Seismic Design Issues and Strategies using the Proposed Loadings Code

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ABSTRACT

The proposed Loadings Standard has a number of major changes from the current 1992 version. New seismic hazard spectra and scaling factors can result in significant changes in design actions. The introduction of a "constant displacement" region in the spectra could have serious implications to design.

The authors have developed preliminary designs to the proposed code for forty structures for the Wellington and Auckland regions. This paper overviews the experience gained from this project. One of the most significant outcomes of the study is the applicability of using base shear as a means of scaling response spectrum analyses

1 INTRODUCTION

The New Zealand Loadings Standard, NZS4203:1992 [1], is currently under going a major revision and will be progressively superseded by a joint New Zealand / Australian Standard. Part 4 of this standard covers earthquake actions. A draft of this standard was circulated for comment in late 2000 [2]. This draft contained a number of major changes from the provisions of the current standard, NZS4203. Considerable comment was made on the draft which prompted investigation and action on a number of items, leading to a redrafting of the new standard for comment in 2002 [3].

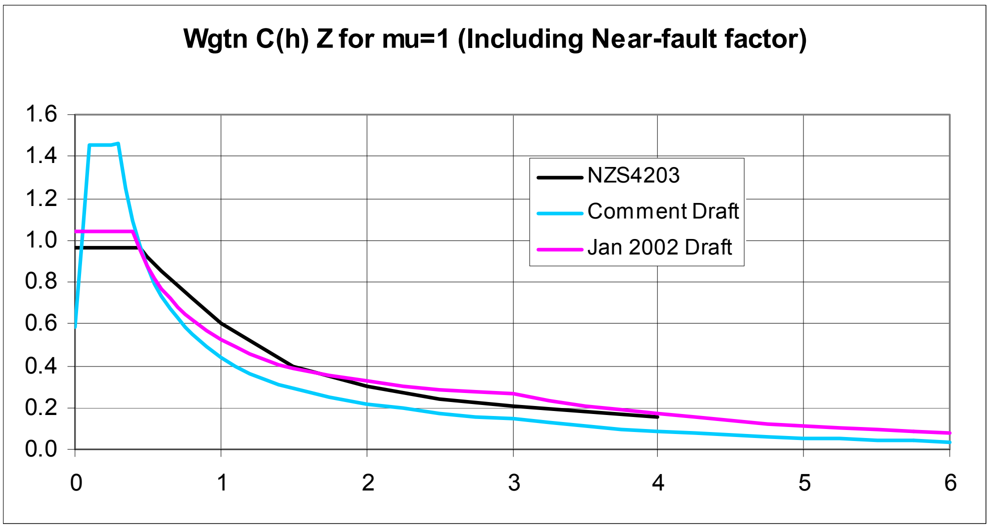
This paper reports on experience gained from a BRANZ Inelastic Response research project which involved extensive use of the Draft for Comment [2]. (An overview of this study may be found in the conference paper 3.3 presented by King, Davidson & McVerry). A discussion of the parts of the draft that have subsequently been revised following the findings of the study has been provided, along with areas where it is felt that some further refinement may be required. The emphasis of this paper is on the implications of the changes on the design process, rather than regulatory issues. However it is worth noting that an agreement with the Building Industry Authority that the structural design procedures could not be prescriptive allowed the code drafting committee more scope in the revised 2002 draft [3].

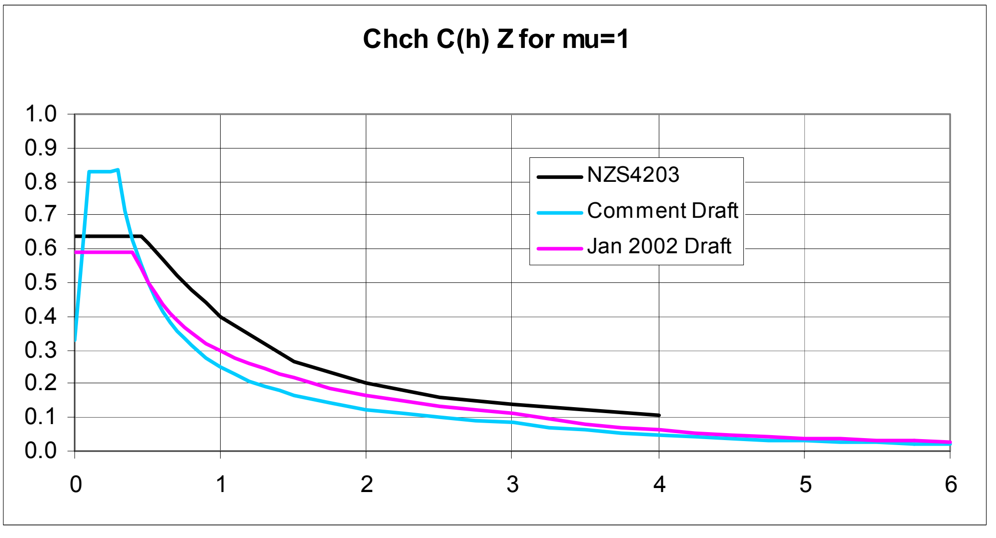
2 ISSUES

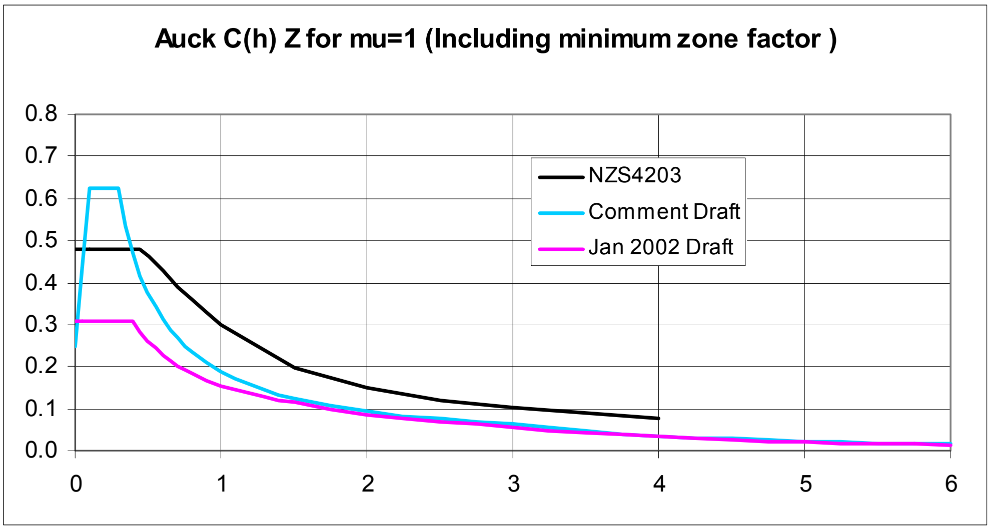
2.1 *Hazard Spectra*

The hazard spectra presented in the drafts are based on a probabilistic seismic hazard model recently developed by the Institute of Geological and Nuclear Sciences. The hazard spectra are presented in a form similar to those in NZS4203, with revised tables for the basic seismic hazard coefficients, revised (and more detailed) Zone factor tables/maps, and revised R factor values (now re-defined as the return period factor rather than a risk factor). A new feature is the inclusion of a near-fault factor "N(T,D)", applied for locations that are within 20 kms of major faults. This factor varies between 1 and 1.72. Additionally a minimum zone factor is defined which overrides the zone factor from the seismic hazard model for low hazard regions such as Auckland. This is intended to ensure the adequate behaviour of structures under the maximum credible earthquake event.

Comparable Hazard Spectra from NZS4203, the 2000 draft issued for comment [2], and the Jan 2002 revision of the draft [3] are presented for selected locations in Fig. 1.







The Hazard Spectra for the 2000 Draft for Comment clearly varied greatly in both shape and magnitude from those used in NZS4203.

There were three main changes in the spectra in the Draft for Comment from the 1992 Standard. Firstly, there is a overall reduction in the magnitude of the coefficients. Secondly the relative magnitude of the coefficients at the short period end of the spectra were increased markedly compared with the spectral values at the longer periods. The third modification was the introduction of a range of "constant displacement" for structures that have periods longer than three seconds. The consequence of these changes are discussed below.

2.1.1 *Magnitude*

With the use of Draft for Comment spectra, the design seismic load for mid and long period structures would be approximately 60-70% of that calculated using NZS4203:1992 (assuming an Sp factor of 0.67 is retained). With this, structures that would previously have been designed as ductile, could generally be designed as limited ductile, while those previously have been designed as limited ductile could generally be designed as nominally elastic.

Experience from the BRANZ Inelastic Response study showed that with the reduced level of seismic load, inter-storey deflections and/or minimum steel requirements rather than strength tended to govern design. As a result nominally elastic or limited ductile design would be applicable for most design situations.

For short period structures, the seismic load would be approximately 40% greater than under NZS4203:1992. This could have significant consequences for typical low rise shear wall/braced type construction.

2.1.2 *Relative magnitude of spectral ordinates*

When using the spectra in the Draft for Comment for some structures, the higher structural modes tended to have a major influence on design; to a degree where they dominated the base shear. An example of this is illustrated in the design of a shear wall structure which has a first mode period of 1.5 seconds (@ 70% mass participation) and a second mode of 0.3 seconds (@ 20% mass participation). For Site class C, the seismic coefficients for these two modes would be 0.42 and 2.08 respectively. The relative base shear from the two modes would then be 0.29 and 0.42. That is, the base shear would be approximately 1.45 times that for the first mode. With NZS4203:1992 the corresponding ratio would be 0.7. (Note that for this example, the base shear calculated using a response spectrum analysis would be approximately 1.2 time that for the equivalent state evaluation. With NZS4203:1992 the corresponding ratio would be 0.85.)

This domination of the higher modes on the response of these structures meant that the "equivalent static" method would not be able to be used as a suitable means of analysis.

2.1.3 *Constant Displacement*

For structural periods longer than 3 seconds where the hazard spectra are based on a "constant displacement" hypothesis, the seismic load is proportional to structure stiffness. Therefore, if a structure has a period in this range and complies with the inter-storey drift limits, its stiffness and strength can be arbitrarily reduced further and still satisfy the code. This appears to be an unsatisfactory situation.

2.1.4 *Rapid Changes in Short Period End*

In the short period range of the hazard spectra of the Draft for Comment, the seismic coefficient, C_h, varies rapidly with structural period. This could lead to difficulties, as there is uncertainty in estimating the effective stiffness of a structure for seismic analysis, and small changes in stiffness could result in base shear values changing by as much as 100%.

2.1.5 *Modifications to the Draft for Comment*

From figure 1. it can be seen that the spectra of the Jan 2002 Draft are generally similar in form to those used in NZS4203. Therefore the issues arising from the relative magnitude of the seismic hazard coefficients of the Comment Draft Spectra have generally been resolved.

There still remains however significant changes in the level of earthquake loads from NZS4203. In general there is a reduction in the level of seismic hazard, particularly in regions of low seismicity. The above figures show a reduction of approximately 40% for Auckland and 20% for Christchurch. The exception is for regions of high seismicity, where the Near Fault Factor can amplify the seismic hazard, or where the more detailed Zone maps identify local peaks. For Wellington City, the introduction of the Near Fault Factor raises the level of hazard back up to the level of NZS4203.

For regions of low seismicity, the application of a minimum zone factor means that the level of the latest draft spectra is essentially the same as for the original draft spectra issued for comment. However due to the revision of the low period range of the spectra, there is now a reduction in the level of earthquake loads for short period buildings also. As result it would be expected that the majority of buildings in these regions would be designed as nominally elastic.

The region of "constant displacement" in the hazard spectra still remains. Whereas the concept of "constant displacement" is accepted by the authors as an accepted observation from seismic hazard studies, the implications it introduces for design have yet to be researched. It is possible that a strict adherence to P delta design criteria may negate its effect, however at this time, it may be prudent to stay with the well known "constant velocity" hypothesis that is used in the current Loadings Standard.

2.2 ***Earthquake Records for Time-History Analysis***

The BRANZ Inelastic Response Study exposed difficulties in identifying earthquake accelerogram records that had spectra that matched the relatively large spectral ratios that were present between the short and long period peaks in the Draft for Comment spectra. Consequently, the selection and scaling of earthquake records became a major issue. The outcome of the discussions required to resolve this has been a well thought out procedure for scaling the records that has found its way into the Jan. 2000 Draft.

2.3 ***Response Spectrum Base Shear Scaling***

The Draft for Comment did not prescribe scaling for response spectrum analyses (relative to equivalent static). This was fortunate, as in this draft, the base shear from a response spectrum analysis was not necessarily a measure of first mode response (see above discussion). Therefore base shear was not an reasonable parameter on which to base a comparison between "response spectrum" and "equivalent static" analyses. The omission of base shear scaling for response spectrum analyses, while having some technical merit, did however mean that torsion effects for irregular buildings were not specifically covered by this draft.

Base shear scaling has been reinstated in the revised draft of Jan 2002. With the revised form of the hazard spectra, it appears that base shear scaling is again appropriate for regular structures. However with this, base shear scaling essentially remains unchanged from NZS4203, that is, possible short comings of the method have not been addressed.

Base shear scaling typically serves two functions. Firstly it is a "reality" check; essentially a check that the designer has performed the response spectrum analysis correctly. The second function is to account for uncertainties arising from torsion in irregular buildings. There are however questions as to the suitability of base shear scaling for performing these functions.

Using base shear scaling as an analysis check can penalise a competent engineer carrying out a rigorous analysis. This is particularly so for buildings with vertical irregularities (such as a podium) or multiple diaphragms, where base shear scaling is not appropriate. Additionally, there are problems in application for buildings where there is not a distinct dominant mode.

Base shear scaling does provide some allowance for torsional effects, but it may not necessarily accurately describe structural demand. Other approaches are available, such as the application of bi-directional earthquakes (e.g. SRSS full spectra in one direction and @ 70-80% in orthogonal direction, or SUM of full spectra in one direction and @ 30% in orthogonal direction) and/or dynamic factors for torsion. These approaches are used in other codes, for example the IBC [4]. An alternative provision would be to prohibit buildings with a torsion dominant first mode.

2.4 *Structural Performance Factor*

The Draft for Comment requested commentators to state their preference for one of two options for the form of the Structural Performance (Sp) factor. One involved assigning the 0.67 value specified in NZS4203 to all structures with a ductility factor equal to or greater than 1.25. For other structures, i.e. elastic (as opposed to nominally elastic) structures, a value of 1.0 was specified. The alternative option involved evaluating the Sp factor as a function of ductility and structural redundancy and regularity.

The revised draft of Jan 2002 has adopted the first option, i.e. assigning a Sp factor of 0.67 to all except for elastic buildings. This appears to be a response to feedback that the variable option was "too complicated", and a feeling by the code committee that in the absence of research to support an alternative, the status quo should remain. This solution however defies logic and flies in the face of approaches of other codes. For example, the IBC [4] through its use of the "R or Response Modification Factor" and the "Displacement Amplification Factor" effectively uses "Sp" factors as low as 0.5 for ductile structures and as high as 2 for structures of limited ductility. It would appear that further research should carried be out before resorting to the existing simple but perhaps non conservative approach used in the existing code. There is also the issue of consistency with other earthquake guidelines that are currently being developed. For example, the concession of specifying an Sp factor of 1.0 for buildings with a ductility factor less than 1.25 may have problems with application for Earthquake Risk Buildings, and may conflict with NZSEE guidelines for these structures.

2.5 *Inter-story Drift Limits*

Experience from the BRANZ Inelastic Response study highlighted inter-storey drift limits as a critical factor in seismic design. The Jan 2000 Draft still maintains the inter-storey drift limits specified in NZS4203. Given that inter-storey drifts often control design, should a more detailed set limits be provided ? For example, should different limits be specified for shear wall buildings or coupled shear Walls (assuming the current limits were essentially evaluated for moment frames). Again for example, the UBC uses different drift limits for masonry wall structures than for others.

CONCLUSIONS

The hazard spectra in the proposed Jan 2002 draft code are generally lower than those in the current Loadings Standard. As a consequence, if these spectra are accepted, more structures will be able to be designed as “nominally elastic” and “limited ductile”. In addition, the proposed hazard spectra have a region of “constant displacement”. Current seismic design procedures allow the stiffness and strength of structures that have dominant modes of vibration in this region to be altered arbitrarily. This appears to be unwise and should be investigated before becoming codified.

Base shear scaling in the modal response spectrum method of analysis procedure has been retained. From a technical point of view this is unnecessary. Its major use is to possibly ensure sufficient strength is provided to structures that have modes of vibration that are dominated by torsion. This form of scaling is patently incorrect for some structural forms, and it is believed that there are more appropriate methods of ensuring satisfactory structural seismic designs.

A uniform Structural Performance Factor of 0.67 has also been retained. This is inconsistent with implied factors in other codes and will lead to non conservative designs. This should be re addressed.

REFERENCES

1. Standards New Zealand (SNZ) 1992. General Structural Design and Design Loadings for Buildings (The Loadings Standard). NZS 4203. Standards New Zealand, Wellington
2. Standards New Zealand 2000. Draft Structural Design – General requirements and design actions Part 4 Earthquake Actions. DR00902. Standards New Zealand, Wellington
3. Standards New Zealand 2002. Draft Structural Design – General requirements and design actions Part 4 Earthquake Actions. Standards New Zealand, Wellington.
4. International Building Code 2000, International Code Council, 2000.