A discussion on the difference between New Zealand's philosophy for the seismic design of new buildings and seismic assessment of existing buildings, and the issues that arise

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ABSTRACT: In New Zealand, the philosophy adopted to assess the seismic performance of existing buildings differs from that used to design new buildings. This paper discusses the issues that arise as a result of these differences, including misleading terminology used to communicate assessed strengths to non-technical stakeholders, the treatment of structural resilience, and design issues which arise when strengthening existing buildings. As the way we assess existing buildings can impact decisions on occupancy and strengthening, it is important these issues are well understood. This paper proposes a possible solution by introducing new terminology, but highlights the need for the industry to develop and agree upon an assessment and strengthening approach which is consistent and transparent.

1 INTRODUCTION

New Zealand is a country prone to seismic activity. The New Zealand Building Code adopts best practice seismic standards to design new buildings to withstand expected levels of earthquake shaking with a very low probability of collapse. However, a large proportion of the country's building stock was constructed prior to the adoption of current standards, and is not expected to perform as well during a significant earthquake event. With the adoption of Earthquake-prone Building Policies by local authorities, and the 2010-2011 Canterbury earthquakes, the seismic assessment of existing buildings has become increasingly important, and in some cases, vital to building stakeholders. The philosophy adopted to assess existing buildings differs from the design philosophy used for new buildings, which is unknown to many of these stakeholders. This paper seeks to discuss the differences between the two philosophies and issues that arise.

2 SEISMIC DESIGN PHILOSOPHY FOR NEW BUILDINGS

2.1 AS/NZS1170 Loadings Standard

In New Zealand, new buildings are designed in accordance with compliance documents of the New Zealand Building Code (NZBC), which sits beneath the Building Act. The compliance document for clause B1 structure cites other loading and material design standards as verification methods or acceptable solutions. One such standard is the loadings standard, AS/NZS1170, which outlines the performance objectives of new structures, including the current seismic design philosophy.

NZS1170.5 states that the buildings are to *"achieve a level of performance during earthquakes so that:*

1. *Frequently occurring earthquake shaking can be resisted with a low probability of damage sufficient to prevent the building from being used as originally intended; and*
2. *The fatality risk is at an acceptable level."*

The first objective is termed the serviceability limit state (SLS), where building deflections are limited to avoid damage during an earthquake which has an annual exceedance probability of approximately 5%.

For the second objective, the fatality risk is closely associated with the risk of collapse. That is, loss of life only occurs if there is a partial or substantial collapse. Given the limitations of current engineering knowledge and inherent uncertainties involved in reliably predicting when a structure will collapse, the standard does not consider it practical to design new buildings to a collapse limit state. Instead it considers a lower limit state, where the response of a structure can be more reliably predicted. This is termed the ultimate limit state (ULS). So buildings are designed to this lower ULS level, and inherent redundancies within the design procedures are relied upon to provide confidence that acceptable collapse and fatality risks are achieved.

This margin between ULS and the collapse limit state has more recently been termed "resilience" in an Interim Design Guidance document released by the Structural Engineering Society of New Zealand (SESOC, 2012). The commentary of NZS1170.5 assumes a margin of at least 1.5 to 1.8 will be available for ductile structures. Presumably this factor accounts for:

- Probable material strengths being greater than the lower characteristic strengths assumed in design.
- Strength reduction factors used in design.
- Strain hardening of materials.
- The accumulation of local failures or strength degradation required to form a collapse mechanism.
- Further resilience provided by secondary elements ignored in the design and structural redundancy.

2.2 **SESOC Interim Design Guidance 2012**

The SESOC Interim Design Guidance document (2012) continues the design philosophy set by NZS1170.5 but makes the margin termed "resilience" more explicit. Observations from the 2010-2011 Canterbury earthquakes suggest levels of resilience implied by NZS1170.5 are not always achieved, in particular for non-ductile, nominally ductile and irregular structures. The Interim Design Guidance makes further design recommendations to attend to these issues, which include:

- Explicitly designing for a resilience factor of 1.5 for forces, and $1.5/S_p$ for displacements, where the resilience margin is not addressed by the materials or loadings standard.
- Including additional lateral force resisting elements in torsional structures to increase redundancy.
- Defaulting to S_p=1 where capacity design has not been used.
- Other detailing recommendations which improve structural performance and resilience.

This margin termed "resilience" forms one of the differences between the design of new buildings and assessment of existing buildings.

3 **SEISMIC ASSESSMENT PHILOSOPHY FOR EXISTING BUILDINGS**

3.1 **Earthquake-prone Building Legislation**

The purpose of assessing existing buildings typically stems from Building Act legislation. Section 122 of the Building Act defines the meaning of an earthquake-prone building as follows:

1) *A building is earthquake prone for the purposes of this Act if, having regard to its condition and to the ground on which it is built, and because of its construction, the building—*

    a) *will have its ultimate capacity exceeded in a moderate earthquake (as defined in the regulations); and*

    b) *would be likely to collapse causing—*

        i) *injury or death to persons in the building or to persons on any other property; or*

        ii) *damage to any other property.*

For the purpose of the clause above, the regulations define a moderate earthquake as *"an earthquake* *that would generate shaking at the site of the building that is of the same duration as, but that is one-third as strong as, the earthquake shaking (determined by normal measures of acceleration, velocity, and displacement) that would be used to design a new building at that site."*

Under Section 124 of the Building Act, territorial authorities (TAs) have the power to erect warning signs or fence off a building if it is deemed to be earthquake-prone. In addition, depending on the earthquake-prone building policy adopted by the TA, they may also require structural improvement (more commonly referred to as "seismic strengthening") to be carried out. Thus seismic assessments have become important for determining whether a building is earthquake-prone, and the extent of seismic strengthening required to satisfy local TA policy.

3.2 **NZSEE Redbook**

The NZBC does not cite a national standard or guidance document for assessing existing buildings. However, the most widely accepted and most referenced guidance document in earthquake-prone building policy is the New Zealand Society for Earthquake Engineering (NZSEE) "Assessment and Improvement of the Structural Performance of Buildings in Earthquakes" (first published in 2006). This document is commonly referred to as the "Redbook". Whilst other overseas documents such as FEMA356 (2000) are available, this paper focuses on the use of the Redbook.

The Redbook cites the Building Act and describes its interpretation of Section 122 as follows:

a) "ultimate capacity" means ultimate limit state capacity as defined in current design standards.

b) "likely to collapse causing injury or death to persons in the building" means that collapse and therefore loss of life could well occur as a result of the effects of earthquake shaking on the building.

c) "earthquake that would generate shaking at the site of the building one-third as strong as the earthquake-shaking that would be used to design a new building at that site" means that the inputs of load, displacement, velocity and/or acceleration used for a new building are scaled by one-third, but the duration would be unchanged. Note that this last point becomes very significant if a designer chooses to use time-history analysis to demonstrate acceptable performance.

Point (a) and (c) are self-explanatory and consistent with the use of the current loadings standard. The Redbook further clarifies point (b) to mean that collapse is not an expected performance, but rather an overall expectation. It recognises sub-clause 122 (1) (b) as being rather ambiguous and would prefer that it was deleted.

As the goal is to assess the performance of a building in an earthquake, the Redbook typically uses probable material strengths as opposed to lower characteristic material strengths which are used in new design. In addition, higher strength reduction factors are specified for certain materials – such as reinforced concrete and steel.

So to summarise the assessment philosophy above:

1. Seismic performance is assessed based on a building's ULS capacity. This is usually reported as a percentage of AS/NZS1170.5 loads or New Building Standard (%NBS).
2. To better reflect a building's actual response, probable material strengths and reduced strength reduction factors are used when calculating the ULS capacity.
3. Due to the underlying expectation that collapse "could well occur", no regard is given to resilience beyond ULS. This is consistent with the use of probable material strengths and higher strength reduction factors, which would otherwise contribute towards the resilience of a newly designed structure.

Point 1 is consistent with new building design, and results from the inherent difficulties with assessing a collapse limit state. The latter 2 points are where the assessment philosophy deviates from new design philosophy.

While point 3 provides a better reflection of the wording of the Building Act, because resilience is ignored, buildings assessed to have the same %NBS may still perform differently. This is because for some structures, the ULS capacity more closely reflects the collapse limit state than others. For example a ductile moment frame will typically exhibit more resilience against collapse beyond its ULS capacity than a brittle unreinforced masonry building. Also, those with secondary load paths or structural redundancy may provide better resilience.

3.3 EAG Detailed Engineering Evaluation Guidelines

Following the 22 February 2011 Christchurch earthquake, the Department of Building and Housing (DBH) Engineering Advisory Group (EAG) released a draft document "Guidance on Detailed Engineering Evaluation of Earthquake Affected Non-residential Buildings in Canterbury". Its scope differs from that of the Redbook in that its purpose is to address buildings which have been affected or damaged by an earthquake. It is limited to the Canterbury region, for which it was written. However, it does extend the existing concept of "critical structural weaknesses" (CSW).

The term critical structural weakness was originally used in the Redbook to refer to structural deficiencies which could significantly reduce seismic performance and increase the likelihood of collapse. These included plan and vertical irregularity, short columns, building pounding and site characteristics. These deficiencies can be easily identified from a visual observation of the building, and were included for use in the Initial Evaluation Procedure (IEP).

The EAG recognised the potential for CSWs related to localised detailing, herein referred to as "detail" CSWs, which are usually only picked up from a thorough review of drawings. Some examples include insufficient seating to precast floors or stair supports, non-ductile connectors between precast panels and portal frames, inadequate or brittle floor diaphragm ties, and brittle shear failure of critical gravity columns.

The EAG define both a displacement controlled and a force controlled CSW as follows:

- *"A displacement controlled CSW is one which may contribute nothing to the resistance of the building as a whole, but which is not able to tolerate deformation of the structure."*
- *"A force controlled CSW is one that develops increasing load as the force or deformation on the overall structure increases, and the failure of which may cause premature failure of the structure as a whole."*

In essence, a detail critical structural weakness is a structural element or detail that has little or no resilience beyond its ULS capacity or deformation; the failure of which results in local, partial or total collapse.

The EAG document provides a simplified method for assessing detail CSWs which incorporates demand-side or target capacity multipliers with the IEP or simplified assessments. These essentially factor down the assessed %NBS by the multiplier which is typically 2. The factors appear analogous to the resilience margin of 1.5-1.8 from NZS1170.5. The purpose of these factors is to restore the relativity of ULS to the collapse limit state and ensure resilience, which seems somewhat contradictory to the NZSEE Redbook and Building Act which appear to ignore resilience.

The guideline states that these multipliers were not intended to apply to a detailed assessment of CSWs. However, it does not clarify whether any resilience factor should be applied when undertaking a comprehensive analysis. In this case, an engineer may default to the Redbook philosophy of ignoring resilience. The author is unsure whether this was the intent of the EAG. Other engineers may interpret this differently, which could lead to different assessed strengths for the same building.

4 ISSUES ARISING FROM DIFFERENCES IN PHILOSOPHY

The main differences between the design philosophy for new buildings and the assessment of existing buildings are the use of characteristic versus probable material strengths, strength reduction factors, and treatment of resilience. Issues arise when the two philosophies intersect as this is where inconsistencies arise.

4.1 %NBS Terminology

One such issue is the percentage of New Building Standard terminology (%NBS), which is commonly used to report the seismic strength of an existing building. The New Building Standard terminology implies new design philosophy, but in fact the assumptions of the assessment philosophy are applied. So a building assessed to be 100% NBS will not necessarily perform as well as a new building, and a brand new building that is assessed should achieve greater than 100% NBS. The Redbook and EAG guidelines recognise this fact, and the reason for this is existing buildings are not expected to perform the same as a new building and a higher level of risk is considered reasonable. Although known to the engineer, this is not often communicated to the building owners, insurers, or prospective property buyers being advised. The question to be asked is whether the expectations of non-technical stakeholders are being well managed with the existing terminology.

4.2 Treatment of Resilience

A second issue is that the influence of resilience on seismic performance is not reflected in the reported %NBS. This could be resolved by accounting for resilience in seismic assessments. But the current wording of the Building Act suggests that this should be ignored when assessing a building against the earthquake-prone threshold.

The current assessment philosophy removes sources of resilience which can be easily quantified, such as those from strength reduction factors and conservative material properties. However, it is difficult to quantify sources resulting from structural redundancy and secondary elements, so these are currently ignored. This means that current %NBS figures will not necessarily provide a consistent comparison of building performance between structures of different forms and materials. Recent documents released by SESOC (2013) have recognised this, and the need for further guidance and industry consensus is apparent. This is particularly important if a seismic grading system for buildings is to be adopted, such as that proposed by QuakeStar (Parker et. al., 2012).

To address critical structural weaknesses, which are deficiencies with negligible resilience, perhaps a solution would be to assess and report these separately. The EAG guidelines appear to take this approach, but as mentioned previously, whether a resilience factor should be included in a comprehensive assessment could be clarified further. The author is of the opinion that any resilience factor should be neglected when assessing against the earthquake-prone threshold, as this better reflects the current wording of the Building Act. But CSWs should then be highlighted separately so they are recognised as a non-resilient element. This allows stakeholders to make informed decisions and retrofit CSWs appropriately.

In highlighting CSWs to non-technical stakeholders, engineers do need to exercise sensitivity and societal awareness. Particularly in Christchurch post-earthquake, the term “critical structural weakness” can be highly emotive and cause unnecessary “knee-jerk” reactions. The author considers that structural deficiencies should only be reported as a CSW when there is a possibility the weakness can be initiated prematurely. That is, a brittle element that is 1.5-1.8 times stronger than the weakest resilient element should not be reported as a CSW, as it is no longer critical. Note that subsequent strengthening of the weakest element may then cause the deficiency to become a CSW.

4.3 Design of Seismic Strengthening

The third issue arising from differences in new design and assessment philosophies is in seismic strengthening. Guidance from Section 13.3.10 of the Redbook can be summarised as follows:

- For the structural improvement of existing lateral force resisting components, typically adopt probable material strength and stiffness properties, and apply a strength reduction factor of 1.
- If the structural improvement results in a considerable increase in strength, in excess of (say) 50%, adopt the strength reduction factor from the applicable material standard or use lower bound material strengths.

- Any new element incorporated to add strength or stiffness to an existing building should be designed using lower characteristic material properties, and strength reduction factors as laid out in the relevant material standard.

The author disagrees with the mixing of probable material strengths and unity strength reduction factors for existing elements, with new design philosophy for new elements.

Firstly, there is a heightened risk of confusion and error for the design engineer, particularly when maintaining the correct hierarchy of strength. There is a risk of not providing sufficient reserve capacity to a strengthened existing element, above the overstrength of a new yielding element which is introduced. For example, say a new ductile eccentrically braced frame (EBF) is introduced to a structure. Existing diaphragms will then be strengthened using probable material strengths instead of lower characteristic values. Because of this, the margin of protection against overstrength actions coming from the EBF will be less than that allowed in new design.

Secondly, there is a potential for introducing inelastic torsion. For example, say there are two ductile shear walls resisting seismic loads in a particular direction – one is an existing wall and the other is newly introduced to provide additional strength and stiffness. Because the two walls are evaluated using different strength reduction factors and material properties, there is a potential for the new wall to be 30% stronger relative to the existing wall which is not considered in the response. Thus the existing wall is likely to yield first, creating a torsional response.

The treatment of resilience when strengthening existing buildings has not been given much attention in existing guidelines. But the EAG do partially address this by requiring CSWs to be identified as part of any assessment. It could be considered that it is then the professional engineer's responsibility to rectify the CSW, under the IPENZ Code of Ethics obligation to safeguard people and minimise the risk of endangering life.

5 POSSIBLE SOLUTIONS

It is important that issues raised herein are addressed appropriately, as the way engineers assess buildings affects critical decisions on occupancy, whether a building is required to be strengthened, financial aspects such as funding and insurance, and thus people's livelihoods. The purpose of this paper is not to give the final solution, but to initiate the discussion, for the industry to agree upon and then resolve.

The goal of any solution should be consistency, to avoid confusion; and to provide transparency for the benefit of the stakeholders being advised.

One option could be to better distinguish between new building design and existing building assessment philosophies through terminology as follows:

- The existing %NBS term more closely reflects new design philosophy and should be used to report strengths when evaluated using new design philosophy.
- A new term that better reflects the assessment philosophy can then be adopted for reporting the strength of existing buildings. The term should avoid implying compliance with material standards, but indicate a comparison against the current loadings standard, for example percentage of Earthquake Building Standard (%EBS).
- Earthquake-prone legislation will need to be updated to refer to one of these terms, most likely the latter.
- When assessing a building against the earthquake-prone threshold, the current assessment philosophy should be adopted. That is, using probable material properties, higher strength reduction factors, and ignoring resistance, as this better reflects the current wording of the Building Act.
- CSWs should still be identified separately as recommended by the EAG, to allow these to inform decisions on occupancy and strengthening. For a comprehensive assessment, resilience factors should be ignored to be consistent with the assessment philosophy.

- Weaknesses which exist but are not critical at the assessed seismic strength could also be identified and labelled as non-critical structural weaknesses (NCSWs).
- When strengthening a building, new design philosophy should be adopted for both existing and new structural elements. That is, use of lower characteristic strengths, strength reduction factors from current material standards, and consideration of resilience as described in the SESOC practice note. It does mean achieved percentages will be less than assessed values, but this is where the two terminologies will distinguish the difference. Earthquake-prone building policies will need to clarify which terminology they are referring to for target levels of strengthening, most likely the %NBS term.

The above attends to all the issues raised in terms of confusion of terminology, treatment of resilience, and design of strengthening. An alternate option could be to assess existing buildings using new building design philosophy. This does away with having two philosophies so there is no conflict, but Building Act legislation will need to be amended to reflect this. For example, if the current performance criteria are to be maintained, the 33% threshold for earthquake-prone buildings would need to be decreased to maintain currently accepted risks.

The above does not address how to include sources of resilience which are difficult to quantify, which is another problem altogether.

6 CONCLUSIONS

The philosophy adopted to assess the seismic performance of existing buildings differs from that used to design new buildings. Key differences include the use of probable material properties, higher strength reduction factors, and exclusion of resilience for the assessment of existing buildings; compared to lower characteristic material properties, normal strength reduction factors, resulting in inherent resilience in design standards for new buildings.

Issues arise as a result of these differences when the two philosophies intersect. The issues raised herein are summarised below:

- The percentage of new building standard (%NBS) terminology, currently used to report the assessed seismic strength of existing buildings, implies a comparison with a new building adopting new design philosophy. But in fact the assumptions of the assessment philosophy are adopted. As a result, the expected performance of the building is not being accurately communicated to non-technical stakeholders.
- The influence of resilience is not reflected in the reported %NBS. This better reflects the current wording of the Building Act. But it is still important to highlight critical structural weaknesses (CSWs) to allow building owners to rectify these and make informed decisions on occupancy.
- When strengthening, existing Redbook guidelines apply assessment philosophy assumptions for evaluating existing elements, but new design philosophy for new elements. This has the potential for increased confusion for the engineer, when maintaining the correct hierarchy of strength, due to the mixing of lower characteristic and probable material strengths. In addition, this method could inadvertently introduce inelastic torsion to a strengthened building.

These issues influence the way we assess and report on existing buildings, and the subsequent decisions on strengthening and occupancy which are made. It is therefore important these issues are addressed appropriately.

One possible solution proposed was to distinguish between existing building assessment and new building design philosophies through terminology. The %NBS term more closely reflects new design philosophy and should be used in conjunction with this philosophy. Another term, such as %EBS, could then be introduced for the assessment of existing buildings, which reflects the assessment philosophy. To reflect resilience in assessments, CSWs should be highlighted separately, but resilience factors ignored to remain consistent with the assessment philosophy. Then when strengthening a building, new design philosophy can be adopted and the level of strengthening achieved reported using the current %NBS terminology.

The purpose of this paper was not to give a definitive answer, but to initiate the discussion for the industry to agree upon a solution. The goal of any solution should be consistency, to avoid confusion; and transparency for the benefit of the stakeholders engineers are advising.

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