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Understanding and Improving the Seismic Resilience of Hospital Buildings

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ABSTRACT

The establishment of Te Whatu Ora – Health New Zealand has enabled more direct national oversight of public hospital buildings across New Zealand. This has also led to the need for a more comprehensive understanding of the seismic status of hospital buildings, and what is needed to address their vulnerabilities. A national seismic work programme has been established by Te Whatu Ora to address these issues, including the establishment of a Health Seismic Engineering Group to develop technical guidance for the design of new hospital buildings.

Post-earthquake functionality of hospitals will to a great extent depend on the performance of non-structural elements, systems and specialist medical contents. The seismic assessment of these can be highly complex and time consuming. Rather than taking a compliance approach, a qualitative triage approach is proposed, focusing on the critical systems needing to support key medical and surgical function following an emergency.

This paper outlines the seismic work programme and summarises the findings of a recent report prepared by Kestrel Group on the seismic resilience of public hospital buildings. This report addressed issues such as the reliability of seismic assessments, options for identifying the vulnerability of non-structural elements, clarifying Importance Level categorisations applicable to the various medical functions delivered in hospital buildings and the need for more specific post-earthquake arrangements with engineering practices.

1 INTRODUCTION

A number of public hospital buildings across New Zealand were constructed in eras that preceded the advent of modern seismic codes. Some more modern hospital buildings have also been found to contain design shortcomings that were highlighted by the Canterbury and Kaikoura earthquakes and more recent advances in engineering knowledge. Seismic assessments have been undertaken for the majority of hospital buildings over the past decade, but not all. Some key hospital buildings have been found to have low seismic ratings, with some receiving earthquake prone building notices from their local territorial authority.

An initial review of a sample of seismic assessments of key hospital buildings commissioned by various District Health Boards (DHBs) was undertaken for the Ministry of Health by Kestrel Group in 2019, and provided an input to the Ministry's June 2020 Current State Assessment report. That initial review of DHB seismic assessments highlighted the age and lack of consistency of some of the assessments, and that they typically covered only the primary structural elements. A further observation was that the critical aspect that affects the ability of hospital buildings to enable the delivery of acute services following an earthquake had not been assessed – namely, the adequacy of the seismic restraint of non-structural elements such as ceilings, partition walls, building services, pipe runs and heavy specialist medical equipment.

Kestrel Group was commissioned by the Ministry of Health's Health Infrastructure Unit in March 2021 to build upon this previous work. This included summarising the key seismic information held on hospital buildings, and developing a framework for categorising the seismic risk of existing hospital buildings and enabling the prioritisation of mitigation work. In addition, guidance was sought on other aspects such as the interpretation of Importance Levels, approaches to evaluating non-structural elements and the components of seismic information that should be included in business cases, and recommendations for developing technical guidance for new and existing hospital buildings.

The report was reviewed by a group of practitioners with experience in the design and assessment of New Zealand hospital buildings and MBIE Building System Performance engineers, and also by a group of hospital facilities management personnel.

During the course of this project, the Government announced the formation of a new Crown entity, Te Whatu Ora-Health New Zealand. On 1 July 2022 Te Whatu Ora took over the planning and commissioning of services and the functions of the previous 20 DHBs to remove duplication and provide more effective national planning.

2 OVERVIEW OF THE KESTREL GROUP REPORT

2.1 Scope of Report

The report by Kestrel Group provides analysis, commentary and proposed technical guidance in the following key areas:

1. A summary of the key information that the Ministry has obtained from DHB seismic assessments
2. Outline of the seismic information components that should be included (or drawn upon) in a business case that is seeking funding for seismic work or campus redevelopment
3. Guidance on which operational areas of hospital facilities should be categorised as Importance Levels 3 and 4
4. A recommended approach for evaluating the adequacy of seismic restraint and associated measures for non-structural elements
5. A framework for categorising the components of seismic risk associated with hospital facilities, and development of risk rating scales for these components
6. A prioritised strategy for addressing low rating/ high risk buildings, including the approach to gathering information that is not known or is incomplete
7. Outline of the purpose, scope and nature of technical guidance to the sector and designers that Health NZ can produce for DHBs for the design and assessment of hospital buildings, including briefing and reporting templates for seismic assessments.

2.2 Key Findings and Observations

The key findings and observations from the report are briefly summarised below:

- *Understanding the current seismic risk profile of hospital buildings*
  - A significant number of hospital buildings have not yet had seismic assessments undertaken or reported on
  - A number of key hospital buildings have low seismic ratings for life safety in rare earthquakes
  - There is considerable variation in the reliability of seismic information currently held on key hospital buildings
  - The post-earthquake functioning of hospital buildings is highly dependent on the performance of non-structural elements
- *Addressing areas of inconsistency and uncertainty*
  - More consistent use of seismic information is needed in investment business cases for hospital redevelopments
  - There is a need for a greater appreciation of the impact of seismic strengthening on clinical services
  - Clarity is required around the Importance Level categorisations that apply to the different functional uses of hospital buildings
  - A systematic approach to evaluating the seismic vulnerability of non-structural elements is required
- *A structure for consistent management of seismic risk in hospital buildings*
  - A risk categorisation of hospital buildings to reflect known levels of vulnerability and resilience is proposed
  - Prioritising the mitigation of seismic risk across New Zealand hospitals should take into account the wider consequences for the community of key buildings not being functional
  - Prioritising the mitigation of seismic risk across New Zealand hospitals needs to take account of current information gaps
  - A Seismic Policy is required to outline the expectations and requirements for hospital buildings, supported by a Seismic Risk Management Strategy to establish the basis and priorities for managing buildings with identified seismic vulnerabilities
  - Seismic performance objectives and expectations for new and strengthened hospital buildings need clearer definition
  - There is a need for national technical guidance for both the strengthening of existing and the design of new hospital facilities
  - Hospital emergency plans should more clearly define the post-earthquake decision-making process relating to alternative facilities
  - Specific Priority Response Agreements need to be formalised with engineers to enhance effective post-earthquake responses

2.3 Recommendations and Conclusions

The report outlined 23 recommendations, presented under the following seven themes:

1. *Update seismic information to address gaps and reliability issues*
2. *Prepare technical guidelines for designing new and assessing existing hospital buildings for Health New Zealand*
3. *Establish a framework to enable the systematic categorisation of seismic vulnerabilities and identification of information gaps*
4. *Develop a Seismic Policy and Seismic Risk Management Strategy for Health New Zealand*

5. *Actively progress seismic risk mitigation*
6. *Ensure that hospital emergency plans provide greater emphasis and clarity around early post-earthquake decision-making*
7. *Establish specific arrangements with engineers for post-earthquake response at each main hospital*

The following concluding observations were made:

- Hospital buildings, particularly those with clinical and associated functions, are extremely complex facilities with multiple points of vulnerability to earthquake shaking. There are many challenges in understanding the nature and extent of the vulnerabilities, and in communicating them.
- While much of the report focuses on buildings as individual structures, it is fundamental that a campus-wide approach to both buildings and infrastructure is adopted. Part of this involves understanding the difference between *meeting minimum building regulatory requirements* and *achieving the necessary levels of resilience across a hospital campus* (extending to regional and national levels, where necessary) to enable the delivery of medical services to the community following major adverse events.
- In many cases, currently low rating hospital buildings will need to continue to be used for some years until replacement facilities can be constructed. In most situations this is likely to be acceptable from a life safety risk perspective, provided that clear timelines and expectations are established, documented and managed. Buildings with potentially brittle failure mechanisms affecting the primary structure should however receive specific consideration.
- The expectation that a number of hospital buildings may not be usable immediately following a major earthquake requires a stronger focus on alternative facility identification and post-earthquake decision-making in hospital emergency plans.

3 DISCUSSION ON AREAS OF WIDER PRACTITIONER INTEREST

This section provides commentary on key areas from the Kestrel report that are considered to be of interest to earthquake engineering practitioners, and that may have wider relevance beyond hospital buildings.

3.1 Importance Levels for Hospital Buildings

There has been a lack of consistency in the way that importance level classifications have been applied to hospital buildings for both assessment and design purposes across the previous DHB network. A clarification of those hospital buildings that warrant classification as Importance Level 4 (IL4) structures (ie. those with *special post-disaster functions*) to address this information void is proposed.

In order to distinguish between meeting the minimum requirements of the Building Code for individual buildings and meeting the service delivery expectations of the wider hospital campus overall as framed in the Civil Defence Emergency Management Act and National Health Emergency Plan (including site-wide infrastructure), the following definitions are proposed:

- ***Special post-disaster function*** – for hospitals, having appropriate emergency medical and surgical facilities and arrangements to enable the treatment of casualties from the disaster event
- ***Post-disaster service continuity*** – the ability to continue to provide medical services to people already in the hospital at the time of the disaster event, which cannot practically be provided immediately elsewhere in the local community.

The associated key concept is that *overall hospital disaster capability* is the ability to deliver *special post-disaster functions* and *post-disaster service continuity*.

Drawing upon these definitions and concepts, the report proposes that buildings housing any of the following services or functions relating to *special post-disaster functions* should be categorised as IL4:

- **Key Clinical Areas** (including operating theatres, Emergency Department and Intensive Care Units, and associated ward capacity)
- **Critical Clinical Support Functions** (including radiology and laboratories)
- **Other Specialist Functions or Services**
- **Infrastructure and Supplies** (facilities providing services required for the above functions)

New IL3 hospital buildings that are designed in accordance with low damage seismic design principles will inherently have a good level of resilience, with the difference in performance from a new IL4 building not as great as for existing IL3 and IL4 buildings.

It is also important to realise that the focus of importance levels is primarily on deriving the structural parameters for individual buildings. They do not in themselves inform the wider need and requirement for campus-wide resilience, including in relation to infrastructure.

3.2 Reliability of seismic assessments

Due to changes to the earthquake-prone buildings provisions of the Building Act and the revision of the national seismic assessment guidelines introduced in 2017 (along with the subsequent guidance on assessing concrete buildings issued in November 2018), a number of seismic assessments previously obtained by DHBs have a lower coverage and hence reliability than assessments carried out from 2019. The key impacts of these changes relate to the need to include heavy non-structural elements within assessments, and for buildings that are structurally interconnected to have a single overall rating.

Also, some assessments were only qualitative Initial Seismic Assessments (ISA), rather than quantitative Detailed Seismic Assessments (DSA). *Reliability categories* are therefore proposed to enable a more transparent understanding of the usefulness of the seismic ratings for life safety, as per the following table.

Table 1: Assessment Reliability Categories

Reliability Category	Reliability Expectation	Assessment Type and Date
REL1	High reliability	From post-July 2017 DSA
REL2	Reasonable reliability for primary structure	From post-July 2017 ISA/pre-July 2017 DSA
REL3	Limited reliability	From pre-July 2017 ISA
REL4	Low reliability	From pre-2011 IEP
NI	None	No information

Significant investment decisions on existing buildings should be based on reliable and appropriately detailed seismic information.

3.3 Non-structural Elements

A key area of operational vulnerability of existing hospital facilities during and following earthquakes relates to non-structural components such as ceiling systems, fire sprinkler pipes, pipe runs for medical gases and steam, and specialist medical equipment. Even for buildings with relatively recent seismic ratings that do take heavy non-structural elements into account, there is typically little or no information about the status of other non-structural systems and medical equipment. Where these elements are not adequately restrained or separated, damage in earthquakes can be considerable, with associated impacts on functionality in addition to life safety concerns.

A visual representation of non-structural elements in hospital buildings and their relationship with standard seismic assessment procedures is shown in Figure 1.

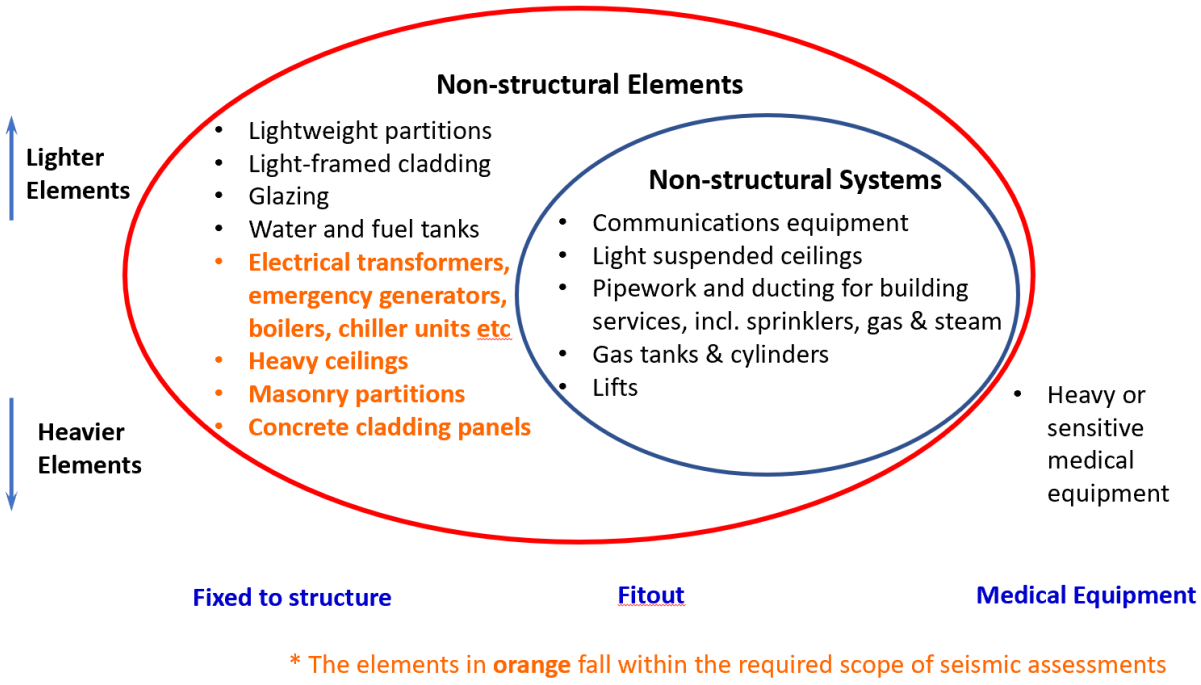

Figure 1: The Anatomy of Non-structural Elements in Hospital Buildings

The lack of information on the seismic vulnerability of non-structural systems limits the understanding of the level of resilience of hospital buildings and site-wide infrastructure, and the likelihood of their being able to function following a significant earthquake. However, the likelihood of having key facilities such as operating theatres rendered unusable due to damage to non-structural elements in earthquakes appears quite high for many hospital buildings.

There is a vast array of non-structural elements in hospitals, and the failure of any one of these has the potential to render a building and its associated services unusable following a significant earthquake. Observations from recent earthquakes overseas (Holmes 1999, and Mitrani-Reiser et al, 2012) and in New Zealand (McIntosh et al, 2012) has highlighted that certain heavier components such as emergency generators, elevators (lifts), suspended ceilings, water storage tanks and bulk oxygen tanks are more prone to damage or failure than other non-structural elements.

The report proposes that a higher-level review of non-structural components that avoids using a compliance approach be used, based on a qualitative evaluation to gather 'big picture' information as rapidly and efficiently as possible. This triage-based approach builds upon the approach in FEMA E-74 (FEMA 2011), The proposed approach suggests non-structural elements be evaluated under each of the three areas of

Element restraint, ***Element movement capacity*** and ***Internal capability of specialised equipment***. The vulnerability of each of these areas is to be categorised in relation to the likelihood of *functionality* of the building to be affected under levels of earthquake shaking consistent with the design of new IL4 buildings.

3.4 Continued Functionality

Seismic resilience has been defined as the ability of a system to reduce the chances of a shock, to absorb such a shock if it occurs and to recover quickly after a shock. This concept is scalable and can be applied at both community level and individual facility or building level. The seismic resilience of acute care facilities has previously been explored (Bruneau and Reinhorn, 2007), and *Functional Recovery* is the subject of current international research, including by QuakeCoRE, the New Zealand Centre for Earthquake Resilience, Te Hiranga Rū. Recent research has also looked at creating a post-earthquake hospital functionality database and dashboard (Mayer and Boston, 2022).

The interruption to the functionality of a building following an earthquake (or other event) can be represented in a plot of *Functionality (or Service Level)* against *Time*.

Figure 2 indicates conceptually the effects of losing different degrees of functionality as a result of increasing damage. In the first case (green line), there is only a small reduction in functionality, with the ability for hospital operations to continue without interruption. In the second case (red line), there is a more significant loss in functionality which results in the building no longer being functional (or usable). Depending on the degree of damage and loss of function, the building may not be functional for a short or long period of time.

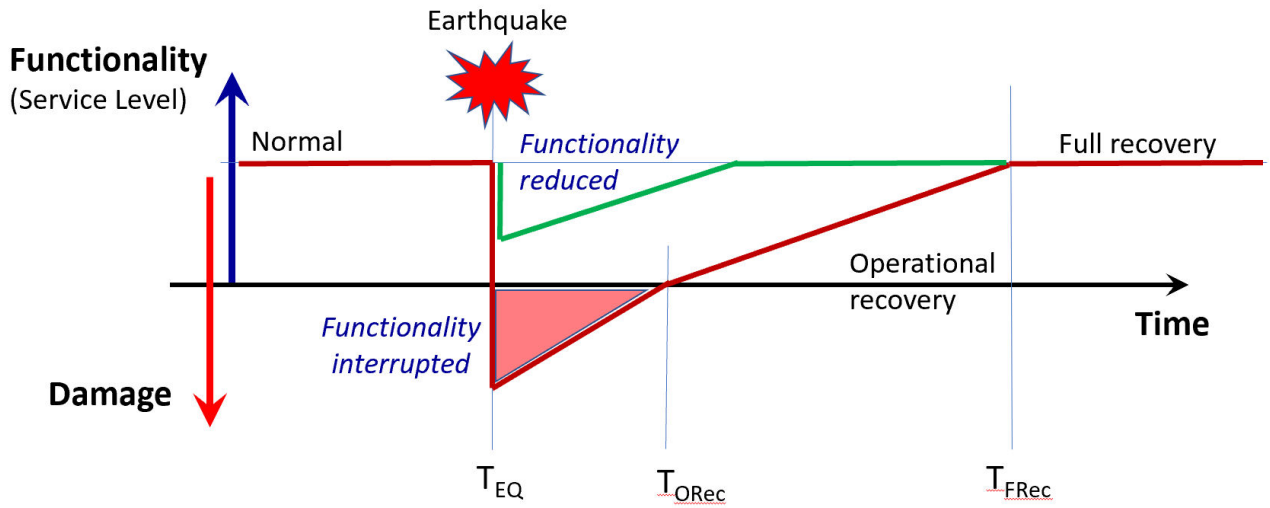

Figure 2: Depicting the impacts of earthquakes on functionality

This representation can also be used to convey in general terms the expected performance of a new operational facility that fully complies with the IL4 SLS2 requirements, and existing IL4 buildings with different expected losses of functionality. Figure 3 shows the expectation that a new IL4 building will continue to remain operational, and be able to be restored to full functionality within a relatively short period of time. Also shown is an existing building that does not meet the equivalent SLS2 requirements that correspond to operational recovery and would therefore not be functional for a period of time.

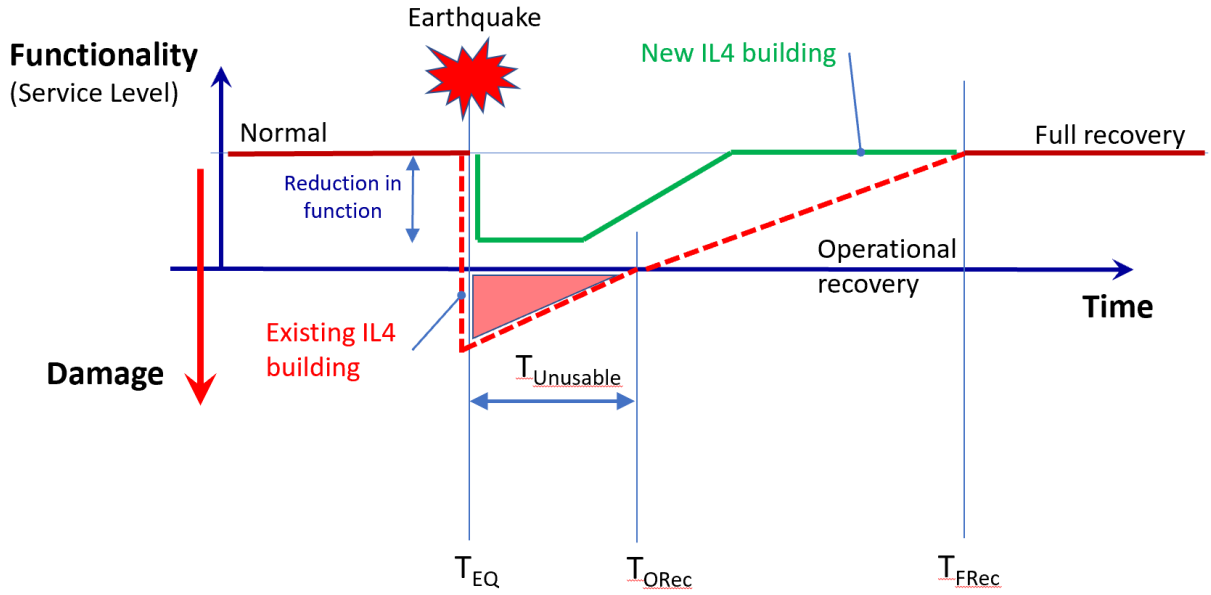

Figure 3: The difference in functional impacts of earthquakes on new and existing IL4 buildings

Understanding how long a building is likely to be unable to function and hence deliver critical services for and what governs this is are key assessment objectives, particularly in relation to non-structural elements. Achieving continued operational functionality (or at least minimising the length of time that a building is unusable for) represents the seismic upgrading objective for IL4 buildings in relation to SLS2 requirements.

3.5 Response Arrangements

Given the observation that there is a high likelihood of having key facilities rendered unusable due to damage to non-structural elements in earthquakes, hospital emergency plans must clearly outline the post-earthquake decision-making and implementation process. This should include nominated alternative facilities with reasonable degrees of resilience and appropriate backup infrastructure.

A decision to continue to deliver services in a damaged building or evacuate to an alternative facility is a significant one that needs to take into account a number of clinical and functional considerations and compromises. Well-focused and early input from structural engineers that are familiar with the buildings is a key aspect of hospital emergency planning. It is therefore essential that specific arrangements are in place with engineering consultants to respond to any earthquake event as required. These should take the form of a Priority Response Agreement as previously outlined by the New Zealand Society for Earthquake Engineering (NZSEE, 2005). The specific response expectations and mechanisms need to be clearly mapped out, including outline inspection plans and the nature of initial reporting. The response arrangements for the engineers should be integrated within hospital emergency plans, with associated annual 'readiness' activities to ensure that the arrangements are up to date.

The option of having seismic instrumentation installed in key hospital buildings is also recommended for further consideration. This could reduce the time taken by engineers to evaluate the response of the structure to significant earthquake shaking, hence hastening continued occupancy or re-occupancy decisions.

4. THE CURRENT TE WHATU ORA–HEALTH NEW ZEALAND WORK PROGRAMME

A work programme has been established by Te Whatu Ora to support the recommendations in the Kestrel report, and includes the following priorities:

1. Updating the seismic information held about all public hospital buildings, including obtaining information about those buildings not yet assessed, and developing an approach for the prioritisation of mitigation work
2. Preparing a Seismic Policy and Seismic Risk Management Strategy to guide a uniform approach across all hospital buildings
3. Preparing technical guidelines that establish seismic performance objectives for new and existing hospital buildings and associated design criteria
4. Putting in place more specific procedures and arrangements for post-earthquake response, including implementing priority agreements with engineers

A national seismic assessment panel is being established to undertake further assessments, both of hospital buildings that haven't been assessed and to update earlier less reliable assessments where considered necessary. Building typologies have been established in order to focus on where assessments are required.

A specialist engineering panel (the Health Engineering Strategy Group) is also being established to prepare technical guidelines for designing new and assessing existing hospital buildings. One of the early areas of focus of this group will be to establish seismic performance objectives for new and strengthened hospital buildings, covering both *life safety* and *building functionality.*

5. SUMMARY

The report by Kestrel Group has provided Te Whatu Ora with a broad representation of the seismic risk profile of New Zealand's public hospital buildings, along with recommendations to improve the way these risks are managed.

Overall summary observations from the report are as follows:

- A number of hospital buildings currently have low seismic ratings. More work is however needed to get a more complete understanding of the seismic risk profile of our hospital buildings, particularly in relation to non-structural elements
- Seismic strengthening of hospital buildings, particularly those delivering acute medical services, is extremely difficult and disruptive
- The likelihood of having key facilities such as operating theatres rendered unusable due to damage to non-structural elements in earthquakes appears quite high for many hospital buildings
- There is a need to look beyond individual buildings, and consider how a hospital campus as a whole is likely to respond to a major earthquake, including infrastructure services
- The first few hours after a major earthquake involves critical decision-making around which buildings can and can't be used. Greater emphasis should be placed on the technical aspects of earthquake response in hospitals and across the health sector network. Arrangements for local engineers for rapid building assessments need to be made more specific, as does the decision-making around which buildings may need to be evacuated

A work programme has subsequently been established by Te Whatu Ora to implement the report's recommendations, including the establishment of a national seismic assessment panel and a technical advisory group.

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