Improving the Seismic Resilience of New Zealand Hospital Buildings

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Abstract

The establishment of Health New Zealand | Te Whatu Ora in 2022 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.

Following a 2022 independent report which highlighted key areas of the vulnerability of hospitals to earthquakes, a national seismic work programme was established by Health NZ. This included the establishment of a Health Engineering Advisory Group to develop technical guidance for the design of new hospital buildings, with a particular focus on the post-earthquake functionality of non-structural elements, infrastructure systems and specialist medical contents. Part of this work has involved clarifying Importance Level categorisations, and the functional recovery requirements applicable to the various medical functions delivered in hospital buildings.

Another key workstream has focused on improving the post-earthquake response of hospitals by establishing Priority Response Agreements between engineering practices and the hospitals. These agreements document the understanding that nominated locally-based engineers familiar with the buildings will give the hospitals their priority as they respond following a major earthquake.

This paper, authored by members of the Health Engineering Advisory Group, outlines the Health NZ seismic work programme and progress made over the past two years to improve the seismic resilience of New Zealand's hospitals. The key features of the draft technical guidance for the design of hospital buildings, which builds upon the Australasian Health Facilities Guidelines, are outlined.

Keywords: hospitals, post-earthquake functionality, post-earthquake response, resilience.

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.

In July 2022 a Crown entity, Health New Zealand - Te Whatu Ora (Health NZ) was created to take over the planning and commissioning of services and the functions of the previous 20 District Health Boards to remove duplication and provide more effective national planning.

The status of seismic information across New Zealand's hospitals was summarised in a report by Kestrel Group in 2022 (Kestrel, 2022). Key issues addressed in the report included 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 the need for technical guidance for new and existing hospital buildings. This report contained a number of recommendations to better understand and address the vulnerability of hospital buildings, and these formed the basis of a seismic work programme initiated by Health NZ.

This paper summarises the Health NZ seismic work programme and the recently completed technical guidance for the seismic design of new hospital buildings. The establishment of Priority Response Agreements to enable the rapid response of local engineers to hospitals following major earthquakes is also outlined.

2 Setting the Scene: The Kestrel Report

The report by Kestrel Group contained a number of observations about the current status of hospital buildings in New Zealand. The key points included:

- 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.
- Seismic strengthening of hospital buildings, particularly those delivering acute medical services, is extremely difficult and disruptive
- In many cases, currently low rating hospital buildings will therefore 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.
- 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

The report emphasised the vulnerability of non-structural elements (such as ceilings, partition walls, building services, pipe runs and heavy specialist medical equipment), and the criticality of their continued operation to enable hospital buildings to deliver acute services following an earthquake. It highlighted the lack of clear design criteria for non-structural elements in new hospital buildings, and that the adequacy of the seismic restraint of non-structural elements in existing hospital buildings had rarely been assessed.

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

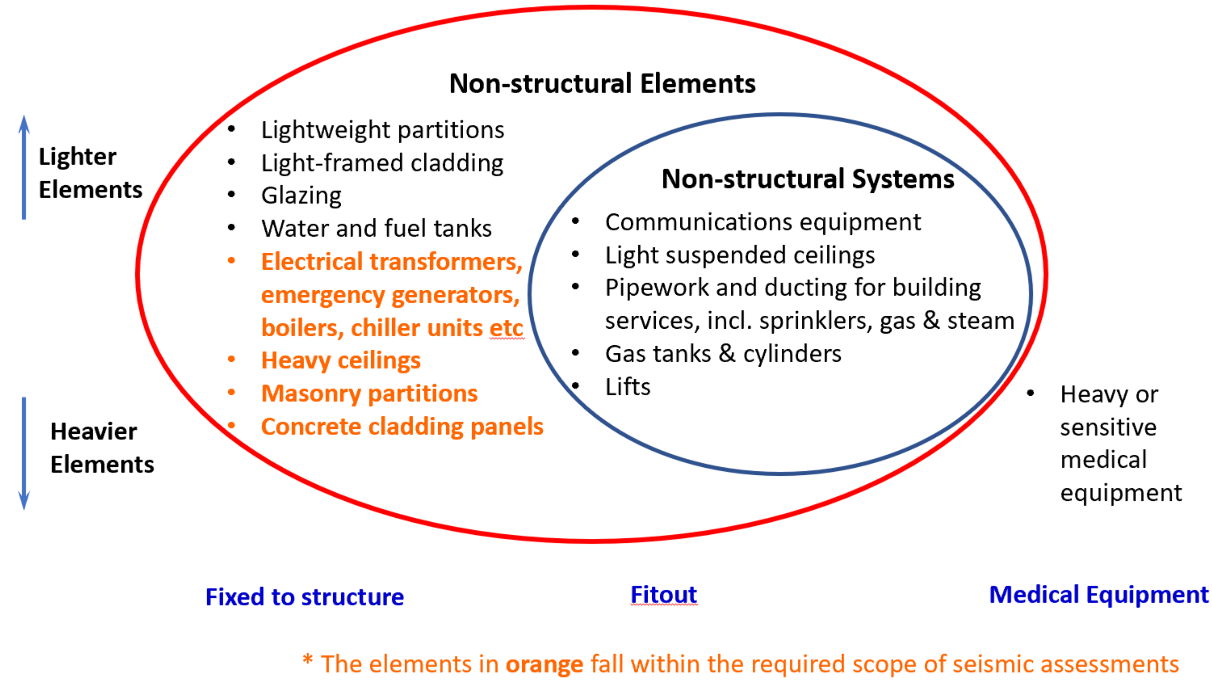

Figure 1: The Anatomy of Non-structural Elements in Hospital Buildings (Kestrel Group, 2022)

The report presented 23 recommendations under seven key themes. These were accepted by Health NZ and incorporated within the Seismic Work Programme which commenced in July 2022.

3 The Health New Zealand Seismic Work Programme

A seismic work programme was established by Health NZ in 2022 to support and implement the recommendations in the Kestrel report, with 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 and structural 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 was established at the end of 2022 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 Advisory Group, comprising the authors of this paper) was established from the wider panel to prepare technical guidelines for designing new and assessing existing hospital buildings.

The following sections in this paper outline the output from the two key elements of this work programme as at the end of June 2024.

4 Health New Zealand Seismic Design Guidance

4.1 Overview

The *Technical Guidelines for the Seismic and Structural Design of Hospital Buildings* (Health NZ, 2024) is one of several design guidance notes that Health New Zealand has developed to support safe, fit-for-purpose health facilities. This document is in draft form at the time of preparing this paper, and is subject to formal approval from Health NZ prior to its release.

The Seismic Design Guidance clarifies where Health New Zealand requires designers to go beyond the requirements of the Building Code (and where they only require the Code to be met). One of the key new areas of focus of the Guidance is to establish a seismic performance framework for new and strengthened hospital buildings, covering both *life safety* and *building functionality.*

The main driver for the Guidance has been to define technical criteria around 'functional', as this has never been defined in design standards or by Health New Zealand or its predecessors. Acute services buildings are required by the Building Code and AS/NZS1170.0 to be functional following a 500 year earthquake, but different interpretations of what 'functional' means have had cost impacts on both primary structure and non-structural elements (e.g. partitions and services restraints). Key new material provides clarification and specific criteria for designing to achieve appropriate levels of post-earthquake functionality. This involves an emphasis on non-structural elements and their impact on the design of the primary structure and building services.

While the primary focus of the Guidance is on the design of new acute services buildings, coverage is also given to the full range of building types, including extensions to existing buildings.

The Guidance provides information and requirement that relate to design process aspects. This includes for example the need for more comprehensive geotechnical information at masterplanning stage, and the requirement for a *Non-Structural Element Seismic Strategy* to be established at the concept design stage.

4.2 Classifying Hospital Building Functions and Importance Levels

The Guidance divides hospital facilities into four building categories and assigns the various clinical functions or services to each category. Each category is then associated with a particular importance level and its own functional continuity requirement.

The four categories are:

Acute Services: Acute Services and essential support services (ie. *special post-disaster functions* in accordance with AS/NZS1170.0). This includes Emergency Departments, Operating Theatres and Intensive Care Units. These are designated at Importance Level 4 (IL4), with enhanced functional continuity requirements.

Other Inpatient Facilities: Including general wards. These facilities are designated at IL3, however they have an enhanced functional continuity requirement, beyond that prescribed in the New Zealand Standards for IL3 facilities.

Other Medical Services: Including inpatient facilities, elective surgery, and non-critical medical services. These are designated at IL2. They also have a modest functional continuity requirement beyond code requirements.

Other Medical Services: Generally non-medical facilities such as offices, kitchens, and laundries. These are designated at IL2.

4.3 Seismic Performance Requirements

The seismic performance requirements in the Guidance are defined in a series of cascading levels as shown in Figure 2, starting at the broad outcome objective relating to life safety, functional continuity, and asset protection. These proceed through to more detailed requirements, progressing from general descriptors of performance goals intended to be understood by non-technical readers, to a description of likely post-earthquake physical states, which serve as pivot to the detailed engineering criteria for design engineers.

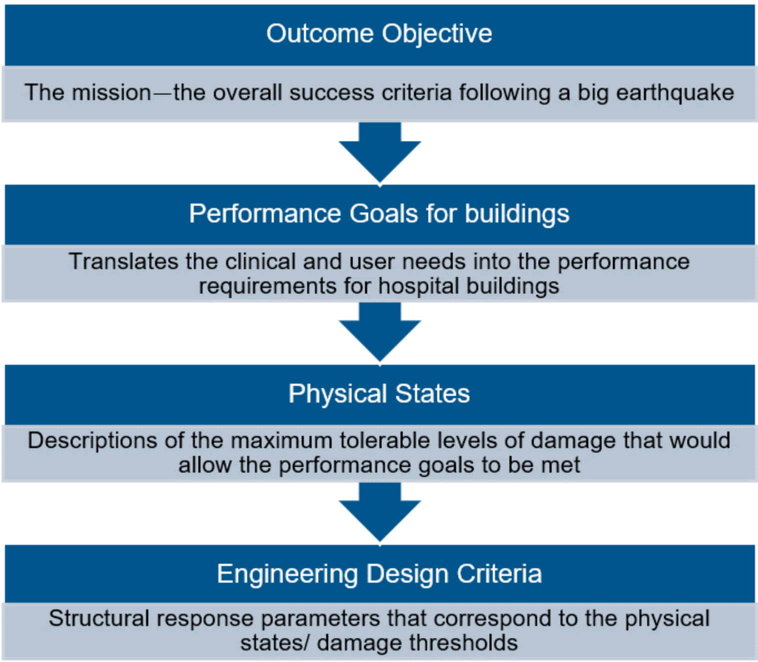

Figure 2: The cascading relationship between the overall Outcome Objective, Performance Goals, Physical States and Engineering Criteria

A key aspect of the Guidance is the descriptions of tolerable reduction in functionality, as well as anticipated timeframes for functional recovery. These are show graphically in the diagram below.

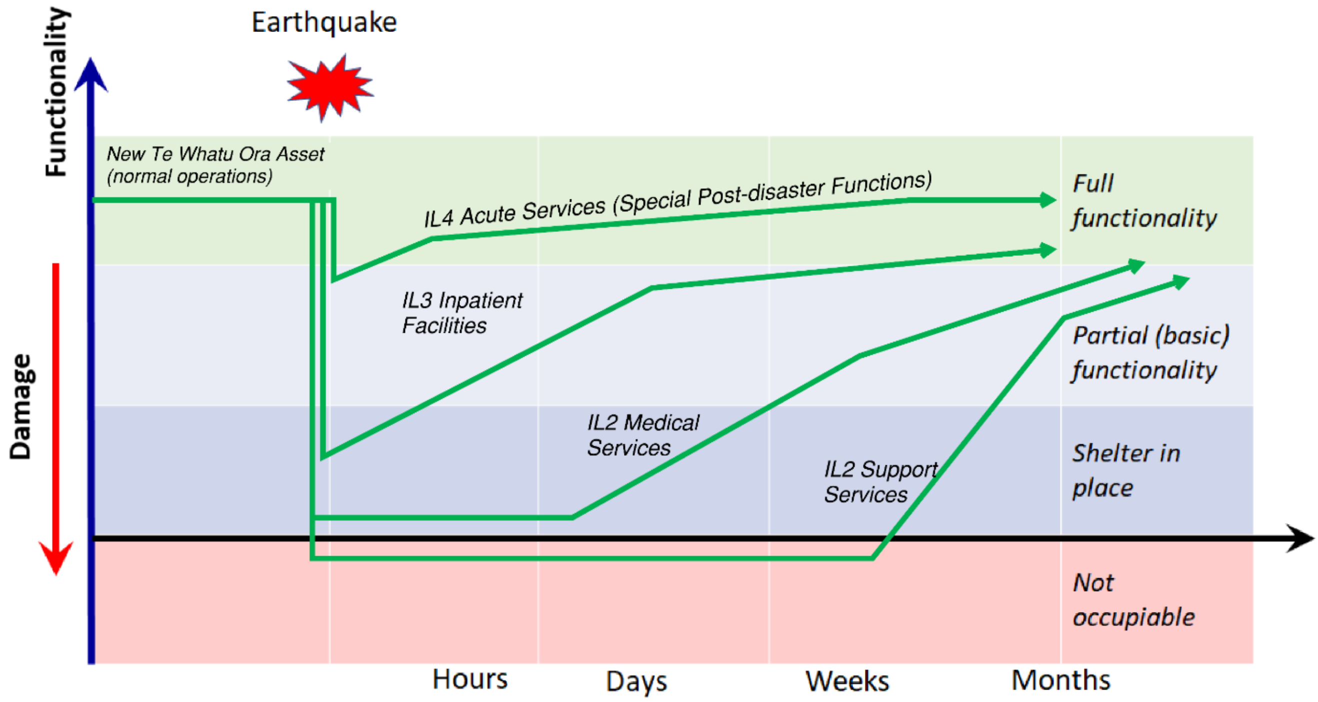

Figure 3: Tolerable reductions in functionality for Health NZ assets, and timeframes to full recovery, indicated in graphical form for different asset types (health service categories).

Design return periods are defined for each building category and limit state. A Damage Control Limit State (DCLS) is introduced to reflect the asset protection objective, alongside the SLS2 objective reflecting Continued Functionality. The return periods for DCLS and SLS2 have been aligned to streamline the engineering checks required.

<table>
<tr><th rowspan="3">Health Service Category</th><th rowspan="3">Importance Level</th><th colspan="4">Annual Probability of Exceedance for Seismic Hazard</th></tr>
<tr><th>Damage avoidance (also implying unimpeded continued use)</th><th>Asset protection objective</th><th>Continued Functionality objective</th><th>Life Safety objective</th></tr>
<tr><th>SLS1</th><th>DCLS</th><th>SLS2</th><th>ULS</th></tr>
<tr><td>Acute Services</td><td>IL4</td><td>1 / 25</td><td colspan="2">1 / 500</td><td>1 / 2500</td></tr>
<tr><td>Inpatient Wards</td><td>IL3</td><td>1 / 25</td><td colspan="2">1 / 250</td><td>1 / 1000</td></tr>
<tr><td>Other Services - Medical</td><td rowspan="2">IL2</td><td rowspan="2">1 / 25</td><td colspan="2">1 / 250</td><td rowspan="2">1 / 500</td></tr>
<tr><td>Other Services - Support</td><td>1 / 250</td><td>n/a</td></tr>
</table>

Table 1: Design limit states and return periods, defining the criteria for meeting Seismic Performance Goals.

4.4 Structural and Geotechnical Requirements

A wide range of detailed engineering requirements are covered within the Guidance. These address both process related matters, such as roles and responsibilities and documentation requirements, as well as technical requirements.

Many of the process related matters are intended to ensure that current good practice is undertaken early in the design process, where it can most effective. These include:

- Incorporating engineering information into the master-planning phase. This includes early geotechnical input, consideration of the engineering implications of altering or refurbishing buildings, and considering campus-wide earthquake resilience.
- Commentary regarding site-wide resilience, including approaches for considering building adjacencies, and interdependencies between various types of infrastructure.
- Information relating to design review, including regulatory Peer Review and review against the requirements of the Guidance.
- Specific documentation requirements relating to Design Features Reports, Movement Acceleration and Loading Reports, Non-Structural Element Strategies, and Geotechnical Reporting.
- Requirements to consider and present a range of structural options.
- Expectations for structural engineers to report on embodied carbon content in the structure.

Important technical requirements include:

- Definitions of design return periods, including elevated requirements for SLS2/DCLS limit states.
- Specific robustness requirements, including reference to *Earthquake Design for Uncertainty* (NZSEE, 2022) and *Interim Design Guidance of Conventional Structural Systems* (SESOC,2022).
- For durability purposes, a specified Intended Design Life of 100 years is required, with particular emphasis on areas which cannot easily be accessed for maintenance. A 50 year design life is applied for deriving seismic design loadings.
- Clarification of the requirements for vibration, generally basing it on the requirements of HTM 08-01.
- Clarifications regarding structural performance in fire, emphasising the requirement for post-earthquake risk management (rather than compliance) for fire safety systems, and acknowledging that the existence of managed emergency procedures in hospitals can be used as part of the risk mitigation.
- Clarifications regarding adaptability, intended to avoid unreasonable impediment to future adaptability/alteration, but discouraging blanket overprovisioning.
- Advice on how Health NZ expects designers to ‘road test’ the draft Technical Specification TS 1170.5:2024.
- Geotechnical clarifications including encouragement for settlement tolerant design, appropriate consideration of repairability and risk-based foundation selection.
- Damage control recommendations, which are ultimately expected to align with the SESOC *Low Damage Seismic Design Guidelines* (in preparation).

4.5 Non-structural Elements

A significant portion of the Guidance is focus on non-structural elements, as these are crucial to the ongoing operational continuity of a hospital, and because seismic design information for non-structural elements is currently somewhat limited. The opportunity has therefore been taken to capture industry best practice.

The Guidance defines a number of process-related elements for the design of non-structural elements, including:

- Requiring the implementation of a *Non-Structural Element Seismic Design Strategy*, beginning in concept design. This is to be led by the seismic designer, with active input required from other design disciplines.
- Setting out expectations for documentation, BIM modelling, and coordination.
- Defining roles and responsibilities.
- Providing a process to facilitate load coordination between structural engineers and designers of non-structural elements, with associated expectations for structural system robustness.

The technical requirements for non-structural elements are set out on element-by-element basis. Topics covered include:

- Appropriate ductility limits to avoid undue damage.
- Strategies for managing movement and displacement incompatibility.
- Advice around concrete anchor selection, including appropriate use of C1/C2 categorisation.
- Recommended drift limits for partitions and façades to avoid excessive damage.
- Requirements for validation and testing of ceiling systems.
- Enhanced design requirements for elements that could cause significant consequential disruption such as liquid containing tank or systems, hazardous systems, and vertical transportation.

4.6 Existing buildings

The Guidance includes sections on alterations to existing buildings and seismic assessment and retrofit work.

A decision-making framework for the evaluation and treatment of existing buildings is included. In addition to assessment for life safety purposes, high-level guidance for evaluating continued functionality aspects is also provided. This is aimed at achieving the outcome objectives in the guidance for post-earthquake functionality *as nearly as is reasonably practicable*, rather than involving a rigorous assessment across all non-structural elements.

The need to consider the earthquake performance of adjacent buildings across the campus at the time of masterplanning and business case development is emphasised, and guidance provided. This includes consideration of the potential operational impacts of adjacent buildings that have the potential to fail in larger earthquakes, as well as life safety aspects.

5 Priority Response Agreements

5.1 Background

It is vital that decisions on which hospital buildings can continue to be used following damaging earthquakes are made quickly. A key component of the decision-making process is timely input from experienced engineers that are familiar with the buildings.

The first few hours after a major earthquake involves critical decision-making around which hospital buildings can and can't be used. A decision to either continue to deliver medical 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, with compromises inevitably being required. 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. 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. 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.

A Priority Response Agreement between engineering practices and operators of critical facilities documents the understanding that nominated locally-based engineers familiar with the buildings will give operators their priority as they respond following a major earthquake. They are typically annually renewable set of arrangements that defines the expectations and responsibilities of both parties following a major earthquake. Priority Response Agreements were first promoted by NZSEE in 2005 (NZSEE, 2005) and have been adopted by a number of organisations responsible for delivering essential services. However while many of the former District Health Boards have close working relationships with engineering practices, a review in 2022 highlighted that very few specific arrangements were in place across the hospital sector.

5.2 The February 2023 Turkey earthquakes

The devastating earthquake and subsequent aftershocks that affected a significant part of Turkey and Syria on 6 February 2023 provided further examples of the consequences of major urban hospitals not having direct technical support from local engineers capable of rapid response.

As part of the reconnaissance efforts following the Kahramanmaraş earthquake sequence, the Earthquake Engineering Research Institute (EERI) Buildings Team visited the population centres that were most affected by the earthquakes. Thirty-seven hospital buildings in the affected region were visited by the EERI reconnaissance team and the operational status six weeks after the earthquakes was documented (EERI, 2023).

The EERI team recorded that hospitals constructed after 2010 were either partially or fully open but nearly all older buildings were closed. There was little evidence of structural damage in buildings less than 20 years old, but where closed this was due to damage to non-structural systems. Emergency generators were critical to continued operations, and failure led to some closures. Elevator restart had to wait for technicians to arrive, even when the elevator system was not actually damaged. Imaging equipment was typically still in the original position but needed recalibration, and this was also subject to the limited availability of technicians.

The EERI report notes that damage to non-structural partitions and cladding made patients and staff afraid to stay or return. Trained structural safety assessors were not available in the first few days for some hospitals. Hospital management made decanting decisions quickly after the earthquake shaking stopped, as they did not know if or when engineers would arrive. The lack of timely evaluations and safety assessments caused some hospitals to evacuate, which may have been unnecessary in some cases. Transferring patients to other facilities due to structural damage, non-structural damage, or "cautious" evacuations overwhelmed surrounding hospitals. Many patients did not survive the transfers.

Recommendations in the EERI report included the need to have on-call experienced structural engineers, preferably those familiar with the facility, available by phone/video link for consultation on post-earthquake safety assessments immediately after the event.

5.3 Outline Structure of Hospital PRAs

The agreements aim to nominate three engineers who are local to the hospital and specific representatives from the hospital Emergency Planning and Property/ Facilities Management departments. While three is a somewhat arbitrary number of engineers, it provides reasonable assurance that at least one engineer familiar with the site and buildings will be able to attend within a reasonable period of time, along with the wider backing of the practice. The national set of engineering practices that are party to the centrally-organised set of agreements also provides what is effectively a national support network.

The PRAs are a best endeavours agreement, having due regard to the range of personal situations that the nominated personnel may face after a major earthquake. When able to respond, the nominated locally-based engineers will give the hospital their priority with the full backing of their engineering practice. The engineering consultancies were selected based on their proximity to and familiarity with the hospitals. Some of the larger hospitals have teams from two engineering consultancies named in their PRA.

5.4 Rapid Assessment Plans

Rapid Assessment Plans are developed for each hospital, and set out the details of:

1. How post-earthquake rapid assessments will be undertaken for key hospital buildings; and
2. How the findings for each building will be conveyed to hospital incident management

The Health Engineering Advisory Group has developed a standard Rapid Assessment Plan template which is structured in two sections:

- **Part A** provides information to help with the preparation and maintenance of the Rapid Assessment Plan. It is intended to assist prior to an earthquake.
- **Part B** is the Rapid Assessment Plan itself. It is intended for use on the ground during and immediately after an earthquake.

  Hospital-specific information is provided under the following sub-headings:

  - Safety Information
  - Contact Details
  - Onsite Communication
  - Meeting Point

- Priority Building and Default Inspection Priority
- Building Information
- Available Seismic Instrumentation

Information relating to Response Activation, Response Procedure and Occupancy and Evacuation Decisions is standard across all hospitals.

With respect to activation, the Hospital Rapid Assessment Plans are to be immediately activated in response to any earthquake large enough to cause concern to either the hospital team or the nominated engineers. If in doubt, nominated engineers should begin making their way to the hospital meeting point and call the Duty Service Person on the way. In more moderate earthquakes that result in only nominal damage, there is high value in the reassurance provided by responding engineers. The ability of modest events to serve as a 'live drill' for communication protocols is also considered beneficial.

In practice, the creation of the Rapid Assessment Plans also serves as a catalyst for the consolidation of critical information. Most notably, this involves the collation of existing documentation in a readily accessible form, and agreement within the hospital as to which individuals will serve as the primary interface to the engineering team.

It is emphasised that in an emergency situation, it is the Hospital Incident Controller's role (in consultation with other hospital stakeholders, and considering ongoing technical advice) to make decisions about evacuation or continued occupancy of a building. Input from engineers is inevitably influential, but engineers are not the decision-makers in this situation.

These agreements are focused on structural engineers, but it is acknowledged that similar agreements should also be put in place for other critical services such as building services engineers and lift technicians in future phases of this work.

6 Summary

The Health New Zealand seismic work programme for hospital buildings established in 2022 covers new building design, the assessment of existing buildings and the enhancement of post-earthquake response arrangements. It has been overseen by a group of New Zealand's leading earthquake engineers with extensive experience with new and existing hospital buildings.

A key output from this programme has been the Seismic Design Guidance. This document establishes a seismic performance framework for new and strengthened hospital buildings, covering both *life safety* and *building functionality.* One of the key areas of focus of the Guidance is to provide more specific criteria to meet the serviceability limit state (SLS2) requirements in AS/NZS1170.0 for hospital buildings that house acute services to ensure functionality following a 500 year earthquake, as this has never been defined in design standards or by Health New Zealand or its predecessors.

A key component of the post-earthquake decision-making process for critical facilities operators is timely input from experienced engineers that are familiar with the buildings. This is particularly the case for hospital buildings, where decisions to continue to deliver medical services in a damaged building or evacuate to an alternative facility are significant ones. Major earthquakes around the world continue to highlight the life safety risks associated with transferring patients in such situations.

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