

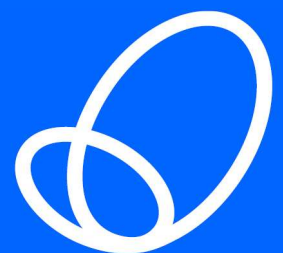
# **C5 EVIDENCE PROJECT**

## **PHASE ONE REPORT**

**Evidence of impacts of the technical proposal (yellow) C5 section of the Seismic Assessment Guidelines on a sample of building assessments, and recommendations for further activities in the project's second phase.**

**Prepared for the Ministry of Business, Innovation & Employment.**

**19 December 2019**



**engineering**  
**new zealand**  
Institute of Engineering Professionals



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This report was drafted, edited and produced by Engineering New Zealand. It was reviewed by the project's advisers, senior Engineering New Zealand personnel plus advisers appointed by Engineering New Zealand including the Technical Challenge Group which is drawn from senior management committee representatives of Structural Engineering Society (SESOC), New Zealand Society of Earthquake Engineering (NZSEE), New Zealand Geotechnical Society (NZGS) and Society of Fire Protection Engineers (SFPE). Members of Engineering New Zealand's Precast Floor Assessment Monitoring Group have also provided input and reviewing services.

Engineering New Zealand is grateful for input and support we have received from members of the structural engineering community. Alongside the evidence commissioned directly for the project, this report's substantive contents include data gathered, analysed and provided through practitioner goodwill: we acknowledge and thank everyone who has contributed their time to build and develop this rich evidence base.

*This report and its contents were produced for MBIE solely for the purposes of the C5 Evidence Project and should not be relied on for any other purpose. The author and Engineering New Zealand do not accept any liability in respect of its use by any other person.*

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# EXECUTIVE SUMMARY

The 2017 Engineering Assessment Guidelines (known as the “Red Book”) (refer [Appendix 3: Glossary of terms](#)) are mandatory technical guidelines for engineers to use when carrying out seismic assessments of potentially earthquake-prone buildings.

Last November, a proposed technical revision to Section C5 of the Engineering Assessment Guidelines (“the Yellow Chapter”) (refer [Appendix 3: Glossary of terms](#)) was released by the engineering sector. The Yellow Chapter reflects the most up-to-date engineering knowledge.

In early 2019, MBIE asked Engineering New Zealand to gather and report on evidence of how the Yellow Chapter impacts seismic assessments of buildings.

Engineering New Zealand commissioned and reviewed six building assessments. They provided information to reveal differences between Red Book C5 (concrete section) and Yellow Chapter assessments – and to explain the reasons for these differences.

There was little substantive difference in New Building Standard (%NBS) (refer [Appendix 3: Glossary of terms](#)) ratings between the Red Book and Yellow Chapter. However, the Red Book and Yellow Chapter identified different vulnerabilities in buildings. While the overall %NBS rating were similar, component scores differed in some cases. Given the Yellow Chapter represents the latest engineering knowledge, this means that retrofits using Red Book assessments may not address buildings’ greatest vulnerabilities.

Both the Red Book and Yellow Chapter produce lower %NBS ratings than the 2006 Guidelines.

None of the buildings had been previously assessed to the Red Book, nor had others that this report refers to, indicating that the actual regulatory impact of its application is minimal for concrete buildings.

We also gathered feedback from consultants along with the results. Consultants say the Yellow Chapter is a significant improvement on the Red Book but it could be made easier to use so that engineers are more likely to produce consistent results. Feedback also indicates a small number of areas where technical clarification and improvement are necessary.

All practitioners involved with this project have relayed that having two guidelines is creating market uncertainty, along with the lack of clarity around its regulatory status. Engineers are using the Yellow Chapter where they can, in preference to the Red Book, because it represents the latest engineering knowledge.

This market uncertainty means that some owners are holding back on having assessments undertaken. More importantly, retrofits aren’t being done. Consultants say building owners want confidence that retrofit work will be aligned with any imminent regulatory environment - and effectively addresses weaknesses in their buildings that pose risk to people’s lives and safety.

We recommend the following:

1. Expand assessment data on precast floors to further analyse detailed evidence of impacts, and
2. A managed programme to make the technical knowledge informing and underpinning the Yellow Chapter more robust.

## INTRODUCTION

The 2017 Engineering Assessment Guidelines (known as the “Red Book”) are mandatory technical guidelines for engineers to use when carrying out seismic assessments of potentially earthquake-prone buildings.

Last November, a proposed technical revision to Section C5 of the Engineering Assessment Guidelines (“the Yellow Chapter”) was released by the engineering sector. The Yellow Chapter reflects the most up-to-date engineering knowledge. It’s been informed by what engineers learned from the investigation into the partial collapse of Statistics House following the Kaikōura earthquake as well as earthquakes leading up to that, which provided unprecedented opportunities in modern times to learn about building behaviour. It also provides the latest information on other aspects of the assessment of concrete buildings.

The Yellow Chapter currently sits outside of the Earthquake Prone Building (EPB) (refer [Appendix 3: Glossary of terms](#)) regulatory environment, which requires the Red Book to be used for assessments for EPB purposes.

## PURPOSE OF THIS PROJECT

Engineering New Zealand delivers technical programme management services and technical expert advice to MBIE in support of the building regulatory system, under a pilot arrangement that started in December 2018.

In early 2019, MBIE asked Engineering New Zealand to gather and report on evidence of how the Yellow Chapter impacts seismic assessments of buildings. MBIE wanted to understand any difference in %NBS results between the Yellow Chapter and the Red Book. This would help MBIE make informed decisions about incorporating the Yellow Chapter into the regulatory system.

In April 2019, Engineering New Zealand proposed a project that was approved to proceed as the C5 Evidence Project.

This report analyses the impact of the Yellow Chapter on a small, targeted sample of buildings representing a range of typologies. It is the key deliverable of Phase One of the C5 Evidence Project.

Approval to proceed with the project’s recommended Phase Two activity is expected from MBIE in mid-November. Pending approval, and the outcomes of Phase Two, a final report will be issued to MBIE by Engineering New Zealand in October 2020, to complete the project.

## SCOPE OF THIS REPORT

This scope of this report includes:

- Building assessment data, including comparative %NBS earthquake ratings
- A summary of findings, by building (using anonymised/generic descriptions) and collectively
- Relevant consultant observations about the Yellow Chapter and its application
- An analysis of findings and rationale for undertaking further assessments.

As part of their brief, consultants were asked to comment on the usability of the Yellow Chapter and to identify any specific areas that would benefit from technical clarification or refinement.

## PROCESS FOR PHASE ONE

Engineering New Zealand appointed project advisers Rob Jury and Dave Brunson to provide advice throughout the project. Other advice was sought internally and externally as needed, including from members of the Precast Floor Assessment Monitoring Group (PFAMG) (see page 6) and Engineering New Zealand's Technical Challenge Group (refer [Appendix 3: Glossary of terms](#)) provided input and review of both the Phase One process and drafts of this report.

An assessment sample size of six buildings was agreed with MBIE for Phase One.

### Types of buildings that were targeted

Engineering New Zealand and its advisers developed broad building typologies from which specific examples were drawn. These sets of buildings were considered most likely to show differences between Red Book and Yellow Chapter assessments. They were:

- Pre-1976 non-ductile, cast in situ (refer [Appendix 3: Glossary of terms](#)) frame structures<sup>1</sup>, and
- Post-1976 ductile primary system (refer [Appendix 3: Glossary of terms](#)) with precast concrete floors (refer [Appendix 3: Glossary of terms](#)) – covering both frame and wall structures.

We targeted buildings that were three storeys or taller, with a focus on six or more storeys.

### Sourcing specific buildings for the project

In February 2019, Engineering New Zealand approached engineering consultancy firms to carry out Yellow Chapter assessments for this project. Both large commercial firms and smaller structural engineering consultancy practices were approached.

Sourcing suitable buildings was challenging, because of the specific types of building we needed and because engineering practices had limited capacity in the necessary time frame.

Furthermore, although building owners would receive free assessments of their building, and these results would be anonymised in our report, engineers still needed to obtain owner permission due to the potential implications of lower %NBS ratings, even if these were not "official".

We discovered that no building owners had undertaken Red Book assessments. This meant we needed to commission dual assessments using both the Red Book and Yellow Chapter for all Phase One buildings.

### The assessment process

Thirteen proposals for potential building assessments were submitted by consultants to Engineering New Zealand. Shortlisting resulted in requests for fully costed proposals for eight building assessments, which were submitted by engineers in April 2019 and included by Engineering New Zealand in the final project proposal to MBIE.

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<sup>1</sup> Less emphasis was needed on this typology due to two existing datapoints from previous worked examples on pre-1976 concrete frame buildings, prepared as part of the development of the Guidelines and Yellow C5: one was three storeys and the other 10 storeys and both had shown little difference in scores or ratings between the Red Book and Yellow Chapter.

From these, and on MBE's approval of the final project proposal, four consultants were commissioned to assess six buildings of four different typologies under the terms of the project.

The selected buildings covered Importance Levels (refer [Appendix 3: Glossary of terms](#)) 2, 3 and 4.

During Phase One, one building ceased to be available, so a consultant dropped out of the process. They were replaced by an existing consultant who agreed to conduct an additional assessment under the project's terms, of a demolished building, using drawings of its main structure.

In addition to briefing material and information sessions, Engineering New Zealand provided consultants with ongoing access to advice from the project advisers plus additional subject matter experts when queries arose.

Engineering New Zealand developed and produced this report based on analysis of the consultants' results.



# ANALYSIS OF THE ASSESSMENTS

## METHOD OF ANALYSIS

The six commissioned building assessments were received and reviewed by the project's advisers, who found them sound and of an appropriate quality.

The reports and drawings provided sufficient information to reveal differences between Red Book and Yellow Chapter assessments and to explain the reasons for these differences.

As the same Importance Level was used when applying both the Red Book and the Yellow Chapter, relative comparisons were not affected.

Where results were either close to 34%NBS – the threshold where buildings may potentially tip into becoming earthquake-prone – or changed between the two versions, they were scrutinised to ensure the assessment methodologies had been appropriately applied.

None of the Phase One buildings had previously been assessed against the requirements of the Red Book.

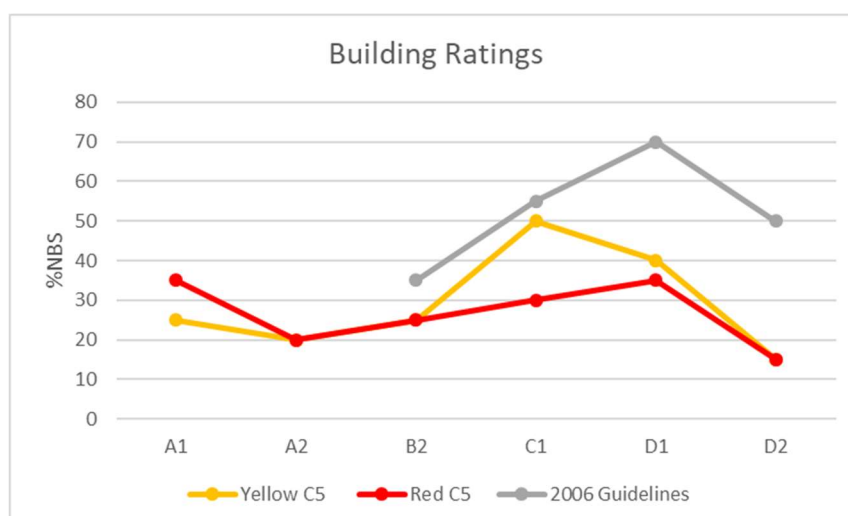
Ratings from each of the assessments are summarised in [Appendix 1](#) and element scores in [Appendix 2](#). It's important to distinguish between element *scores* and overall building *ratings*.

## HIGH-LEVEL OBSERVATIONS

There was **no substantive difference in %NBS ratings** between the Red Book and Yellow Chapter. For three buildings, the final %NBS rating did not change between Red Book and Yellow Chapter. Some minor gains or losses were made in either direction over the six buildings: two went up and one went down using the Yellow Chapter.

However, the Red Book and Yellow Chapter **identified different vulnerabilities** in buildings. While the overall %NBS results were similar, the scores of building elements were different. Given the Yellow Chapter represents the latest engineering knowledge, this means that retrofits using Red Book assessments may not address the greatest vulnerabilities.

Both the Red Book and Yellow Chapter produce **lower %NBS ratings than the 2006 Guidelines**.



More detail can be seen in [Appendix 1](#).

## Identifying the right vulnerabilities

A %NBS rating is based on the lowest score found in the assessment. This means that the building's "weakest link" determines its %NBS rating.

Correctly identifying a building's weaknesses is critical for designing effective retrofitting that improves its performance. Identifying the wrong vulnerability can lead both to ineffective work being done and the right work not being done. It can mean that a building does not perform as well as it could in the next earthquake.

Looking at these component scores is more important for judging the differing impacts of the Red Book and Yellow Chapter than looking at the %NBS ratings alone.

## Differences between Red Book and Yellow Chapter component scores

- Scores for individual elements within all buildings changed when comparing Red Book and Yellow Chapter.
- Different weaknesses were highlighted by these different scores.
- In three cases, the Yellow Chapter identified different governing susceptibilities from the Red Book. This means that the "weakest link" governing the overall %NBS result was different under the respective guidelines.
- In three buildings, the governing element score did not change the %NBS result.
- In pre-1976 buildings, the individual score changes were more related to columns.
- In post-1976 buildings, the individual score changes were more related to floors (such as diaphragm actions or precast unit issues).

More detail can be seen in [Appendix 2](#).

## Buildings falling below 34%NBS

It is possible that Yellow Chapter may lift some buildings above the 34%NBS threshold compared with the Red Book – but the reverse may also apply – and it is not clear how many more building assessments we would need to accurately gauge this. For example:

- One building, coded as C1, was below 34%NBS under the Red Chapter and had this status changed under the Yellow Chapter (from 30%NBS to 50%NBS).
- One building, coded as A1, was marginally over 34%NBS under the Red Book and fell below this threshold under the Yellow Chapter (from 35%NBS to 25%NBS).

Buildings more likely to be rated less than 34%NBS are typically mid- to high-rise buildings in higher seismic regions.

## OUR PRECAST FLOORS ASSESSMENT MONITORING GROUP PROVIDED ADDITIONAL DATA

### About the Precast Floors Assessment Monitoring Group

Earlier this year, Engineering New Zealand, NZSEE, SESOC and Concrete NZ Learned Society established an informal working group to actively monitor assessments of precast concrete floors. The focus of this practitioner-based group, referred to as the Precast Floors Assessment Monitoring Group (PFAMG), is to

monitor how the Yellow Chapter is operating in practice and understand where additional supporting material would help practitioners.

The group is co-ordinated by Engineering New Zealand and comprises the relevant societies' presidents or their nominees, along with authors of the Yellow Chapter and the Guidelines Technical Editor. The group also includes representatives from four major structural engineering practices closely involved in assessing multi-storey buildings (including the three who undertook the assessments as part of Phase One).

The group has been meeting on a monthly basis since March 2019. It is a proactive, voluntary (non-remunerated) undertaking by members of the engineering profession.

### **Sharing assessment intelligence**

The PFAMG has been confidentially sharing anonymous information from assessments undertaken by the four consulting practices involved.

This dataset was built up during the period April to August 2019. The information recorded includes:

- Key parameters relating to the building – number of storeys, seismic zone, codes that it was designed to, its primary structural system, precast floor system and support details
- Key assessment parameters (e.g. peak drift) and outcomes from applying the Yellow Chapter (both floors [all potential failure modes] and primary building system)
- Information relating to previous assessments – guideline used and outcomes (floors and primary building system)

A total of 23 buildings is currently in this dataset, ranging in height from one storey to more than 21 storeys. Twenty-one feature hollowcore floors, and two have double tee (*refer [Appendix 3: Glossary of terms](#)*) floor systems.

### **Observations from this dataset**

Analysis undertaken so far has been limited due to resourcing constraints. It is clear that the Red Book was rarely used for the assessment of concrete buildings, with engineers waiting for the revision that came out in November 2018. None of the 23 buildings currently in the database have been assessed using the Red Book.

Three buildings' floors decreased in score from 70%NBS and 90%NBS (for two buildings) under the 2006 guidelines to 24%NBS and 15%NBS (for two buildings) under the Yellow Chapter, respectively.

With respect to the difference between floor and building (including floor) scores, the following preliminary observations can be made from the 13 buildings that enabled this comparison:

- 23% (3) had a lower floor score (mainly Wellington buildings with a ULS drift >1.8%)
- 54% (7) had a higher floor score (mainly Auckland buildings with a ULS drift <0.62%)
- 23% (3) had no difference between the floor and the primary building structure

Most buildings in this dataset have a range of precast floor unit configurations. This requires a number of individual calculations for each building to ensure that the governing floor score is obtained. In such cases the lowest score has typically arisen from a small number of units with non-standard configurations.

### **Next steps for this group**

Funding is being provided by Quake Centre to prepare some worked examples using the Yellow Chapter. This will help practitioners understand how non-EPB assessments should be undertaken when using this draft guideline.

These examples will build on those used in previous industry seminars and enable another round of practitioner training.

This group is available to assist this project during Phase Two.

# DISCUSSION OF FINDINGS AND FEEDBACK

## RED BOOK ASSESSMENTS WON'T LEAD TO THE RIGHT RETROFIT

Because the Yellow Chapter is based on latest knowledge of building behavior, it is expected that it better indicates where susceptibilities and potential weaknesses lie within buildings. With respect to buildings with precast floors, the Yellow Chapter covers all precast systems, while the Red Book only addresses hollowcore floor systems.

This means it provides better information about what to remediate in terms of reducing risks to public safety.

Retrofit recommendations based on the Red Book will not necessarily target the current thinking about what are a particular building's most significant weaknesses.

## HAVING TWO GUIDELINES IS CREATING MARKET UNCERTAINTY

### Engineers are using the Yellow Chapter, not the Red Book

Engineers are communicating their preference to use the Yellow Chapter, which represents the latest engineering knowledge, to their clients (building owners). They are also investing in the Yellow Chapter, such as by developing worked examples to support its application in practice.

### Engineers would prefer clarity

Consultants observed that having both the Red Book (regulation) and the Yellow Chapter (current knowledge) in circulation adds confusion to an already complex system. They want one set of guidelines to refer to when assessing buildings and they want this to represent the most up to date knowledge.

A universal observation shared with us by engineers during this project is that from their perspective, there is no perceptible downside to adopting a refined version of the Yellow Chapter into regulation but there is considerable upside.

### Building owners are confused

Consultants provided feedback that there is confusion and misunderstanding about seismic building assessment regulation, including what %NBS results mean.

Businesses and government agencies vacating buildings has contributed to this confusion. Some building owners are setting a precedent for building scrutiny, closures or departures over and above what is required in current regulation. Business owners are also acutely aware of health and safety risk. This means they are concerned to make all reasonable efforts to safeguard staff and other people from any perceived risks presented by buildings.

The existence of both the Red Book and Yellow Chapter adds complexity to building owners' choices and decisions, both in terms of undertaking assessments and deciding what to do about results. Building owners want confidence and trust in seismic assessment guidelines and they expect regulation to be based on the latest knowledge.

There is also reluctance by some building owners to carry out seismic assessments unless driven by market forces.<sup>2</sup>

## **MARKET UNCERTAINTY MEANS ASSESSMENTS (AND RETROFITS) AREN'T BEING DONE**

Phase One of this project has revealed that very few Red Book building assessments exist. The first implication of this is that the actual regulatory impact of the application of the Yellow Chapter is minimal for concrete buildings. A second implication for buildings with precast concrete floors is that, in general, buildings' existing assessments and %NBS ratings use earlier guidelines that don't consider floor systems. So for most buildings with precast floors, the %NBS ratings and some scores can be expected to decrease when reassessed, whether using the Red Book or Yellow Chapter.

Feedback indicates the Red Book hasn't been used because engineers were waiting for the Yellow Chapter to come out. Consultants have also said the concrete section of the Red Book is difficult to apply in practice.

Furthermore, some engineers are advising clients to wait until the Yellow Chapter's regulatory status is confirmed before undertaking assessments of their buildings.

Assessments being delayed means longer time frames till appropriate retrofits are in place. This delay itself increases market uncertainty and decreases public confidence in buildings. It also means any risk a building poses to the public exists over a longer time frame.

Building owners want to make the best calls about where to focus investment in their capital assets. This means they want confidence that retrofit work is be aligned with any imminent regulatory environment. They also want to know that retrofits address the weaknesses in their building that pose risk to people's lives and safety.

## **THE YELLOW CHAPTER COULD BE EASIER TO USE**

Consultants were asked to provide feedback about using the Yellow Chapter in practice. This is a sample of what they said:

### **Many aspects are improvements on the Red Book**

*The new provisions for columns with round bar are simple and should improve consistency. The new detailed provisions for assessment of elements with round bar reinforcing are straightforward to apply.*

*The direct rotation method is user friendly, with the calculation of limits for loss of axial capacity being straightforward using this method (for shear-controlled columns).*

### **But the Yellow Chapter could be more usable**

*The use of the assessment guidelines requires many different steps - some of which are not in a linear order.*

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<sup>2</sup> This situation is not assisted by the growing knowledge in the industry that the earthquake hazard in Wellington, which is fundamental to the assessment of %NBS scores and ratings, may be understated in the current earthquake Standard.

*There are several provisions which result in a step-change in the assessments, and these are not immediately clear to readers. The addition of flow charts directing practising engineers to these step-change behaviours is recommended.*

*The clauses having disproportionate impacts on the %NBS scores should be moved to the beginning of sections and visually highlighted.*

*The non-ductile columns Severe Structural Weakness provisions could use clarification, as there are two possible interpretations of the wording that give different results. The step function from the SSW (refer [Appendix 3: Glossary of terms](#)) could potentially frustrate consistency in some assessments.*

*There is considerable complexity associated with the assessment of precast floors, and due to the requirements for iteration, a spreadsheet is considered necessary.*

Feedback has highlighted that the general flow of the document could be improved, plus a need for navigational aids, and clear announcement of “step functions”. There’s also the need to better define what comprises a Severe Structural Weakness (SSW) for concrete columns, particularly those with moment resisting frames.

### **User-focused content development would be beneficial**

From our experience managing the complaints processes for engineers, uncertainty in guidance documents can lead to inconsistent application, complex complaints and ambiguity for consumers. These all undermine trust and confidence in the profession and regulator.

Engineering New Zealand concludes that senior technical expertise alone doesn’t produce material that suits all users - especially those who are less experienced. In the future we believe an effective, innovative approach would include an instructional designer and / or learning design facilitator in the development process, alongside typical users, so that guidelines are more likely to be consistently applied by all engineers.

### **Collaborative processes may boost market confidence**

Engineering knowledge will continue to develop over time. Future earthquakes will advance understanding of how buildings perform in the same way that the Canterbury and Kaikōura earthquakes have and findings from research.

These advances in knowledge need to be reflected in how we assess and retrofit buildings – and in the guidance that underpins this work.

In the future Engineering New Zealand will be happy to work with MBIE to outline a clear regulatory pathway, which will reduce confusion and increase market confidence.

## **RECOMMENDATIONS**

Engineering New Zealand recommends that Phase Two activities, including those we will lead and manage, comprise the following:

## EXPAND ASSESSMENT DATA ON PRECAST FLOORS

Phase Two was expected to involve additional whole building assessments of types that Phase One identified as needing further investigation. The purpose of this was to gather further comparisons of results from the Red Book and Yellow Chapter. Up to 12 more buildings were included in the preliminary scope and budget for Phase Two, pending outcomes from Phase One activity.

We no longer see the need to undertake additional complete individual building assessments. Instead, we recommend using the range of assessment information from the Precast Floors Assessment Monitoring Group to confirm the impact of the Yellow Chapter on the scoring of precast floor systems. This would involve carrying out Red Book assessments of precast floors from a targeted sample drawn from the PFAMG building cohort, to aid comparisons with their existing Yellow Chapter assessments and glean more detailed evidence of impacts.

The work involved is less than would be required for individually commissioned, comparative whole building assessments and has been costed in the attached budget.

**We recommend:** that Engineering New Zealand commissions Red Book assessments of the precast floors of up to six buildings from the PFAMG building cohort, including scores, results and comparison feedback, to further inform decision-making regarding the Yellow Chapter's regulatory status. To ensure the selected buildings will optimise required evidence the project intend to shortlist options with input from members of the Precast Floor Assessment Monitoring Group. Findings will also be analysed to ensure there is no technical contention in the Yellow Chapter around when precast floors are likely to fall below 34%NBS - and that this is an appropriate result when it does occur.

## REFINE AND IMPROVE TECHNICAL CONTENT

Phase One evidence has revealed that some technical refinements to the Yellow Chapter would enhance the consistency of outcomes. These will continue to be tested during Phase Two. Regardless of regulatory status, engineers continue to focus on investing in and improving the Yellow Chapter and senior structural engineering currently volunteer their time working collegially to ensure latest knowledge is gathered, discussed and can be applied.

There are inevitable benefits to engineering practice and the regulatory system when senior engineers dedicate time to working in a well-managed, collegial capacity to stay abreast of latest knowledge. Engineering New Zealand recommends managing a programme of work as a professional undertaking, targeting improvements to the proposed guideline. This will ensure that the Yellow Chapter's contents are as technically sound as possible and will help future-proof engineering knowledge in an area important to public safety.

**We recommend:** that Engineering New Zealand establishes and manages a group of leading technical specialists, in consultation with the guideline partners, to conduct further analysis of findings and define the areas of the Yellow Chapter to review and refine.



# APPENDIX 1: ASSESSMENT RESULTS AND RATINGS TABLE

## SUMMARY OF COLLECTIVE BUILDING ASSESSMENT REPORTS

**Table 1:** Phase One assessment summary table highlighting building characteristics and %NBS ratings

Building Type	Building #	Location	Year of construction	No. of Storeys	Red C5	Yellow Chapter	2006 Guidelines
<b>A: Pre-1976 non-ductile cast in situ with frame structure</b>	A1	Wellington	1961/62	9	35%NBS	25%NBS	N/A
	A2	Auckland	Early 1960s	6	20%NBS	20%NBS	N/A
<b>B: Post-1976 ductile primary system with precast concrete floors – frame structure with hollow core floor</b>	B2	Wellington	1984-86	7	25%NBS	25%NBS	35%NBS
<b>C: Post-1976 ductile primary structure with precast concrete floors – frame structure with flange-hung double tee floor</b>	C1	Wellington	1990	4	30%NBS	50%NBS	55%NBS
<b>D: Post-1976 ductile primary structure with precast concrete floors – wall structure</b>	D1	Wellington	1984-86	14	35%NBS	40%NBS	70%NBS
	D2	Auckland	1985	14	15%NBS	15%NBS	50%NBS

## APPENDIX 2: SUMMARY OF ASSESSMENT SCORES FOR BUILDING ELEMENTS

Table 2: C5 Evidence Project Phase One SUMMARY OF SCORES

Building	Description	Location	Direction	Element	Assessment Scores			Rating			Comments				
					Method			Method							
					2006 Red	Red C5	Yellow C5	2006 Red	Red C5	Yellow C5					
A1	Pre 1965 high-rise RC frame, insitu floors, plain reinfm't	Wellington	Longitudinal	Column splice Lvl 2 to 5			30%				Different governing behaviour due to Yellow C5 5.5.2.2 plain bars. Requires columns to be considered unreinforced.				
				Transverse	External beam/column joint shear Lvl 3 to 5		35-40%								
			External beam/column joint and internal column splice Lvl 2 to 5				25-30%								
			Beam/column joint at Lvl 1, External beam/column joint Lvl 4 to 6		35-40%										
									35%NBS(IL2)	25%NBS(IL2)					
A2	Pre 1965 high-rise, RC frame, insitu floors, plain reinfm't,	Auckland		Column shear (infill wall contact)		25%	20%					Lower shear capacities calculated for yellow but C7 modified shear capacities (varying Vs by crack angle) may need to be reviewed given new shear model and $\alpha$ factor			
				Column flexure		30%	30%						Red book limits to close to elastic behaviour, Yellow allows high inelastic deformation which increases the score initially, but once 0.5 SSW factor applied to loss of axial provisions, 55%NBS reduces to 30%NBS.		
				Column shear		35%	25%							Red book has higher capacities, Yellow allows more localised shear capacity exceedances. SSW applied	
				Beam/column joint shear		20%	25%							Minor difference in score due to yellow book joint stiffness modification for joint anchorage, retained as considered to be consistent with anchorage failure and joint degradation.	
				Beams										Not controlling and not impacted	
				Diaphragms										Not controlling and not substantially impacted	
				Infill walls - falling out		20%	20%								Both DSAs similarly controlled by full height infill walls falling out as force controlled SSNS elements using C10 and NZS1170.5 P&P loading (not affected by changes to Part C5)
				Deformation controlled SSNS											Yellow 20% lower than Red due to higher drifts resulting from 0.7 factor for anchorage of plain bar in primary frame.
									20%NBS(IL4)	20%NBS(IL4)					

Building	Description	Location	Direction	Element	Assessment Scores			Rating			Comments
					Method			Method			
					2006 Red	Red C5	Yellow C5	2006 Red	Red C5	Yellow C5	
B2	Post 1984 6-storey RC RC frames, precast floors	Wellington		Gravity framing	40%	25%	25%				Probable G380 yield stress 10% higher in yellow which increases shear demand. G380 overstrength factor 1.55 yellow 1.25 red but no impact this building. Column shear capacity less in yellow than red. Concrete and axial load contributions similar, steel contribution reduced by 25%. Deformation at onset of loss of axial load capacity in Yellow improved capacity of lightly reinforced columns in upper stories
				Primary frames	>80%	100%	100%				Increase in material properties benefitted B2 as G380 in cols and G275 in beams. Column shear capacity less in Yellow than Red.
				Perimeter column tie in	<65%	80%	100%				Yellow higher than red. Specific requirements rather than reliance on NZS3101 (2.5% drift cf 5% and 15% column shear cf 20%)
				Precast floor (hollowcore)	<65%	34%	25%				Displacement demand 40% higher in Yellow (difference $2/(1/S_p)$ ). Capacity/drift relationship is not linear in Yellow. Bearing set as 5 in Yellow, calculable in Red (1 to 2 typical). Elongation estimates larger in Yellow
				Floor diaphragm		35%	35%				Governed by PGA. Suggested may be too conservative. Without guidance on allowances for creep and shrinkage difficult to allow anything for mesh.
				Stairs	35-40%						
				Blockwall clearance to frame	35%						
				Pounding	40%						
											35%NBS(IL2)
C1	Post 1976, 4 storey, precast floors	Wellington		Primary frames	>100%	>100%	>100%				Rotation capacities were found to be within 10%. Buckling of perimeter columns not identified as issue.
				Precast Floors (TT)	55%	30%	50%				Units span 1.5x beam span. Remaining seating after allowance for tol, spall and bearing was 18.5 Red, 11.5 Yellow. Elongation increased 10.1mm/1%drift for Red, 4.9mm/1% Yellow but under Yellow spalling increased at 25.8mm/1%. Red uses constant spalling allowance. Under Red Drift capacity = 0.91%, demand = $1.41 \times 1.5 / 0.7 = 3.02\%$ , Rating = $.91 / 3.02 = 30\%$ . Under Yellow capacity = 1.47%, demand = $1.41 \times 2 = 2.82\%$ . Rating = $1.47 / 2.82 = 52\%$ .
				Floor diaphragm		50%	50%				Excludes mesh
				Stairs		90%	100%				Inadequate movement joint. Noted that the closing allowance was only 10 mm and scored less than 34%.
				Top storey columns	100%						
							55%NBS(IL3)	30%NBS(IL3)	50%NBS(IL3)		

Building	Description	Location	Direction	Element	Assessment Scores			Rating			Comments
					Method			Method			
					2006 Red	Red C5	Yellow C5	2006 Red	Red C5	Yellow C5	
D1	Post 1984, 14 storey, RC shear core, precast floors	Wellington		Gravity framing		35%	45%				Reinforcing contribution to column shear reduces by 25% from Red to Yellow, concrete and axial load contribution similar. Deformation calc at onset of loss of gravity load carrying capacity typically improved the displacement behaviour of the columns.
				Primary core wall	75%	100%	100%				Additional capacity for coupling beams available from Yellow compared with Red.
				Precast floor (hollowcore)		100%	75%				Displacement demand 40% higher for Yellow over Red (2/(1/Sp)). %NBS sensitive to non-linear relationship between capacity and drift. Red allowed calculation of bearing allowance. This leads to 3 to 4 mm additional seating capacity. Yellow results in larger elongation demands.
				Floor diaphragm	70%	35%	40%				Difficulty in taking mesh into account due to requirement to allow for creep and shrinkage effects but no guidance provided for this. E-W direction scored 80%NBS for 2006 Guidelines.
								70%NBS(IL2)	35%NBS(IL2)	40%NBS(IL2)	
D2	Post 1984, 14 storey, RC frame, precast floors	Auckland		Primary structure	100%	50%	55%				Direct rotation method used for shear walls for Yellow. Similar results from Red and Yellow. Plastic hinging above podium. Ductility demands modest (1.25-2). Beam/col joints have sufficient capacity but Red gave much higher capacity than Yellow.
				Podium Walls	50%						
				Precast floors (hollowcore)		15%	15%				Loss of seating on blk work and RC walls (30 available compared wthe 50 to 70 on beams). Applied to small number of units. Red rated negative moment for upper 4 floors as 20 - 30%, Yellow 90%. Unclear if negative moment check still required if scaled drift <1%.
				Podium diaphragm	50%						2006 based on score of transfer diaphragm at Level 4
				Tower roof diaphragm	70%	60%	40%				Mesh not included for Yellow
				Other tower diaphragms		90%	60%				Mesh not included for Yellow.
				Stairs	100%	<50%	<50%				Inadequate movement joint for Red and Yellow
				50%NBS(IL3)	15%NBS(IL3)	15%NBS(IL3)					

## APPENDIX 3: GLOSSARY OF TERMS

<b>Cast in situ</b>	Floors that are poured in place as the building is built.
<b>Double tee floor system</b>	Precast floor units that resemble two T-beams joined to each other.
<b>Ductile primary system</b>	The building is designed to be flexible and allow for deformations to occur in earthquakes.
<b>EPB</b>	Earthquake prone building. Can also refer to the Earthquake Prone Building legislative regime introduced in 2017.
<b>Importance Levels</b>	Classification of a building on a scale of 1 – 5 determined by risk to human life, the environment, economic cost and other risk factors in relation to that building's use.
<b>Precast concrete floors</b>	Floor elements that are cast elsewhere rather than poured as the building is built. Precast floors have a brittle failure mechanism meaning they may not perform well within flexible buildings in earthquakes.
<b>Red Book</b>	The 2017 Earthquake Assessment Guidelines which became part of the EPB regulatory system on 1 July 2017. Section C5 focused on concrete buildings.
<b>SSW</b>	Severe Structural Weakness. A defined weakness that has the potential to lead to severe loss of the gravity-load-resisting system of the building.
<b>Technical Challenge Group</b>	A group of senior representatives of structural engineering technical groups and societies providing strategic advice to Engineering New Zealand to effectively deliver Technical Project Management services to MBIE.
<b>Yellow Chapter</b>	Referred to as the technical proposal (C5) by MBIE. This is the revised section of the guidelines, released in November 2018, which contains latest knowledge about building behaviour in seismic events but does not have regulatory status.
<b>%NBS</b>	Indicates the percentage of the New Building Standard that a building achieves in terms of protecting life in earthquakes. When engineers calculate a %NBS earthquake rating, they are basically assessing the capability of a building to resist earthquake shaking. They do this by determining its probable capacity to resist shaking and comparing this against the ultimate limit state loading requirements for new buildings defined in the New Zealand Earthquake Loadings Standard issued on 1 July 2017 (NZS1170.5).

