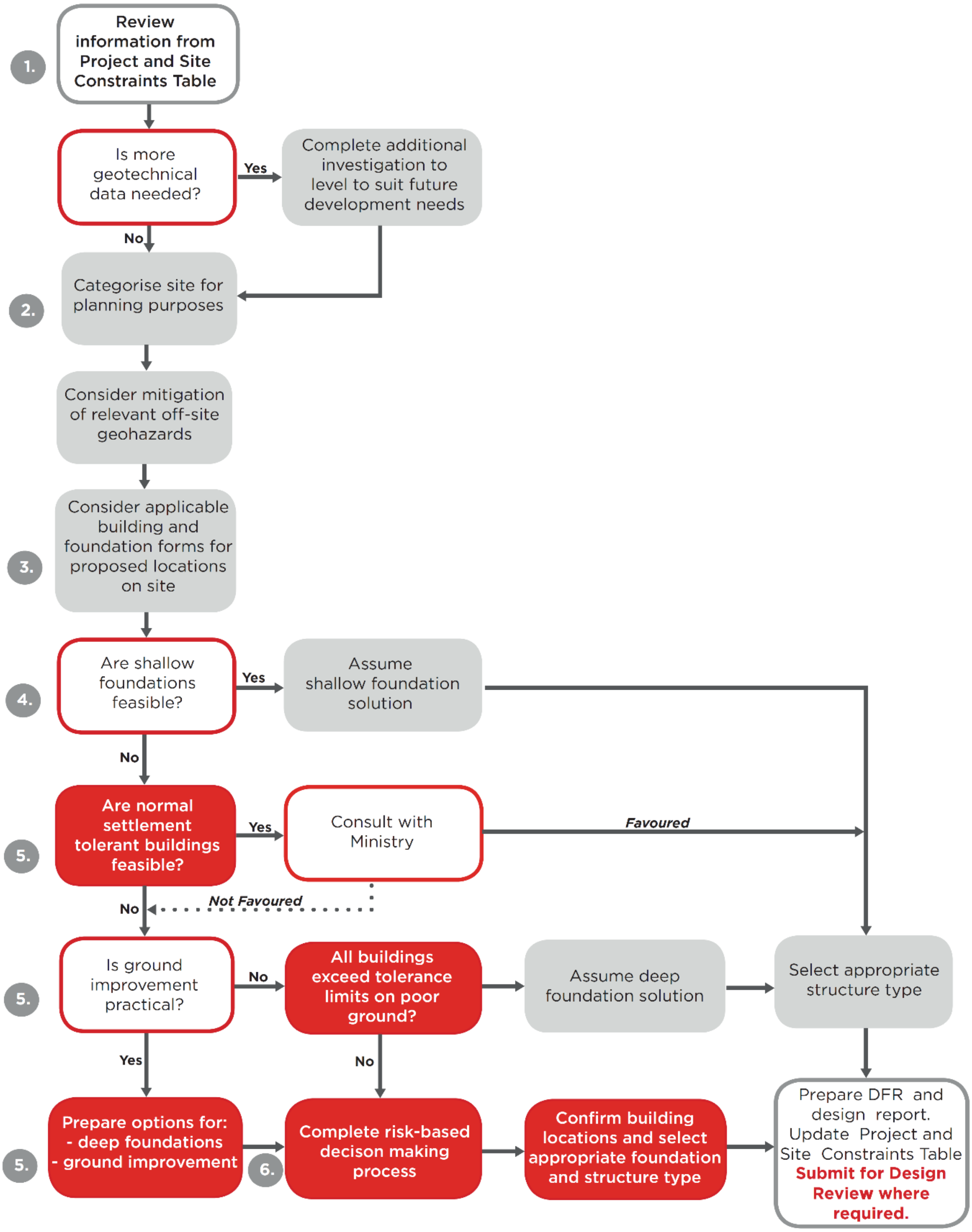

Figure 2.1: Master Planning structural and geotechnical risk assessment.

Notes to Figure 2.1 (refer to numbers in grey circles):

1. The existing information for the site in the Project and Site Constraints Table (PSCT) should be reviewed and noted before commencing any further evaluation. Once all of the material (which should be recorded on the PSCT) is assembled, the geotechnical engineer in conjunction with the structural engineer should review the need for further investigation, considering the following:
    a. Is the proposed location of the buildings on the site absolutely fixed? If not, or if there is distinct advantage in relocating, sufficient testing may be required to review alternative locations.
    b. If additional testing is required, consider whether there is efficiency in doing sufficient on-site work at this phase for the full design phase, or whether the work should be staged.
2. Categorise or zone the site. In the Master planning phase, geotechnical cross-sections may be a useful tool to understand and describe the site. The site should be partitioned if appropriate by ground type, with regard to topographical features that may limit development, e.g. streams or banks, sloping ground, off-site hazards such as rockfall or landslip, etc. This will identify preferred areas for development and areas that should be avoided for building on. Areas not suitable for building might be suitable for some ancillary buildings or car parking, sports grounds or other outdoor activity areas.
3. Consider applicable building and foundation forms for the proposed site locations. At the Master Planning phase, the site zoning should be used if possible to inform bulk and location planning for the site, avoiding significant hazards to the greatest degree possible. If site planning precludes avoiding areas of greatest hazard, this should be taken forward to the risk assessment in later phases.
4. If all buildings can be constructed on normal shallow foundations (without the need to design for additional tolerance to settlement), then suitable structure types can be used and no further risk assessment is expected.
5. If some or all buildings are not suitable for normal shallow foundations, then options for ‘settlement-tolerant’ buildings, ground improvement, and deep foundations should be considered (where feasible in each case).
6. For sites where more than one option is feasible, a risk-based selection process should be followed. The process should follow the general framework outlined in Figure 7.1, but to a level that reflects the preliminary nature of the analysis, noting the principal purposes of Master Planning as outlined above.

2.4 Preliminary Design Phase

The purpose of the Preliminary Design phase is to refine the cost estimate and to confirm the building systems for the following design phases.

At the commencement of the Preliminary Design phase the geotechnical information should be reviewed, and the Master Plan assumptions validated to ensure that the project can be completed and consented. Further geotechnical investigation may be required, which may include re-evaluation of previous design decisions. If the outcomes have implications for either the project budget or building siting the architect and Ministry should be advised, and a solution agreed prior to completing further Preliminary Design.

By the completion of the Preliminary Design phase, it is expected that the foundation and structural system will have been finalised, pending only the Detailed Design and documentation development through subsequent design stages. Options analysis must be provided including demonstrating the overall cost-effectiveness of the favoured solution. All assumptions for the geotechnical assessment or proposed foundation systems must be verified except where there may be benefit in allowing potential design alternatives from contractors.

The Preliminary Design phase should be considered at a building-by-building level, recognising that site planning may require the adoption of different solutions for different parts of the site. However, it is essential that the subsequent development of the site is considered and that the selected foundation systems will support future development. This should include consideration of differential settlement and compatibility with any future development adjacent the current development.

If there are future development plans for possible adjacent buildings, there should be sufficient information in the DFR that a compatible foundation system can be assumed or that there is a means for controlling future differential settlement between the adjacent structures. Equally, if the current development involves extension to an existing building, care should be taken to mitigate against the impact of differential settlement, but also to ensure a compatible foundation system in the event of earthquake. Full separation of a new building from an existing may be preferable.

The outline of a Preliminary Design process is provided in Figure 2.2. The risk-based selection process referred to is described in Section 7.3.

Designers will be required to submit their projects for design review as set out in the Design Review framework. With respect to structural and geotechnical engineering aspects, the role of the design review is to assess whether the proposed design is likely to meet the Ministry requirements as set out in this document. The review process does not relieve the designers of their primary responsibility to ensure compliance with Ministry requirements and is not intended to establish compliance with the Building Act 2004, which remains the responsibility of the designers.

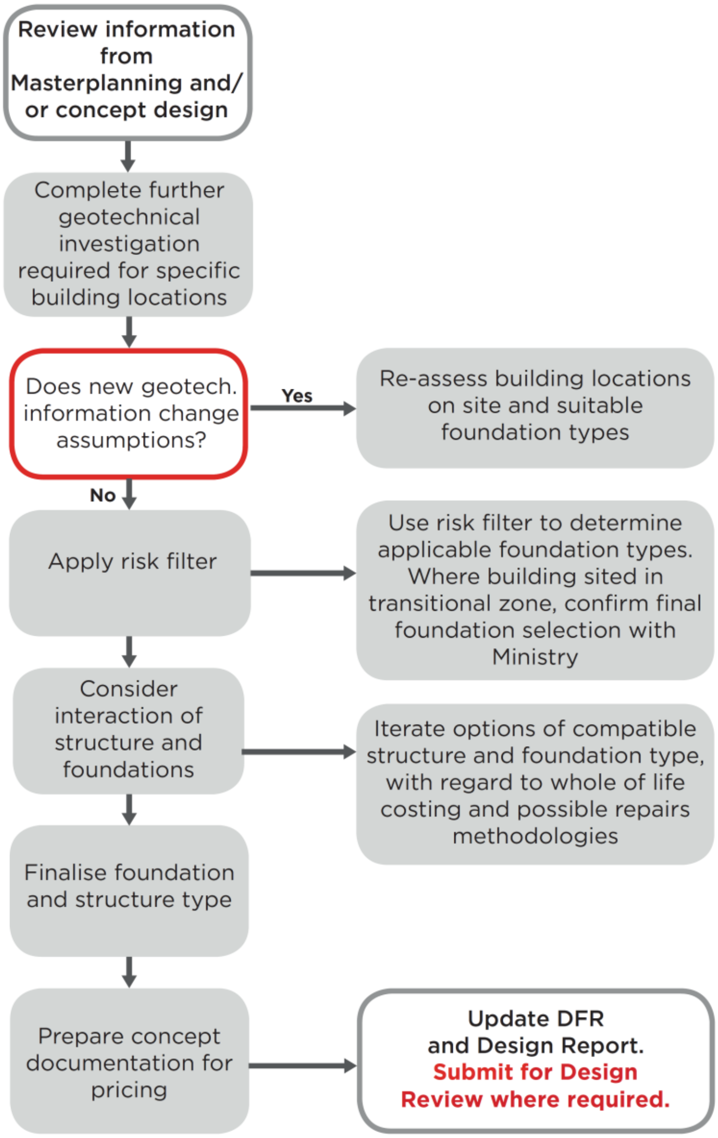

Figure 2.2: Preliminary Design process.

2.5 Building Consent and Demonstrating Compliance

All projects are required to have a building consent in accordance with the Building Act 2004 (unless the work can be exempt under schedule 1 of the Act). The designers must ensure that the documentation for the project is sufficient to demonstrate compliance with the Building Act 2004, to the extent required by a Building Consent Authority (BCA). It is not expected that the BCA will verify compliance with the Ministry guidelines.

This section outlines how compliance with the New Zealand Building Code and the Ministry's Structural and Geotechnical Requirements is to be demonstrated.

In some cases, compliance with the Ministry requirements may require the adoption of an Alternative Solution. The method of compliance via an Alternative Solution must be clearly articulated in the design documentation and on the relevant Producer Statements.

2.5.1 Demonstrating Compliance with the Building Code

The overarching structural requirement is (from B1.3.2):

> *Buildings, building elements and sitework shall have a low probability of causing loss of amenity through undue deformation… throughout their lives….,*

as well as (from B1.3.1):

> *Buildings, building elements and sitework shall have a low probability of rupturing, becoming unstable, losing equilibrium, or collapsing… throughout their lives.*

Compliance can be achieved through the use of *Acceptable Solutions* and *Verification Methods*, or by the adoption of *Alternative Solutions*.

Verification Methods are tests or calculation methods that prescribe one way to comply with the Building Code. Acceptable Solutions give specific construction details, often for commonly used building materials, systems and methods.

Alternative Solutions also demonstrate how building work complies with the Building Code where a building design differs completely or partially from an Acceptable Solution or Verification Method. They take many different forms, and may draw upon Acceptable Solutions and Verification Methods when demonstrating how proposed building work will comply as an Alternative Solution. They are more common in geotechnical design given the limited range of application of B1/VM4 (and that document's inherent shortcomings, particularly with regard to assessment of foundation settlements), and may be nothing more than normal professional engineering analysis and design. However in structural design a peer review (partial or full) of an Alternative Solution is sometimes required to demonstrate compliance.

Designers should certify that their design complies with the Building Code using Producer Statements (PS1 *Design,* and PS2 *Design Review* where required). It is essential that the means of compliance used for all structural elements be clearly and consistently identified in the respective Producer Statements.

The question of whether or not a PS2 peer review and statement is required should be established by the design team with the BCA at an early stage in the design process. Where it is determined by the BCA that a PS2 is required, the peer reviewer is to be selected independent of the design team and in consultation with the Ministry's Delivery Manager. The peer reviewer should be involved early in the project design stage (e.g. at preliminary design).

As discussed further in the commentary below, any design that involves a settlement-tolerant building will be an Alternative Solution. A foundation that meets the following Ministry criteria:

> *Foundation design shall limit the probable maximum differential settlement under serviceability limit state load combinations of AS/NZS 1170 Part 0 to a level that the structure can accommodate with only minor damage that can be readily repaired.*

will also meet the requirements of the Building Code in terms of SLS settlements, as long as "…the structure is specifically designed to prevent damage under a greater settlement [than 25mm over 6m]" (B1/VM4 clause B1.02).

In order to demonstrate compliance of a settlement-tolerant building to the BCA, designers must clearly show that the proposed design complies with Clause B1.3.1 of the Building Code (i.e. meeting ULS criteria). This should be clearly set out in the DFR, with supporting reports and calculations.

Commentary on B1/VM4 of the NZBC and Settlement-tolerant Building Design

Clause B1.02 in Appendix B of B1/VM4 has led over time to a level of confusion amongst practitioners as to the acceptable level of deformations in foundation design. In particular it has led to the incorrect but widely held belief that compliance with the NZBC requires a settlement limit of 25mm over 6m under SLS loadings. The second half of the sentence that makes up clause B1.02 clearly states however "…unless the structure is specifically designed to prevent damage under a greater settlement".

Clause 1.0.3 of B1/VM4 states that SLS deformations are not covered in the document. This implies that any solution relating to foundations and SLS are Alternative Solutions. In practice, however, the subsequent comment that introduces Appendix B ('which may be of assistance') is generally taken to mean that foundations which can be shown to settle less than 25mm over 6m under SLS loadings established from standard engineering calculations are automatically 'deemed to comply' with the requirements of an Acceptable Solution. Following the 'deemed to comply' route is however neither compulsory, nor the only means of compliance with the NZBC.

Furthermore, Clause 1.0.5 of B1/VM4 states "This document must not be used to design foundations on loose sands, saturated dense sands or on cohesive soils having a sensitivity greater than 4". Thus by definition B1/VM4 excludes design of foundations on liquefiable soils.

The acceptance of greater SLS displacements under the SGR's settlement-tolerant building approach (while still remaining NZBC compliant) is an Alternative Solution, for which a specific strategy is required.

The Ministry of Education provides the following SLS design requirement statement, to provide a point of reference against which to evaluate foundation designs for NZBC compliance purposes:

> Foundation design shall limit the probable maximum differential settlement under serviceability limit state load combinations of AS/NZS 1170 Part 0, to a level that the structure can accommodate with only minor damage that can be readily repaired.

This statement complies with the requirements of B1.3.2 of the NZBC, which is the overarching requirement. MBIE support this approach in principle as a valid means of compliance.

Commentary on NZS3604 and School Buildings

NZS3604 can be used as an Acceptable Solution for small, regular school buildings that meet IL2 requirements (i.e. of capacity up to 250 people) and other relevant limitations in the standard.

Modern school buildings typically have large open spaces that exceed the limits of NZS3604 diaphragms and tend not to have the bracing wall distribution or redundancy of typical NZS3604 buildings. For these types of buildings, the use of NS3604 for determining the seismic bracing demand and for the specification of wall bracing elements is not suitable and specific engineering design is required.

The use of NZS3604 for individual elements (e.g. timber wall studs) may still be suitable, but represents an Alternative Solution compliance pathway, and this should be clearly identified in the DFR and on the PS1.

2.5.2 Demonstrating Compliance with the SGR

Compliance with the SGR should be demonstrated by a section within the DFR listing the specific sections of the SGR that have been followed in the design. Where further narrative or information is required by the SGR (e.g. in relation to settlement-tolerant building design), this should also be included in this section.

A statement from the designer within this section of the DFR is also required to certify that the design meets the SGR requirements, in addition to those of the Building Code. Any desired departure from these requirements must be stated in the DFR and approved by the Ministry, via the design review.

A PS1 *Design* Producer Statement is purely for purposes of obtaining building consent, and would normally not be sufficient to establish compliance with the SGR, given that aspects of the design may go beyond the Building Code requirements.

Compliance with the SGR will be reviewed at a high level, through the design review process. A PS2 peer review for building consent is not sufficient for the purpose of satisfying the Ministry that compliance with the SGR has been achieved.

2.5.3 Compliance through Construction

The engineer, on completion of the works, is to confirm that the building work has been carried out in accordance with the consented plans and the Building Code, via the provision of a PS4 *Construction Review*.

If the engineer requires that specific elements of construction be inspected they must provide a list of the elements and specify the level and frequency of construction monitoring and how remedial works will be monitored and cleared as the project progresses (refer section 3.7).

If a design change is made during construction, an amendment to the building consent must be applied for and approved unless the work is considered minor. In any event, the change must be appropriately documented.

On completion of the project, a full set of all updated construction documents (including sketches and site instructions) and models (where used) should be supplied to the Ministry (refer section 3.8).

3. DOCUMENTATION AND PROJECT RECORDS

Key Summary Points

- A Project and Site Constraints Table (PSCT) must be updated at every stage of a project and used as a risk register (section 3.2).
- A Design Features Report (DFR) must be prepared and progressively updated from the Master Planning phase onwards (section 3.3).
- A Geotechnical Report must be prepared and progressively updated from the Master Planning phase onwards, or earlier (section 3.4).
- All geotechnical data (new and old) must be uploaded to the NZGD (section 3.5).
- Construction records must be kept for the project, including as-built details for all below-ground components (section 3.6).

3.1 General

Good design documentation is critical to the success of construction projects. Design documentation must be well organised and presented for the design reviews, consenting and construction. Documentation should generally follow the phases and deliverables as described in the NZCIC design and documentation guidelines, with the addition of a Master Planning phase, for which the Ministry will supply its own requirements.

It is essential that useful information that is discovered and/or generated about a project or site is made available to all who may work on the project. This requires that a record is made that may be transferred between project personnel and updated as the project proceeds.

3.2 Project and Site Constraints Table

As part of the Master Planning process, all available information on actual or potential project and site constraints or opportunities that could affect the development should be identified, researched and summarised. The Project and Site Constraints Table (PSCT) provides a framework for this and must be updated for every phase of the design process. This table is available from the Ministry's online Property pages and is included within the Ministry's *Project Brief* document.

Note that the PSCT is not restricted to structural and geotechnical information. The structural and geotechnical engineers are expected to contribute to its preparation. It is expected that the Ministry's project representative will provide the initial version of the table, including any known information and existing documentation, ready to receive contributions from other subject matter experts, as appropriate, and ensure that the table is appropriately updated at the various project phases.

The PSCT should be used as the basis for a project risk register. This in turn is also expected to be closely linked to the cost estimates at various stages of the project development to ensure that all project uncertainties are understood and appropriately addressed. Consideration should also be given to possible future site development as well as the immediate stage(s) of development.

3.3 Design Features Report

A key component of well-organised engineering documentation is a Design Features Report (DFR). A DFR should be prepared at the Master Planning Design stage (even if information is 'high-level' at the time of writing) and then continually updated through the design process.

DFRs are concise summaries (authorised by Chartered Professional Engineers) to record the key considerations and design methodologies adopted to achieve both the building owner's requirements and compliance with the Building Code (and any additional requirements that must be communicated to building consent officers, constructors, owners and users). As a minimum, the DFR should provide basic information on the building and foundation, including:

- A brief narrative summarising the seismic design philosophy adapted for the building, with a focus on the primary lateral load resisting systems.
- Foundation investigation and design methods and results as derived from the geotechnical report, including a detailed description of the site geotechnical model. Graphical representation of the site geotechnical model should be provided (see Figures 3.1 and 6.1 as examples). Note that this information should reflect any uncertainty in the derivation and modelling (e.g. graphically and/or by way of note).

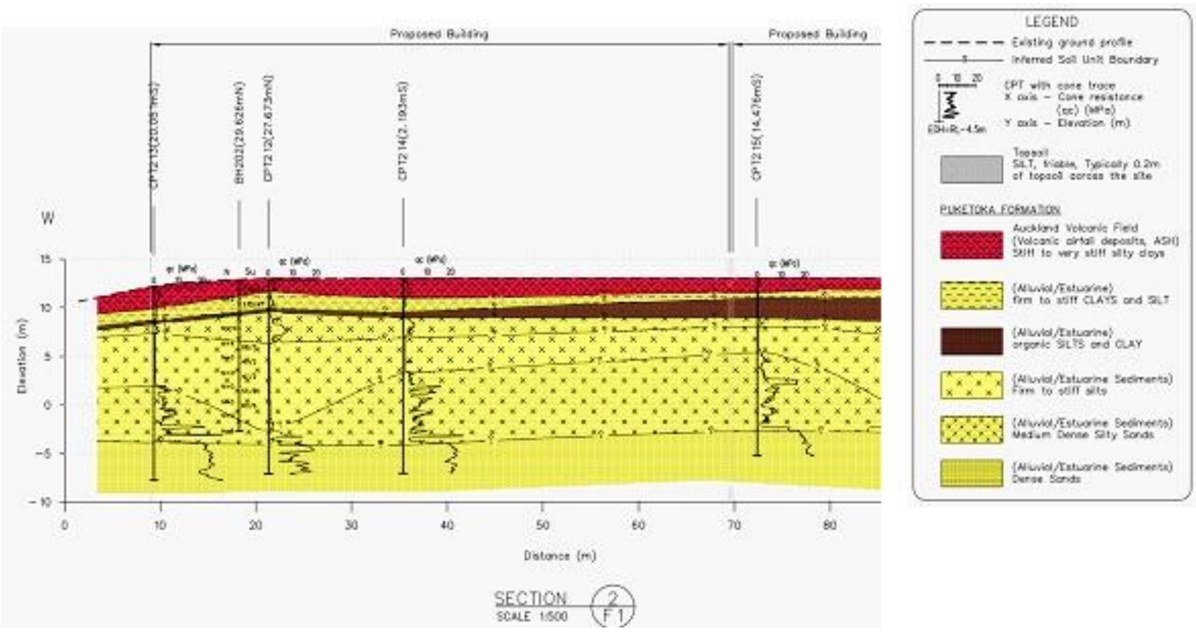

Figure 3.1: Example graphical representation of the site geotechnical model.

- Building design methods, load assumptions, load paths and assumed structural ductility demand.
- Strengthening levels achieved where the project scope includes strengthening existing buildings.
- Expected building deformations and design actions/requirements for secondary elements and non-structural elements (to be designed by others), including a one-page summary of SLS1 and SLS2 deformations that can be used by the project architects and service engineers in their design processes.
- An outline of the expected building performance and the damage hierarchy of building elements.

- A section demonstrating compliance with the SGR including a statement from the designer to certifying the design against the SGR.
- Identification of key elements for construction monitoring, noting elements requiring specific inspection (refer section 3.7.2).
- Expected maintenance requirements during the building life.
- Provisions for inspection and testing of the building after a design event.
- Anticipated repair or reinstatement strategies and methodologies in the event that design loads are imposed on the structure (refer to section 4.3)
- Any building performance monitoring requirements considered relevant or appropriate, e.g. monitoring for settlement or lateral movement.
- Outline any implications where it is proposed to connect into existing buildings, particularly for any continued use/post event operations, where the existing building performance may vary from the new, or meet the Ministry's performance criteria.

Design strategies should be articulated and put in place for the envisaged structural design. This should be identified at the Master Planning phase, at least in narrative and outlined in diagrammatic form.

It is expected that the DFR will require input from a number of parties, including both the structural and the geotechnical engineers, as well as the civil engineering consultant. An extensive DFR template is available from the Structural Engineering Society New Zealand (SESOC) website (www.sesoc.org.nz, on the members' page).

3.4 Geotechnical Reporting

Designers must ensure that a comprehensive interpretive and factual Geotechnical Report is provided prior to the commencement of Master Planning design work – or earlier if geotechnical investigations are carried out for other purposes (e.g. site acquisition and due diligence). Further guidance is provided in Section 6.

As a critical input to the Master Planning phase, the geotechnical investigation should identify likely areas of poor ground. The Master Planning phase should specifically address the probable foundation solutions, as an input into the overall cost plan. This should include, but is not limited to, consideration of land classification across the site to identify areas of 'better' ground that could provide for more cost-effective construction solutions. The investigation should also identify specific foundation aspects such as soil improvement, piles, any unusual foundation configurations and any key design assumptions or criteria that will influence later design stages.

3.5 New Zealand Geotechnical Database

Designers must ensure that all geotechnical data collected for a school project is uploaded to the New Zealand Geotechnical Database (NZGD) as soon as practicable after its collection. This includes all data that has been referred to or used in any way from investigations carried out for the Ministry by previous design teams, and for any design-build projects. The Ministry wishes to avoid the loss of data as a result of design team changes, and requires that the data is available for future potential developments at a school site.

Data upload is required prior to design reviews.

3.6 Submissions for Design Review and Building Consent

Designs submitted for design review must have a DFR that refers to relevant sections of this document, along with design information at a level of detail relevant to the phase of design. A PSCT is also required at each stage, updated progressively. The DFR will also be required by the BCA to support a building consent submission.

The requirements for each design stage are set out below.

3.6.1 Master Planning phase:

i. A summary of relevant geotechnical information, including a full geotechnical report.

ii. A summary of relevant potential future ground deformation impacts on the structure (which should include the designer's estimate of impacts on the operation of the structure) and nature and method of repairs for different return period events.

iii. A summary of relevant cost information (initial capital cost for foundations and estimated cost of repairs should certain events occur in the future).

iv. An initial version of the DFR, including a summary of recommendations. For projects that include the strengthening of existing buildings the initial DFR should summarise the current building strength status of each building and the proposed strengthening work, including the strengthening target level, level of strengthening complexity and a summary of the non-structural scope proposed (e.g. refurbishment scope).

v. A completed PSCT.

Refer to Tables 7.1 and 7.2 for the indicative template for the required information from (ii) and (iii) above.

3.6.2 Preliminary Design phase:

i. A summary of relevant geotechnical information, including a full geotechnical report.

ii. Update of the information provided at Master Planning/Concept stage (where applicable).

iii. Updated version of the DFR including specific reference to the geotechnical information used for foundation design and a summary of the strengthening works proposed to any existing buildings.

iv. Updated PSCT.

v. An outline of the design process to be followed during the Detailed Design phase.

3.6.3 At building consent submission stage:

i. A summary of the level of building displacement, impact on the structure and repair approach.

ii. The completed DFR.

3.7 Construction Monitoring

3.7.1 General

The appropriate involvement of the geotechnical and structural engineer is essential during the construction phase to ensure that:

- The design is being correctly interpreted; and
- The construction techniques are appropriate and to ensure the intent of the design is met, and
- The work is completed generally in accordance with the plans and specifications.

For school projects it is expected the minimum level of construction monitoring service is ‘CM3’, as outlined in the Engineering New Zealand Construction Monitoring Services guideline.

3.7.2 Elements Requiring Specific Inspection

Irrespective of the overall level of construction monitoring that is considered appropriate, where individual building elements require more specific monitoring during construction, it is the responsibility of the designer to identify and make arrangements for this via the DFR and construction documentation.

The Ministry requires the following elements to be subject to specific inspection during construction, and to be included in the construction review Producer Statement (PS4):

- Secondary structural and non-structural seismic restraints (e.g. for building services, suspended ceilings and partition walls - refer to sections 10.3, 10.4 and 10.5).
- Grouting of ducts, splices and other cast in elements in precast concrete.
- Masonry veneer ties, where veneer is specified in areas where students may congregate, or in areas adjacent to access and egress paths (refer section 10.2.2).

The responsibility for the construction monitoring of these elements should be clearly outlined in the DFR. Where appropriate for a supplier’s engineer (e.g. for suspended ceiling restraints) to undertake the construction monitoring, this should be clearly outlined in the structural specification with the requirement for the supplier to provide a PS4 on completion of the works.

3.8 Construction Records

Construction records must be collected through the construction process and retained for key project elements. This applies particularly to design and supply elements of the buildings that are not typically quantified on construction drawings, and to elements that may be varied during construction. It is also important for elements that are not readily visible (e.g. foundation elements, buried services, etc.) to have ’as-built’ type information appropriately recorded in a form that the Ministry can readily retain within their information management system. Where appropriate, information should be added to the PSCT.

It is noted that construction records may take several forms, including:

- The consent documentation as well as any amendments to accommodate requested design changes or to adjust to changed construction or site conditions.
- Detailed documentation prepared by the contractor (or sub-contractors) in response to performance specifications (and subject to review by the consultants).
- Records of actual dimensions, or details recorded for construction of elements for which generic details were provided prior to construction, for example:
    - Pile driving records.
    - Final levels for the depths of piles.
    - Final levels for the underside of foundations.
    - Final depths of ground improvement.
- As-built drawings of any subsoil drainage including cleanout and discharge locations.
- As-built drawings of in-ground services.
- Issued site instructions
- Updated models (where used).

Where appropriate, designers should add notes to specifications requiring contractors to gather and submit information in order to comply with the above requirements.

4. SEISMIC PERFORMANCE REQUIREMENTS FOR STATE SCHOOL BUILDINGS

Key Summary Points

- Performance criteria for state school buildings are aligned with, but sometimes exceed, those from the Building Code (section 4.1).
- The Ministry has particular requirements around tolerable damage and repairability following damaging events (section 4.2.2).
- Foundations should not be the weak link in the hierarchy of damage suffered by a building (section 4.2.3).
- Buildings are to be both repairable and also able to be inspected and tested after a design event (section 4.3).
- A method statement outlining the anticipated repairs is to be included in the DFR from the preliminary design stage onwards (section 4.3).

4.1 General

The performance requirements of the New Zealand Building Code represent the minimum requirements for all school projects. The Ministry has specific asset management and education objectives which lead to additional requirements that designers are also required to meet for school buildings across all clauses of the Building Code.

If there is a perceived conflict between the Building Code and the Ministry design requirements, clarification should be sought from the Ministry through the Ministry's project representative. <u>Under no circumstances shall the Ministry design requirements be interpreted to allow a level of performance less than the minimum requirements of the Building Code.</u>

This section outlines the additional Ministry requirements in relation to B1 Structure.

4.2 Ministry Seismic Performance Requirements

The Ministry's seismic requirements for school buildings are outlined for three levels of earthquake shaking, broadly characterised as follows:

- *Minor earthquake shaking* that can be expected to occur *several times* during the life of the building;
- *Significant earthquake shaking* that can be expected to occur *on more than one occasion* during the life of the building; and
- *Major earthquake shaking* that can be expected to occur *at least once* during the life of the building.

These levels of earthquake shaking correspond to the serviceability and ultimate limit states (SLS1, SLS2 and ULS).

The following requirements should be regarded as the design principles which underpin the more specific requirements outlined in the following sections. They should be referred back to if situations arise that this document does not specifically cover.

4.2.1 Minor earthquake shaking

For *minor* earthquake shaking (corresponding to a 25 year return period, or SLS1 design levels), the performance requirements in B1.3.2 in relation to amenity apply, with the following clarifications and additional Ministry requirements:

1. The building structure must have no significant reduction in capacity.
2. The non-structural elements of the building must remain intact and attached to the structure.
3. Mechanical, electrical and hydraulic services must remain fully operational.
4. The building must retain functional connections to the overall site services reticulation system.
5. A building should only suffer *readily repairable* damage that does not affect the continued use of the building. Such repairs should be able to be completed either:
   - immediately; or
   - in conjunction with normal building maintenance activities (i.e. the building damage is sufficiently low enough that the continued use of the building is not affected while repairs are pending).

The corresponding SLS1 criteria that result from these requirements are defined in section 5.2.

4.2.2 Significant earthquake shaking

For *significant* earthquake shaking (corresponding to 100 and 250 year return periods for IL2 and IL3 respectively, or SLS2 design levels), the Ministry has requirements that go beyond the current requirements in the Building Code.

The following performance criteria shall be met following a significant earthquake:

1. Any reduction in capacity of the structure should not compromise its ability to undergo a subsequent ULS event with acceptable performance (refer to section 9.6).
2. The non-structural elements of the building must, in the main, remain intact and attached to the structure, with no impact on safety or access and egress.
3. Mechanical, electrical and hydraulic services that are essential to the continued use of the building either must remain functional, or are designed in such a way to be reinstated or otherwise re-provisioned in an acceptable manner.
4. The building must either retain functional connections to the overall site services reticulation system, or be reconnectable or otherwise supplied with such services in a timeframe to be agreed with the Ministry and as outlined in the DFR.
5. The building may suffer *tolerable damage*, which is defined as when the building may continue to be used for its intended purpose, but with some reduced amenity, including:
   - Reduced mechanical and electrical function, provided that all building warrant of fitness elements remain operational.
   - Loss of function of other non-structural elements that does not impact on safety or access.

   While some reduced amenity is allowable, there should be a suitable margin of resistance to the impact of deformation under a subsequent ULS event.
6. Repairs should be able to be implemented over a standard holiday break, although off-site work, planning and consents may be undertaken outside that period.

The corresponding SLS2 criteria that result from these requirements are defined in section 5.2.

4.2.3 Major earthquake shaking

For *major* earthquake shaking (corresponding to a 500 or 1,000 year return periods for IL2 and IL3 respectively, or ULS design levels), the performance requirements in B1.3.1 in relation to life safety apply, with the following additional Ministry requirements.

1. The connections to the overall site services reticulation system should be repairable in a practical manner.
2. It is desirable that following a ULS event, a building that is otherwise lightly damaged does not require demolition due to irreparable damage to the foundations. The foundation system in a building should not be the weak link in the hierarchy of damage and there must be an identifiable repair or recovery strategy, provided that the associated cost is acceptable to the Ministry.

The corresponding ULS criteria that result from these requirements are defined in section 5.2.

4.3 Repairability and Inspectability

In buildings that have been designed to accommodate potential foundation movement, designers must give consideration to the type and extent of repairs that may be required following the movement (including the potential impact on building services).

Details of all building repairs and expected timeframes (including foundation re-levelling) that are anticipated during the design life of a structure should be included in the DFR (starting at Preliminary Design phase). This should include a method statement(s) demonstrating that the repairs should be practically achievable and provide an indication of the likely extent, duration and cost of anticipated repair work.

Designers also need to consider how foundation and superstructure elements of the building can be readily inspected after triggering events, to ascertain what damage has been incurred and repairs that are necessary. Such considerations need to be clearly communicated in the DFR, and coordinated with the architect and other relevant designers.

5. DESIGN LOADINGS

Key Summary Points

- The Ministry has specific asset management and education objectives which lead to additional requirements above and beyond the Building Code (section 5.1).
- SLS2 events must be considered in some cases where the AS/NZS 1170 does not require it, for both structural and non-structural elements (section 5.2).
- Importance Levels vary for Ministry school buildings depending on building size, use and occupancy (sections 5.2 and 5.4).
- The Ministry has seismic performance criteria for specific building elements (section 5.3).

5.1 General

Design loadings should be generally calculated in accordance with AS/NZS1170, for the applicable importance levels, with the exception of Ministry load levels for seismic design (section 5.2) and assessment (section 5.4), that go beyond the requirements in section B1 of the Building Code as outlined in the previous section. The purpose of this is to achieve a consistent level of performance for buildings in seismic events, including consideration of the likelihood of damage in moderate levels of shaking.

5.2 Design of New Buildings

Seismic design loads for Serviceability Limit State 1 (SLS1) and Ultimate Limit State (ULS) shall be as stated in NZS1170.5. Seismic design loads for Serviceability Limit State 2 (SLS2) shall be generally as defined in AS/NZS1170 for IL4 buildings, as modified in this document to cover school building uses.

The Importance Level (IL) and associated return period requirements with examples of how they relate to new state school buildings are provided in Table 5.1 following.

Table 5.1: Importance levels and return periods for seismic design of school buildings.

Description	Importance Level	School Building Use[1]	Return Periods		
			SLS1	SLS2	ULS
Low risk associated with human life, or economic, social or environmental consequences	IL1	Small ancillary buildings that are not usually occupied (e.g. isolated garages) and <$30m^2$.	n/a	n/a	100 years
Medium risk associated with human life, or economic, social or environmental consequences	IL2	Larger ancillary buildings (e.g. Boiler Houses and standalone administration offices)	25 years	n/a	500 years
		Buildings of lightweight construction, with less than 250 occupants[1] in a block [3]	25 years	100[4] years For secondary structural and non-structural elements only[5]	500 years
		All buildings of heavy construction, with less than 250 occupants[1] in block[3]	25 years	100[4] years	500 years
High risk associated with human life, or economic, social or environmental consequences	IL3	Buildings of lightweight construction, with 250 or more occupants[1] (IL3)	25 years	250[4] years For secondary structural and non-structural elements only[5]	1000 years
		All buildings of heavy construction[6], with 250 or more occupants[1]	25 years	250[4] years	1000 years
		Assembly halls, gymnasiums, performance arts buildings etc. where occupants may congregate	25 years	250[4] years	1000 years

Notes:

1. Building occupancy numbers should be established on the basis of normal occupancy levels (not maximum occupancy loads as used for fire design purposes). They should also be based on possible future occupancy as well as currently predicted numbers or numbers supplied by the schools.
2. Where more than one use type occurs in a single building, the higher use category prevails in the design of the building.
3. A block should be considered as either a single structure or a collection of structures that share common egress paths and/or essential services. For a section of a building to be regarded as separate for the purposes of establishing the Importance Level, there must be seismic joints, independent egress paths and it must have independent essential services (i.e. it could continue to function without the adjacent structures).
4. A return period of 100 years or 250 years has been used for this document, equating to approximately to 50% of the ULS loading, and the expected deformation of the superstructure should be checked at the SLS2 load level. For buildings on potentially liquefiable soil this SLS2 return period should be regarded as 'indicative', given that in some cases the trigger point for soil liquefaction within a significant portion of the soil column (and which is expected to result in non-trivial building deformation) may occur at a return period other than 100/250 years. In such cases the designer should clearly state in the DFR the return period of the earthquake that is expected to trigger re-levelling (or equivalent degree of building repair i.e. foundation/superstructure disruption that is beyond the tolerable level) as outlined further in section 3.3.
5. For secondary structural and non-structural elements only with the objective of ensuring that buildings will be usable following such an event, even if requiring subsequent repair (refer to Appendix A).
6. For the purposes of this document, *heavy construction* refers to buildings with concrete or concrete masonry walls and/or concrete suspended floors.

Commentary on Load Levels for Seismic Design

The Ministry is seeking greater assurance that its buildings will be usable following earthquakes that are significant but lower than that under ULS design levels, and more surety on how the building will be reinstated. These are specific Ministry requirements that are beyond the basic Building Code requirements and involves the verification of the SLS2 condition for particular buildings. A level of demand is used that reflects a similar relativity of the SLS2 to ULS loading to that which is used for IL4 buildings. This gives return periods for SLS2 of 100 and 250 years for IL2 and IL3 buildings respectively, refer table below. These values are summarised in Table 5.1.

Seismic Design Loading Inputs

	IL2		IL3		IL4	
	T	R	T	R	T	R
SLS1	25	0.25	25	0.25	25	0.25
SLS2	100	0.5	250	0.75	500	1
ULS	500	1	1000	1.3	2500	1.8
Ratio SLS2/ULS	-	0.5	-	0.58	-	0.56

Notes:

T = the return period (in years) for the level of shaking defined for the load case under consideration.

R = the Return Period Factor from Table 3.5 of NZS1170.5, for calculation of seismic loads for the design of structures.

SLS2 represents an intermediate level of seismic loading, intended to ensure that school buildings contribute to the resilience of local communities by being usable as a school following a moderate earthquake.

It is not considered necessary to apply SLS2 requirements to timber-framed buildings for example, due to their inherent resilience (although reporting likely relevelling requirements is still useful for such buildings). It is acknowledged that for some sites, 'compliance' with the SLS2 criteria may not be achievable at reasonable cost. Sites that are on poor ground may be prone to settlement or lateral spread displacement that would incur significant cost to eliminate. In such cases, an alternative path to compliance with the Ministry requirement may be necessary and should be raised with the Ministry project lead and documented in the DFR.

5.3 Performance Criteria for Specific Building Elements

It is recognised that it is possible for designers to interpret and apply some Ministry building performance criteria differently in relation to specific building elements. While it is impractical to cover every situation, more detailed guidance on the behaviour of individual elements is included in Appendix A.

Depending on the criticality of the element for post-earthquake occupancy, it may be acceptable for it to be damaged, requiring repair, but in all cases, elements that could cause injury or harm must be suitably restrained to prevent toppling or falling.

5.4 Assessment and Strengthening of Existing Buildings

For the assessment and strengthening of existing school buildings, the required Importance Levels are summarised in Table 5.2.

Table 5.2: Importance levels for assessment and strengthening of existing school buildings.

Building Category	Buildings of Higher Occupancy and/ or Heavy Floor Construction	Buildings of Lower Occupancy and not of Heavy Floor Construction
Building Use	Classroom buildings >250 persons, Assembly Halls, Gymnasiums and buildings of two or more storeys with suspended concrete floors and/ or heavy roofs	Classroom buildings <250 persons, Administration Blocks, other buildings (see Note below)
Importance Level	IL3	IL2

Note: Ancillary structures (irrespective of floor area) that are separate from other buildings and are not usually occupied (i.e. they are minor structures where failure is not likely to endanger human life), may usually be assumed to be IL1 for the purposes of assessment and strengthening.

6. GEOTECHNICAL INVESTIGATIONS AND REPORTING

Key Summary Points

- Comprehensive geotechnical assessments and subsurface investigations are required at very early stages, particularly prior to the Master Planning design being carried out (section 6.1).
- Site planning that responds to geotechnical considerations is required. Ground classification or ‘zoning’ is useful to facilitate this process (sections 6.2 and 6.3).
- NZS 3604 ‘Good Ground’ is a concept of limited use in professionally engineered structures such as most school buildings (section 6.3).
- Geotechnical reports are to be comprehensive, and provide specific design data for the structural designer (section 6.4).
- Graphical representations of ground conditions are required where appropriate (section 6.4 g).
- Ground deformations from liquefaction are to be carefully considered (section 6.5).

6.1 Geotechnical Investigations

It is important that appropriate geotechnical investigations are carried out early in the project planning cycle, and expanded as the project scope is developed and refined. For new sites this should begin at the site selection and acquisition stage. As budgets are set early in a project, it is vital that any geotechnical constraints or risks that might affect costs are also known at a very early stage.

At the beginning of Master Planning, there should be a reasonable coverage of subsurface investigation points across the entire school site to broadly define the likely geotechnical constraints and opportunities. This should not be limited to the anticipated or preferred current build locations (which often change through the design phases) but for any possible future development or redevelopment of the school. Master Planning design (i.e. ‘bulk and location’ optioneering) should not proceed until this information is available. Unless the site has been thoroughly investigated at an earlier date, it is unlikely that sufficient geotechnical information for Master Planning can be derived wholly from a desktop study.

Typically, once the Master Plan is finalised, further stage-specific and building-specific investigations are required as input to Preliminary Design. Occasionally additional investigation may also be required to allow refinement for Developed Design. To avoid unnecessary expenditure on repeating previous investigation work, it is important at these stages to check for the presence of data from investigations that may have been done by previous design teams.

For guidance on investigation densities and depths, as well as appropriate investigation tools, the designer should refer to the MBIE/NZGS Module 2 – *Geotechnical Investigations for Earthquake Engineering.*

6.2 Site Planning

Careful site planning can reduce potential future damage to buildings due to hazards (such as flooding, ground movement etc.) and provide cost-effective school developments. The geotechnical investigation and reporting should support and inform this process. Subject to a detailed assessment of the geotechnical hazards at a particular site, planners/designers should consider locating buildings on the most stable areas of the site and less critical elements (e.g. playing fields and car parking) on areas that may be subject to greater land disruption. Potential off-site hazards should also be considered as part of this process.

For example, on potentially liquefiable ground, buildings should be located as far as practicably possible from watercourses (existing or infilled, where known) and potentially unstable slopes.

6.3 Ground Classification

A site plan indicating the presence of geohazards, and their potential interaction with the proposed building development, is a required input into the master planning process as it clearly communicates the hazards to the overall design team. This can be achieved by way of illustrating appropriate ground classification(s) or zoning, along with other geotechnical hazards. One of the first elements of this is to establish ground classification(s) or domains based on expected future land performance and the potential impacts on buildings and site infrastructure.

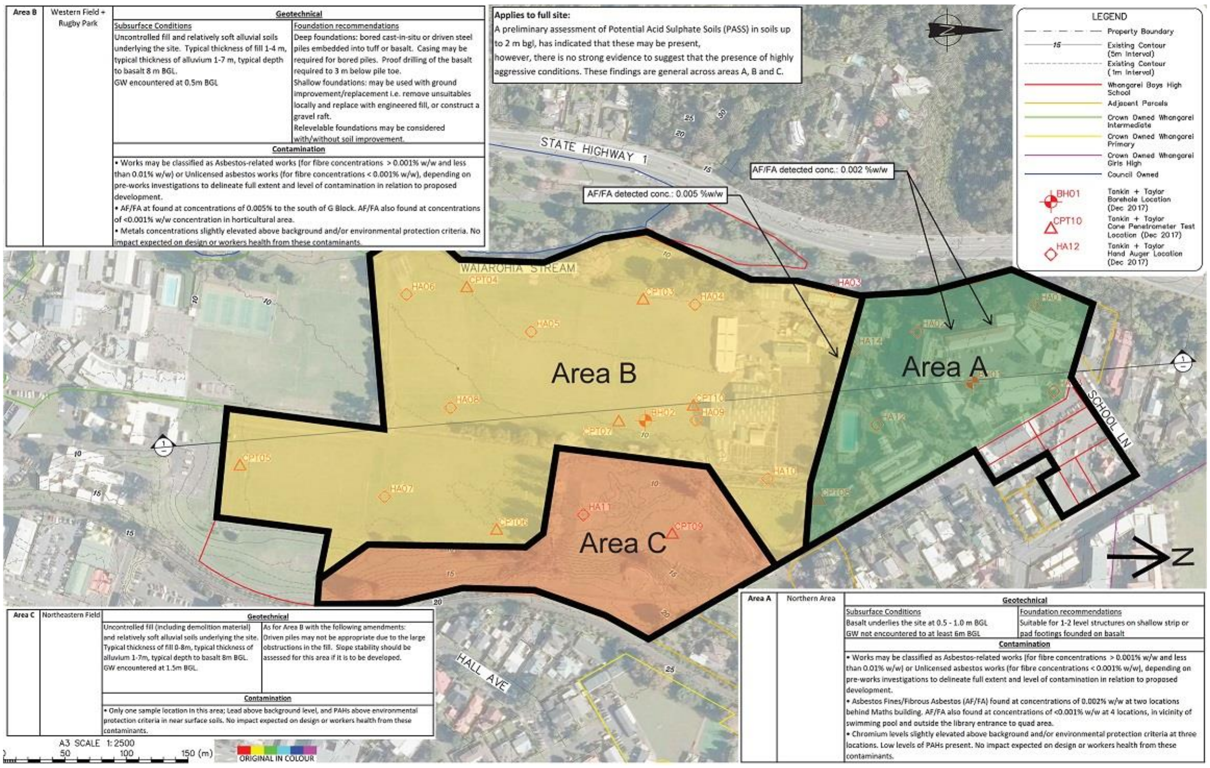

Figure 6.1: Example of a site zonation plan.

For any particular site and project, different hazards will be dominant making ground classification or zoning for most sites unique to the site. For example, on sites where liquefaction is a dominant hazard, it may be appropriate to zone the land using foundation Technical Categories, refer to the Ministry of Building, Innovation and Employment (MBIE) Residential Building Guidance[2], in particular the information relating to the foundation Technical Categories (TC1, TC2, TC3). Although the use of Technical Categories are restricted to residential properties in the Canterbury Earthquake region, similar classifications (e.g. 'TC1-like', 'TC2-like' etc.) may provide a means to inform the assessment (and communication) of likely land performance within school sites with regard to liquefaction. Further, separating out areas where lateral spread is a particular hazard will be a particularly useful adjunct, if this approach is taken.

Commentary on 'Technical Categories'

In Christchurch the Technical Category zoning was based on detailed observations of actual site performance during design level earthquakes. In areas that have not had this level of testing and observation, consideration of other factors that might affect land performance (e.g. crust thickness, likelihood and effect of ejecta, influence of building weight etc.) may also be crucial. Additionally, the MBIE Technical Categories were developed in relation to relatively standard residential buildings. There is no implication that MBIE foundation solutions for particular Technical Categories are directly transferrable to buildings that are not of this nature. Where Technical Category like behaviour is used in determining site zonings, other potential hazards must also be recognised.

In other cases, for example where soil strength or compressibility under static conditions is the main concern, zoning a site into areas where shallow foundations are feasible or not will be useful (along with the underlying cause of the zoning).

Commentary on 'Good Ground'

The simplistic notion of 'good ground' was originally derived so that non-engineers could safely make use of the non-specific design code NZS 3604. This concept is most applicable to small, lightweight, low-rise structures with well distributed vertical and lateral load resistance.

In areas of softer ground, the simplistic concept of 'good ground' can be misconstrued as placing sometimes unnecessary restrictions on the use of shallow foundations. In particular, the Ministry fully expects that professional engineers will not regard the notional 'good ground' limit of 300 kPa as being a barrier to the use of shallow foundations, but rather use well considered specific engineering design (SED) in such instances.

6.4 Geotechnical Scope and Reporting

The following geotechnical scope and reporting is required for all school projects:

a. Guidance is provided in the MBIE/NZGS Module 2 'Geotechnical Investigations for Earthquake Engineering' (Section 5) for the provision of geotechnical reports. Further to that guidance, the Ministry requires the provision of a combined 'interpretive' and 'factual' geotechnical report (i.e. more than a 'summary' or 'memo').

b. Bearing in mind that construction budgets can be set prior to even Master Planning stage, it is important that the geotechnical report provides comprehensive and technically justified advice on soil/rock types and depths, appropriate foundation types, as well as specific design data (bearing capacities, settlements, spring stiffnesses, liquefaction deformations, pile capacities

[2] Ministry of Business, Innovation and Employment. (2018). Repairing and rebuilding houses affected by the Canterbury earthquakes. https://www.building.govt.nz/building-code-compliance/canterbury-rebuild/repairing-and-rebuilding-houses-affected-by-the-canterbury-earthquakes/

and depths, expansive soils etc.) that can be used for the selection and sizing of foundations appropriate to the stage of design.

c. The geotechnical report is to always consider a shallow foundation solution, or include a clear explanation of why it is not appropriate. Advice is to be provided on all other potentially feasible foundation solutions as well. Foundation systems for ‘settlement-tolerant’ buildings are to be considered where appropriate, and SLS2 considerations are to be covered (including advice on shaking levels where significant ground deformations begin to occur for liquefiable sites). As discussed in section 5.2, for buildings on potentially liquefiable soil the SLS2 return period should be regarded as ‘indicative’, given that in some cases triggering of liquefaction within a significant portion of the soil column (and which is expected to result in non-trivial building deformation) may occur at a return period other than 1 in 100/250 years.

d. Seismicity (in accordance with MBIE/NZGS Module 1 ‘Overview of the Guidelines’ for geotechnical issues) is to be considered for all sites anywhere in New Zealand, and a check for the presence of active faults (from the Active Fault Database) is to be made for each school site.

e. Where appropriate, slope stability for any part of the site that might be affected is to be assessed, as well as any other geotechnical hazard that potentially affects the site.

f. Retaining wall design parameters are to be provided where appropriate, including recommended seismic design parameters (refer to MBIE/NZGS Module 6 ‘Earthquake Resistant Retaining Wall Design’ for more information).

g. Issues discussed elsewhere in this document (e.g. site zoning, geotechnical cross sections etc.) are to be covered in the report

   For example, a graphical representation of the site geotechnical model is strongly encouraged where appropriate, but does not necessarily need to be sophisticated in its presentation – see Figure 6.2.

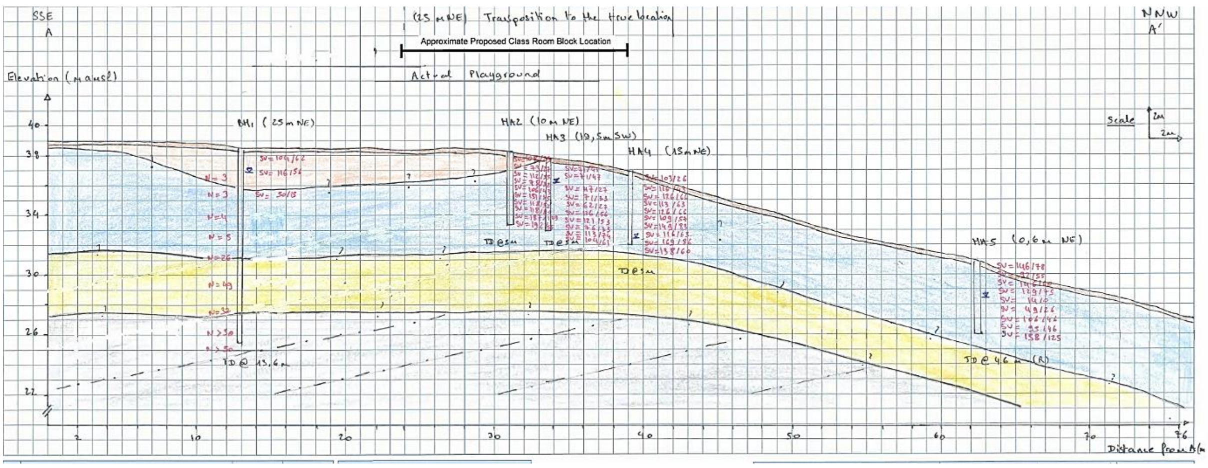

Figure 6.2: Example geotechnical cross section.

h. Site plans, borelogs, CPT traces, liquefaction analysis outputs and the like are to be appended to the report to support any advice given in the body of the report, and all factual data is to be uploaded to the NZGD (see section 3.5).

i. A foreword or tabulated summary of key requirements/advice is to be provided.

6.5 Assessment of Liquefaction-Induced Ground Deformations

Assessing the potential for ground movement or ground surface damage as a result of the effects of liquefaction is an inexact process. In some cases, the current methodologies can introduce an unknown degree of conservatism, and in other cases a degree of unconservatism. To help mitigate this, the geotechnical engineer should consider whether the following will be beneficial:

a. For sites where the soils are silty, and calculated deformations seem excessive, for CPT-based analyses the geotechnical engineer should consider if the estimated fines content (FC) data is appropriate. It can be beneficial to carry out soil sampling and laboratory testing to check the actual susceptibility of the soils (based on plasticity index and fines content), and to also check that an appropriate correlation between CPT-derived Ic values and FC is being used (Boulanger & Idriss, 2014)[3].

b. The geotechnical engineer may consider the position and thickness of the liquefiable layers in relation to the foundation level. Careful consideration of non-liquefiable 'crust' thickness, as set out in Ishihara (1985)[4] or the use of the liquefaction severity number (LSN) may be useful in judging if the liquefiable layers will in fact result in material (i.e. significant to the building) surface damage. Conversely, where the liquefiable materials exist in very close proximity to the foundations, deformations may be exacerbated due to building weights, ejecta of liquefied materials and foundation punching failures.

c. Assessment of the performance of buildings (that have been subject to liquefaction under design levels of loading) already on the site may provide a guide on potential future performance of new buildings.

d. In most cases a range of potential ground surface deformations are derived from a number of CPT results. While it may be prudent to base ULS design decisions on values from the upper end of the range, for SLS1 and SLS2 design decisions (i.e. where building amenity is being considered and building rupture is not a consideration) a mid-range value may be more appropriate.

e. Ongoing research into these issues is currently being carried out both nationally and internationally, so keeping abreast of new developments in this field is advantageous.

[3] Boulanger, R.W. & Idriss, I.M. 2014. *CPT and SPT based Liquefaction Triggering Procedures*. Report No UCD/CGM-14/01 Dept. of Civil & Environmental Engineering, College of Engineering, University of California at Davis.

[4] Ishihara, K. 1985. "Stability of Natural Deposits during Earthquakes", *Proc. 11th International Conference on Soil Mechanics and Foundation Engineering*, pp 321-376.

7. FOUNDATIONS

Key Summary Points

- Structural and geotechnical engineers are required to collaborate and take a holistic approach to design (section 7.1).
- Deformation capacity and compatibility of the structure needs to be fully considered (section 7.2.1 c).
- Consideration of repairability is a design requirement (section 7.2.1 c).
- Mixed foundation systems are not recommended (section 7.2.1 e).
- Shallow foundation systems must always be considered and are preferred where feasible, economical and have predictable behaviour (sections 7.2.1 d and 7.2.2).
- Retaining walls must be separated from building structures (section 7.2.1 g).
- Nominal deformation limit guidelines from B1/VM4 do not necessarily apply to Ministry buildings, and therefore careful consideration of settlement-tolerant building design is required (section 7.2.2).
- A risk based selection should be used for all foundation systems, except for sites where simple shallow foundations are an obvious option (section 7.3).

7.1 General

This section outlines the Ministry's requirements for foundations generally.

Foundations sit at the interface of the geotechnical and structural disciplines, and both disciplines should work collaboratively together to achieve a holistic design.

7.2 Foundation Systems

7.2.1 Key Considerations

It is essential that structural and geotechnical engineers work together from the outset to achieve a fully integrated approach to the selection and design of robust foundation systems and structural form. The nature of the site, the form of the structure and the materials used need to be compatible in order to achieve the most favourable outcome in terms of reasonable cost and desired performance. To achieve this the following should be considered:

a. A component-by-component approach to cost control may lead to an undesirable combination of materials, form and configuration if performance under both in-service and extreme events is not taken into consideration, particularly on poor ground. For example, when considered in isolation, brickwork may be the lowest cost and maintenance cladding, but may increase foundation demands and deformations, and result in increased damage during a seismic event, potentially leading to much higher lifecycle build and repair costs.

b. In considering foundation performance, it is critical that the natural deformation capacity of the proposed superstructure is taken into account. For sites where earthquake shaking-induced ground deformation is likely to happen, the increased ductility demand implied by the possible ground deformation may need to be added to that which may be expected from the shaking itself, when considering appropriate detailing.

c. Building designs that are able to accommodate movement, under either static or dynamic loading, without structural failure may be deemed acceptable if they are repairable (refer section 7.3 for guidance). However, designers need to consider the implication of cycles of deformation and repair, in assessing ductility demand and likely repair solutions.

d. Preference is to be given to shallow foundation systems where possible and economic (see section 7.3).

e. Mixed foundation systems within the same building footprint are not recommended (e.g. suspended timber floor with slab on grade), unless suitable allowance is made for differential movement (e.g. under strong earthquake shaking or underlying compressible soils). Such situations may require a specifically designed structural separation or other movement-tolerant feature to be provided over the full height of the structure.

f. The Canterbury earthquakes have shown concrete slabs on grade, particularly those with little or no reinforcement, to be particularly vulnerable to liquefaction induced ground deformations or soft soil movement. This has manifested as differential settlement of the floor, slab cracking, opening of construction joints, liquefaction ejecta intrusion and damage to underlying damp proof membranes and in-ground services. This has often resulted in expensive reinstatement or complete building replacement. Designers are therefore expected to give particular consideration at the design stage to future performance (and potential repair strategies) of floor slabs, foundation elements and services, particularly in areas of higher seismicity, in order to deliver cost-efficient structures. Avoidance of thin floor slabs is recommended, and current experience is that 'waffle slabs'' or raft slabs can be as economic as NZS 3604 – type foundations, due to their simplicity and speed of construction.

g. Retaining walls should be structurally separated from building/foundation walls.

7.2.2 Shallow Foundation System Preference

In order to ensure the most cost-effective long-term solution, a shallow foundation option must be considered for all sites.

While it is recognised that shallow foundation systems are not always feasible, or are in all cases the most cost-effective long term solution for a particular building, the Ministry will not necessarily accept a deep foundation system, or significant ground improvement schemes, without evidence (clearly documented in the DFR) that a shallow foundation system was thoroughly considered and shown to be not feasible or cost-effective.

Further detailed discussion on the interaction of ground deformation with structural systems, and the design of settlement-tolerant buildings, is contained in Section 8.

Background to Shallow Foundation System Preference

On sites where rigid adherence to the Building Code guidance may otherwise generate an inefficient solution, (i.e. where the foundation cost would otherwise be disproportionately high) the Ministry wants designers to help them manage risk rather than simply avoid it. To this end, while designers are expected to follow the general recommendations of AS/NZS1170 when verifying compliance with SLS1 and SLS2 requirements, the Ministry will accept foundation solutions which exceed the recommended displacement criteria from B1/VM4 (which, as discussed in the commentary box in section 2.5 is not mandatory, it is informative only – B1/VM4 in fact states that the criteria may be exceeded if the structure is specifically designed to manage a greater level of deformation under appropriate circumstances). This does not conflict with or override the requirement to comply with the Building Code itself.

7.3 Risk Based Foundation Selection

Foundation selection should be carried out on a risk-based approach, so that capital and potential future repair costs can be compared for various options. A framework for a risk based selection process is presented graphically in Figure 7.1. Using the key inputs as noted in the figure and as described in the preceding sections, the capital cost and repair costs can be estimated for different options. This allows an assessment of the most economical solution for the site, noting that other factors may also require consideration.

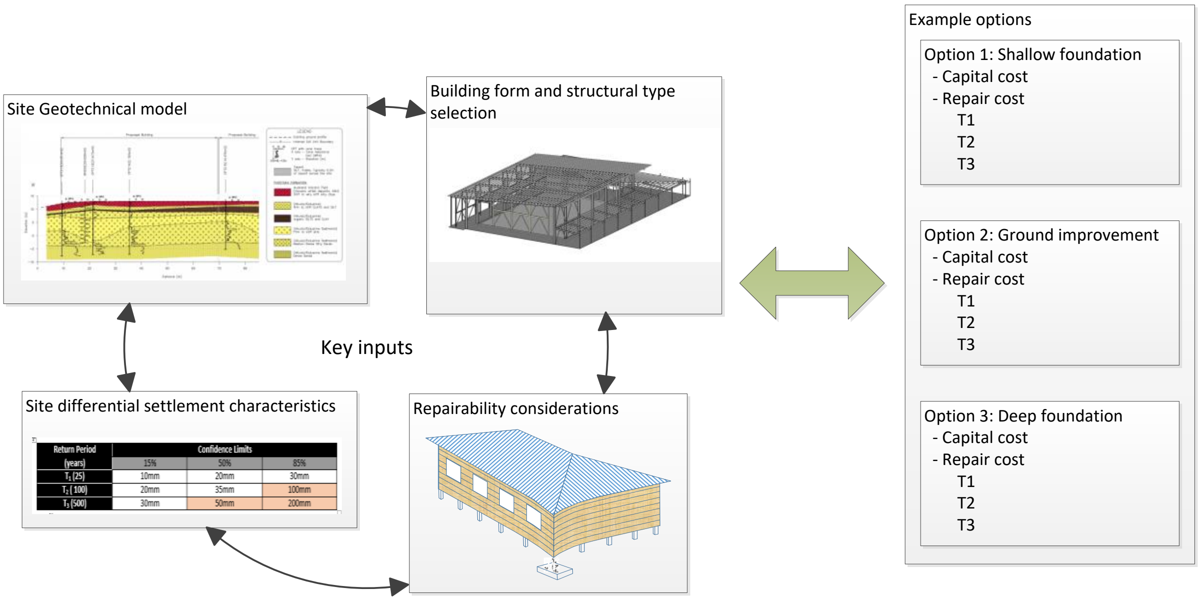

Figure 7.1: Framework for risk based selection process.

There are several stages to the process (which may be iterative depending on the number of options considered and the level of detail which is required).

Step 1 Determine the ground deformation characteristics for the site (e.g. differential ground settlement and lateral displacements). These values will help determine the range of options to consider and will be used for the risk study.

Step 2 Decide on the range of options that may be under consideration, generally following the process described in Figure 2.1. Note that there may be little value in preparing multiple foundation options for sites where simple shallow foundations are an obvious option. Equally, for sites that will not allow practical ground improvement and for which shallow foundations would likely result in unacceptable settlement, deep foundations may be the only feasible option. In the latter case, this may preclude the need to develop a range of solutions, but the rationale for this conclusion should be clearly articulated in the DFR.

In other cases a range of options should be considered, generally as follows:

a. A shallow foundation option (Mandatory), with repair options.

b. Ground improvement with shallow foundations and repair options, if required. More than one ground improvement option may be possible for a site, but for Master Planning, if the site characteristics allow it, ground improvement options may be treated generically (for preliminary design purposes only), assuming a generally consistent level of cost and performance.

c. Deep foundations (piles). For Master Planning, these may be treated generically, assuming a consistent level of performance regardless of pile type.

Step 3 Consider displacement/performance criteria as outlined in section 4.2 (i.e. *readily repairable* damage at SLS1 and *tolerable damage* at SLS2).

Step 4 Develop foundation and structure configurations that will work for the selected options. Some superstructure options may work equally well for more than one foundation system (and vice versa) but other integrated foundation and superstructure combinations may be unique. In all cases, compatibility of the superstructure with the foundation should be considered, taking into account the possible damage that will result from ground deformations.

Indicative approach

One approach for developing these solutions, such as for potentially liquefiable ground, is as follows:

a. Determine the likely differential settlement that may occur under a SLS2 event. As discussed in section 6.5 this can be based on the average of the assessed range with regards to liquefaction-related settlement.

b. Determine the differential settlement that may occur in a full ULS event. Again, for liquefaction-related settlement, this should be taken from the upper end of the assessed range as discussed in section 6.5.

c. Sum the SLS2 and ULS differential settlements. This is the differential settlement that could be expected for a building that may continue to be used following a SLS2 event and then experience a full ULS event. Note that the differential settlement will vary according to whether or not ground improvement is used.

d. Develop structural systems that are able to tolerate this range of movement, taking into account also the non-structural elements of the building that should be operational following the SLS2 event.

e. Check for acceptable performance at SLS1.

Step 5 Develop the required assessment criteria for the options, for inputs to the selection process. This step requires designers to consider the likely differential settlement that may occur either in earthquakes or over time in settlement prone sites, and to consider the likely timeframes over which it may occur.

Indicative approach

An approach for developing these criteria is as follows:

a. Determine the ULS displacement that each system may tolerate, including the effects of ductility demand. This may be from a combination of the likely building displacement under lateral load, combined with the differential settlement.

b. For each of the building systems, the threshold differential settlement for repair is then the lesser of:

   i. The differential settlement corresponding to the full inelastic capacity of the system, less the ULS differential settlement, or

   ii. The maximum differential settlement that can be tolerated by the structural and non-structural systems and still remain usable.

c. Guidance on tolerable deflections may be found in Section 9 and in NZS1170[5].

d. For each of the systems, for foundations subject to ongoing settlement from static loads, or from seasonal variations, estimate the likely frequency of repair, based on the threshold settlement for repair.

The decision-making parameters can now be determined for each system. Refer to Table 7.1 for an example of the selection criteria

Table 7.1: Foundation selection sample criteria.

Foundation Options	**Geotechnical Parameters**		**Building Parameters**	**Repair Parameters**			
	(A) SLS2 differential settlement	(B) ULS differential settlement	I Maximum inelastic displacement capacity	(D) Max. tolerable differential settlement to maintain normal use	I Max. differential settlement for margin to ULS	(F) Differential Settlement Repair threshold	(G) Estimated interval between repairs
Option 1: shallow foundations							
Options 2: ground improvement with shallow foundations							
Options 3: deep foundations							

Notes:

1. Column E = Column C – Column B
2. Column F = lesser of Column D or Column E
3. Column G may be estimated for sites prone to continuing settlement under static load or from seasonal variation

Step 6 Estimate an order of cost for repair, either explicitly or as a function of the total cost (i.e. damage ratios for each of the proposed systems).

Step 7 In some cases, from the output of the above, it may be useful to complete a risk-cost analysis to determine the total capital plus weighted risk cost for each option. This may then be compared to the other known costs and non-price attributes to assist the decision-making process.

Refer to Table 7.2 for a sample template for representing the indicative building system impact, nature of damage and anticipated repairs, and the associated costs and disruption. In this table, the likely differential settlements and repair/ operating costs should be represented as a range or band.

[5] Guidance is given in Table C1 of AS/NZS1170.0:2002, Appendix C, and in Table C7.1 of NZS1170.5 commentary. Note that both of these are for SLS1 and can be relaxed for assessment of SLS2 limits. For more detailed guidance, users may refer to the fragility data in the US guidance, FEMA/ACT 58 Performance Assessment Calculation Tool (PACT), which is available on-line. Users should take care to ensure relevance to local conditions when using this data.

Table 7.2: Indicative Building System Impact, Repairability and Cost Comparison Framework (example from hypothetical school).

Option 1: Shallow foundations + timber floor	**Foundation Capital cost = $4M**		
Design case	**SLS1**	**SLS2**	**ULS**
T (years)	25	200 – 500	1,000
Differential settlement (mm)	15 – 25	80 – 120	>200
Disruption	Some minor 'cosmetic' work may be required. No disruption to building operation.	Re-levelling required to 20% of the floor area. Grout injection of foundation pads/beams and mechanical re-levelling of floor area with 1 to 2 months duration. Work able to be planned for a school holiday period. Limited temporary accommodation/decanting costs (could use Hall/Gym as temporary classroom space).	Major repairs required including re-levelling of foundations and floor area (80% of area) with duration of 4 to 6 months. Expected to require temporary accommodation/decanting using MTBs.
	Cosmetic cracking of wall finishes. Building services operational. Weathertight (no reinstatement work required).	Redecoration of interior space(s) involving replastering and repainting. Sticking doors and windows. Some repairs to non-structural elements. Some cladding repairs. Building services readily reinstated – most located within accessible subfloor. Fire protection systems readily reinstated. Weathertightness readily reinstated.	Foundation re-levelling using mechanical lifting and grout injection. Liquefaction ejecta removal. Replacement of some structural elements. Extensive non-structural repairs. Most service connections to be replaced. Seismic separations reinstated. Significant repairs expected to reinstate weathertightness.
Repair/ Opex costs ($M)	$0.1M	$2M – $3M	$20M - $40M

Note: A table such as this is to be produced for each foundation option, and presented in the Design Features Report for design review

8. SETTLEMENT-TOLERANT BUILDING DESIGN

Key Summary Points

- Settlement-tolerant design may be desirable on ground where conventionally-designed simple shallow foundations appear not to be feasible (section 8.1).
- Nominal deformation limit guidelines from B1/VM4 do not necessarily apply to state school buildings (section 8.1).
- Ground deformations, their interaction with structural systems, and potential repair methodologies, over a range or combination of design events needs to be carefully considered (section 8.2).
- Settlement-tolerant design is not suitable where the magnitude and timing of deformations are not readily assessable (section 8.3.1).
- Significant foundation deformation can occur at shaking levels well below ULS, and the return period of damage is to be assessed (section 8.3.1).
- Both total and differential settlements are to be considered in design (section 8.3.1).
- Different building types have different vulnerabilities to ground deformations (section 8.3.2).
- Repairability must be carefully considered and allowed for in design (sections 8.3.3).
- Simple superstructure structural design strategies are suggested (section 8.5).

8.1 General

Shallow foundations must be considered for all new state school buildings and on all sites. On ground that may not appear suitable for simple shallow foundations (if making reference to simplified documents such as B1/VM4), this requirement often may be able to be achieved through 'settlement-tolerant building design', while still complying with the Building Code. It is important to note that this is not a new or special concept. Settlement-tolerant building design simply means using normal engineering analysis and design procedures to produce a building that is suitable for the ground conditions, and the constraints and deformations that those ground conditions will impose on the building. The operational impacts of adopting a settlement-tolerant building design will need to be presented to and agreed by the Ministry via the design review process.

This section provides guidance to enable designers to assess and provide relevant information as part of the Ministry design information requirements.

8.2 Overview and Principles

In many cases when considering the design of the building as a whole, rather than minimising potential building settlement by using deep foundations or ground improvement, cost-effective solutions using shallow foundation systems may exist for Ministry-owned school buildings where:

- Deformation behaviour is predictable;
- The implication of the displacements is adequately addressed; and
- Repair and reinstatement are practical (including consideration of suitable future relevelling methodologies and the effects on drainage and services).

Even under long-term load conditions on soft/compressible ground, or ground that has liquefaction potential from infrequent earthquake events, consideration can be given to shallow foundations (possibly with some ground improvement) rather than immediately defaulting to deep foundations.

Designers will need to present to the Ministry information on such options that demonstrate:

- The damage is quantifiable in both magnitude and temporal occurrence; and
- The building will remain usable; and
- The building may be relatively easily repaired; and
- The repairs may be implemented in a planned manner (e.g. over standard holiday period(s)) without an unacceptable impact on the operation of the school; and
- A suitable repair methodology has been developed, as discussed in section 4.3.

Once the designers have worked through a risk-based foundation selection process (as outlined in section 7.3), the Ministry will then be able to assess an acceptable level of risk, and work with designers to determine acceptable performance and relevelling criteria (i.e. serviceability limit states).

8.3 Design Considerations

A settlement-tolerant building will likely be a more economic design on settlement-prone ground than a structure that requires foundation deformations to be quite limited. A settlement-tolerant building is expected to have its superstructure (and services) designed to accommodate the expected total and/or differential settlements that may exceed nominal limits (e.g. Appendix B of the Building Code B1/VM4), while still being usable for its specific intended purpose (or be readily repairable).

Whether the building movement is due to static loading or earthquake, the expected displacements should be assessed, with regard to their probability and extent, as well as the impact on building operability (or usability). Designers should consider the range of possible outcomes in determining their design approach.

Designing settlement-tolerant buildings therefore requires:

- A systematic evaluation of the hazard, the impacts on the ground and hence on the structure, and the uncertainties associated with the analysis.
- Consideration of the options to manage the building movement-related risks, which includes consideration of how potential building damage can be observed and readily repaired or reinstated.

Key considerations when undertaking a settlement-tolerant design include ground deformation, the building type and vulnerability, and building repairability.

8.3.1 Ground Deformation

Ground deformation on settlement prone ground may be due to either:

a) *static load conditions* arising from a range of causes including time dependent, seasonal or moisture related; and/or

b) *dynamic conditions* arising from response to soil-structure interaction, liquefaction or lateral spread under the effects of seismic loading.

In such cases designers may traditionally choose to avoid the settlement using ground improvement or deep foundation systems. Alternatively, designers could choose to accept the assessed settlement and design the structure to accommodate these deformations. In all scenarios the designers should ensure that the building can be readily repaired (section 4.3) in line with the guidance set out in section 7.2.

If the building is subject to static settlements, and a settlement-tolerant strategy is adopted it is very important that both the magnitude and the timing of the settlements are properly assessed using conventional, well understood and industry-accepted analysis methods. This is to support the identification of the optimal building system, considering both whole of life costing, and the potential for operational disruption.

For example, settlements in organic materials such as peat are not able to be predicted to any great degree of accuracy (neither in terms of magnitude nor in terms of timing) and therefore these materials may preclude a 'settlement-tolerant' approach. Conversely settlements in natural clay materials (where adequate sampling and laboratory testing has been carried out) can be assessed using well-established analysis methods, to a degree of accuracy that is likely to result in an adequate understanding of the future behaviour of a building (i.e. for both primary and secondary consolidation induced settlements).

For school buildings, this requires firstly that the superstructure can be shown to tolerate the predicted movement, and then secondly that the building may be re-levelled/repaired within reasonable time and cost (for example within a standard holiday period for the on-site implementation work, or otherwise without significant impact on the operation of the school), as agreed with the Ministry. In general, it is differential movement (vertical or lateral) that has the most adverse impacts on foundation and superstructure performance and therefore this document mostly focusses on differential movement. The impacts of differential movement may be considered in different ways, including for example:

- **Structural:** Excessive differential ground movement may result in loss of capacity, if the rotation or extension of structural elements reduces the margins available to resist further shaking and displacement. For example the amount of ground deformation and resulting foundation disruption that can be tolerated from an SLS2 event, depends on the ability of the building to absorb the impact of deformation whilst retaining a suitable margin of resistance to the impact of future deformation under a significant earthquake, such as a ULS event (refer to section 4.1).
- **Non-structural:** Displacements and rotations may cause damage to non-structural elements such as partitions, ceilings, doors and windows and mechanical and electrical equipment. The impacts can range from minor aesthetic aspects through to affecting the use and amenity of a building.

While it is not usually practical to put quantifiable measures on amenity, the other effects can be measured and their impact can be assessed. In order to analyse the effects of ground deformation induced building movement under earthquake loading, it is necessary to assess the likely ground displacement as a function of the return period of the earthquake causing the ground displacement, and the confidence limits on what the displacement may be.

The foundation and building designer is advised to treat ground deformations carefully, in the knowledge that the numbers are inexact and therefore a design must never be critically reliant on their accuracy. For this reason, lightweight, settlement tolerant buildings are always a better design solution on potentially liquefiable ground.

In the case where settlement is purely or primarily as a result of gravity (or static) loading, designers must consider both total and differential settlements, and should use generally accepted analysis and design methods for determining appropriate foundation sizes. In some cases overall differential settlement limits might be overly restrictive and it may be more useful to consider floor slope as the controlling performance parameter, in discussion with the Ministry. Further guidance is provided in Section 4.

The impact of total settlement may be negligible for structural design, but will influence matters such as service connections, flood levels, drainage, and finished floor levels. Where significant total settlement is expected, designers should ensure that sufficient allowance for drainage is provided so that minimum falls are maintained if and when the expected settlement occurs. If the building is located in a flood zone then some consideration should be given to potential impacts on finished floor levels.

Impact of ground deformations on school buildings

Ground deformation was the most significant factor for damage to school buildings to emerge from the Canterbury earthquakes. It was frequently observed that many buildings which were otherwise not particularly vulnerable to earthquake shaking damage suffered moderate to severe damage through the inability of the structure to accommodate differential settlement or lateral ground movement[6]. It is evident that the damaging effects of significant differential movement are often initiated at a level of shaking that falls between the SLS1 and ULS design levels of shaking.

While the most severe differential settlement is typically related to liquefaction, excessive settlement may also result simply from the effects of shaking and soil-structure interaction during earthquakes. Ground deformation can also occur in the ordinary course of events, for example where a building is founded on soft or compressible material.

8.3.2 Building Type and Vulnerability

Different building types are expected to have different vulnerability to the effects of ground deformation. For example, lightweight buildings (e.g. buildings with metal roofs, timber cladding and raised timber floors) can deform relatively easily in sympathy with the ground profile. However, heavy and brittle buildings cannot easily deform with the ground and will sustain greater damage.

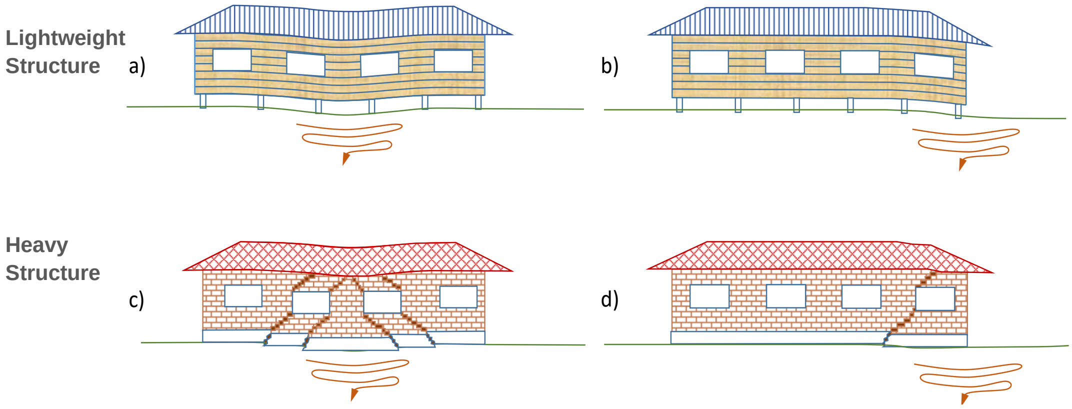

Figure 8.1: Indicative impact of ground settlement on lightweight verses heavy buildings.

[6] Lateral ground movement covers, as appropriate, global lateral movement, lateral spread or lateral stretch.

Further, modern design of classroom spaces tends towards providing large, flexible use areas that facilitate collaborative teaching and learning. Such building types generate distributions of vertical and lateral load that typically concentrate towards the perimeter of the floor plates. The interaction of such load distributions with the underlying ground should be carefully considered to understand the likely building performance with respect to foundation deformation.

The vulnerability of the 'building system[7]' to ground deformation is influenced by a number of factors:

1. The vulnerability to settlement under static (gravity) load conditions. In most cases, the settlement can be relatively simply controlled by increasing the bearing area of the foundations.
2. The vulnerability to time-related or seasonal effects (such as shrink-swell behaviour in clays or settlement in peats) may be independent of the foundation load.
3. The vulnerability to settlement under lateral load, without liquefaction. The overturning effects on the foundations tend to be greater because a heavier building's inertia generates greater seismic load. Hence the differential settlement effects may also be greater, particularly in cases where the seismic lateral load resistance is concentrated into relatively few elements with high overturning moments.
4. The vulnerability to settlement under lateral load, with liquefaction. This is considerably more complex. Firstly, the increase in pore pressure leading to liquefaction (and highest reduction in soil shear strength) does not necessarily coincide with the peak seismic actions causing the overturning pressures. (This is very difficult to assess, and until assessment methods are supported by further research, in most cases should not be relied upon). However, once the pore pressure has increased, it may take a considerable time to dissipate, meaning that the soil capacity will be reduced for a considerable time. The 'crust'[8] depth may be critical, as it helps to prevent punching failure of the foundations.
5. The vulnerability of the building system to ground deformations can also be influenced by the stiffness of the foundations – planar tilt of a stiff foundation system will often be less damaging (and easier to repair) to the building than flexural distortion of the foundations.

In all cases, the effect of ground settlement will be a function of the building type (e.g. building weight, lateral system and stiffness of the structure) and the soil-structure interaction.

Lateral Load Systems

The form of the lateral load-resisting system also has a significant effect on the behaviour. Concentrating the lateral load resistance into a few highly loaded elements such as braced frames or shear walls may be structurally efficient. However on settlement-prone soils, a more effective total system solution may be to distribute the lateral load resisting systems as much as possible (for example by using moment frames) to avoid aggregating overturning actions.

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[7] The 'building system' refers to the overall structure that provides the performance intended by the user – i.e. foundation, superstructure, services and internal layout.

[8] With respect to liquefaction, the crust is all the non-liquefiable deposits extending in a continuous layer from the ground surface downwards, including all materials above the water table. The crust helps to contain the liquefied material, even out deformations, bridge weaker areas, and spread the bearing load of foundations.

Building Flexibility

In general, buildings constructed of flexible material such as timber or steel, or in flexible forms (such as a moment frame, by comparison with walls or braced frames) will be less likely to be damaged through the effects of settlement. The interaction of the primary structure with the secondary structure and non-structural elements is also important, noting that the primary structure may only comprise 20-30% of the total cost of the building. Hence it is essential that these other elements also are considered in preparing a recommended 'building system' solution.

8.3.3 Repairability

Repairability is the ease and ability to identify damage and repair a structure and is a key requirement for the design of settlement-tolerant buildings, and must be considered early on in the design process.

It must be recognised that for a building to be considered repairable, a practical and specific means of implementation must be available. This assists in satisfying the requirement in B1/VM4 (if being followed) for buildings to be designed to prevent damage under greater settlement (than the 25mm in 6m nominal limit – see commentary on B1/VM4 in section 2.5).

For a timber building with raised timber floors on shallow piles, provided there is reasonable access to the sub-floor space, the process of relevelling may be quite straightforward. Relevelling the same timber building on a concrete slab on grade may, however, be more of a major undertaking, if there is not sufficient consideration of the required detailing for future jacking or grouting. In some cases this may require the addition of jacking and/or grouting ports, the inclusion of a stiff sub-base to allow ease of use of injection releveling methods, or the inclusion of jacking pads for mechanical lifting. 'Double concrete raft slab' foundations are also commercially available, with built-in mechanical jacking systems.

It is anticipated that in general, lightweight and flexible buildings will be more easily repaired than heavy, brittle buildings.

Consultation with the Ministry on foundation options and recommended solutions will typically be via the design review process. However, discussions with the Ministry's project personnel should also occur in the early stages of the project.

8.4 Usability Following an Event

In all cases, lightweight and flexible structures should be first considered as a primary means of damage control. In addressing the effect of settlement, regardless of cause, designers should consider the following questions:

1. Does the predicted displacement compromise the functionality of the building?
2. Does the predicted displacement compromise the ability of the building to resist (or accommodate) the effects of further ground movement, principally due to earthquake?

If either of these criteria apply, a building has reached the triggering displacement at which point repair must be undertaken. In determining whether to use a settlement-tolerant building approach, it is therefore necessary to be able to estimate both the likely magnitude of the deformation and the frequency with which repair may be required (or the probability of the design event that would trigger such repairs occurring during the expected life of the building). The nature, practicality and costs of the repair methodology must also be identified and assessed.

For relatively straightforward ground conditions and 'conventional' foundation systems, efficiency in the design process can be achieved simplistically in either of two ways:

1. By designing to SLS2 design criteria with assumed S_p=0.7 and structural ductility factor μ, such that 1.0≤ μ ≤2.0, and then detailing for ductility in accordance with the relevant material provisions for twice the chosen design ductility. This should automatically satisfy the conventional ULS design condition. Note that a capacity design procedure will have to have been followed, and that some of the other additional seismic design requirements may require explicit checking.
2. By designing conventionally for ULS, but with a limited ductility demand, and then adding a simple displacement check at S_p=0.7 and 1.0≤ μ ≤2.0. The displacement at SLS2 is likely to be more critical than the ULS (factored) displacement, but this can be allowed for by setting a target ULS displacement that is reduced accordingly.

When considering design options, a risk-based design methodology should be followed, as detailed in section 7.3.

9. STRUCTURE

Key Summary Points

- The Ministry has additional mandatory requirements that are over and above the Building Code (section 9.1).
- Designers need to carefully consider the building footprint layout and configuration (section 9.2).
- Designers need to provide for additional ductility to significant load bearing elements (section 9.3).
- Designers need to carefully consider and detail for deformation compatibility (section 9.4).
- Guidance is provided for SLS2 repairability limits for primary structural elements (section 9.5).
- Guidance is provided for designing to meet Ministry SLS2 performance criteria, including consideration of ground deformations on the superstructure (section 9.6).
- All design load allowances should be clearly documented on the drawings and in the DFR (section 9.8)
- Guidance is provided for the design of conventional ground floor timber decks (section 9.9).
- The use of proprietary products does not relieve the designer of their responsibility to ensure the products are accompanied by recognised certification (section 9.10).

9.1 General

All new state school buildings shall be designed in accordance with the Building Code, and as extended by these requirements. Designers may either demonstrate compliance with the Building Code through use of the Acceptable Solutions or Verification Methods, or by use of Alternative Solutions (refer to Section 2.5). This section outlines specific structural considerations and requirements for state school buildings.

9.2 Building Shapes and Configuration

Regular building shapes of smaller footprint area will generally provide better overall building and foundation performance under seismic shaking. However, this must be balanced against the use of larger footprint buildings to increase the ratio of floor area to cladding area, which is generally more cost-effective. Re-entrant corners and floor plans that 'neck' between larger areas should be avoided, where possible. Regular building shapes also reduce potential weathertightness problems resulting in more durable buildings.

Footprint areas are encouraged to be kept as small as possible on ground that is liquefiable and/or subject to lateral ground movement[9]. This will help to reduce the impact of differential settlement and lateral movement that has caused significant issues for many larger footprint buildings in Canterbury that were otherwise relatively undamaged. Notwithstanding this, it is preferable to use single-storey buildings on poor ground, where site space planning allows.

Lighter-weight building materials should be used to promote the use of shallow foundation systems and reduce seismic demand, particularly for buildings on poor ground.

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[9] Within this document, earthquake-induced lateral ground movement may include global lateral movement, lateral spread and lateral stretch.

If large floor plates are unavoidable, movement joints should be installed to control the effects of long-term shrinkage and expansion; and to control the impact of potential lateral ground movement. Example building configurations are presented in Figure 9.1.

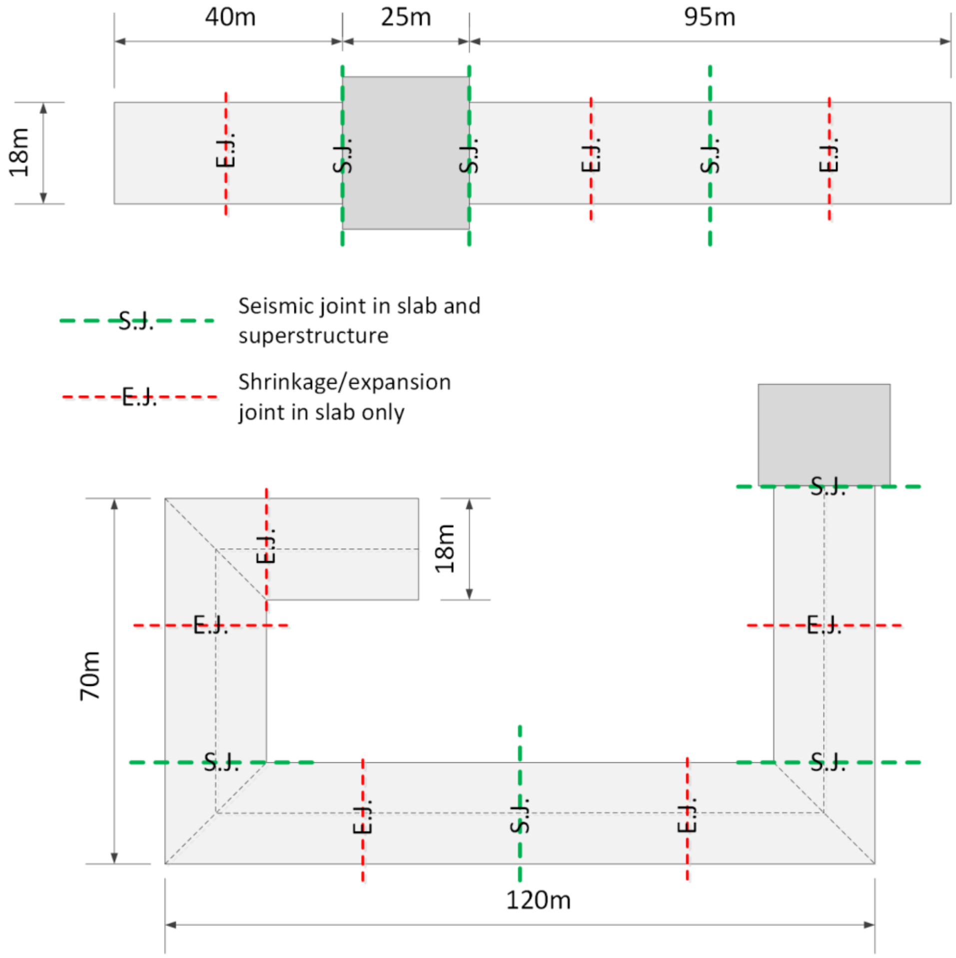

Figure 9.1: Example building plan configurations and joint layouts.

Joints should be located in areas where the concentrated movement may be most easily dealt with but in general, excessive slab panel aspect ratios should be avoided. Recommended aspect ratios are presented in Figure 9.2.

Seismic joints in floor slabs should in all cases be coordinated with structural movement joints in the superstructure and substructure. Dual lateral and vertical support lines may be required in order to maintain stability in the event of large movements.

It is noted that appropriate detailing for construction joints and shrinkage control may provide beneficial foundation flexibility and facilitate readily repairable and cost-efficient structures.

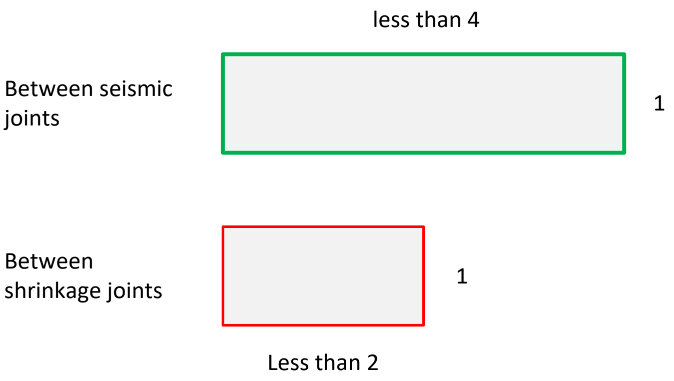

Figure 9.2: Maximum slab panel aspect ratios.

9.3 System and Element Ductility

9.3.1 Significant load bearing elements in multi-storey buildings

The Ministry requires that significant load bearing elements in buildings of more than one storey are designed to be as robust as practicable, in order to provide a greater measure of protection against the damaging effects of seismic movement.

In buildings of more than one storey, all steel and concrete columns (or column elements within walls constructed of concrete and concrete masonry) shall be detailed for ductility in accordance with the additional provisions of the relevant standards, regardless of the building system ductility that the designer has elected to use.

In practice, this means that all affected columns and column elements within walls must be detailed so the columns are capable of developing full ductility ($\mu \geq 3$). Designers may have elected to design the overall structure for elastic or nominally elastic actions ($\mu \leq 1.25$), but this Ministry requirement recognises that these displacements may be exceeded under a larger earthquake. Designing for additional ductility can be achieved for only a nominal increase in cost and may result in considerable savings in post-earthquake repairs, and a greater likelihood of the building remaining usable in the event of a significant earthquake.

9.3.2 Steel Rod and Flat Bracing

Steel rod or flat bracing should be limited to $\mu \leq 1.25$, and should not be used to brace storeys of heavy construction.

9.4 Deformation Compatibility

Stiff elements that are not separated from the surrounding structure will almost certainly govern the seismic response of a building. Designers need to consider this and detail carefully for the expected movement of structure, including foundation rotation if this is significant. Non-structural elements that are stiff and/or brittle should be provided with adequate movement allowance (e.g. partition wall deflection heads and suspended ceilings). Alternatively, primary lateral load resisting structural systems shall be designed to be sufficiently stiff that non-structural elements which are reliant on them for support are restrained to within their deformation capacity at the appropriate limit state. Refer to Appendix A for further guidance.

Where siting a building across different soil types (or soils that have extreme variations in either the depth of or to soils that are prone to settlement) cannot be avoided, the designer should consider foundation types that minimise the impact of these factors.

Buildings with significantly different pile lengths or depths of foundation should be avoided, particularly in areas with elevated seismic loadings.

9.5 Primary Structure Repairability Limits

School buildings should be designed to meet the qualitative performance requirements for structural and non-structural elements (refer section 4) and as outlined for specific elements in Appendix A.

Further, designers should ensure primary structural elements are designed to limit SLS2 displacements to the lesser of the repairability limits provided in Table 9.1 below, or the limits determined by deformation compatibility of non-structural elements that are reliant on the primary structure for support.

Table 9.1: Guidance on repairability drift limits for primary structural elements.

Material/System	Element	SLS2 Repairability limit
Concrete or structural steel	Ductile moment frame (μ≥3)	0.8% (1 in 125)
	Non-ductile moment frame (μ≤1.25)	0.42% (1 in 240)
	Ductile shear wall	0.4% (1 in 250)
	Non-ductile shear wall	0.2% (1 in 500)
Structural steel	Ductile moment frame	0.8% (1 in 125)
	Ductile braced frame(1)	0.8% (1 in 125)
	Limited ductile or non-ductile braced frame	0.2% (1 in 500)
Structural timber	Frame systems	0.8% (1 in 125)
	Braced frame systems	0.2% (1 in 500)
Wall systems	Timber or metal stud framed wall systems	0.5% (1 in 200)
	Concrete block wall	0.3% (1 in 333)

Notes:

(1) *Ductile steel braced frame* includes frames incorporating diagonal yielding elements such as buckling restrained braces (BRBs) or eccentrically braced frames (EBFs) designed so that the yielding elements can be replaced without decommissioning the building.

9.6 Usability Following Subsequent Earthquakes

The Ministry's performance criteria essentially require a building to have sufficient capacity to undergo a SLS2 event and a ULS event, consecutively. While this may at first seem onerous, it is important to consider the difference between the design ductility demand and the actual ductility capacity of a system. For most situations, no additional capacity will be required, but there may be a need to evaluate member ductility, particularly in cases where settlement is significant.

Consider first a building that is not expected to undergo any significant differential settlement in a SLS2 earthquake. In this case, a building should undergo little or no inelastic displacement as a consequence of the shaking, if it is to satisfy SLS2 criteria. Hence there will be no significant residual drift and therefore no reduction in the ULS deformation capacity of the building. No additional work would be required in these cases. Moreover, the displacement capacity is inherently built into a modern building by virtue of compliance with the special seismic design clauses of the material standards, which include deemed to comply provisions in order to ensure survival of a significantly greater event than the design earthquake.

In the case of a building on more settlement-prone ground, there may be significant displacement of the ground and this must be assessed. The assessment should consider the residual displacement imposed onto the primary lateral-load resisting system of the building and/or its foundations, independent of the deformation caused by the lateral loading, but with similar effect. If the residual deformation significantly reduces the available capacity of one or more elements, then it may in turn significantly impact the overall building capacity.

Depending on the number and distribution of lateral load resisting elements (i.e. the level of redundancy) this may require mitigation and/or may trigger the requirement to relevel to restore capacity.

There are a number of different approaches that could reduce the potential impact of differential movement and/or mitigate its impact including:

1. By detailing for reserve ductility capacity in excess of what is required for the same structural system on ground where significant settlements are not expected. Designing to meet the SLS2 criteria practically limits the ULS ductility demand approximately to $\mu_{ULS} \leq 3.5$. However, by detailing for a greater level of ductility, additional deformation capacity can be relatively easily added without changing member sizes, in many cases. This goes together with limiting drifts under SLS2 in order to limit damage to non-structural elements, even though the lateral load resisting system may be capable of resisting greater deformations. This means that the total of the SLS2 and ULS deformations may be significantly less than the actual deformation capacity of the system as a whole.
2. By using systems that have a suitable degree of redundancy such as using well-distributed multi-bay moment resisting frames, which are slightly over-designed. This will minimise the impact of differential settlement in a single location as to the extent that the reduction in capacity from the loss of one or two bays only of a frame may not represent a significant reduction in overall capacity. This requires consideration of resulting accidental eccentricities also, whereby an orthogonal system should be supplied that has the capacity to resist the full torsional loading that may result from the partial loss of part of the overall system.
3. By specifically evaluating the potential member ductility demand that is imposed by the settlement and ensuring that the additional member demand has no significant impact on the system demand.

The above requirements should be followed through in the detailing of secondary structural and non-structural systems that may impact on life safety.

For a worked example demonstrating how this is practically achieved refer Appendix B.

9.7 Building Materials

The use of building methods or materials that have particular aesthetic attributes should be subject to careful consideration of function, constructability and repairability. For example, the detailing of polished concrete floors or sculpted or textured precast panels needs to be carefully considered in seismically active areas.

9.8 Future Flexibility: Additional Superimposed Load Requirements

A key design principle for new state school buildings is to allow flexibility in the internal layout to adapt to changes in teaching pedagogy over time. Similarly, flexibility should also be incorporated into the building design to allow for reasonable changes to the building over its lifetime (e.g. changes to floor linings, addition of acoustic ceiling tiles).

To ensure a consistent approach across the property portfolio, a minimum ‘future proof’ additional superimposed dead load of 0.5kPa should be included in the total superimposed dead load provision for suspended floor levels.

Designers should recognise that as this additional load may never be applied to the structure over its design life, it should not be considered where it has a stabilising effect on the structure (e.g. under wind uplift).

For clarification, all design load allowances shall be clearly documented on the structural drawings and outlined in the DFR for future reference.

9.9 Design of External Decks (Conventional Ground Floor Decks)

The categories and wording in Table 3.1 of the Loadings Standard NZS1170 Part 1 indicates the requirement for a 4kPa floor loading for the applicable activity/occupancy area C3 – Areas without obstacles for moving people.

Given that the floor loading requirement for classrooms is typically 3kPa, the Ministry considers this higher load requirement to be conservative for decks located in close proximity to the ground, due to the low consequence of failure that may arise from what is an extreme loading situation.

It is considered that this higher level of loading, if it were to occur, would typically only occur over a short duration for a deck. Therefore, the Ministry will accept the higher foundation settlements and member deflections in the event the deck is ever exposed to the higher level of loading.

However, for the strength design of conventional, non-cantilevered deck framing the designer should design the deck framing under the higher 4kPa where the loading may be taken as ‘Brief’ for the purposes of selecting the factor k_1 from Table 2.4 in NZS3603.

Where decks that are in close proximity to the ground might be used as outdoor learning spaces, an additional check is to be carried out with a 3kPa live load considering a ‘Medium’ duration load factor.

This should result in the same foundation systems for both conventional ground floor decks and the floor system in associated classroom areas.

All other timber decks (e.g. cantilevered or balcony) should be designed for the full live load, with the loading taken as medium for the purposes of selecting the k1 factor.

9.10 Proprietary Products

All proprietary products should be accompanied by certification from a recognised certification body or testing agency (in NZ) certifying that the product is suitable for use in the application for which it has been specified. Particular care should be given to high risk elements such as suspended ceilings and seismic restraint of non-structural systems.

10. NON-STRUCTURAL SYSTEMS

Key Summary Points

- The structural engineer is responsible for ensuring the non-structural system performance requirements are distributed to the design team (section 10.1).
- Non-structural elements have the same performance requirements under design loadings as the building (section 10.1).
- The design and construction monitoring responsibilities of the various engineering parties involved in non-structural systems are to be clearly documented prior to the award of construction contracts (section 10.1).
- Heavy cladding should be considered holistically with respect to safety, whole of life cost and additional loading on the building (section 10.2.1).
- There are particular Ministry requirements with regard to the use of masonry veneer cladding systems (section 10.2.2).
- Glazing systems are to be designed for anticipated building movements (wind and earthquake) and in some situations require safety film to be applied (section 10.3).
- The designers of partition walls and ceiling systems are to ensure they laterally secured and protected from damage (sections 10.4 and 10.5).
- The design of mechanical and electrical systems must take account potential ground movement, and deformation compatibility with other elements, and ensure that the mechanical and electrical systems are secured, and that suspended services have independent lateral and vertical restraint (section 10.6).
- The use of proprietary products does not relieve the designer of their responsibility to ensure the products are accompanied by NZ recognised certification (section 10.7).

10.1 General

The performance of non-structural systems (including drainage, water supply, communications infrastructure, mechanical and electrical plant and equipment, cladding, ceiling systems and partitions) has been one of the major determining factors in the post-earthquake operability of buildings, regardless of structural damage. As a significant component of community resilience and well-being, it is important that school buildings remain operational after significant events such as earthquakes. Therefore, designers should take particular care to ensure that all elements of buildings are suitably addressed.

In general, the non-structural systems of a school building should meet the same performance requirements as required of the building as a whole (refer to section 4.2). This means that:

- After an SLS1 earthquake, all aspects of the building should be fully operational, needing only easily implemented repairs that do not materially impact on use.
- After an SLS2 earthquake, a building should be able to be used as intended, but with repairable damage that may be completed over periods such as the scheduled school holidays.

All non-structural systems, and in particular those which may impact on the continued use of a school building (e.g. fire protection systems), must be appropriately detailed in accordance with the relevant standards or good practice for the required loads and/or movements calculated from NZS 1170.

Further guidance is given on the performance requirements for selected non-structural elements in Appendix A.

As the Ministry non-structural performance criteria are outlined in this document, it is the responsibility of the structural engineer to circulate the non-structural performance requirements to the wider design team. Where secondary structural elements are a contractor design item (e.g. ceilings or partition walls), the structural engineer should clearly outline the required Ministry performance requirements of these elements and the appropriate design load derivation in the DFR, including the requirement for a PS1 and PS4 (section 2.5.1 and 3.7.2) by the designer of those elements.

The design and construction monitoring responsibilities of the various engineering parties involved in this work (i.e. the design engineer and relevant contractor/ sub-contractor engineers), are to be clearly documented prior to the award of construction contracts in order to ensure that the damage protection objectives of the Ministry are met.

10.2 Heavy Cladding

10.2.1 General

When considering the use of heavy cladding, the architectural and structural engineering implications should be considered in a holistic fashion. For example, brick veneer cladding has many advantages for school buildings when considered over the whole building life, but it may not be suitable for all locations, with consideration of geotechnical conditions, seismic load and protection from falling hazards.

It should be noted that the additional seismic mass of the cladding system may impose a considerable penalty on the design of the lateral load systems, especially in cases where the overall seismic load significantly exceeds the wind load or when the building is sited on soft ground. The impact will vary according to a number of factors, but is less likely to apply for areas where the Seismic Hazard Factor (Z), is lower than 0.3. If comparing whole-of-life costings for cladding systems, the added cost impact of the heavy cladding system should include a factor to allow for additional foundations and lateral bracing.

10.2.2 Masonry Veneer

Masonry veneer is a durable and cost-effective cladding system that has many advantages for school buildings when considering a whole-of-life approach, but it may not be suitable for all applications. Care should be applied when specifying masonry veneer cladding in the following situations:

- In areas where students may congregate or in areas adjacent to access and egress paths as masonry veneer can present a falling hazard in earthquakes.
- For timber-framed buildings in high seismic regions (indicatively where $Z \geq 0.3$) as the masonry veneer will likely start to drive the design of the structure.
- On liquefiable and poor ground (irrespective of seismicity) as the additional seismic mass will likely result in greater building settlements due to soil structure interaction effects (e.g. 'ratcheting').

Where it is considered appropriate for masonry veneer to be used, the NZ Clay Brick & Paver Manufacturer's Association Design Note TB1 – 2018[10], which has BRANZ appraisal, should be followed for design and construction specification. In addition to Design Note TB1, the Ministry has the following requirements:

- Masonry veneer should not be used above rooflines.

[10] Design Note TB1 – January 2018, *2 Storey Clay Brick Veneer Construction – Made Easy*, NZ Clay Brick & Paver Manufacturer's Association

- Veneer panels beside windows or doorways (piers) should be no less than 950mm in width.
- Veneer should have a maximum thickness of 90mm, and the weight is not to exceed 180 kg/m^2. Veneers in excess of 180kg/m^2 will require specific design – refer NZS 4230:2004[11].
- The veneer cavity shall be a minimum of 40mm and a maximum of 60mm. It should be noted that the cavity is measured from the tie fixing to the inside face of the veneer. This also means the edge of the foundation and framing line will need to be constructed to tighter tolerances than typical construction practice.
- Gable end trusses should not be used for restraining veneers. All gable ends are to be framed full height walls with studs at a maximum of 400mm centres.

  Note: External Moisture Acceptable Solution E2/AS1[12] of the Building Code Compliance Document requires a rigid air barrier over gable ends opening into roof cavities, and the 40mm minimum cavity needs to be considered in this regard. It may be necessary to line the inside of the framing to gable ends.
- If the spacing or positioning of a tie is not specified in TB1, then NZS 4229:2013[13] will apply.

For masonry veneer supported by concrete masonry, the spacing of ties in Design Note TB1 applies, except in what is designated Earthquake Zone 4 in NZS 4229: 2013 (South Island Z >0.4), where specific engineering design will apply.

If masonry veneer is specified in areas where students may congregate or in areas adjacent to access and egress paths, the structural engineer's construction monitoring engagement should include specific inspections of the veneer and veneer ties during construction, with particular emphasis on inspection of the upper courses (refer to section 3.7.2).

The Specification should also outline the requirement for a master mason to undertake the construction of the brick veneer and to provide a PS3 at the completion of the work.

10.3 Glazing

Glazing systems shall be designed with sufficient clearance to accommodate the full lateral displacement implied by the design level wind or earthquake, with allowance for inelastic drift calculated in accordance with NZS1170.5.

Safety film should be applied to overhead clerestory glazing panels and glazing above egress ways in existing buildings in higher seismic locations.

All glass must be installed to New Zealand Standard 4223.3:1999. In some circumstances the Ministry requires a higher standard to be adopted. Details are available at the Ministry's online Property pages.

10.4 Partitions

Partitions shall be protected from damage either by limiting seismic drift of the primary structure to less than the drift which causes onset of damage for the partitions, or by providing seismic protection to the partitions (such as sliding head restraints combined with appropriate detailing at partition junctions).

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[11] NZS 4230: 2004 – Design of Reinforced Concrete Masonry Structures
[12] Compliance Document for NZ Building Code Clause E2 External Moisture Acceptable Solution E2/AS1
[13] NZS 4229:2013 - Concrete Masonry Buildings Not Requiring Specific Engineering Design

10.5 Ceiling Systems

In general, ceilings must be laterally secured and designers must consider deformation compatibility in the detailing of edges and junctions with structural elements or where the ceiling may interact with other non-structural elements such as light fittings, sprinklers and partitions.

Suspended ceiling systems, where used, shall be designed in accordance with AS/NZS 2785.

10.6 Building Services and Site Infrastructure

Mechanical and electrical systems (including ICT and security system elements) shall be secured in accordance with NZS4219. Unless the design of ceiling systems has specifically considered the additional weight and behaviour of services in the design of lateral restraint, all suspended services elements shall have independent lateral and vertical restraint.

Deformation compatibility with other non-structural elements and with primary structure must be considered in the configuration and design of building services and supporting elements. The potential interaction between buildings and adjacent ground (and particularly the building foundation elements) may impact on building services. This is especially the case where the design, as agreed with the Ministry, anticipates and allows for significant ground and foundation movement. In this case the ability of services to tolerate differential movement must be addressed (e.g. oversized sleeves at foundation interfaces and ensuring pipe falls are not at minimum requirements). Repair strategies must be developed to cover the building services as noted in section 4.3.

For buildings located in liquefiable ground, below slab services should be either within, or tied to the building slab and foundations to prevent damage due to localised soil ejecta.

10.7 Proprietary Products

All proprietary products should be accompanied by certification from a recognised certification body or testing agency (in NZ) certifying that the product is suitable for use in the application for which it has been specified. Particular care should be given to high risk elements such as suspended ceilings and seismic restraint of non-structural systems.

11. ALTERATIONS AND ADDITIONS

Key Summary Points

- All alterations and additions must comply with the Building Act and may trigger accessibility and means of escape from fire upgrades (section 11.1).
- The design engineer should carefully consider the performance of any alteration or addition and its interaction with the existing structure (section 11.2).
- Guidance is provided based on good practice and experience gained from observations of building performance during previous earthquakes (section 11.3).

11.1 General

Alterations and additions to state school buildings shall be designed in accordance with the relevant sections of the Building Act and Building Code, as extended by these requirements.

Designers should note in particular the following sections of the Act:

> **S17 – All building work must comply with Building Code**
>
> The new building work must comply with the relevant code provisions relating to that work, to the extent required by the Act. For example, if a new structural wall is to be constructed, then the wall should be detailed with ductile detailing expected within current design standards. However, the wall will not necessarily have to be designed so that the building, after alterations, can take 100% of the lateral load demand required of a new building.
>
> **S112 – Alterations to buildings**
>
> This requires that after the alteration, the building should comply as nearly as reasonably practicable with provisions of the Building Code regarding disabled access and means of escape from fire; and otherwise to no less an extent than before the alteration. This means that the structural performance of the existing building overall should not be less than prior to the alterations taking place.

Notwithstanding S112, altered school buildings will need to be strengthened in line with the Ministry's Earthquake Resilience Policy (Section 12).

In establishing the current seismic strength of a building, refer to section 12.4 for guidance on using existing Ministry seismic assessments, and section 12.3 for where new seismic assessments will need to be undertaken. The Seismic Assessment of Existing Buildings[14] must be used for all new assessments.

Section A10 of Part A 'Assessment Objectives and Principles' of that document also provides general guidance on the seismic improvement of buildings.

11.2 Displacement Compatibility

In the case of building additions, designers must exercise judgement to determine if the new addition should be structurally independent of or connected to the existing building.

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[14] Ministry of Business, Innovation and Employment, Earthquake Commission, NZSEE, SESOC and NZGS, *The Seismic Assessment of Existing Buildings*, July 2017.

Where the existing building has seismic capacity below the Ministry target capacity, it may be more efficient to connect the two and use the new addition as the strengthening element. In this case, designers will need to take care to ensure:

1. That displacement compatibility is considered, so that the required load transfer to the new structure is achieved.
2. That the implications of inelastic deformation are considered, so that the deformation capacity of the existing structure is not exceeded before the new structure has fully developed its capacity (including the effect of ductility).
3. That the foundation system of each are included in the above and have taken into account the impacts of potential differential settlement.

Where a new addition may lead to an adverse torsional response, or is not otherwise structurally compatible with the existing structure, it may be more efficient to seismically separate the new from the existing, provided that appropriate detailing is used to mitigate against potential pounding and to ensure non-structural elements crossing the joint are able to accommodate the movement. In considering additions to buildings with flexible diaphragms, the flexible diaphragm will generally not transfer significant torsional actions, meaning that torsional response will not develop. Further, new additions will be unlikely to contribute significantly to the capacity of remote lines of the existing structure.

For buildings with rigid concrete diaphragms, consideration should be given also to management of shrinkage. The existing concrete floor will generally have experienced all or most of the shrinkage that it is likely to experience, but any new concrete will shrink and if restrained by stiff vertical elements, this may lead to damage.

11.3 Other Considerations

The following guidance is provided based on established good practice and experience gained from observations of building performance during the Canterbury and Kaikoura earthquakes:

- Additions/alterations should use the same foundation system as for the existing building unless suitable consideration is given to the design of movement-tolerant building elements (e.g. seismic joints).
- Careful consideration should be given to the potential variability in the ground conditions beneath the existing and new parts of the building. Movement-tolerant joints should be incorporated where differential foundation movement is anticipated.
- Mixing piled foundations with shallow foundations, for the same building, should be avoided (even if a seismic gap is provided).
- For additions/alterations to concrete floor slabs and/or ground beams, joints should be dowelled to control vertical movements and detailed to allow some repairable lateral extension.
- Floor slab movement joints should be installed as noted in section 9.2. If the aggregate floor plate is small enough it may be possible to tie additions to existing floor slabs, but the impact of differential movement shall be addressed. If the potential for differential movement is too great, a full separation may be required, and independent vertical and lateral load systems may be needed.
- Ensure that weather-tightness will be maintained at the interface of the existing and new superstructure elements, and that these junctions are detailed to allow some lateral extension.

12. ASSESSMENT AND STRENGTHENING OF EXISTING BUILDINGS

Key Summary Points

- The Ministry's short-term goal is to ensure no state school buildings are earthquake-prone. The medium-term goal is to have school buildings strengthened, as near as is reasonably practicable, to 67% NBS (section 12.1).
- Seismic assessments of a number of school buildings have been completed as part of previous Ministry programmes (section 12.2).
- New seismic assessments should be undertaken in accordance with 'The Seismic Assessment of Existing Buildings: Technical Guidelines for Engineering Assessments' developed by NZSEE, SESOC and NZGS, in conjunction with MBIE and the Earthquake Commission (section 12.3).
- Concrete buildings shall be assessed in accordance with the 'Technical Proposal to Revise the Engineering Assessment Guidelines' released in November 2018, unless the assessment is required for earthquake-prone buildings purposes (section 12.3).
- Existing seismic assessments were typically undertaken in accordance with the 2006 NZSEE Guidelines and engineers should be aware of the potential impact of subsequent changes to the Building Act and the seismic assessment guidelines (section 12.4).
- At the time of master planning, or building refurbishment is undertaken, all buildings of two or more storeys and of heavy construction should be subject to engineering review, and where necessary, seismic assessment (section 12.4).

12.1 Ministry's Earthquake Resilience Policy

The Ministry's short-term goal is to ensure no state school buildings are earthquake-prone, with identified critical vulnerabilities addressed as soon as practicable. For buildings rated less than 34%NBS, 'short term' should be interpreted as being an expectation that strengthening works would be planned for inclusion in the schools next '5 Years Agreement' (5YA) round.

The medium-term goal is to strengthen school buildings, as near as is reasonably practicable, to 67%NBS in conjunction with other property upgrade and refurbishment work.

In practice, the 67%NBS target will not be rigidly enforced as a specific target for seismic risk purposes, but requires that reasonable strengthening should be undertaken at the time of upgrade or refurbishment. This reflects how the Ministry has integrated the treatment of seismic risk within a larger property asset management process. The Ministry may accept a lower strengthening target where it can be demonstrated that the cost to strengthen to 67%NBS would be disproportionately high. For example, there may be specific critical structural weaknesses that can be easily addressed to raise the building up to a rating of say 55%NBS. This represents a cost-effective risk treatment without simply seeking to meet the broad target represented by '67%NBS'. Other factors which may be taken into account include the construction of the building (heavy or lightweight) and the remaining expected life and use/occupants of the building.

12.2 Previous Ministry Seismic Assessment Programmes

12.2.1 General

For over 30 years, the Ministry have responded to changes in the Building Code requirements in relation to the performance of buildings in earthquakes.

In the late 1990s, the Ministry conducted a national seismic survey of the school building portfolio and undertook priority works to address primary seismic risk elements, thereby improving seismic resilience. This work included the removal or strengthening of unreinforced masonry elements and the removal of heavy tile roof and ceiling material.

Following the Canterbury earthquakes, the Ministry put considerable effort into understanding the likely seismic performance of its school buildings, both in the greater Christchurch area and nationally. This resulted in the establishment of the Detailed Engineering Evaluation (DEE) and the Earthquake Resilience (EQR) programmes.

Seismic assessments for both the Greater Christchurch DEE and national EQR programmes were typically undertaken in accordance with the 2006 New Zealand Society for Earthquake Engineering Guidelines.

12.2.2 Greater Christchurch DEE Programme

The DEE programme ran from 2011 to 2014 and assessed the seismic capacity of approximately 2,700 state school buildings in the Christchurch, Selwyn and Waimakariri districts. The DEE programme is outlined in a report titled 'Greater Christchurch Earthquake Resilience Programme, Contextual Report for Detailed Engineering Evaluations' dated May 2014.

All timber-framed classrooms, steel-framed school buildings, portal-framed halls/gyms and ancillary buildings were assessed as part of the Greater Christchurch DEE programme.

12.2.3 National EQR Programme

The EQR programme ran from 2012 to 2016 and included approximately 15,000 state school buildings nationally (outside of the Christchurch, Selwyn and Waimakariri districts). The EQR programme is outlined in a report titled 'Earthquake Resilience Programme Contextual Report' dated September 2020.

The EQR programme adopted a risk-based approach to prioritising seismic assessments based on a building's level of potential risk to life safety in an earthquake. This resulted in the broad categorisation of school buildings into the Ministry's EQR Programme Priority Categories as presented in Table 12.1. These Priority Categories closely align with the Profile Categories defined in the MBIE EPB Methodology, and are similarly based on risk to life-safety in an earthquake. Correlations between the EQR profile categories and MBIE EPB profile categories are discussed in the Earthquake Resilience Programme Contextual Report.

Under the EQR programme, seismic assessment requirements depended on the priority classification of the building and review criteria, as summarised in Table 12.2.

Table 12.1: EQR programme building priority categories.

Priority Category	Description	Year Built	Comments
1A	Buildings constructed from unreinforced masonry (URM).	N/A	URM buildings present high potential seismic risk and were therefore given their own category.
1B	Buildings of two or more storeys of heavy construction.	Pre 1998	The 'year built' criteria for Priority 1B buildings was set in consideration of the changes made to New Zealand concrete code and design standards in and around 1995. It includes a 2 year allowance as lag time for buildings designed after 1 January 1996, or completed before 1 January 1998, that were designed to the standards and material codes in place by the end of 1995.
2A	Single-storey buildings of heavy construction.	Pre 1976	The 'year built' criteria for Priority 2A buildings was set in consideration of the changes made to New Zealand design standards (NZS4203) which outlined the requirement for ductile detailing.
2B	Single-storey assembly type buildings with heavy or irregular aspects.	Pre 1976	Priority 2B buildings are single-storey buildings with large open floor areas such as libraries, gymnasiums and halls. They can include mezzanine floors over part of their floor plan.
2C	Single-storey other assembly type buildings.	Pre 1935	This 'year built' criteria considers the introduction of New Zealand building design standards in 1935 following the Napier earthquake.
Other	One and two storey timber-framed buildings, and ancillary buildings (caretakers' sheds, changing rooms, free-standing walls).	N/A	This category includes timber-framed classrooms. These types of buildings present a low life-safety seismic risk and have much greater seismic resilience than buildings of heavier construction. Ancillary structures such as pool change rooms, vehicle garages/sheds and caretakers' sheds were also included in the 'Other' category, as their low occupancy and typical structural form means they also pose a low seismic life safety risk.

Table 12.2: Seismic assessment requirements based on EQR priority categories.

EQR Priority Category	Assessment Requirement
1A	All classroom and administration blocks were assessed by a structural engineer (ISA and/or DSA).
1B	All buildings in this category were assessed using ISA methodology, with a DSA applied where considered necessary.
2A, 2B, 2C	All buildings in this category were reviewed by the EQR Team. This review process evaluated criteria including date of construction, seismic hazard factor (Z), building type (weight) to determine whether or not a seismic assessment was required (ISA and/or DSA). Many of the buildings in these categories did not have specific engineering assessments undertaken due to their inherent seismic capacity (as established the research and testing work undertaken by the Ministry in the early stages of the EQR programme) and hence low seismic life safety risk.
Other	No seismic assessment was required through the EQR programme. Assessments were to be undertaken in conjunction with future programmed asset management processes.

12.3 Undertaking New Seismic Assessments on Existing Buildings

Assessments should be carried out in accordance with 'The Seismic Assessment of Existing Buildings: Technical Guidelines for Engineering Assessments' that has been developed by the NZSEE, SESOC and NZGS, in conjunction with MBIE and the Earthquake Commission. The Importance Level used in the assessment should be as outlined in section 5.4.

Concrete buildings should be assessed in accordance with the 'Technical Proposal to Revise the Engineering Assessment Guidelines' released in November 2018, unless the assessment is required for earthquake-prone buildings purposes.

In considering the results of new assessments, reference should be made to the principles of the Ministry's Earthquake Resilience Policy as outlined in section 12.1.

Where significant structural work is proposed to existing school buildings and no assessment has been completed, the project engineer should assess the seismic capacity of the buildings to the extent necessary to ensure that the structural modifications do not adversely affect the strength of the building. A full seismic assessment is unlikely to be necessary for modifications to timber-framed classroom blocks, for example. It is however important that these buildings are inspected during the Master Planning phase to identify features that could adversely influence their performance in a significant earthquake. These include buildings with heavy roofs and/or located on sloping sites (or other geotechnical related vulnerabilities), along with buildings where previous alterations have removed walls, resulting in bracing walls greater than 10m apart without robust diaphragm assessment or retrofit. Where these issues are encountered, further engineering review and strengthening are likely to be necessary.

All new assessments should be reported on using the Ministry's template which is available from the Ministry's Property Page.

12.4 Using Existing Seismic Assessments for School Buildings

Existing seismic assessment reports may be available for buildings that were included in previous Ministry programmes, such as the greater Christchurch DEE and national EQR programmes.

Seismic assessments for these programmes were typically undertaken in accordance with the 2006 New Zealand Society for Earthquake Engineering Guidelines. Accordingly, when using assessments from these programmes, engineers should be aware of potential impact of the subsequent changes to the Building Act and the seismic assessment guidelines.

One of the key changes to the Building Act provisions was the requirement for heavier parts of buildings to be included in seismic assessments. This was typically not undertaken as part of the earlier Ministry assessments, although engineers undertaking those assessments did identify heavy overhead elements. Precast cladding elements were generally not assessed, or if they were, this was not against the likely ultimate limit state displacement of the building.

There have also been subsequent changes to the concrete buildings section of the seismic assessment guidelines as a result of learnings from the impact of the Kaikoura earthquake on multi-storey buildings in Wellington. This has led to the release in November 2018 of the 'Technical Proposal to Revise Section C5 of the Guidelines', referred to as the Yellow C5 chapter. While this document cannot currently be used for earthquake prone buildings purposes, it should be used for all other seismic assessments of concrete buildings.

The key issues and implications as a result of the changes to the legislation and assessment guidance can be summarised as follows:

1. The seismic ratings from the DEE and EQR assessments do not typically include scores for the heavier parts of buildings.
2. The seismic ratings from the DEE and EQR assessments may overstate the ratings for older multi-storey buildings (Priority Category 1B).
3. The seismic ratings from the DEE and EQR assessments for multi-storey buildings with precast concrete floor systems (Priority Category 1B) are likely to reduce when the November 2018 guidelines are applied.
4. A number of existing multi-storey buildings that were outside the scope of the EQR programme (i.e. post-1997) will have precast concrete floor systems (and in some cases, large precast cladding panels) that have not been assessed.

The ESG have undertaken a high-level review of the Ministry's multi-storey buildings (pre- and post-1998), including reviewing the EQR assessments of pre-1998 buildings. This review has identified some buildings where further information and review is required, principally relating to post-1997 buildings which have typically not been subject to any assessment. There is also a limited number of buildings of earlier construction where further assessment of specific elements is considered necessary.

One of the key recommendations from this more recent work is that at the time major school redevelopment or master planning is undertaken, all buildings of two or more storeys and of heavy construction should be subject to engineering review, and where necessary, seismic assessment. The issues outlined above should be taken into account in such reviews.

Appendix A

DETAILED PERFORMANCE

REQUIREMENTS FOR

STRUCTURAL AND NON STRUCTURAL ELEMENTS

APPENDIX A: DETAILED PERFORMANCE REQUIREMENTS

This section provides guidance on acceptable performance criteria for building elements in order to demonstrate compliance with both the Building Code and the additional Ministry requirements as stated in section 4.2.

A1 Structural Requirements

Buildings should be designed to meet the following criteria, according to ground conditions and building element.

Note that the term ‘significant’ in Table A1 below is contextual according to the nature of the element under consideration and the other elements (both structural and non-structural) that may be impacted by movement.

This table shall be read in conjunction with Table A2 in section A2. Refer also to section 7.3 for guidance on a general design process.

Table A1: Performance requirements for structural elements.

Element/System		Good Ground	Other Ground
1. Foundations without specifically designed re-levelling capability			
1.1. Concealed or inaccessible elements, including piles.	SLS1	No obvious displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.
	SLS2	No obvious displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.	Limited residual displacement or offset acceptable, within drift limits of most vulnerable elements (generally up to 0.5% for plasterboard linings).
	ULS	All elements shall be within rotation and displacement limits implied by the New Zealand Building Code (NZBC).	All elements shall be within rotation and displacement limits implied by the NZBC.
1.2. Elements that are accessible for inspection without disruption to school	SLS1	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.
	SLS2	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.	Limited residual displacement or offset acceptable, within drift limits of most vulnerable elements (generally up to 0.5% for plasterboard linings).
	ULS	All elements shall be within rotation and displacement limits implied by the NZBC.	All elements shall be within rotation and displacement limits implied by the NZBC.
2. Foundations with specifically designed relevelling capability			
2.1 Concealed or inaccessible elements, including piles.	SLS1	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.
	SLS2	No obvious significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.	Some residual displacement or offset is acceptable, within stated repair threshold limits. Should maintain capacity to resist additional displacement from a full ULS level event.
	ULS	All elements shall be within rotation and displacement limits implied by the NZBC.	All elements shall be within rotation and displacement limits implied by the NZBC.

2.2 Elements that are accessible for inspection without disruption to school	SLS1	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.
	SLS2	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.	Some residual displacement or offset is acceptable, within stated repair threshold limits. Should maintain capacity to resist additional displacement from a full ULS level event. May trigger need for limited repair in areas of greatest displacement.
	ULS	All elements shall be within rotation and displacement limits implied by the NZBC.	All elements shall be within rotation and displacement limits implied by the NZBC.
3. Superstructure in buildings without specifically designed re-levelling capability			
3.1 Primary lateral and gravity load resisting structure	SLS1	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.
	SLS2	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.	Some residual displacement or offset is acceptable, within stated repair threshold limits. Should maintain capacity to resist additional displacement from a full ULS level event. May trigger need for limited repair in areas of greatest displacement.
	ULS	All elements shall be within rotation and displacement limits implied by the NZBC.	All elements shall be within rotation and displacement limits implied by the NZBC.
3.2 Secondary structure	SLS1	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.
	SLS2	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.	Some residual displacement or offset is acceptable, within stated repair threshold limits. Should maintain capacity to resist additional displacement from a full ULS level event. May trigger need for limited repair in areas of greatest displacement.
	ULS	All elements shall be within rotation and displacement limits implied by the NZBC.	All elements shall be within rotation and displacement limits implied by the NZBC.

4. Superstructure in buildings with specifically designed re-levelling capability			
4.1. Primary lateral and gravity load resisting structure	SLS1	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.
	SLS2	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.	Some residual displacement or offset is acceptable, within stated repair threshold limits. Should maintain capacity to resist additional displacement from a full ULS level event. May trigger need for limited repair in areas of greatest displacement.
	ULS	All elements shall be within rotation and displacement limits implied by the NZBC.	All elements shall be within rotation and displacement limits implied by the NZBC.
4.2. Secondary structure	SLS1	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits.
	SLS2	No significant displacement or offset. Settlement under combined effects of long-term and short-term loading within acceptable limits. Function of element being supported is unaffected.	Some residual displacement or offset is acceptable, within stated repair threshold limits. Should maintain capacity to resist additional displacement from a full ULS level event. Function of element being supported is unaffected. May trigger need for limited repair in areas of greatest displacement.
	ULS	All elements shall be within rotation and displacement limits implied by the NZBC.	All elements shall be within rotation and displacement limits implied by the NZBC.

A2 Non-structural Elements

As the Ministry non-structural performance criteria are outlined in this document, it is the responsibility of the structural engineer to disseminate the non-structural performance requirements to the wider design team. Where secondary structural elements are a contractor design item (e.g. ceilings or partition walls) the structural engineer should clearly outline the required performance requirements of these elements in the design features report.

The table on the following pages lists the typical range of non-structural elements of a building and the corresponding level of damage expected for the limit state levels of SLS1, SLS2 and ULS for new buildings in accordance with the structural loadings standard AS/NZS1170 Part 0 and NZS1170 Part 5.

Section 5.2 of this document outlines when the Ministry requires buildings or secondary and non-structural elements to meet the SLS2 requirements regardless of Importance Level.

The primary SLS2 requirement is stated in clause 3.4.2 (b) of AS/NZS1170.0 as:

- *The structure maintains operational continuity after the SLS2 earthquake.*

For earthquake, clause 2.1.4 (b) (ii) of NZ1170.5 notes:

- *All elements required to maintain those operations … are to be maintained in an operational state or are to be returned to a fully operational state within an acceptably short time frame (usually minutes to hours rather than days) after a SLS2 earthquake.*

Table A6 is prepared on the basis that systems and equipment are installed in accordance with the requirements of *NZS 4219:2009 – Seismic Performance of Engineering Systems in Buildings*.

Key to Table A2:

N = No Damage.

O = Operable. May have reduced function, provided that safe environment is maintained and that repairs may be carried out without significant disruption to continued operation of school. *This has an SLS2 focus, and the elements that are required to have continued operability are highlighted with orange shading in the following table.*

R = Repairable, either without significant disruption to continued operation of school, or within limited closedown periods (e.g. after hours, weekends, school vacations).

R1 = Element may be severely damaged by failure of surrounding structure or building fabric, requiring replacement of element with surrounding structure or element, but element would otherwise remain repairable.

X = May require replacement.

X1 = Element may be severely damaged, requiring replacement but must retain structural integrity. Elements that could fall or topple causing life safety hazard must be fully secured.

X2 = Element may be severely damaged, requiring replacement but must continue to hold hazardous contents, or must continue to support emergency service function.

The building elements in the following table that are required to sustain either no significant damage or remain operable under SLS2 or ULS are highlighted.

Table A2: Performance requirements for non-structural elements.

Building System	Level of Damage Expected			Comments
	SLS1	SLS2	ULS	
1. Building envelope				
1.1. Roofing	N	O	X1	
1.2. Flashings	N	R	X	
1.3. Glazing	N	O	X1	
1.4. Exterior cladding systems	N	O	X1	
2. Floors and stairs				
2.1. General floors	N	R	X1	
2.2. Corridors	N	O	X1	
2.3. General access stairs	N	O	X1	
2.4. Stairs required to be used for emergency egress	N	O	X2	
2.5. Secondary access stairs	N/O	R	X1	
3. Partitions				
3.1. Partitions not required as smoke barriers	N/O	R	X1	
3.2. Partitions required as part of the fire and smoke control system.	N	O	X2	Refer also to section 12 of this Table
4. Ceilings				
4.1. Lightweight ceiling systems, the failure of which will not cause failure of other systems	N	R	X1	Design in accordance with Parts section in NZS1170.5. Note weight limitation applies to entire system. Assess as P.3/P.7 to NZS1170.5 Table 8.1
4.2. Heavy (acoustic or other) ceilings (>0.25kPa)	N	R	X1	Assess as P.2/P.6 to NZS1170.5 Table 8.1
4.3. Any ceiling systems, the failure of which may compromise other systems	No less than the affected systems			Assess as P.2/P.5 to NZS1170.5 Table 8.1

5. Ventilation systems				
5.1. Passive ventilation systems, typically openable windows but could include trickle vents or louvres manually operated	N	O	X	
5.2. Passive ventilation systems as above, automatically controlled				
5.2.1. Able to switch to manual operation	N	O	X	
5.2.2. Not able to switch to manual operation	N	N	X	
5.3. Mechanical ventilation systems				
5.3.1. Supply and extract fans including heat recovery ventilators	N	O	X1	
Air heating elements/batteries	N	O	X1	
5.3.2. Ducting and associated dampers, grilles, louvres and other air control devices	N	R	X1	
6. Heating and cooling systems				
6.1. Hot water Radiators				Connections between pipework and radiators may come loose due to differential movement and will require checking and tightening
6.1.1. Radiant panels	N	N	R	
6.1.2. Fan Coil units (either dx or water)	N	O	R	
6.1.3. Air Conditioning outdoor units	N	O	R	Check refrigerant charge and mounts following event
6.1.4. Air conditioning refrigerant pipework	N	O	R1	Pipework running through structural elements may be damaged in a ULS event
6.1.5. Centralised boiler plant	N	O	R	Following a large event (SLS2 and ULS) we recommend that a boiler inspector be engaged to inspect the boiler installation for damage
6.1.6. Fuel bunker and feed	N	O	R	The structure of the coalbunker may be damaged in a SLS2 or greater event. Inspection recommended, included for alignment of feed systems
6.1.7. Circulating pumps	N	O	R	
6.1.8. Distribution pipework, valves and equipment	N	O	R1	Pipework running through structural elements may be damaged in a ULS event
6.1.9. Gas supply, including valves and metering	N	N	R	Inspection of gas distribution pipework and valve trains recommended to check for damage and leakage following SLS2 or greater event
7. Water Supply				

7.1. Mains supply at building perimeter	N	N	R	Mains water supply will be subject to operation of utility network being operational
7.2. Buried pipes and junctions inaccessible for inspection	N	N	R1	
7.3. Pipes and junctions that are accessible for inspection	N	N	X	
7.4. Automatic back-flow preventers connected to a potable water supply	N	N	R1	
7.5. Storage tanks – potable supply	N	O	X	
7.6. Storage tanks – fire-fighting	N	N	X2	
7.7. Hot water storage	N	O	X2	
8. Drainage				
8.1. Stormwater within building envelope				
8.1.1. Pipes and junctions inaccessible for inspection	N	N	X	
8.1.2. Pipes and junctions that are accessible for inspection	N	R	X	
8.2. Stormwater connection at building perimeter	N	R	X	
8.3. Stormwater storage tanks	N	O	X	Underground stormwater storage tanks, both retention and detention, may be displaced by ground movement resulting in pipe connections failing. Support structures for above ground tanks will require inspection and may require replacement/repair of structure
8.4. Foul water within building envelope				
8.4.1. Pipes and junctions inaccessible for inspection	N	N	X	
8.4.2. Pipes and junctions that are accessible for inspection	N	R	X	
9. Doors and windows (note ventilation systems above)				
9.1. Automatic doors and windows (including electromagnetic or automatic doors or windows that open or close on fire alarm activation)				
9.1.1. Interfaced fire or smoke doors or windows	N	O	O	
9.1.2. Access controlled doors	N	O	O	
9.1.3. Automatic Doors	N	O	O	
9.2. Manually operated doors and windows				

9.2.1. Required for emergency entry or egress	N	O	O	
9.2.2. Not required for emergency entry or egress, but required for security	N	R	X1	
9.2.3. Other doors and windows	N	R	X1	
10. Lighting systems				
10.1. Emergency lighting systems	N	N	X	
10.2. Other lighting				
10.2.1. Lighting in operational spaces	N	O	X	
10.2.2. Lighting in other spaces	N	R	X	
11. Electrical systems				
11.1. Main switchboard	N	N	O	
11.2. All electrical reticulation within building	N	N	R1	
11.3. Emergency power systems	N	O	O	
12. Emergency Systems				
12.1. General Emergency systems				
12.1.1. Systems for communicating spoken information intended to facilitate evacuation	N	N	O	
12.1.2. Signs for communicating information intended to facilitate evacuation	N	N	X2	
12.1.3. Final exit (as defined by A2 of the Building Code)	N	N	X2	
12.2. Fire Systems				
12.2.1. Automatic systems for fire suppression (for example, sprinkler systems)	N	N	X2	Pipework running through structural elements may be damaged in a ULS event
12.2.2. Mains water supply to sprinkler and hydrant systems	N	O	R	Mains water supply will be subject to operation of utility network being operational
12.2.3. Automatic or manual emergency warning systems for fire or other dangers	N	N	X2	
12.2.4. Fire separations	N	O	R	
12.2.5. Smoke control systems				
12.2.5.1. Mechanical smoke control	N	N	X2	
12.2.5.2. Natural smoke control	N	N	na	

12.2.5.3. Smoke curtains	N	N	X2	
12.2.5.4. Smoke separations	N	N	X1	
12.2.6. Escape route pressurisation systems	N	O	X2	
12.2.7. Riser mains for fire service use	N	N	X2	
13. Lifts, Escalators, or other systems for moving people or goods within buildings				
13.1. Passenger-carrying lifts required for access for people with disabilities	N	O	X	
13.2. Passenger-carrying lifts not required for access for people with disabilities	N	R	X	
13.3. Service lifts including dumb waiters	N	R	X	
13.4. Escalators and moving walks	N	R	X	Would not apply to schools
14. Other systems				
14.1. Building maintenance units for providing access to the exterior and interior walls of buildings	N	R	X1	Would not apply to schools
14.2. Audio loops or other assistive listening systems	N	O	X	

Appendix B

WORKED EXAMPLE – DESIGNING

FOR SLS2 AND ULS

APPENDIX B: WORKED EXAMPLE – DESIGNING FOR SLS2 AND ULS

Worked Example – Designing for SLS2 and ULS

Consider an IL3 two-storey building for which the average assessed differential settlement (SLS2) is 60mm and the ULS differential settlement is 100mm, giving a total of 160mm. Assume an average bay length of 8000mm between adjacent columns and a storey height of say 3800mm.

Option 1: Detail for additional ductility and limit drifts

Assuming a moment resisting frame, design the structural system for displacement and strength, for lateral loading from the SLS2 case, using nominally ductile (μ = 1.25, Sp = 0.7) actions. ULS could be satisfied by simply detailing for limited ductility (μ ≥ 3) without any increase in loads. If however the key (hinging) elements were detailing for full ductility (μ ≥ 6), the structure may continue to support lateral load with reliable capacity to approximately twice the displacement implied by the full ULS condition.

To assess the impact of the settlement, consider the full differential settlement of 160mm at a single column in a frame as below:

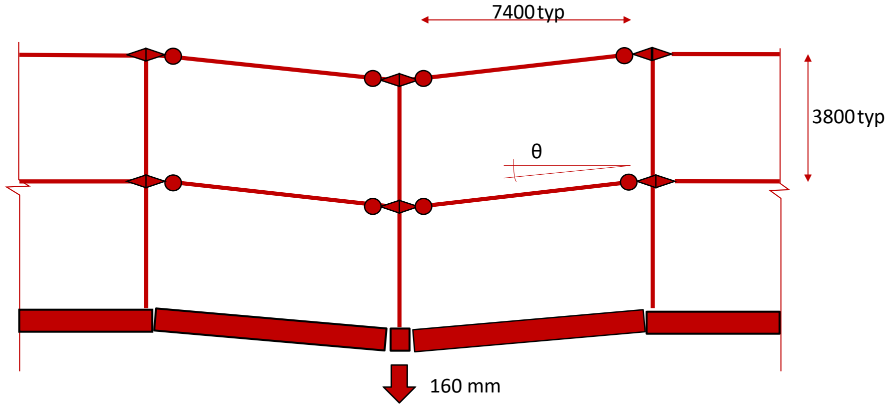

Figure B1: Single Column Frame.

Assume a design drift of say 0.25% under the SLS2 case (in order to limit the damage to non-structural elements). Therefore the implied drift from the ULS case is

$$\Delta_{ULS}= 0.25\% \times \frac{k_{\mu,SLS2}}{k_{\mu,ULS}} \times \frac{R_{ULS}}{R_{SLS2}} \times \mu_{ULS} \times k_{DM} = 0.25\% \times \frac{1.14}{2.14} \times \frac{1.3}{0.75} \times 3 \times 1.2 = 0.83\%$$

(Note this assumes a period T≤ 0.4sec).

The rotation demand on the plastic hinge from the total SLS2 and ULS settlement is:

$$\theta_p = \theta - \theta_y$$

$$\theta_y = \frac{2Fy}{E_s h} \times 0.5 h_b = 0.25\%$$

$$\text{Therefore, } \theta_p = \theta - \theta_y \cong \theta - 0.25\% = \frac{160}{7400} - 0.25\% = 1.91\%$$

This is within what would normally be acceptable for general structures and so does not imply any life safety concern. Hence, no further action is required.

Option 2: Consider adding redundancy

If this is a multi-bay frame, what proportion of the frame may be lost for no significant impact? In a case like this, assuming two similar frames (each side of the building) and an alternative orthogonal system to resist accidental eccentricities, if two beams were lost out of a total of say 10 (5 bays each side) thereby reducing capacity to 80%, then there would be no significant loss of overall capacity if the frames were slightly overdesigned, by a factor of 25% (i.e. 80% x 1.25 = 100%).

Obviously the effect of earthquake-induced settlement may be more widespread than this, but some reduction in overall capacity may be acceptable, provided the building is unlikely to become a life safety issue.

Conversely, if this were a braced frame or shear wall structure, there is likely to be little redundancy, assuming the required capacity would be aggregated into relatively few stiff elements. This could possibly exacerbate the situation, as an imposed settlement affecting the bracing elements may impose a permanent displacement on the remainder of the structure, even though the element itself may remain relatively unaffected. This is illustrated below, where it can be seen that the rigid frame may pull the structure over. Increased bearing pressures and punching effects under the toe of rocking walls or braced frames may make these locations more susceptible to settlement than multi-bay frames, where typically only the end columns undergo significant changes in axial load due to lateral loading.

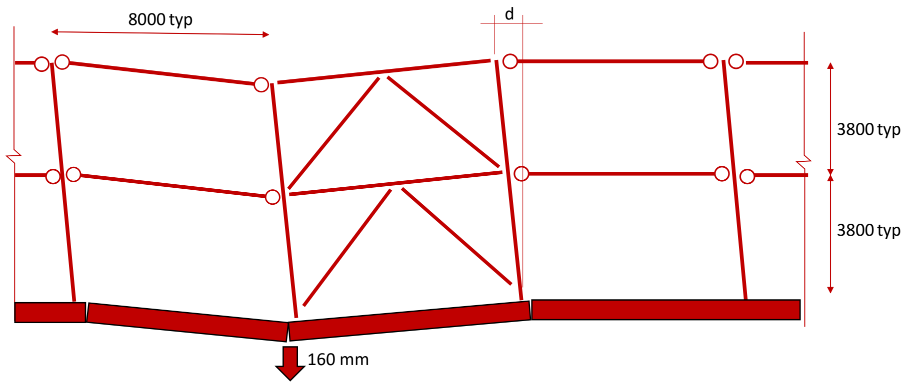

Figure B2: Single Column Frame.

In a case such as this, the settlement imposes an equal drift (in this case, 160/8000 = 2%) on the balance of the structure, if there are no other significant lateral load resisting elements that could counteract the displacement. This means that damage, which may be localised in the case of a moment frame structure, may be more widespread for a rigidly braced structure.

Given the likely ability of a braced frame or wall to displace a long way before becoming unstable, the displacement may not be of any other consequence, provided that the other elements of the primary gravity system, secondary structural and non-structural elements have the capacity to accept this deformation, but the damage may be more extensive than a building with more redundancy. It is important that the movement is recognised in the design and detailing of all elements.

Option 3: Evaluate the actual member ductility demand.

For the example structure from Option 1.

Given a plastic rotation under SLS2 plus ULS: $\theta_p = 1.91\%$

Check against the rotation limits of NZS3101:2006, clause 2.6.1.3.4

Note that, as the rotation is primarily uni-directional, amplify the calculated rotation in accordance with 2.6.1.3.2 b(ii)

$$\theta = \theta \times 1.63\sqrt{\mu - 1} = 1.91\% \times 1.63 \times \sqrt{(6 - 1)} = 6.96\%$$

By comparison, the calculated limit for a ductile region, unidirectional, is:

$$\theta_{max} = \emptyset_{max} l_p = K_d \frac{2Fy}{E_s h} \times 0.5h_b = 38 \times \frac{2 \times 500}{200{,}000 \times h} \times 0.5h = 9.5\%$$

For a limited ductile region, unidirectional,

$$\theta_{max} = \emptyset_{max} l_p = K_d \frac{2Fy}{E_s h} \times 0.5h_b = 22 \times \frac{2 \times 500}{200{,}000 \times h} \times 0.5h = 5.5\%$$

However, the implied rotation is also reduced for limited ductility

$$\theta = \theta \times 1.63\sqrt{\mu - 1} = 1.91\% \times 1.63 \times \sqrt{(3 - 1)} = 4.40\%$$

Therefore, although the margin is reduced, detailing to satisfy μ = 3 would be adequate, with no other requirements to be satisfied. However, it is necessary to perform enough quantitative analysis to be able to verify this.

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