BUILDING PERFORMANCE

UNCLASSIFIED

C5 Evidence Project

Phase Two: Final Report

Findings prepared by Engineering New Zealand

28 September 2021

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

New Zealand Government

Introduction

As outlined in MBIE's Building System Regulatory Strategy Building for the Future, MBIE's vision is to achieve high-performing building regulation that supports better buildings for New Zealanders.

Regulatory stewardship is at the heart of how MBIE will achieve this. We are committed to embracing continuous improvement and seek to regularly review and improve the guidance, regulatory frameworks, and information we provide in light of new and emerging evidence.

Engineering Assessments

Engineering assessments of existing buildings are undertaken in New Zealand for a range of purposes.

Engineering assessments that are conducted as part of the Earthquake-prone Building system (outlined in sections 133AA to 133BZA of the Building Act 2004) must be undertaken in a prescribed way. The Engineering Assessment Guidelines (commonly known as the 'Red Book') is the methodology that must be used as an input to help decide whether or not a building is earthquake-prone under the Building Act.

Engineering assessments that are conducted for reasons outside of the Earthquake-prone Building system can use different methodologies. These assessments are largely undertaken using best engineering practice.

C5 Evidence Project

In 2019 MBIE commissioned Engineering New Zealand to carry out an evidence-based assessment of how the outcome of engineering assessments of concrete buildings differ when using the Red Book and those undertaken using proposed revisions to Section C5 (commonly known as the 'Yellow Chapter').

This first phase of this C5 Evidence Project was released by Engineering New Zealand in December 2019, and can be found at this link.

Phase Two of the C5 Evidence Project assessed a further 12 buildings using the Red Book and the Yellow Chapter with a specific focus on precast concrete floor systems. While there were some notable differences in the assessments of some individual buildings, the evidence also revealed little difference, on average, in overall %NBS between Red Book and Yellow Chapter assessments.

The requirement for engineers to use the Red Book when carrying out engineering assessments to help identify potential earthquake-prone buildings is set under the Building Act 2004 and the EPB methodology. The release of this report **does not change** the existing requirement to use the Red Book to identify earthquake-prone buildings.

Acknowledgements

MBIE would like to thank Engineering New Zealand and the expert panel who contributed to Phase Two of the C5 Evidence Project. MBIE appreciates the valuable insight this report has given us into the current assessment methodology, and its implications for management of existing building stock in New Zealand.

Appendix A: C5 Evidence Project – Phase Two: Final Report

C5 EVIDENCE PROJECT

PHASE TWO: FINAL REPORT

Report

Evidence of impacts of the technical proposal (yellow) C5 section of the Engineering Assessment Guidelines on a sample of building assessments.

Prepared for the Ministry of Business, Innovation & Employment (MBIE).

Tuesday, 2 February 2021

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This report was drafted, edited and produced by Engineering New Zealand as the key output of the C5 Evidence Project. It was reviewed by the project's advisors, senior Engineering New Zealand personnel and advisors consulted by Engineering New Zealand, including the Programme Challenge Group, which is drawn from senior management committee members of the Structural Engineering Society (SESOC), New Zealand Society of Earthquake Engineering (NZSEE), New Zealand Geotechnical Society (NZGS) and Society of Fire Protection Engineers (SFPE).

Engineering New Zealand is grateful for the input, interest and support we have received from members of the structural engineering community, especially SESOC and NZSEE. Alongside the evidence commissioned directly for the project, our report's substantive contents includes data analysed and provided through practitioner goodwill: we are especially grateful to members of Engineering New Zealand's Precast Floors Assessment Monitoring Group, who have provided important input and reviewing services, and we acknowledge and thank everyone who has contributed their time to produce this rich evidence base.

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EXECUTIVE SUMMARY

The Engineering Assessment Guidelines, commonly known as the Red Book, provide a regulated technical basis for engineers to carry out seismic assessments of existing buildings within New Zealand. The Red Book was released by the Ministry of Business Innovation & Employment (MBIE) in mid-2017 as part of the Earthquake-Prone Building (EPB) legislative regime. On 30 November 2018, MBIE and its guideline partners released the technical proposal (yellow) C5 section (Yellow Chapter), which was based on further understanding about the impacts of earthquakes on building behaviour.

In early 2019, MBIE asked Engineering New Zealand to gather evidence of how Yellow Chapter seismic assessments of buildings compare to those carried out using section C5 of the Red Book. The project's objective was to provide insight into the impact of the Yellow Chapter on a range of building assessments to help MBIE make decisions about its regulatory status.

The evidence gathered included specific comparative scores and ratings from the application of both versions to the selected buildings. Practitioners who undertook the assessments also provided qualitative information about their experience of applying the Yellow Chapter compared to the Red Book. Additional insights were provided by members of the Precast Floors Assessment Monitoring Group.

On 19 December 2019, Engineering New Zealand submitted a report to MBIE summarising analysis of six building assessments gathered in the project's first phase, including commentary relating to the findings that explained the reasons for respective differences, plus observations re document use-ability and market feedback. The report made specific recommendations for further assessment activity focused on building floor systems. As a result, MBIE requested more data points. Engineering New Zealand commissioned further building assessment evidence and analysed this as the project's second phase.

Phase Two involved comparative assessment of the precast concrete floor systems of 12 buildings. This focused on both the floor units at the individual level and the floor overall as a horizontal diaphragm to distribute forces to the lateral load-resisting elements.

Datasets from both phases indicate that there is little overall difference in *%NBS* (percentage of new building standard assessed in accordance with the appropriate Engineering Assessment Guidelines) between Red Book and Yellow Chapter assessments of buildings. This finding applies to both pre-1976 concrete buildings and those of more modern construction with precast concrete floor systems. Some building component scores varied, depending on which guidance was applied. This was mostly around the loss of seating for floor units, which were more likely to score moderately or slightly lower using the Yellow Chapter, and diaphragms, which were likely to score moderately higher using the Yellow Chapter. On average across the full project dataset of 18 buildings, the overall impact of using the Yellow Chapter was between a 10% decrease and a 20% increase in *%NBS*. Use of the Yellow Chapter saw two out of the 18 buildings pushed under the 34% threshold, compared to the Red Book values, and three moving above the earthquake-prone level. Our conclusion is that the Yellow Chapter is unlikely to have a measurable impact on assessments undertaken using the corresponding section of the July 2017 Guidelines.

However, practitioners report that the Yellow Chapter provides better insight into vulnerabilities of various building components. This means it better targets the building components that require strengthening, which is important information for engineers to communicate to building owners in terms of retrofitting priorities. Using Red Book assessments won't necessarily lead to the most effective retrofit to address building weaknesses, based on latest knowledge.

Along with members of the Precast Floors Assessment Monitoring Group, our practitioners have expressed a strong view that Yellow C5 is technically superior and more straightforward to use than the corresponding Red Book section. It also has a wider scope of application, covering precast floors such as double-tee and rib and infill systems that are not addressed by the Red Book. Assessments undertaken by different engineers using the Red Book are likely to be less consistent because these floor types are not included.

Feedback from the practitioners who undertook assessments across both phases of the project has also identified where the Yellow Chapter could be made clearer to enable even more consistent practice.

Engineers have told us throughout both phases of the project that the existence of two guidelines creates confusion and further market uncertainty. They would prefer one guideline to use for both optimal assessment and regulatory purposes, and this would support clearer communication with building owners. We have heard that engineers are in practice using the Yellow Chapter, which represents the latest engineering knowledge, and investing in it by developing supporting information like worked examples.

This project also found that very few assessments of concrete buildings have been undertaken by practitioners using section C5 of the Red Book.

The engineering community has embraced this impact study and the opportunity it provided to actively monitor this aspect of the Engineering Assessment Guidelines by observing their impacts on building assessments.

This document is the final report summarising key findings and analysis from both phases of the C5 Evidence Project, plus supporting commentary as per the project's agreed scope.

INTRODUCTION

The 2017 Engineering Assessment Guidelines (known as the "Red Book") are technical guidelines for engineers to use when carrying out seismic assessments of existing buildings. They are cited in MBIE's EPB methodology, which requires them to be used for assessments of potentially earthquake-prone buildings in accordance with section 133AI of the Building Act.

In November 2018, a proposed technical revision to Section C5 of the Engineering Assessment Guidelines ("the Yellow Chapter") was released. The Yellow Chapter reflects more up-to-date engineering knowledge. It was 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 New Zealand building behaviour. The Yellow Chapter also provides the latest information on other aspects of the assessment of concrete buildings.

The Yellow Chapter has not yet been incorporated into the Red Book, which means that it currently sits outside of the EPB regulatory environment.

This project was undertaken in two phases: Phase One involved the assessment of six buildings against both the Red and Yellow versions in 2019, and Phase Two involved the assessment of just the precast concrete floor systems of 12 additional buildings against both documents in 2020.

This report summarises the scope of each project phase, the corresponding findings, and the overall summary of evidence gathered.

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. This project was commissioned by MBIE with the objective of increasing its understanding of the impact of Yellow C5 on building assessments, when compared with the Red Book, particularly on *%NBS* outcomes[1]. It is intended to help MBIE make an informed decision about incorporating the Yellow Chapter into the regulatory system.

The project gathered and analysed the following information:

- *%NBS* ratings derived from using both the Yellow Chapter and Red Book to assess a sample of buildings representing an agreed spread of typologies.
- Practitioner descriptions of differences in *%NBS* between the Yellow Chapter and Red Book (and other guidance used to assess those buildings).
- Practitioner observations about the assessments and their findings.

This project is an example of monitoring of the Seismic Assessment Guidelines.

[1] 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.

APPROACH TO EVIDENCE GATHERING

When commissioning this project, MBIE determined that Engineering New Zealand should commission assessments of a maximum of 18 buildings. This work was managed in two phases of evidence gathering and analysis.

Phase One

Engineering consultants were appointed to assess a sample of six buildings using both the Yellow Chapter and the Red Book. The buildings were selected to represent a range of building typologies, covering both pre-1976 buildings as well as those of newer construction with precast concrete elements. Findings were recorded in a customised and anonymised format. They included the contrasting building assessments as well as any previous detailed seismic assessments (DSAs) undertaken, any change in *%NBS*, and specific examples and reasons for those changes. Findings were analysed to ascertain whether further investigation was warranted for any building type/s and reviewed by industry stakeholders including Engineering New Zealand's Programme Challenge Group and Precast Floor Assessment Monitoring Group (the Monitoring Group).

Engineering New Zealand's Phase One report to MBIE made recommendations for additional building assessments and investigations, which formed the scope of the project's Phase Two. The report also recommended that a technical sub-group conduct further analysis of the findings and establish which areas of the Yellow Chapter to review and refine.

Phase Two

MBIE agreed to Engineering New Zealand's recommendation to specifically assess *building floor systems* in Phase Two, to highlight differences between the Red Book and Yellow Chapter.

In January 2020, Engineering New Zealand approached the engineering consultancy firms that had contributed to Phase One to carry out Phase Two assessments. We targeted these firms because of their proven ability to deliver plus knowledge of the project's aims. We considered building suitability primarily based on the features of the floor systems. Other considerations included building height, location and materials, to ensure a diverse evidence base.

Sourcing timely assessment of suitable buildings was again challenging, as engineering practices had limited capacity during our time frame – especially given the Covid-19 lockdown from March to May 2020. Although building owners would receive free assessments of their building floor systems, and their results would be anonymised, engineers needed to obtain owner permission due to potential implications of (even "unofficial") lower *%NBS* ratings.

As we found in Phase One, no building owners had undertaken Red Book assessments. We had to commission dual assessments using both the Red Book and Yellow Chapter for Phase Two.

As for Phase One, we ran a briefing session for consultants and provided them with material and templates to capture key information. They had ongoing access to project advisors and additional subject matter experts. We again sought additional review internally and externally, including from the Precast Floor Assessment Monitoring Group (the Monitoring Group) and its C5 Technical Sub-group, and Engineering New Zealand's Programme Challenge Group.

Where relevant to this impact study, we captured building owner perceptions about the existence of two documents for assessing buildings. While proactively seeking commentary from clients was out of scope,

consultants are well attuned to their clients' perceptions and where pertinent these are reflected in the evidence presented here.

Summary of buildings assessed

The floor systems of 12 buildings were assessed in Phase Two, covering a good spread of building characteristics, configurations, floor types and locations. The resulting evidence presented in this report includes scores, results and comparison feedback.

The floor systems included hollowcore (including with typical and "spaced" unit arrangements[2]), precast double tees and precast ribs with infill.

The buildings ranged in height from two to 22 storeys, with the median being eight floors. Structural configurations included reinforced concrete moment-resisting frames, concrete shear walls and concrete masonry shear walls. The buildings included eight in Wellington (High seismicity), two in Auckland (Low seismicity), and one each in the Bay of Plenty and Central Otago (both Medium seismicity).

This sample of buildings is representative of buildings likely to be impacted by the Red Book and Yellow Chapter in regard to the assessment of floors, with an appropriate bias towards hollowcore floors.

More detail on the various building configurations is included in Appendix 1.

Assessment approaches followed

The assessment approaches followed the two sets of guidelines (Red Book and Yellow Chapter). For assessments using the Red Book, recourse was made to the recommendations set out in the University of Canterbury Research Report 10 (Purple Book), which is referenced in the Red Book.

None of the subject buildings had been assessed previously to the Red Book provisions, so assessment of their floor systems to the Red Book was needed as part of this impact study. These assessments involved applying Red Book provisions as they would be carried out today, rather than attempting to apply assessment practices dating back to 2017. Knowledge on how to carry out assessments has developed significantly since 2017, in part informed by discussion in the Yellow Chapter of subjects not explicitly covered by the Red Book.

Some guideline requirements, specifically in relation to the Red Book rather than the Yellow Chapter, are open to interpretation – and were interpreted differently by the different assessors. No attempt was made to unify these interpretations, as it was considered that all interpretations (unless completely in error) are valid, in terms of gaining an understanding of the impact of the various assessment provisions.

[2] Typical hollowcore unit arrangements have the units abutting one another. On the other hand, in a spaced configuration, units are spaced 400 mm to 800 mm apart. The gap between units is spanned by permanent timber infill formwork that provides support for the permanent concrete slab poured at the same time as the topping concrete.

KEY FINDINGS FROM PHASE ONE

The buildings assessed in Phase One and their ratings for the Red and Yellow versions are summarised in Appendix 1.

For the six buildings assessed in Phase One, 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. For the other three buildings, there were some minor gains or losses in either direction: two went up and one went down using the Yellow Chapter.

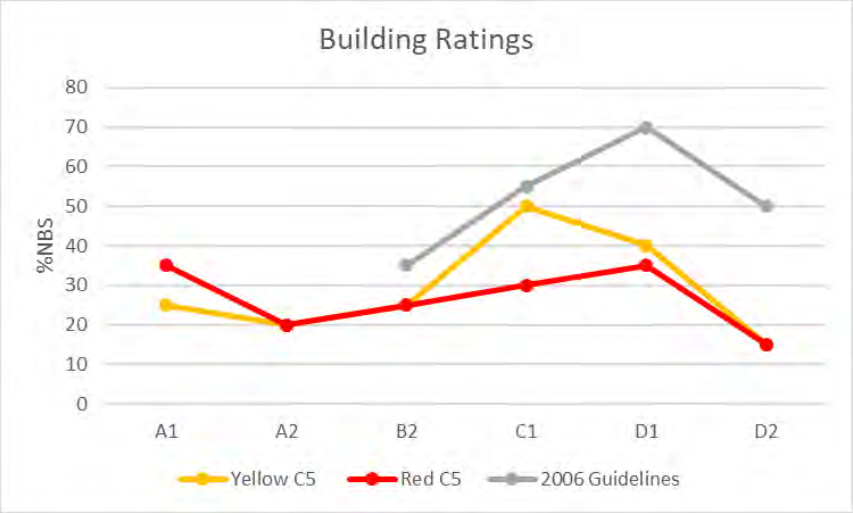

Figure A: Phase One C5 Evidence Project %NBS results of six assessed buildings

DIFFERENCES BETWEEN RED BOOK AND YELLOW CHAPTER BUILDING RATINGS

The Yellow Chapter lifted the ratings of one building above the 34*%NBS* threshold compared with the Red Book – but the reverse also applied. In the sample:

- 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 by both documents as less than 34*%NBS* are typically mid- to high-rise buildings in higher seismic regions.

DIFFERENCES BETWEEN RED BOOK AND YELLOW CHAPTER COMPONENT SCORES

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. This means that retrofits using Red Book assessments may not address buildings' greatest vulnerabilities. Evidence showed that:

- 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 component score governing the overall *%NBS* result was different.
- In pre-1976 buildings, individual score changes were more related to columns.
- In post-1976 buildings, individual score changes related more to floors (such as diaphragm actions or precast unit issues). This finding led to our recommendation for Phase Two's focus on floor systems.
- Consultants in Phase One reported that the Yellow Chapter was simpler, clearer and more straightforward to apply to building assessment work. However, feedback also highlighted that the general flow of the document could be improved, including a need for navigational aids and clearer announcement of "step functions".

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

The work of the consultants and the wider dialogue enabled by the Precast Floors Assessment Monitoring Group established that none of the Phase One building owners had undertaken Red Book assessments between the introduction of the Red Book and the subsequent release of the Yellow Chapter.

KEY FINDINGS FROM PHASE TWO

We received complete data sets of results for 11 buildings and a partial data set for the 12th. The data provided for the 12th building was still useful because it revealed the impact on the precast floor seating of the different guidelines. One building contained two different precast floor systems, creating an additional data point for floor systems (meaning we had 13 data points in total).

Each assessor also provided commentary on issues encountered in the application of the two methods. These comments are discussed later in this report.

Our advisors found that the building assessment reports commissioned and submitted in Phase Two were of an appropriate standard and quality, and the findings within them were sound.

During the review of the assessment reports, a particular focus was given to results that changed from above 34*%NBS* using the Red Book to below 34*%NBS* using the Yellow Chapter (or vice versa), to ensure there was no technical contention around this result in the three buildings where it did occur.

A summary of data obtained for the 12 buildings, including the scores for various components and behaviour types according to the Red Book and Yellow Chapter, is shown in Table 3 in in Appendix 2. Scores for the various failure modes and in relation to the diaphragms are listed, as well as the overall score and limiting failure mode. These scores would only set the *%NBS* rating of the particular building if they were the lowest scores obtained from considering all building aspects, including the scores obtained for secondary structural and non-structural items. Table 2 in Appendix 2 specifically highlights the floor system ratings of the Phase Two buildings.

The impact of each document has been compared graphically by plotting the scores obtained for the various aspects against each other. How much the scores varied can be easily seen from the departure from the diagonal line, which represents identical results for both the Red Book and Yellow Chapters.

The assessment results indicate that the impact on both *%NBS* results and component scores using the Yellow Chapter is low. In the Phase Two findings, the component score most likely to change between Red Book and Yellow Chapter was **loss of seating**. Using the Yellow Chapter reduced the score for the floor systems in five buildings, by between 20% and 40%.

SCORES FOR PRECAST FLOOR UNITS

Figure 1 below shows the scores for the precast floor units obtained using the Red Book and Yellow Chapter for each of the 12 buildings. Each set of bars is labelled with the building identifier (2.1, 2.2, etc.) and the flooring type (where HC refers to hollowcore, TT refers to double tee, and Rib refers to rib and infill flooring). There is little absolute change between the documents (a maximum of 20% change), though in one instance (Building 2.2) the relative change is significant, with the score halving.

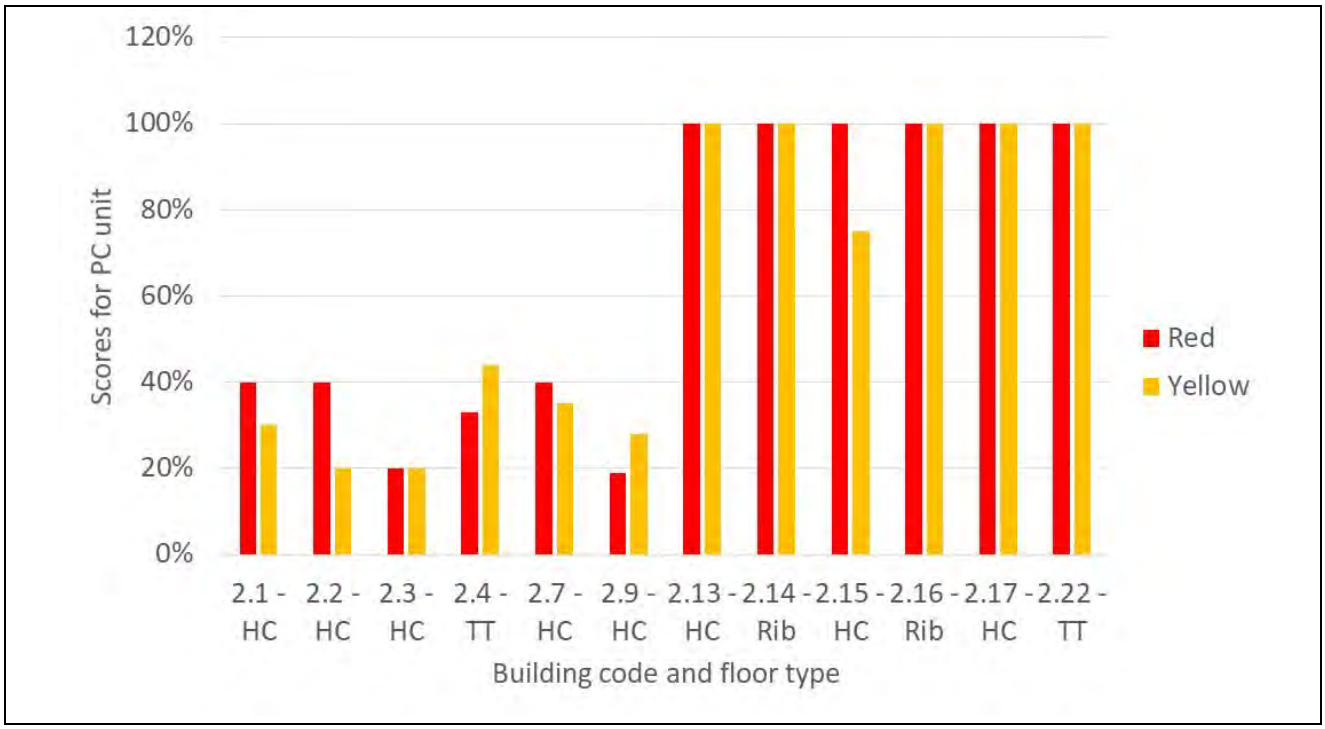

Figure 1: scores for precast floors – bar graph

Figure 2 shows the same data as Figure 1 plotted as a scatter graph. Many graphs in this report are scatter graphs that illustrate variance between Yellow Chapter and Red Book score. They follow this format:

- Scores calculated according to the Red Book are shown on the horizontal (X) axis, while scores calculated according to the Yellow Chapter are shown on the vertical (Y) axis.
- The diagonal dashed orange line (1:1) corresponds to the same score being determined by both documents. For points above this line, the scores calculated using the Yellow Chapter are higher than those calculated using the Red Book; for points below this line, the inverse is true.
- The grey dotted line (Linear (All)) reflects a regression (or best fit) line that passes through the origin. The equation for this regression line is shown on the graphs. Where the coefficient is greater than 1.0, the Yellow Chapter results in higher scores on average; where the coefficient is less than 1.0, the Yellow Chapter results in lower scores on average.
- The dark blue dashed horizontal and vertical lines denote 34*%NBS* scores and consequently the threshold where scores indicate an element makes a building potentially earthquake prone.
- Various labels are applied to the datapoints. These generally show the building identification, followed by some additional information in brackets. For instance, the labels on the graph in Figure 2 show the building identification and the floor unit type. Other labels also include the critical behaviour governing the score of the building according to the Red Book (first) and the Yellow Chapter (second).

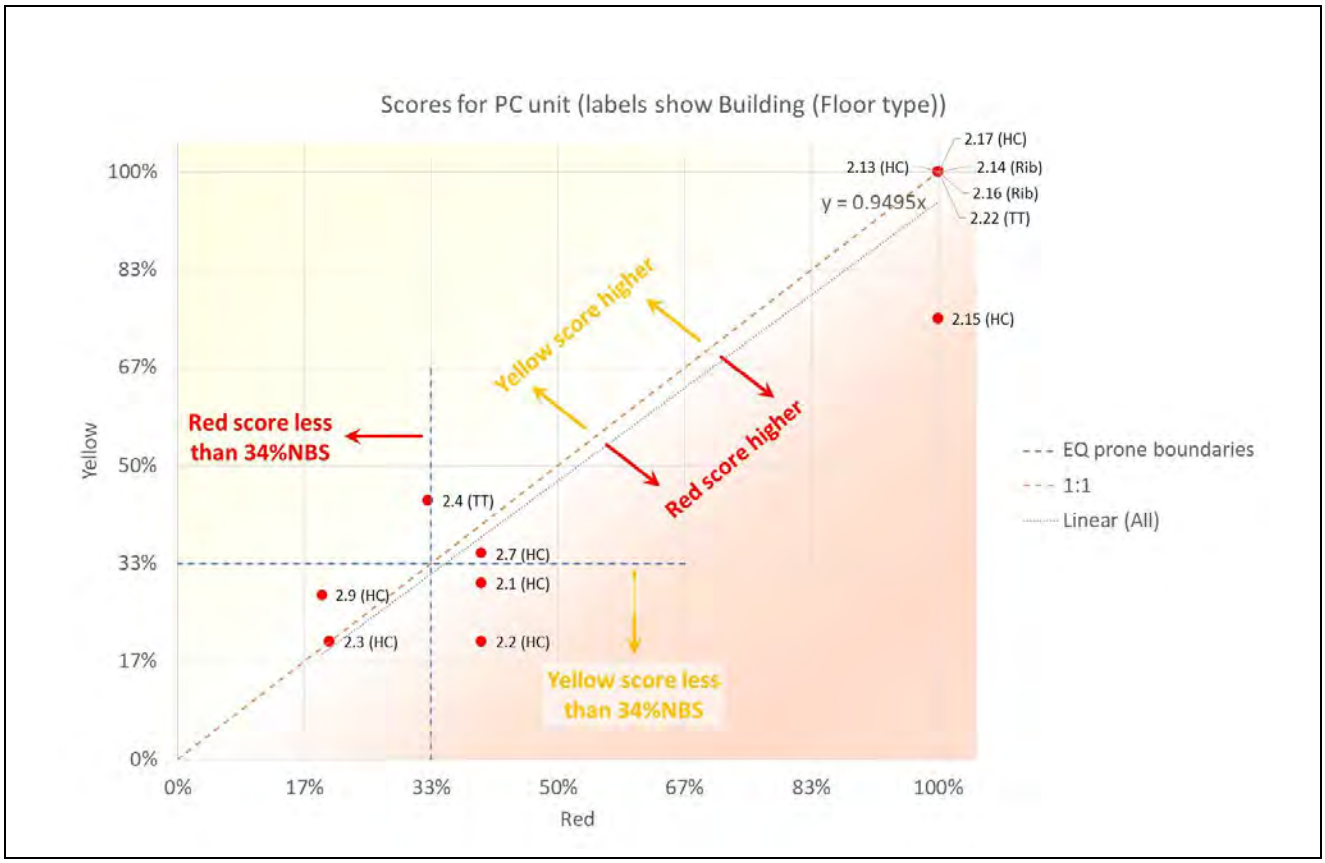

Figure 2: scores for precast floors – scatter graph

Figure 2 illustrates that most precast floor units that had scores of less than 34*%NBS* according to the Yellow Chapter also had scores of less than 34*%NBS* according to the Red Book. Only three datapoints, Buildings 2.1, 2.2, and 2.4, are on different sides of the 34*%NBS* threshold depending which document is used. The former two had scores greater than 34*%NBS* according to the Red Book but less than 34*%NBS* according to the Yellow Chapter, while building 2.4 had a score of 33*%NBS* according to the Red Book and in excess of 40*%NBS* according to the Yellow Chapter.

The regression line for Figure 2 is close to the 1:1 line, showing that there is little difference on average between the Red Book and the Yellow Chapter, with the Yellow Chapter giving slightly lower scores (the coefficient of the regression equation is less than 1.0).

Figure 3 shows similar data to Figures 1 and 2 but with scores according to the Red Book and the Yellow Chapter plotted against the (ultimate limit state) drift for each building. Arrows show where scores have changed between the two documents. This graph shows that for both the Red Book and Yellow Chapter, the precast unit score tends to decrease with increasing drift. This is expected based on the engineering mechanics governing behaviour of precast floor units.

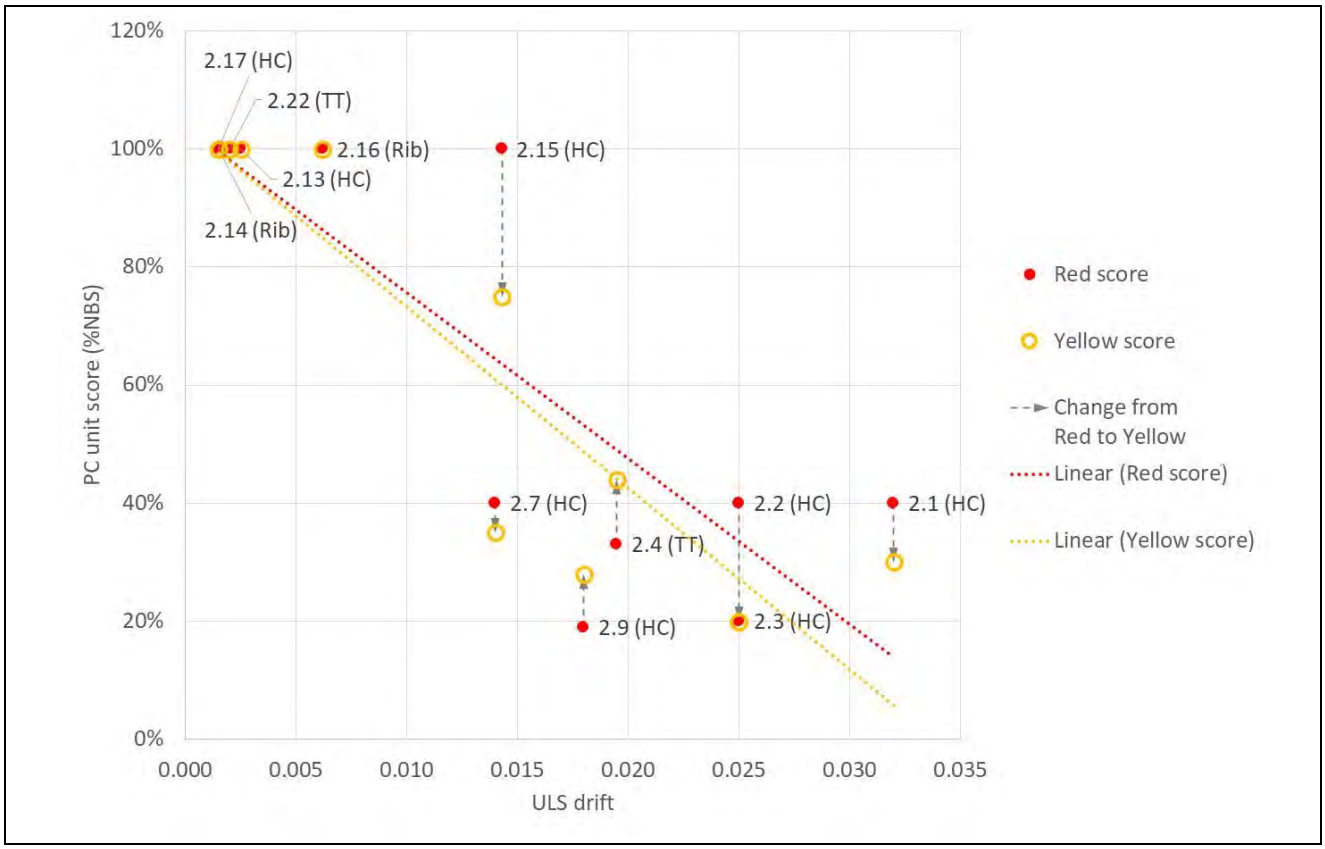

Figure 3: scores for precast floors – relationship to drift

Additional graphs appended to this report (Figures 7 to 11) show how failure mode scores varied when assessed using both the Red Book and the Yellow Chapter. Not all failure modes are applicable to all floor types (e.g. the torsional failure mode is applicable only to hollowcore floor units), so not all buildings appear on all graphs.

For most failure mode scores, there is little appreciable difference between the Red Book and the Yellow Chapter. The exception is loss of support, where the Yellow Chapter tends to produce lower scores than the Red Book. When considering the negative moment failure mode (NMF), Figure 11 shows that building 2.9 was notably affected, dropping from a score of 100*%NBS* to 28*%NBS*. This change arose because assessment of NMF is binary: NMF is either possible or not possible. For building 2.9, the NMF calculation shifted from one to the other because of differences between the Red Book and Yellow Chapter, causing a dramatic change of calculated score. But overall, this change was not material, as the score for the precast floor units of this building actually increased when assessed using the Yellow Chapter (due to the change in scores for the incompatible displacement failure mode).

In summary, whether the Red Book or Yellow Chapter was used had little impact on precast floor unit scores. In 75% of cases, scores using the Yellow Chapter were essentially unchanged from Red Book assessments (i.e. remained on the same side of the 34*%NBS* threshold). The remaining 25% of cases shifted from one side of the 34*%NBS* threshold to the other, with two of the Yellow C5 scores falling below 34*%NBS* and one above.

DIAPHRAGM SCORES

Figure 4 shows the scores calculated for diaphragms under both the Red Book and Yellow Chapter. Here the trends are similar to precast floor units, except that the regression line shows a slight increase of scores

(coefficient greater than 1.0) for the Yellow Chapter. Again, three datapoints (2.2, 2.9, and 2.22) are on different sides of the 34*%NBS* threshold depending on which document is used to determine the score. However, in this case, all three of these buildings had scores of less than 34*%NBS* using the Red Book and at least 34*%NBS* using the Yellow Chapter. In the case of buildings 2.9 and 2.22 (for which the data points are coincident), this change is a result of application of the "deemed not earthquake prone" provisions for diaphragms that were added to the Yellow Chapter. These provisions state that some diaphragms are deemed to possess inherent robustness that means they are not expected to fail during a moderate earthquake, even though it may not be possible to show this mathematically.

As was the case for precast unit scores, the overall difference between the Red Book and Yellow Chapter was limited, with 75% of cases having similar outcomes irrespective of which document was used.

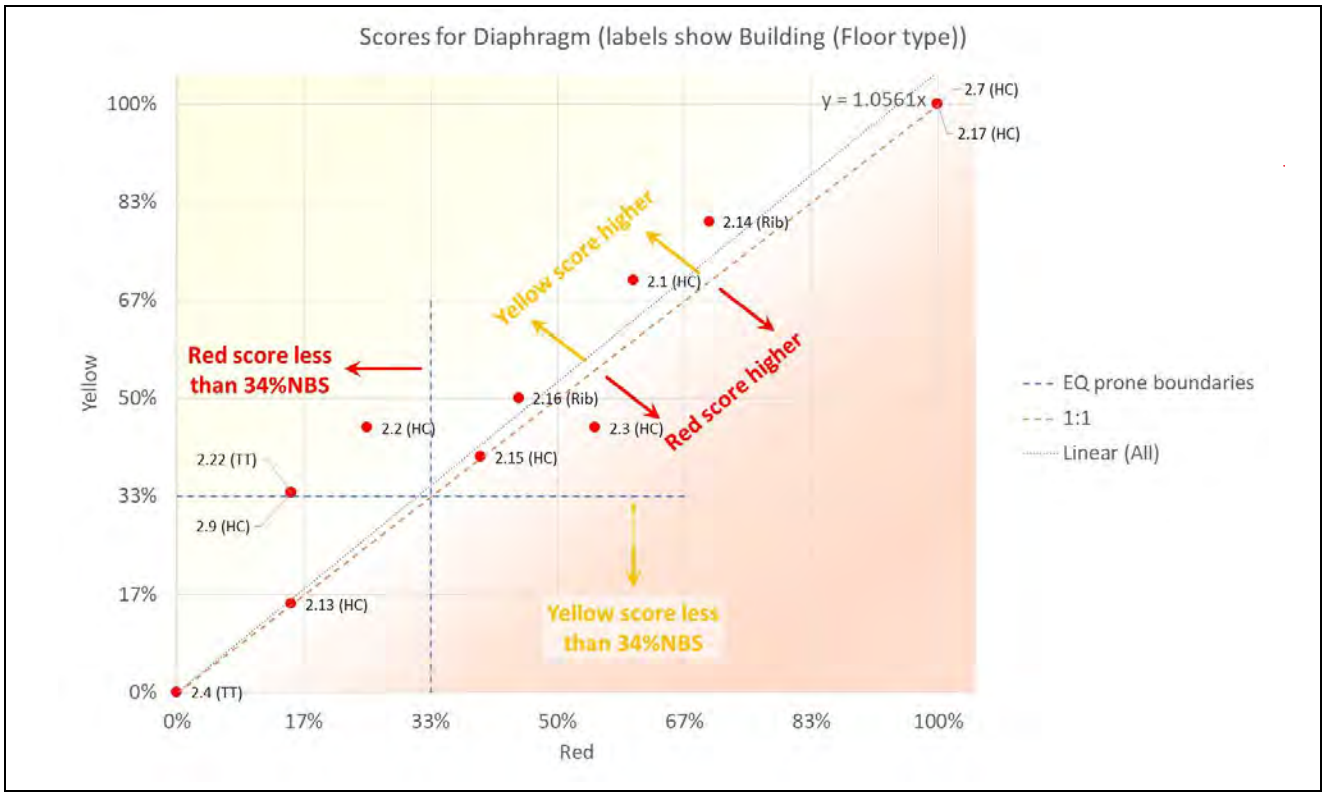

Figure 4: scores for diaphragms – scatter graph

OVERALL SCORES FOR THE FLOORS

Figure 5 shows the overall scores of the floors of each building, using the Red Book and the Yellow Chapter. This overall score is governed by whichever of the precast units or diaphragm scores the least. The labels on each data point show the governing behaviour, first from the Red Book and then the Yellow Chapter. For example, building 2.9 was governed by the diaphragm score according to the Red Book but by negative moment failure (NMF) mode of the hollowcore floors according to the Yellow Chapter. Figure 5 shows similar trends to previous graphs, with little difference between scores from the different documents.

For floors overall, scores in 75% of cases were essentially unchanged, remaining on the same side of the 34*%NBS* threshold. Compared to Red Book scores, the Yellow Chapter moved one floor below 34*%NBS* and raised two floors above 34*%NBS*. Notably, one building (2.2) remained below 34*%NBS* whether assessed to the Red Book or Yellow Chapter, despite having both its precast unit and diaphragm scores materially affected by the change from the Red Book to the Yellow Chapter.

We conclude that the Yellow Chapter produces similar assessment scores for floors to the Red Book but is materially easier to use and more likely to be applied consistently.

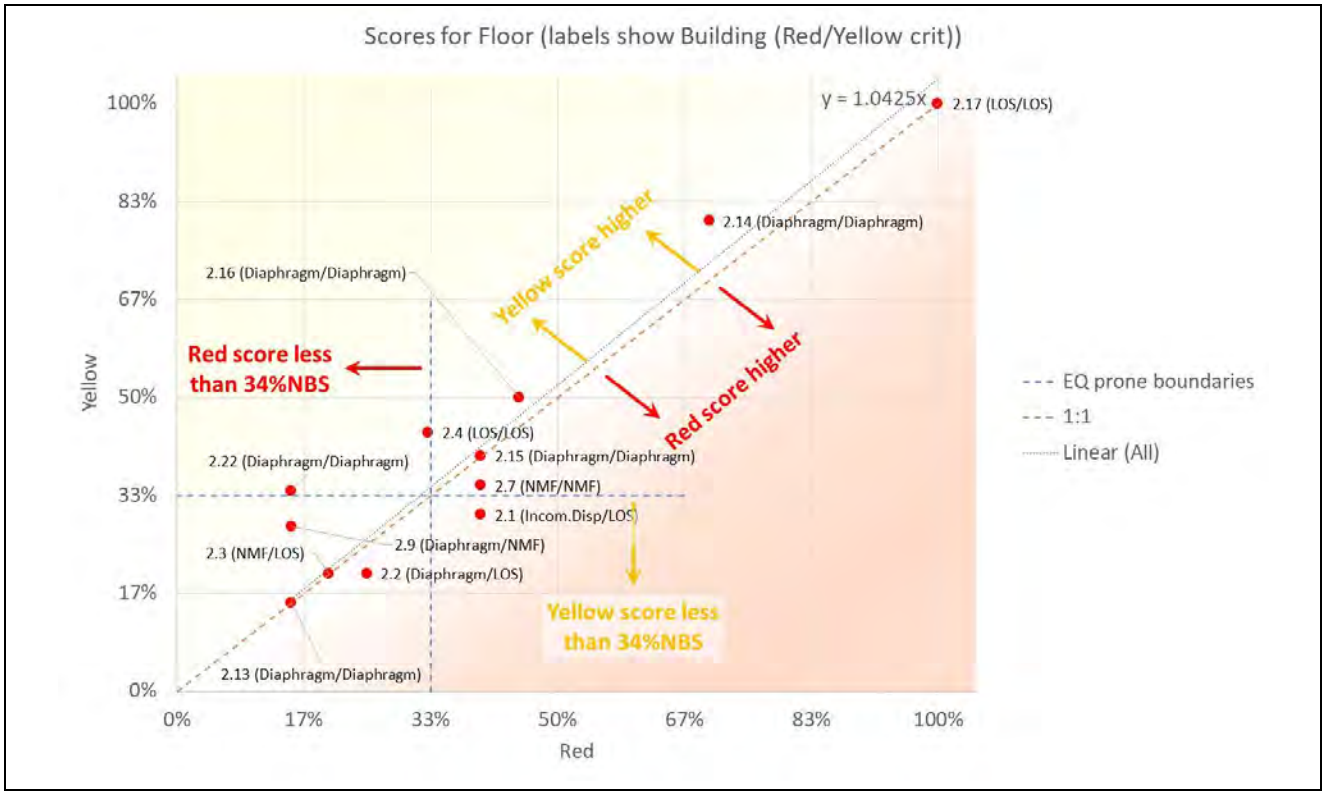

Figure 5: scores for floors – scatter graph

OVERALL IMPACT ON *%NBS*

Figure 6 shows the lowest score calculated for each building in both Phase 1 and Phase 2 according to the Red Book and the Yellow Chapter.

For Phase 1, the score relates to the lowest capacity element of the building and consequently also defines the building rating (*%NBS*).

For Phase 2, the score is the lowest of the scores for the diaphragms or precast floor units. This score relates only to the floors of the buildings and does not explicitly consider other elements of the buildings (e.g. beams, columns, walls, etc). This means it does not necessarily represent the rating for the building. However, the reports provided for Phase 2 generally indicate that floors are the lowest scoring elements of the buildings, so the Phase 2 data in Figure 6 is a reasonable proxy for the building rating.

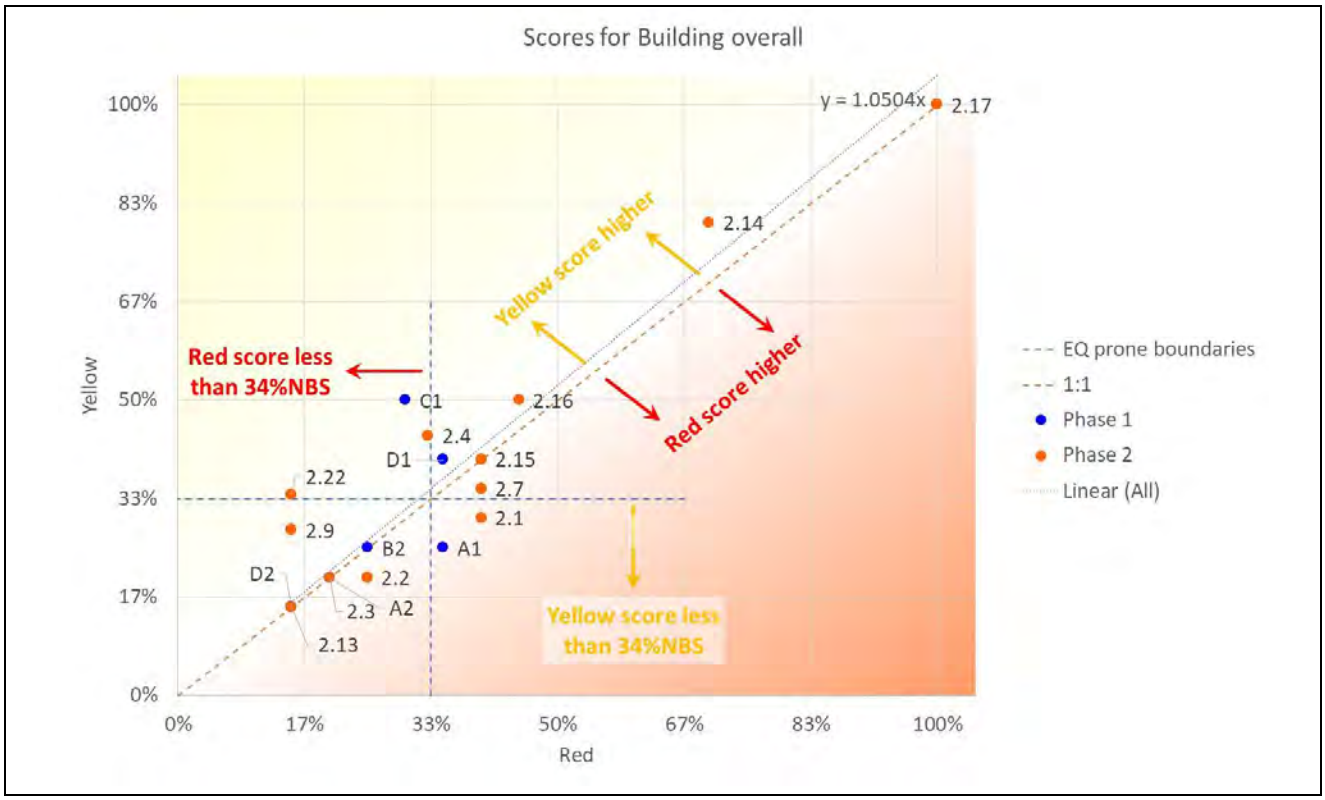

Figure 6: scores for buildings from Phase 1 and Phase 2

PRACTITIONER OBSERVATIONS ON APPLYING RED AND YELLOW VERSIONS

For both phases, we gathered observations about the usability and clarity of the documents, and feedback regarding their use in practice.

MANY ASPECTS OF THE YELLOW CHAPTER ARE IMPROVEMENTS ON THE RED BOOK

Consultants universally said that the Yellow Chapter was clearer than the Red Book. In particular, they reported that the Yellow Chapter can be applied more consistently – and we have seen this in the results. For example, how ULS drifts are increased (or not) is more subject to interpretation in Red than Yellow: it's "much simpler in Yellow".

It was noted that one of the Red Book's key flaws is its lack of specific provisions for assessing precast floors other than hollowcore systems.

Other comments included:

> *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).*

FURTHER IMPROVING THE USABILITY OF THE YELLOW CHAPTER

While consultants and other practitioners were very positive about the document, they noted that the flow of the Yellow Chapter could be even further improved. A technical sub-group of the Monitoring Group has met to discuss usability issues which have been highlighted by its application in practice and identified refinements to some specific areas of the Yellow Chapter.

For example, while the Yellow Chapter is much clearer than the Red Book in directing *how* to grade the impact of non-ductile mesh, further clarity would be desirable on the limited circumstances where the contribution of mesh can be included in evaluating floor system capacity. Practitioner feedback has also highlighted potential benefits in opportunities for enhancement introducing navigational aids, improving the order of information, adding clear announcement of "step functions", and adding flow charts to guide practitioners.

RED BOOK ASSESSMENTS MAY NOT IDENTIFY KEY VULNERABILITIES

Because the Yellow Chapter is based on more recent 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 the Yellow Chapter 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 updated thinking about what are a particular building's most significant weaknesses.

HAVING TWO GUIDELINES CREATES MARKET UNCERTAINTY

Engineers are using the Yellow Chapter, not the Red Book

Engineers are communicating their clear 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.

Engineers report that building owners are confused

Consultants provided feedback that there is confusion and misunderstanding about seismic building assessment regulation.

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.[3]

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 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

[3] This situation is not helped by the growing knowledge in the industry that the earthquake hazard in Wellington, which is fundamental to assessment of *%NBS* scores and ratings, may be understated in the current earthquake Standard.

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.

SUMMARY OF EVIDENCE GATHERED FROM BOTH PHASES

This project found that very few assessments of concrete buildings have been undertaken by practitioners using section C5 of the Red Book.

It also found that the Red Book and Yellow Chapter both typically produce significantly lower *%NBS* ratings than the previous 2006 NZSEE Guidelines as they were usually applied at the time.

KEY TECHNICAL FINDINGS FROM PHASE ONE

- There was little substantive difference in *%NBS* building ratings between the Red Book and Yellow Chapter across both pre-1976 concrete buildings and those of more modern construction with precast concrete floor systems.
- While overall *%NBS* results were similar, the scores of different elements did vary. This means that the Red Book and Yellow Chapter identified different vulnerabilities in buildings, implying that retrofits based on the Red Book may not address a building's greatest vulnerabilities.

KEY TECHNICAL FINDINGS FROM PHASE TWO

- For both floors overall and floor units, we found that scores were essentially unchanged between the Yellow Chapter and Red Book.
- For diaphragms, in a quarter of cases scores were lifted significantly when assessed by the Yellow Chapter (as compared to the Red Book). This change shifted scores from below 34*%NBS* to above 34*%NBS*.

PRACTITIONER OBSERVATIONS ABOUT USABILITY

- Yellow C5 was reported to be a technically superior document that can be applied to a wider range of precast concrete floor systems.
- In Phase One, consultants reported that the Yellow Chapter was simple, clear and more straightforward to use, and a significant improvement on the Red Book.
- Engineers are using the Yellow Chapter for the assessment of concrete elements and buildings. They are only using the Red Book where necessary for earthquake-prone building purposes.
- Certain aspects of Yellow C5 would benefit from review, clarification and/or adjustment so that engineers are likely to produce even more consistent results.

In summary, the Yellow Chapter contains engineers' latest knowledge about building behaviour of concrete buildings in earthquakes and is regarded by engineers as superior to section C5 of the Red Book. It is also a clearer document and more consistent for practitioners to apply than the Red Book. This clarity would be even further improved by the implementation of relatively minor edits to the text in specific areas identified through this project.

The engineering community has embraced this impact study and the opportunity it provided to actively monitor the Engineering Assessment Guidelines by observing their impact on building assessments. Advisers and reviewers have been able to discuss the Yellow Chapter's impact at length, and this represents a good example of the active monitoring that the Guidelines document requires. Through this process engineers have told us that the existence of two documents creates market confusion and adds complexity

to the system for concrete buildings, and hence the engineering sector now hopes that the Yellow Chapter can be integrated within the Red Book.

APPENDIX 1: BUILDING CHARACTERISTICS

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

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

APPENDIX 2: PHASE TWO FINDINGS

Table 2: **Phase Two** assessment summary table highlighting building characteristics and ***floor system*** ratings

Building Type	ID	Location	Year of construction	No. of Storeys	Red C5	Yellow Chapter	2006 Guidelines
1997 concrete moment frame building, Importance Level 3, Hollowcore	2.1	Wellington	1997	3	40%	30%	
1988 concrete moment frame building, Importance Level 2, Hollowcore	2.2	Wellington	1988	22	25%	20%	
Post 1976 concrete moment frame building - , Importance Level 2, Hollowcore	2.3	Wellington		14	20%	20%	
Flange Hung double T	2.4	-		-	33%	44%	
1988 concrete moment frame building, Hollowcore	2.7	Wellington	1988	3	40%	35%	
1985 ductile frame structure , Importance Level 2, Hollowcore	2.9	Wellington	1985	14	15%	28%	
1985 reinforced concrete blockwork wall structure with non-ductile gravity frames, Importance level 2, Hollowcore	2.13	Auckland	1985	3	15%	15%	

Building Type	ID	Location	Year of construction	No. of Storeys	Red C5	Yellow Chapter	2006 Guidelines
1987 reinforced concrete building with perimeter shear walls, concrete shear cores and concrete moment frames, Importance level 3, Rib and Infill	2.14	Auckland	1987	5	70%	80%	
2005 reinforced concrete moment frame structure, Importance level 2, Hollowcore (spaced units)	2.15	Bay of Plenty	2005	3	40%	40%	
1988 reinforced concrete building with perimeter shear walls and concrete moment frames, Importance level 3, Rib and Infill	2.16	Wellington	1988	9	45%	50%	
1988 reinforced concrete building with full length perimeter shear walls in one direction and transverse moment frames., Importance level 3, Hollowcore and Rib and Infill	2.17	Wellington	1988	9	100% (HC) 15% (Rib)	100% 15% (Rib)	
1974 structure with perimeter reinforced blockwork walls, Importance level 2, Double Tee	2.22	Otago	1974	2	15%	34%	

Table 3: Full table of **Phase Two** findings

ID	Version	ULS drift	Floor type	LOS	PMF	Incom.Disp	TOR	NMF	Flange	Diaphragm	PC unit	Floor	PC limit	Floor limit
2.1	Red	3.20%	HC	65%	50%	40%	100%	100%		**60%**	**40%**	**40%**	**Incom.Disp**	**Incom.Disp**
	Yellow	3.20%	HC	30%	40%	35%	100%	100%		**70%**	**30%**	**30%**	**LOS**	**LOS**
2.2	Red	2.50%	HC	40%	40%	50%	100%	100%		**25%**	**40%**	**25%**	**LOS**	**Diaphragm**
	Yellow	2.50%	HC	20%	30%	40%	100%	100%		**45%**	**20%**	**20%**	**LOS**	**LOS**
2.3	Red	2.50%	HC	40%	36%	50%	80%	20%		**55%**	**20%**	**20%**	**NMF**	**NMF**
	Yellow	2.50%	HC	20%	30%	45%	80%	20%		**45%**	**20%**	**20%**	**LOS**	**LOS**
2.4	Red	1.95%	TT	33%							**33%**	**33%**	**LOS**	**LOS**
	Yellow	1.95%	TT	44%							**44%**	**44%**	**LOS**	**LOS**
2.7	Red	1.40%	HC	100%	55%	100%	100%	40%		**100%**	**40%**	**40%**	**NMF**	**NMF**
	Yellow	1.40%	HC	60%	45%	100%	100%	35%		**100%**	**35%**	**35%**	**NMF**	**NMF**
2.9	Red	1.80%	HC	43%	40%	19%	100%	100%		**15%**	**19%**	**15%**	**Incom.Disp**	**Diaphragm**
	Yellow	1.80%	HC	47%	65%	33%	85%	28%		**34%**	**28%**	**28%**	**NMF**	**NMF**
2.13	Red	0.25%	HC	100%	100%			100%		**15%**	**100%**	**15%**	**LOS**	**Diaphragm**
	Yellow	0.25%	HC	100%	100%			100%		**15%**	**100%**	**15%**	**LOS**	**Diaphragm**
2.14	Red	0.15%	Rib	100%	100%			100%		**70%**	**100%**	**70%**	**LOS**	**Diaphragm**
	Yellow	0.15%	Rib	100%	100%			100%		**80%**	**100%**	**80%**	**LOS**	**Diaphragm**
2.15	Red	1.43%	HC	100%	100%			100%		**40%**	**100%**	**40%**	**LOS**	**Diaphragm**

ID	Version	ULS drift	Floor type	LOS	PMF	Incom.Disp	TOR	NMF	Flange	Diaphragm	PC unit	Floor	PC limit	Floor limit
	Yellow	1.43%	HC	75%	100%			100%		**40%**	**75%**	**40%**	**LOS**	**Diaphragm**
2.16	Red	0.62%	Rib	100%	100%			100%		**45%**	**100%**	**45%**	**LOS**	**Diaphragm**
	Yellow	0.62%	Rib	100%	100%			100%		**50%**	**100%**	**50%**	**LOS**	**Diaphragm**
2.17	Red	0.15%	HC	100%	100%			100%		**100%**	**100%**	**100%**	**LOS**	**LOS**
	Yellow	0.15%	HC	100%	100%			100%		**100%**	**100%**	**100%**	**LOS**	**LOS**
	Red	0.15%	Rib	15%	100%			100%			**15%**	**15%**	**LOS**	**LOS**
	Yellow	0.15%	Rib	15%	100%			100%			**15%**	**15%**	**LOS**	**LOS**
2.22	Red	0.20%	TT	100%					40%	**15%**	**100%**	**15%**	**Flange**	**Diaphragm**
	Yellow	0.20%	TT	100%					40%	**34%**	**100%**	**34%**	**Flange**	**Diaphragm**

APPENDIX 3: ADDITIONAL FIGURES

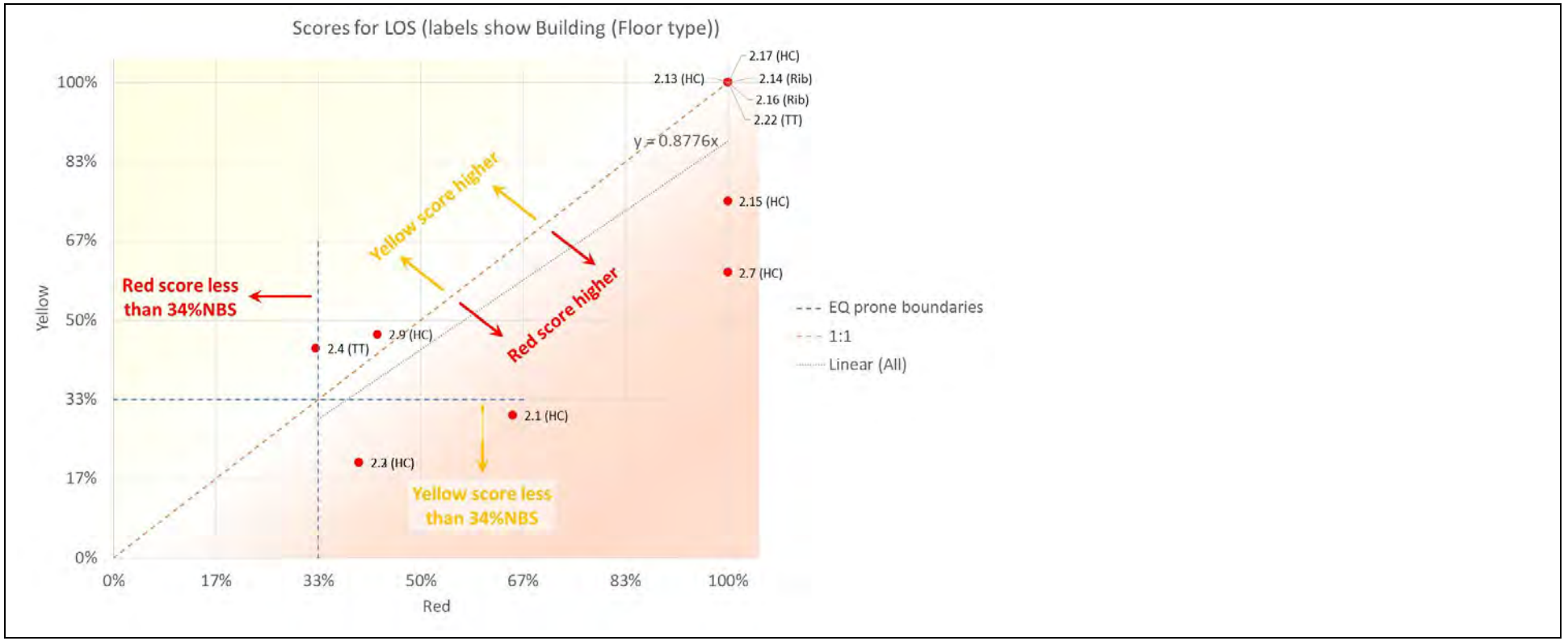

Figure 7: scores for loss of support – scatter graph

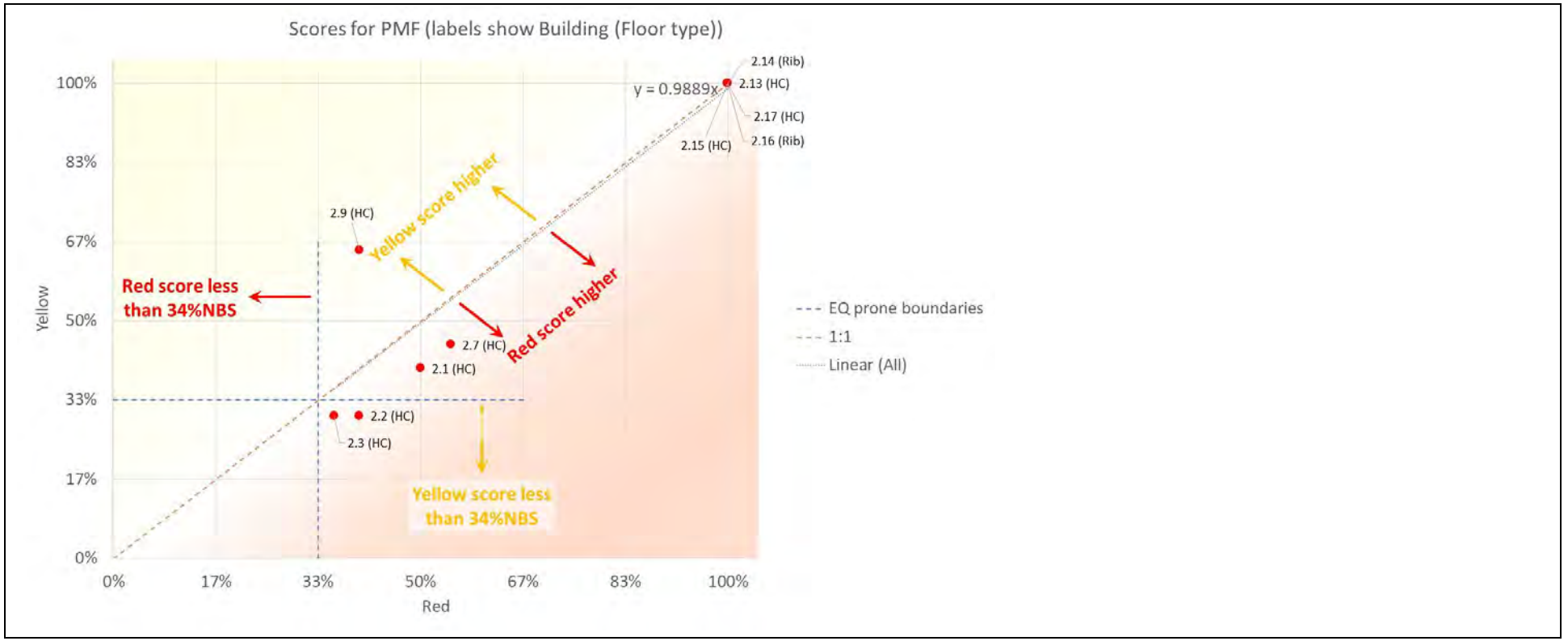

Figure 8: scores for positive moment failure – scatter graph

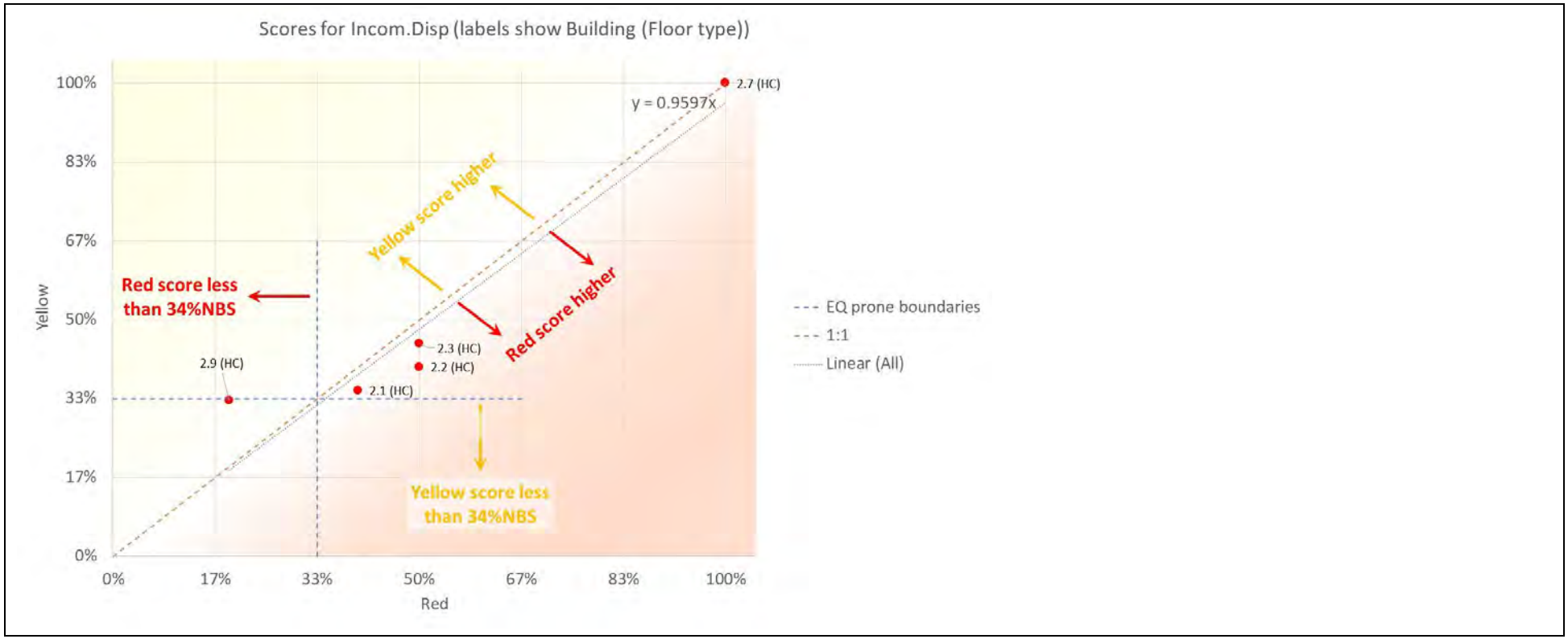

Figure 9: scores for failure due to incompatible displacement – scatter graph

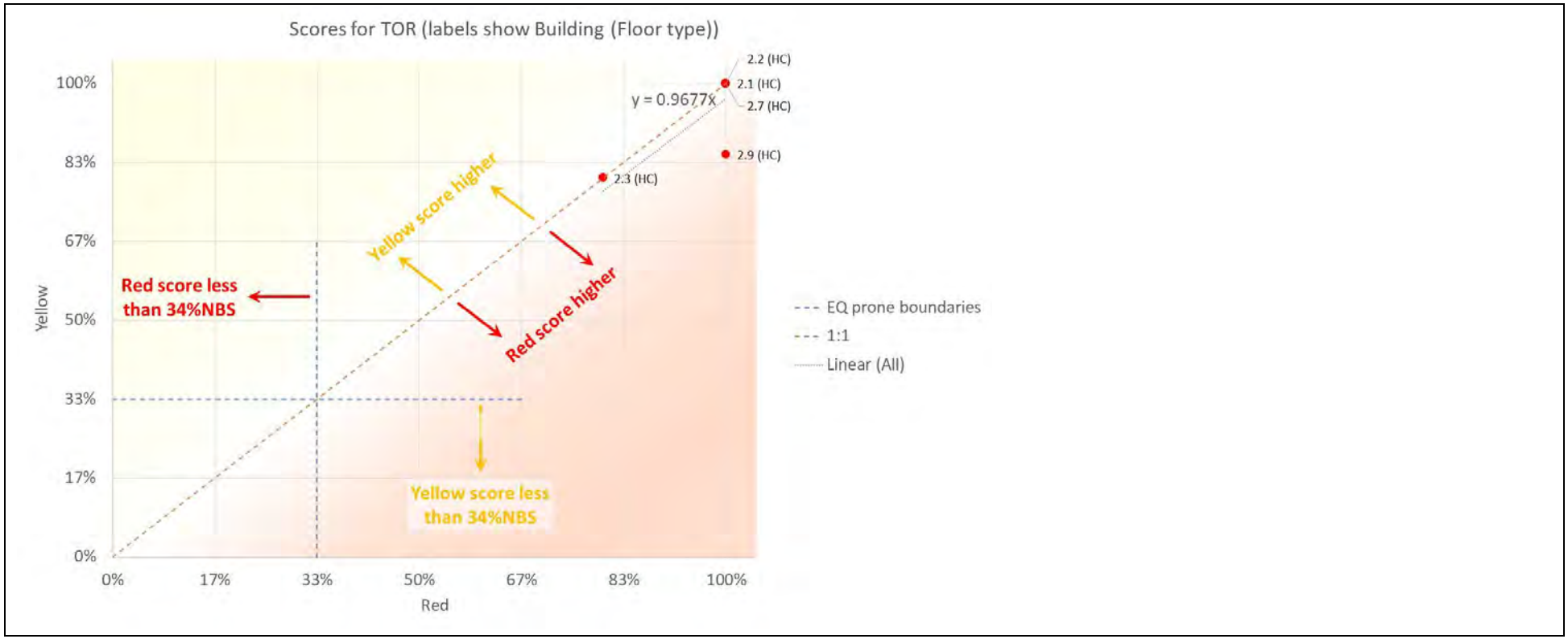

Figure 10: scores for failure due to torsion – scatter graph

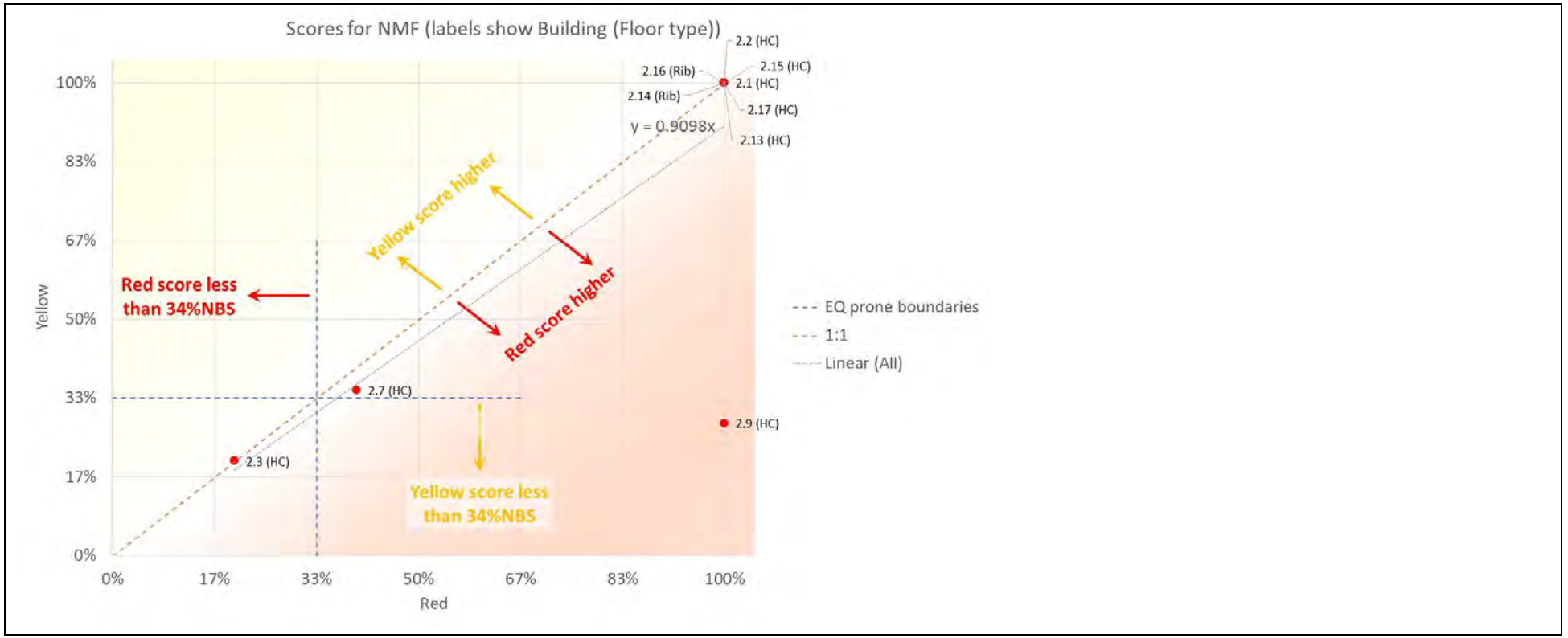

Figure 11: scores for negative moment failure – scatter graph