NZ Industry Nonlinear Response History Guidelines

S.J. Oliver
Holmes, Christchurch, New Zealand.

R. Ballagh
Dunning Thornton, Wellington, New Zealand.

A.T. Giannakogiorgos
Tetra Tach Coffey, Christchurch, New Zealand.

T. Holden
Aurecon, Wellington, New Zealand.

G.J. Morris
Holmes, Nelson, New Zealand.

T.J. Stuart
Compusoft Engineering, Auckland, New Zealand.

T.J. Sullivan
University of Canterbury, Christchurch, New Zealand.

ABSTRACT

Nonlinear response history analysis (NLRHA) provisions in NZS 1170.5 were developed 20 years ago. Significant developments in the selection and scaling of ground moon records have occurred since this standard was originally drafted which means the NLRHA provisions in NZS 1170.5 are out of date. To address this issue SESOC and NZSEE have jointly developed a new Nonlinear Response History Analysis guidelines document. The document includes guidance on the selection and scaling of ground moon records, and the number of ground motion records that should be used. Also included in the document is guidance on how ground moons should be applied to the analysis model, how to treat unacceptable response and how to calculate deformation-controlled and force-controlled engineering demand parameters, and inter-storey deflections. The document also includes guidance on alternative procedures which can be used to determine the seismic design actions on building parts and components when undertaking NLRHA.

1 INTRODUCTION

The NLRHA provisions in NZS 1170.5(SNZ, 2004) were developed 20 years ago. Significant developments in the selection and scaling of ground motions have occurred since the standard was originally drafted which means the nonlinear response history analysis (NLRHA) provisions in NZS 1170.5 are out of date (Morris et al., 2019). To address this issue SESOC and NZSEE have jointly developed a new NLRHA guidelines document.

The new guideline draws upon knowledge that has been gained since NZS 1170.5 was published (including PEER, 2017, LATBSDC, 2023 and ASCE, 2022) and sets out a contemporary approach for establishing earthquake design actions in structure when using NLRHA. It provides a design process for projects when NLRHA is to be used to validate seismic performance of new structures. Using updated seismic hazard information that is expected to be contained in TS 1170.5 (SNZ, 2024), as informed by the Draft TS 1170.5 issued for public comment February 2024 (SNZ, 2024a), it provides recommendations for selecting and scaling ground motion records. The guideline also provides recommendations for modelling structural elements and detailed criteria for evaluating seismic performance. It provides requirements and guidance for determining horizontal design actions for parts of structures and non-structural components.

At the time of writing of this paper the guideline were at a late stage of development with final balloting scheduled to occur in April 2024. As such the content of this paper may be subject to change.

2 DESIGN PROCESS

The new guideline provides an overview of a design process that can be adopted using NLRHA to validate the seismic performance of structures. The process aligns with recommended industry practice whereby designers deliberately proportion structures with enough regularity so that it is possible to identify a clear plastic mechanism. This will enable capacity design principles to be applied, so that should a structure's strength be exceeded, reliable plastic mechanisms can be developed.

New Zealand building standards primarily use ultimate limit state (ULS) design procedures to meet the life safety performance requirement in Building Code Clause B1 that buildings shall have a low probability of collapse throughout their lives. Margins inherent within ULS design procedures are assumed to provide sufficient confidence that acceptable collapse and fatality risks are achieved. This includes seismic detailing provisions, and the application of capacity design procedures for structures that expected to undergo nonlinear behaviour in response to earthquake shaking.

The new NLRHA guidelines present an alternate design methodology whereby building performance at the collapse avoidance limit state (CALS) is used to demonstrate that the Building Code life safety performance requirements have been achieved. The design methodology is based on similar procedures in ASCE 7-22 (ASCE, 2022) and related US performance-based design guidelines (PEER, 2017 and LATBSDC, 2023).

It is acknowledged that explicit evaluation of structural collapse is difficult task requiring (a) a structural model that is able to directly simulate the collapse behaviour, (b) use of numerous nonlinear response history analyses, and (c) proper treatment of many types of uncertainties. This process is excessively complex and lengthy for practical use in design. Therefore, the new guidelines maintain the simpler approach of implicitly demonstrating adequate performance through a prescribed set of analysis rules and acceptance criteria.

When compared with NLRHA using ULS intensity ground motions the design methodology recommended in this document has the following advantages:

- Enables explicit consideration of undesirable plastic mechanisms, including development of soft stories, that have the potential to develop in structural systems beyond ULS when Building Code B1/VM1 capacity design procedures have not been used, or are not appropriate for the structural form under consideration.
- Permits a direct assessment of seismic design actions of seismic resisting systems with a ‘hard stop’ i.e. anti-seismic devices such as dampers.
- Seismic design actions in rocking systems are better quantified.
- Enables non-ductile member actions that develop in structural systems beyond ULS to be better quantified when Building Code B1/VM1 capacity design procedures have not been used.

The document does not preclude design teams adopting other NLRHA design methodologies, including those where Building Code life safety performance requirements are primarily assessed at the ULS, provided the alternative methodologies ensure an appropriate margin beyond ULS is achieved, and adequate consideration is given to modelling uncertainty and ground motion record to record variability. For example application of Building Code B1/VM1 capacity design procedures might be considered an acceptable method to provide an appropriate margin beyond ULS.

When considering validation of building performance for SLS1 earthquake design actions the new guideline recommends a conventional Equivalent Static or Modal Response Spectrum analysis undertaken in accordance with TS 1170.5 on the basis the structural system is expected to respond in a near elastic manner.

2.1 NZBC Compliance Pathway

Use of NLRHA to establish earthquake design actions in structures is specifically excluded from NZ Building Code (NZBC) Verification Method B1/VM1 and will therefore be considered an Alternative Solution. It is anticipated the new guideline could serve as a reference document designers could refer to when developing an alternative compliance pathway.

It is recommended the alternative compliance pathway be clearly defined and documented in a Design Features Report (SESOC, 2021) early during a project life cycle and that the guideline be used as part of that alternative compliance pathway. The peer review process should be initiated as early in the design process as reasonable. Early discussion and agreement of the alternative compliance pathway, related fundamental design decisions, assumptions and approaches will help avoid changes later in the design process that will affect both project costs and schedules.

2.2 Establishing Performance Objectives

The document recommends project performance and design criteria be identified and clearly defined in the Design Features Report early in the design phase. Design performance objectives and design criteria to be considered include those prescribed in AS/NZS 1170.0 (SANZ, 2002) and any project specific performance objectives when these exist.

2.3 Design Methodology

In order to undertake a NLRHA it is necessary to develop a preliminary design of the primary structural systems to a sufficient level of detail to enable the necessary analysis inputs to be quantified. A process for developing a preliminary design is detailed in the new guidelines and is summarised below.

2.3.1 Concept Design

Select the structural systems and materials; their approximate configuration, proportions and strengths; and the intended primary mechanisms of inelastic behaviour. Apply capacity design principles to establish the target plastic mechanisms.

For all members of the structural system, define deformation-controlled (ductile) actions and force-controlled (non-ductile) actions. Categorise each forced-controlled action as being Critical, Ordinary, or Noncritical.

Deformation-controlled actions are defined as those that are expected to undergo inelastic behaviour in response to earthquake shaking and that are evaluated for their ability to sustain such behaviour. Force-controlled actions do not have dependable ductility and are not expected to exceed their yield strength when responding to earthquake actions and are evaluated on the basis of available strength.

Critical force-controlled actions are those whose failure is likely to lead to partial or total structural collapse. Noncritical force-controlled actions are those whose failure is unlikely to lead to structural collapse. Ordinary force-controlled actions are those whose failure might lead to local collapse but are unlikely to affect the overall stability of the structure.

The new guidelines provide details of typical force-controlled actions and recommended categories which can be used by design and peer review teams.

2.3.2 Preliminary Design

Design the structure to resist dead, live, wind, snow and other non-seismic loads to be as detailed in NZBC B1/VM1. Use a rational method to complete the preliminary seismic design of the primary lateral load resisting systems so the target plastic mechanisms identified during the concept design phase will likely be attained and the design will likely be capable of meeting the project performance objectives. Rational seismic design methods referenced in the new guideline that could be considered for the preliminary seismic design include:

- Equivalent Static or Modal Response Spectrum analysis undertaken in accordance with TS 1170.5, ASCE 7-22 or Eurocode 8 (CEN, 2004)
- Performance based seismic design guidelines such as PEER (2017) and LATSDC (2023)
- Direct Displacement Base Design (DDBD) procedures developed by Priestley et al. (2007)
- NZSEE Seismic Isolation Guidelines (NZSEE, 2019)

2.4 Seismic Design Loads

Seismic design spectra are to be determined from TS 1170.5 or from a site-specific hazard analysis for the structural performance limit states that are to be considered.

TS 1170.5 does not provide the required annual probability of exceedance which should be considered for CALS, nor what an appropriate margin beyond ULS might be. The new guidelines recommend the adoption of an additional scale factor, ψ_{CALS}, be used to scale relevant ULS seismic design spectra when assessing structural performance at CALS. It is proposed that an appropriate value for ψ is 1.5.

This value is consistent with the TS1170.5 requirement that potential step-change in soil behaviour should be explicitly considered for shaking intensity up to 150% times ultimate limit state. This value has some precedent within NZ design (e.g. as inferred by the Commentary to NZS1170.5:2004, NZS 3101 (SNZ, 2017), NZSEE Draft Seismic Isolation Guidelines (NZSEE, 2019) and the 2024 public draft of Section C1 of the NZ Seismic Assessment Guidelines (NZSEE, 2024)),

3 GROUND MOTION SELECTION AND SCALING

Selecting and scaling or modifying ground-motions are an important aspect of the overall NLRHA procedure. This section of the Guidelines is intended to improve the reliability of estimates of the seismic demands and structural response of buildings when earthquake-induced ground motions occur. This particular section of the Guidelines were generally developed based on the most contemporary and practical methods, as outlined in the following reference documents:

Commented [GM1]: I added this as I felt it's an important statement.

- ASCE 7-22 Section 16.2 – for prescriptive requirements.
- Baker et al. (2021) Chapter 10 – for holistic guidance.

The intention of the Ground Motion working group is for this conference paper section to describe any of the notable modifications and improvements beyond ASCE 7-22 Section 16.2 that were made during the development of the Guidelines. This includes emphasis where adjustments where required to be NZ specific and adaptions for the TS 1170.5 framework.

3.1 Target Response Spectrum

For each seismic hazard level (for an associated return period / exceedance rate) that is required by the overall design process, a corresponding target 5%-damped acceleration response spectrum is required. The target response spectral ordinates are the RotD50-component ground-motions (Boore, 2006), for consistency with the TS 1170.5 design response spectrum. This is one of the inherent differences between TS 1170.5 and ASCE 7-22 Section 16.2.1, where RotD100 "maximum direction spectrum" is the definition of the target response spectrum (and subsequent ground-motion scaling or matching is performed in the RotD100 domain).

The target response spectrum can be defined by the following two possible methods:

- Method A: using the TS 1170.5 code-based response spectrum. Although not explicit, Method A represents a parametric approximation of a site's uniform hazard spectrum (UHS), however there is a truncated short period "plateau" of spectral ordinates typical of code-based design response spectrum.
- Method B: a derived multi-period response spectrum resulting from site-specific ground-motion hazard analysis. A site-specific hazard analysis can be considered as a more reliable estimate of the seismic hazard at the site in comparison to the code-based spectrum (Method A). The site-specific response spectrum can be developed in terms of a site's UHS (i.e Method B.1) or conditional mean spectrum (Method B.2). Although Method B.2 requirements are generally consistent with those in ASCE 7-22 Section 16.2.1.2, the Guidelines contain additional commentary to provide engineers better insight to common beneficial cases and practical challenges of Method B.2.

Regardless of the whether Method A or B is used to define the target response spectrum, the working group has not made any changes from Equation 5.5(1) of NZS 1170.5:2004. This means the target response spectrum can be multiplied by a factor equal to $(1 + S_p)/2$, where S_p is taken as per Clause 4.4 (unless S_p is otherwise defined by the appropriate material standard).

3.2 Period Range of Interest for Ground-motion Selection and Modification

The Guidelines prescribe a period range for scaling of ground-motions [T_{lower},T_{upper}] to ensure ground-motions represent the specified hazard level at the vibration periods that contribute significantly to the building's lateral dynamic response. Although ASCE 7-22 section 16.2.3.1 was generally adopted, and the period range of interest remains generalized for conventional lateral load resisting systems, some modifications were required for greater consistency with the TS 1170.5 framework and common NZ design cases.

The upper bound period, T_{upper}, is shown in Table 3-1 through Default values for a specified seismic hazard level. Alternatively, the structural engineer may demonstrate alternative values (which may be less than the default values listed) based on evidence from analysis or established ductility relationships. However, T_{upper} must not be less than the lower limits stated in Table 3-1.

Table 3-1: Prescribed values for Upper Bound period.

Seismic Hazard Level	Default values of T_{upper}[1]	Lower limits on T_{upper}[1,2]
SLS2 (and lower)	$1.2T_{max}$	$1.0T_{max}$
ULS	$1.7T_{max}$	$1.3T_{max}$
CALS	$2.0T_{max}$	$1.5T_{max}$

1. Where T_{max} = the maximum fundamental period (including both translational and torsional modes).
2. Applicable limits when structural engineer demonstrates T_{upper} may be less than Default values.

The lower bound period, T_{lower} is equal to the minimum of $0.2T_{1,min}$ and $T_{90\%}$, however the Guidelines recognise that there may be situations when $0.2T_{1,min}$ is not a good indicator of a buildings lower bound period, and using $T_{90\%}$ as the sole indicator may be justified. This reflects modal characteristics that are commonly observed with relatively heavy low-rise systems (much of the NZ building stock).

3.3 Ground-Motion Selection

The guidelines do not impose any changes from ASCE 7-22 Section 16.2.2, only added clarifications and commentary based on the holistic guidance provided in Baker et al. (2021) Chapter 10. An ensemble of not less than 11 ground-motions shall be selected for each target spectrum, and ground-motions shall consist of pairs of orthogonal horizontal ground-motion components.

The overall ground-motion selection procedure requires four key steps: (1) establish target intensity measures (IMs) such as spectral accelerations, significant durations, etc; (2) query database(s) of ground-motions; (3) apply selection criteria; and (4) evaluation criteria for the selected ensemble of ground-motions. Further conceptual background to the procedure is given in Baker et al. (2021, Section 10.4).

An underlying expectation of the Guidelines is that ground-motion selection should be performed in a hazard-consistent manner, and this is reflected through both the disaggregation of the seismic hazard (or at least on the basis of some information around the tectonic regime/zones likely to affect the site) AND also the target IM distribution (SA). The disaggregation results identify the implicit causal parameters (rupture magnitude, source-to-site distance, etc.) that result in the ground-motion hazard but are not measures of the ground-motions themselves. The IM targets provide an explicit description of the characteristics of the ground-motions that result in the ground-motion hazard via the vector of IMs (Baker et al., 2021).

The distinction between implicit causal parameters and explicit IMs is a fundamental concept in ground-motion selection. Historically, the emphasis was placed on implicit causal parameters in ground-motion selection. However, it is now widely appreciated that a focus on explicit IMs is more important (noting that implicit causal parameters from disaggregation affect the development of the IM targets). To summarize this another way, ground-motion selection was once understood to be an “art”, whereas modern practice demonstrates is it is really a “craft”.

3.4 Ground-Motion Modification (Amplitude Scaling, or Mean Spectrum Matching)

For amplitude-scaling, the only difference from ASCE 7-22 Section 16.2.3.2 is that spectral ordinates are not defined as RotD100 maximum direction spectrum. As RotD50 spectral ordinates (Boore, 2006) define the TS 1170.5 target response spectrum (as noted in Section 3.1) then for internal consistency in the procedure the amplitude scaling must also be performed in the RotD50 domain.

It is important to note that the RotD50 target spectrum defined in TS 1170.5 is not consistent or directly compatible with the existing amplitude scaling procedures in NZS 1170.5 (SNZ, 2004). The NZS 1170.5 approach is based on scaling the "larger recorded direction" (ie SA_{Larger}) scaling of as-recorded H1 and H2 horizontal components. Consequently, unless modifications are made to the scaling procedures to account for this difference, the NZS 1170.5 ground motion scaling procedures should not be used with the TS 1170.5 RotD50 spectra.

For Spectral matching, ASCE 7-22 Section 16.2.3.3 was generally not incorporated due to some inadequacies, such as a lack of technical justifications and other complexities which can arise later in the building performance evaluation criteria. In lieu of the requirements ASCE 7-22 Section 16.2.3.3, the following decisions were made for the Guidelines:

- The hybrid Mean Spectral Matching method (Mazzoni et al. 2012) is permitted, without any increases in the target spectrum required. This hybrid method maintains similar advantages of amplitude scaling, in that dynamic characteristics of the individual record are preserved. As such, the Guidelines did not require this method to trigger any subsequent penalties relating to the performance evaluation and analysis post-processing.
- Tight Spectral matching is not permitted. This decision was made primarily due to the concerns associated with diminishing record-to-record variability using Tight Spectral matching in either the H1/H2 component domain (Abrahamson, 1992), or the RotD50 domain. It should be noted that, while tight spectral matching in the RotD100 domain can produce relatively higher degree of record-to-record variability at the component level (and maintain dispersion in engineering demand parameters from analysis), this variation of the tight matching is not expected to applicable for NZ due to the RotD50 target spectrum.

Several penalties and limitations on Spectral Matching were introduced the 2016 edition (ASCE 7-16). However, there are several inconsistencies and lack of consensus across other seismic standards and Guidelines (ASCE 41-23, LA Tall Buildings 2023, for example). These issues and different spectral matching techniques are under more detailed investigation for the 2026 NEHRP Provisions Update Committee (PUC), as investigated by Working Group-1: Ground Motions for the Nonlinear Analysis Issue Team #7. Depending on the outcomes of this work and the future 2028 publication of ASCE 7, the Spectral matching requirements outlined in the Guidelines may need to be revisited.

3.5 Applying Ground-Motions to the Structural Model:

Generally, the Guidelines are consistent with section 16.2.4 of ASCE 7-22 in terms of the general approach, however the specific criteria was subjected to the following two modifications:

1. ASCE 7-16 and 7-22 define near-fault sites as those which are 15 km or less from the surface projection of active fault capable of generating a moment magnitude greater than or equal to 7. Therefore, anything beyond that distance criteria is defined as far-field site, where randomness in ground motions is anticipated.

   For the NZ Guidelines, we reduced this distance criteria to 5km based on many studies demonstrating for sites within 5km there is strong polarization (i.e. directionality) of the ground-motion intensity measures in the fault normal and fault parallel directions, whereas for rupture distances greater than 5 km the ground-motion response are random (Watson-Lamprey and Boore, 2007; Huang et al., 2008; and Shahi and Baker (2012). The change to 5km as the relevant distance criteria is consistent with conclusions and proposed updates for the 2026 NEHRP Provisions Update Committee (PUC), presented in the Whitepaper prepared by Golesorkhi and Gouchon (2023) as part of their work for Issue Team #7 Nonlinear Analysis (Working Group-1, Ground Motions). It is therefore expected that this criteria set in the NZ Guidelines will be consistent with the future 2028 edition of ASCE 7.

All subduction source events which are representative of the Hikurangi subduction fault zone have been classified as "far-field" within the Guidelines. This includes the moderate to near source subduction condition that exists for the Wellington region. ASCE 7-22 does not discuss how to treat this case, however the far-field classification is the suggested interpretation for this NZ-fault specific case

4 ANALYSIS AND PERFORMANCE EVALUATION

4.1 Analysis

It is intended that the analysis attempts to characterise the expected performance of the structure when subjected to seismic demands as closely as possible. To achieve this the new NLRHA guidelines recommend a 3-dimensional mathematical model of the structure be developed with nonlinear force-deformation backbone curves which consider the expected (i.e. 50th percentile) element strength.

Beyond the inclusion of nonlinear force-deformation relationships within desired elements, the fundamental requirements for the analysis model are consistent with established practice when using conventional linear procedures from NZS 1170.5. The key exceptions to this includes: the requirements for accidental torsion, and the specification of inherent (equivalent viscous) damping, each of which are discussed further below.

4.1.1 Accidental Torsion

Traditionally NZS1170.5 and its predecessors have required consideration of accidental torsion arising from the seismic mass being displaced $\pm 0.1b$ where b is measured perpendicular to the direction under consideration. For NLRHA the new guidelines propose this can be relaxed to $\pm 0.05b$ to reflect the direct consideration of potential asymmetric failure.

4.1.2 Inherent damping

Modern international references identify that the traditionally adopted equivalent viscous damping ratio of 5% critical can be excessive in many scenarios. It is therefore proposed that the specification of equivalent viscous damping follow the provisions of ASCE 41-23 (ASCE, 2023) whereby the target elastic equivalent viscous damping ratio, ξ, be calculated from the below expression:

$$\xi = \frac{0.2}{\sqrt{h}} \leq 0.05$$

where h is the height of the structure in meters and should not include any minor top stories that are of markedly lower stiffness and mass than the stories below (e.g. plantrooms, and lightweight penthouse structures), and ξ is subject to the below restrictions:

- When evaluating structural steel buildings without exterior cladding, ξ shall not exceed 0.01.
- For all other situations, ξ need not be taken less than 0.025 when evaluating ULS and CALS.
- For structures using seismic isolation technology or enhanced energy dissipation technology, the equivalent viscous damping ratio selected should conform with the relevant guidelines.

- Higher target elastic equivalent viscous damping ratios are permitted if substantiated through analysis or test data.

It is acknowledged some uncertainty exists with regard to the topic of equivalent viscous damping and future research on this topic would be beneficial.

4.2 Performance Evaluation

The NLRHA procedure is a performance-based evaluation tool and as such it is necessary to prescribe acceptance criteria which the resulting force and deformation demands should be measured against. Structural performance is required to be assessed with respect to both global and element level metrics. The evaluation of these items in the proposed procedures largely follow those included in ASCE 7-22 and are discussed further below.

Except where modified below due to observed unacceptable response, it is proposed that the design action effect be taken equal to the mean value from the suite of analyses.

4.2.1 Global acceptance criteria

4.2.1.1 Unacceptable response

To ensure that the analysis results for a given ground motion are suitable for consideration as part of the ground motion suite, it is necessary to verify whether any response has occurred which would invalidate the analysis. The new guideline recommends the following checks are undertaken to test for unacceptable response.

Unacceptable response to ground motion shall consist of any of the following:

1. Analytical solution fails to converge,
2. Predicted demands on deformation-controlled elements exceed the valid range of modelling,
3. Predicted demands on force-controlled elements exceed their expected strength (i.e. considering expected material properties and a strength reduction factor equal to 1.0),
4. Predicted deformation demands on elements not explicitly modelled exceed the deformation limits at which the members are no longer able to carry their gravity loads,
5. Peak transient story drift ratio exceeds 150% of the permissible value of mean transient story drift.

It is proposed that not more than one ground motion from the suite shall be permitted to produce unacceptable response as defined above. Where a ground motion produces unacceptable response, it is proposed that the design action effect be taken equal to 120% of the of the median value of the entire suite of analyses, but not less than the mean value obtained from the suite of analyses producing acceptable response.

4.2.1.2 Deformation limits

Global deformation limits include items such as structure deformation with respect to site boundaries and neighbouring buildings, and story drifts. NZS1170.5 includes limits for these items with respect to ULS demands. Because the proposed provisions determine the demands applicable for CALS, the resulting deformation demands need to be suitably adjusted by a factor, ψ_{CALS}, to allow direct comparison with the prescribed ULS limits. The value of ψ_{CALS} is the subject of further work to ensure it is compatible with the design spectra included within TS 1170.5.

4.2.2 Element level acceptance criteria

To demonstrate acceptable performance for local elements, the actions for each structural component are required to be designated as being either deformation controlled, or force controlled.

4.2.2.1 Deformation controlled actions

Nonlinear behaviour is to be limited mechanisms that can reliably respond in a ductile manner to deformation demands greater than that corresponding to yield (e.g. ductile beam hinges detailed in accordance with NZS 3101), The nonlinear force-deformation relationship for these items is to be justified by physical testing which will also determine the valid range of modelling. It is expected that all NZ material standard will specify suitable deformation limits for SLS and CALS. Accepting that there may be a lag before these items can be included in relevant NZ standards, and accepting that there may not be a suitable local standard, it will be expected that contemporaneous international literature (e.g. ASCE 41, ACI 318, ANSI/AISC 341) may be consulted for suitable values.

4.2.2.2 Force controlled actions

Force controlled actions are expected to possess very little reliable deformation capacity beyond yield (e.g. a concrete beam in shear) and thus are required to possess additional strength over and above that determined from the analyses. In some cases, it will be possible to apply the basic principles of capacity design to ensure that these elements will not unduly limit the performance of the structure (e.g. capacity design of individual beams to ensure flexural hinging). When this is not possible due to limitations in the procedures for determining suitable demands, or its direct application would be considered excessive, the below provisions are proposed in the new NLRHA guidelines.

Force controlled actions are classified as either “Critical”, or “Ordinary” depending on the consequences of their failure and satisfy the below expression:

$$G + \psi_E Q + \gamma\left(E_d - E_{d,ns}\right) \leq \phi R_n \quad (1)$$

where G, ψ_E, and Q are as defined in NZS 1170.0, $E_{d,ns}$ is the non-seismic portion of the loading, γ is a factor to account for record-to-record variability and is proposed to be taken equal to 1.3, E_d is the design action effect, R_n is the nominal (characteristic) strength of the component determined in accordance with the relevant material standard, and ϕ is the strength reduction factor.

Special attention must be paid to the $\left(E_d - E_{d,ns}\right)$ term in Equation 1. Since superposition rules do not apply to nonlinear analysis, in cases where gravity force distribution is highly unsymmetrical and/or in cases where strong directionality exists in building response where forces in one direction along an axis are significantly larger than the same forces in the other direction of the same axis, orbital plots or contours should be plotted to make sure that straight use of the $\left(E_d - E_{d,ns}\right)$ term does not produce unconservative results (PEER, 2017). It is acknowledged the recommended procedure for determining force controlled actions could be improved and research on this topic is recommended.

5 PARTS AND COMPONENTS

The document provides requirements and guidance for determining horizontal design actions for parts of structures and non-structural components which can be used when nonlinear response history analysis is used as the structural analysis method. In addition to the conventional procedures detailed in Section 8 of NZS 1170.5, this chapter provides two additional methods for computing design actions for parts and components:

1. Use output from nonlinear response history analysis to determine the NZS 1170.5 design response coefficient for parts and components, $C_p(T_p)$.
2. Development of project specific floor response spectra.

5.1 Using NLRHA to Determine Parts Design Response Coefficient

Output from the NLRHA can be used to determine the NZS 1170.5 design response coefficient for parts and components, $C_p(T_p)$. The recommendations in the guideline have been developed from ASCE 7-22 (2022). The horizontal design coefficient, $C_p(T_p)$, can be computed directly from the analysis using Equation 2:

$$C_p(T_p) = a_i \left[\frac{C_i(T_p)}{C_{ph}}\right] \quad (2)$$

where a_i = mean of the maximum values of acceleration at the centre of mass of the support level, obtained from each analysis for the limit state being considered; $C_i(T_p)$ = the part or component spectral shape coefficient, determined from NZS 1170.5; and C_{ph} = the part or component horizontal response factor.

The mean response value was judged to be adequate for computing $C_i(T_p)$ and is consistent with what is used in comparable international building standards when similar parts of components provisions were developed (ASCE, 2022). When assessing, a_i, the maximum values of acceleration at the support level, accidental eccentricity effects may be neglected. This is consistent with the recommendations from the ATC-120 project (ATC,2017), where the influence of torsional response of the structure on floor accelerations experienced by the component was investigated. It was concluded that due to the complexity of the problem and the limited information available, additional study is needed before it is included in the design equations.

5.2 Development of Project Specific Floor Spectra

The guideline provides a procedure to develop project-specific floor response spectra directly from floor acceleration time-history output from NLRHA models. A critical damping ratio of 5% is recommended when computing floor response spectra, unless it can be demonstrated that an alternative damping value is appropriate. For the reasons given above accidental eccentricity effects may be neglected, however analysis models should represent the flexibility of floor diaphragms when this is significant to the response of the structure or part being considered.

6 CONCLUSIONS

This paper provides an overview of the new NLRHA guidelines that have been jointly developed by SESOC and NZSEE. The new guideline draws upon knowledge that has been gained since NZS 1170.5 was developed 20 years ago and sets out a contemporary approach for establishing earthquake design actions in structure when using NLRHA. It provides a design process for projects when NLRHA is to be used to validate seismic performance of new structures. Using updated seismic hazard that it expected to be contained in TS 1170.5 (SNZ, 2023) it provides recommendations for selecting and scaling ground motion records. The guideline also provides recommendations for modelling structural elements and detailed criteria for evaluating seismic performance. Guidance for determining horizontal design actions on parts and non-structural components is also provided.

7 ACKNOWLEDGEMENTS

The authors of this paper would like to acknowledge the significant contributions from the members of the wider SESOC/NZSEE NLRHA guidelines working group. The guidelines were developed on a voluntary basis by the working group. The working group consisted of the following people:

Rowan Ballagh - Dunning Thornton

Brendon Bradley – University of Canterbury

Nick Kerrigan – WSP

Gareth Morris - Holmes

Reagan Chandramohan – University of Canterbury
Andreas Giannakogiorgos - Tetra Tach Coffey
Tony Holden - Aurecon
Rob Jury - Beca
Stuart Oliver – Holmes
Tony Stuart - Compusoft Engineering
Timothy Sullivan - University of Canterbury

8 REFERENCES

Abrahamson, N. A., 1992. "*Non-stationary spectral matching",* Seismol. Res. Lett. 63, 30

ASCE (2022), '*ASCE/SEI 7-22 Minimum Design Loads and Associated Criteria for Buildings and Other Structures',* American Society of Civil Engineers, Reston, VA

ASCE (2023), '*ASCE/SEI 41-23 Seismic Evaluation and Retrofit of Existing Buildings',* American Society of Civil Engineers, Reston, VA

ATC (2017), '*NIST GCR 17-917-44 Seismic Analysis, Design and Installation of Nonstructural Components and Systems – Background and Recommendations for Future Work',* Applied Technology Council, Redwood City, CA 94065

Boore, D. M., J. Watson-Lamprey, and N. A. Abrahamson (2006), "*Orientation-independent measures of ground motion*", Bull. Seismol. Soc. Am.96, 1502–1511.

CEN (2004), "*Eurocode 8 : Design Provisions for Earthquake Resistance of Structures*", European Committee for Standardisation, Brussels, Belgium

Golesorkhi and Gouchon (2023). "*Near-Fault Ground Motions*", White Paper prepared for the 2026 NEHRP Provisions Update Committee (PUC) Issue Team #7 Nonlinear Analysis Working Group-1, Ground Motions.

Huang, Y-N., Whittaker, A. S., and Luco, N. (2008). "*Maximum Spectral Demands in the Near-Fault Region*." Earthquake Spectra, Volume 24, No. 1, pp. 319-341.

LATBSDC (2023), "*An Alternative Procedure for Seismic Analysis and Design of Tall Buildings*", Los Angeles Tall Buildings Structural Design Council, Los Angeles, CA.

Mazzoni, S., Hachem, M., and Sinclair, M., (2012). "*An improved approach for ground-motion suite selection and modification for use in response history analysis*", Proceedings of Fifteenth World Conference on Earthquake Engineering, Lisbon, 2012.

Morris, G.J., Thompson, A.J., Dismuke, J.A. and Bradley, B.A. (2019). *"Ground Motion Input for Nonlinear Response History Analysis: Practical Limitations of NZS 1170.5 and Comparison to US Standards*", Bulletin of the New Zealand Society for Earthqauke Engineering, Vol 52, No. 3, 2019

NZSEE (2019), "*Draft Guidelines for the Design of Seismic Isolation Systems for Buildings*", New Zealand Society for Earthquake Engineering, Wellington, NZ

NZSEE (2022), "*Earthquake Design for Uncertainty: Advisory*", Jointly prepared by New Zealand Society for Earthquake Engineering, Structural Engineering Society New Zealand and New Zealand Geotechnical Society, Wellington, NZ

PEER (2017), "*Guidelines for Performance-Based Seismic Design of Tall Buildings*", Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA

Priestley, M.J.N., Calvi, G.M. and Kolwasky, M.J. (2007). "*Displacement-based seismic design of structures*", IUSSS Press. Pavia, Italy.

SESOC (2021), "*SESOC Commercial Design Features Report Template*", Structural Engineering Society New Zealand Wellington, NZ

SESOC (2022), "*Interim Design Guidance - Design of Conventional Structural Systems"*, Structural Engineering Society New Zealand Wellington, NZ

Shahi, S. K and Baker, J. W. (2012). "*Directionality of Ground Motions in the NGA-West2 Database*." Presentation downloaded from PEER Website. https://apps.peer.berkeley.edu/ngawest2/wp-content/uploads/2012/07/Shahi_Baker_NGA2_directionality-Nov-15-2012-copy.pdf

SNZ (2004). "*NZS1170.5: Structural Design Actions. Part 5: Earthquake Actions - New Zealand*". Standards New Zealand, Wellington, 76pp. https://www.standards.govt.nz/sponsored-standards/building-standards/NZS1170-5

SNZ (2024), "*TS 1170.5 Structural Design Actions Part 5: Earthquake Actions – New Zealand*", Standards New Zealand, Wellington, NZ

SNZ (2024a), "*DZ TS 1170.5 Public Consultation Draft*", Standards New Zealand, Wellington, NZ

SNZ (2017), "*NZS 3101 inc. A1 – A3 Concrete Structures Standard*", Standards New Zealand, Wellington, NZ

Watson-Lamprey, J. A. and Boore, D. M. (2007). "*Beyond Sa_{GMRotI}: Conversion to Sa_{Arb}, Sa_{SN}, and Sa_{MaxRot}*." Proceedings of Bulletin of Seismological Society of America, Vol. 96, No. 5, pp. 1511-1524.