C3.5 Principles and requirements additional to 3.3 for the analysis and design of structures subjected to seismic loading

Whereas in the preceding clauses the general requirements of ACI 318-77 for the design of reinforced concrete structures have been adopted with relatively minor modifications, the additional seismic requirements presented in this clause and the corresponding clauses of subsequent sections are entirely new and markedly different from Appendix A of the ACI Code. These provisions intend to implement the requirements of NZS 4203. They are based on currently accepted design practice, on recent research findings that were available prior to 1980 and to an extent on expertise developed in New Zealand. The recommendations of other standards [3.8], information specifically related to earthquake resistant design in reinforced concrete structures [3.9, 3.10], studies of damage to buildings resulting from catastrophic earthquakes, namely Skopje (1963) [3.11], Anchorage (1964) [3.12], Caracas (1967)[3.13, 3.14], San Fernando (1971) [3.15], and the deliberations of the New Zealand National Society for Earthquake Engineering with respect to the seismic design of reinforced concrete frames [3.16, 3.17] and shear wall structures [3.18], have been considered in particular.

The earthquake loading, principles of seismic design, recommended analysis procedures and several other aspects of earthquake structural engineering are documented in detail in NZS 4203. Therefore the commentary of NZS 4203 should also be consulted when applying this Code. In particular, attention should be given to recommendations, specifically related to reinforced concrete buildings, such as:

(a) The aiming for structural symmetry and geometric uniformity in the planning of buildings

(b) The general requirements for ductility for the structure as a whole and for its components

(c) The development of desirable energy dissipating mechanisms in ductile moment resisting frames and shear wall structures

(d) The preservation of gravity load carrying capacity of members which are not required to be part of the horizontal force resisting system

(e) Capacity design in buildings where energy is expected to be dissipated by inelastic deformations involving flexural yielding

(f) The consideration of actions due to earthquake induced displacements concurrently occurring in the two principal directions of the framing.

No specific recommendations are made for the case where flexural members are slabs (plates) since the seismic behaviour of such members is still being studied. In general slabs are not likely to be useful as primary earthquake resistant elements in framed buildings because of the flexibility of the slab-column systems.

Numerous recommendations are made in the Code with respect to the detailing of primary earthquake resistant structural components because it is considered that this aspect of the design processes is one of the most important.

To clarify the meaning of various loads referred to in New Zealand Standards, in their commentaries and in the references quoted in these documents, the following definitions should be considered to apply to the seismic provisions of this Code of practice.

(a) Code loads are those specified by NZS 4203 for buildings or the MWD Highway Bridge Design Brief[3.22] for highway bridges

(b) Factored loads are those derived from the combinations of loads which in accordance with NZS 4203 are relevant to the strength method of design, which must be used. (See 3.5.1.2.)

(c) Capacity loads are those that, as a result of extreme seismic displacements, would be required to develop the flexural over-strength of members, sub-assemblages or the entire structure as appropriate, in accordance with the principles of capacity design.

(d) Design loads are those which determine the proportioning and detailing of structural components. Depending upon the requirements for the specific component the design load may be the capacity load or the factored load.

C3.5.1 *Methods of design*

C3.5.1.1 For seismic resistance this code considers three groups of reinforced concrete structural systems and requires specific design methods to be used for each.

Fully ductile structures for buildings, such as space frames or structural walls or the combination of these, and bridges, are those in which the lowest of seismic force resistance is provided.

Ductility in this context means ability to deform beyond the yield point into the plastic range of behaviour without excessive loss of strength. The magnitude of the ensuing damage will depend on the extent of yielding that is imposed during an earthquake.

In flexural ductile yielding the deflections into the inelastic range are provided by rotations at selected plastic hinges which normally form at points of maximum bending moments. The relevance of ductility is discussed in the Commentary of NZS 4203. NZS 4203 also provides the definitions associated with ductility, such as ductility factors. A definition of ductility factor for members or structures with no clearly defined yield point is given in Reference [3.22].

To ensure that energy will be dissipated at the selected localities only, capacity design procedures must be used. At specified potential plastic hinge localities, the ductility demand or availability, need not be computed if the detailed provisions of the subsequent sections are met, except for bridge structures in accordance with 3.5.9.

In certain structures, particularly those of irregular small buildings, it is often impractical to provide a structural system that could provide maximum ductility. For such situations structures of limited ductility are considered also to provide satisfactory protection against damage and, in case of an extreme seismic disturbance, collapse. Because such structures must still possess a considerable ability to be ductile, a capacity design procedure is the appropriate design method. However, as earthquake induced design actions are often not critical, a more conservative but less onerous design procedure is considered to lead to an equally satisfactory performance. For this reason the use of a modified strength design procedure, according to Section 14, is also permitted.

When a structure is designed to resist the much larger seismic forces, induced during its elastic response, corresponding with the appropriate structural type factors S, and materials factors M, required by NZS 4203, the strength method of design should be used. As no inelastic deformation is expected to occur in any part of the structure, the additional seismic detailing requirements, set out in subsequent sections, need not be satisfied.

C3.5.1.2 All provisions for minimum seismic requirements are based on the strength method of design and hence for these structures the Alternative Design Method, given in Appendix B, must not be used.

C3.5.1.3 In order to minimize the likelihood that brittle or other undesirable failures would occur while plastic hinges form during large earthquake induced inelastic displacements of the structure, the flexural overstrength of the potential plastic hinges needs to be evaluated. In accordance with the requirements of capacity design this is particularly important when the earthquake induced shear forces in beams (Section 7) or beam-column joints (Section 9) or moments and axial forces in columns of ductile frames (Appendix C3A to this commentary section) are evaluated. The actions derived in the capacity procedure will generally be greater than the corresponding actions calculated from the application of the design seismic loads of NZS 4203 or other appropriate code. The overstrength of reinforcing bars, however, need not be specifically considered when anchorage or splice requirements are established because these requirements are based on the full strength of any bar.

When using Grade 275 Flexural reinforcement the following relationships may be used to determine flexural strengths of beams:

Dependable strength	≃	0.90	Ideal strength
Probable strength	≃	1.15	Ideal strength
Overstrength	≃	1.25	Ideal strength
Overstrength	≃	1.39	Dependable strength
Probable strength	≃	0.90	Overstrength

where the ideal flexural strength is to be in accordance with Section 6, with the value of ϕ taken as unity. The use of probable strength properties is appropriate when, for special structures, the inelastic dynamic response to given earthquake excitations is being studied.

When using Grade 380 flexural reinforcement, greater enhancement of strength due to strain hardening is to be expected, and accordingly the above strength relationships should be modified as follows:

Overstrength	≃	1.40 Ideal strength

For prestressing steel the following assumptions may be used:

Probable strength	≃	1.05 Ideal strength
Overstrength	≃	1.10 Ideal strength

unless the properties are determined from the stress-strain relationship obtained for the prestressing steel to be used.

C3.5.1.6 Inertia forces due to distributed masses at floor levels need to be transferred to the lateral force resisting ductile frames or shear walls. It is necessary therefore that the connecting elements (diaphragms), which are normally non-yielding components, possess adequate strength and continuity for stress transfer. Hence the arrangement of openings, if any, must be rational and the connections must be adequate.

C3.5.1.7 The state of the art in seismic design is changing rapidly. More detailed studies of seismological data and structural response, made feasible by computers, are likely to lead to more realistic and necessarily more sophisticated methods of assessing seismic requirements. This Clause intends to accommodate such future useful developments. However, alternative systems or design methods should be supported by thorough analytical or experimental studies or both, to assure a proper combination of earthquake input and strength and ductility requirements. The acceptance or rejection of such alternative methods lies with the Engineer.

C3.5.2 *Seismic loading*

C3.5.2.1 For various levels of available ductility, NZS 4203 specifies appropriate values for the structural type factor S. Some of the equations in subsequent sections, which express dependence on ductility, incorporate this factor. The value used must be the same as that used in the derivation of the base seismic shear for the structure. Amendments to NZS 4203 may be published after the release of this Code. Therefore designers must ascertain that the appropriate structural type factors used are those given in NZS 4203. For the convenience of the designer the structural type factor S, relevant to each type of reinforced concrete structure covered in this Code, is listed within the appropriate clause of the commentary for this Section only. The structural material factor M to be used in conjunction with the S factors listed in this commentary are given in C3.5.4.1.

C3.5.2.3 Traditionally earthquake forces have been considered to act independently in the two principal directions of the framing system. However, NZS 4203 requires the effects of large inelastic displacements in any direction to be considered. Therefore:

(a) When significant inelastic displacements occur simultaneously in both principal directions of the framing system, it is considered necessary to make provisions for the simultaneous hinging of beams or yielding of all diagonal braces framing into a column or wall during a severe earthquake attack. The purpose of this procedure is to safeguard components, that are required to sustain the primary energy dissipating mechanisms, against premature failure. Columns subject to biaxial bending through two or more plastic hinges of beams at adjacent faces of the column, and to skew shear effects, are typical examples.