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The Codification of Serviceability Criteria in New Zealand

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THE CODIFICATION OF SERVICEABILITY CRITERIA IN NZ

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Summary: Over recent years New Zealand has been reviewing its Standard, NZS 4203, which specifies the design loadings on buildings. In accordance with international trends this has now been published and has been in use for approximately two years. Designers are required to consider both the serviceability and ultimate limit state conditions of buildings and their components. A major difficulty has been encountered in adequately specifying the loading and performance criteria appropriate to satisfy the Serviceability Limit State requirements of the New Zealand Building Code.

This paper details the procedure adopted to derive serviceability criteria which are now published within NZS 4203. The background as to the regulatory requirements relating to serviceability is discussed as is the basis upon which the criteria were decided, the attempts made to remove the suggested limits from the mandatory section of the standard, why this was action was considered appropriate and effectiveness of this action. Comparisons will also be drawn between the criteria stipulated and experiences elsewhere with reasons given to justify the variations encountered.

1 INTRODUCTION

Both New Zealand and Australia have adopted structural design and material standards which are in limit states format. This has been driven by the style developed within our respective building codes which demands consideration of building performance as it approaches its ultimate limit state conditions and also at serviceability limit states. Although now formalised, there is little new in such considerations since both the strength and stiffness of structures have long been the essence of structural design.

This paper addresses the issues relating to prescribing serviceability performance criteria for buildings and their components. It will primarily address the approach used to prepare the recommendation contained within the New Zealand loadings standard NZS 4203:1992 "Standard for General Structural Design and Design Loading for Buildings" (1).

2 LIMIT STATES DESIGN PHILOSOPHY

Limit states design is merely a rationalisation of traditional structural design methodology. The limit states design philosophy requires that the design consider all actions which may be imposed on the system, and that none of these actions results in effects which exceed the two specified limit states namely serviceability limit states, where deformations, deflections and vibration effects are to be maintained below prescribed limits, and ultimate limit states, where instability and collapse are to be avoided. The designer is required to be satisfied that these conditions are met for all combinations of load. Although numerous combinations are possible, the designer is usually able to quickly identify the few loading conditions which govern the design, thereby ignoring other, less critical combinations.

3 THE GROUND RULES FOR SERVICEABILITY

The New Zealand Building Code and the supporting Building Regulations (2) passed into law in July 1992 and became the sole means of approval for New Zealand buildings in January 1993. The code states the performance objective for each of the 37 clauses it contains. Each is followed by a statement of the functional requirements to be met in achieving the stated objective. The performance requirements are specified as to how to satisfy the functionality provisions. Currently it has not been possible to quantified the expected performance in all cases. The underlying philosophy throughout is to ensure occupants and neighbours enjoy an adequate level of health and safety and that the amenity value of the building is maintained.

Structural requirements are contained within Part B of the Code. This part addresses building stability and is divided into two parts namely B1 Structure, and B2 Durability. An expansion of B1 is undertaken here to set the background for the serviceability provisions discusses later.

3.1 B1 STRUCTURE

The Objective of this provision (Clause B1.1) is to safeguard people from injury caused by structural failure and from loss of amenity caused by structural behaviour,

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and to protect other property from physical damage due to structural failure. The Functional Requirements (Clause B1.2) stipulate that the building and its components shall withstand the combination of loads to which they are likely to be subjected during their life. The Performance provisions (Clause B1.3) specify that buildings (and building elements) are to have a low probability of collapsing or becoming unstable throughout their life (Clause B1.3.1), and that they have a low probability of losing their amenity value (usefulness) through deformation, vibration, degradation or other changes to their physical characteristics (Clause B1.3.2). Thus it is compliance with the loss of amenity provisions of Part B1 of the NZBC that demands that the building remains serviceable.

An acceptable evaluation method specified within the approved documents which accompany the NZBC is NZS 4203. It is within the commentary to Clause 2.4 of that standard that serviceability criteria for buildings are suggested.

4 LOADS AND LOAD COMBINATIONS

Within New Zealand, the intensities of forces and loads (and combinations thereof) to be applied to buildings and their parts are prescribed in NZS 4203. NZS 4203 extends beyond being strictly a loading standard to include issues relating to the general design and analysis principles to be followed during design. Acceptable performance criteria are also specified. This is somewhat at variance to AS 1170 (3) which is limited to specifying loads and load combinations only. The structural resistance present is determined by reference to the various structural material standards. Attempts have been made in preparing both the loading and the material standards to ensure that a common level of reliability has been achieved. This has been somewhat diluted by 'soft-conversion' techniques being used by some of the material groups and by the complexity of ascertaining the true reliability of real, complex structures where elemental interaction is acknowledged as contributing greatly to the overall capacity, strength and stiffness present in practice.

Within the loading standards, load factors are specified to amplify the nominal values of each of the loads and load combinations specified. These are prescribed for both ultimate and serviceability limit states. The value of the load factor is determined by considering the reliability of each load case. Loads which vary little with time and are reasonably well defined attract a lower amplification factor that those which are less certain. Thus the target is to get the period of recurrence of each combination to be approximately the same. For serviceability limit state conditions there is a 5 percent probability that the combined factored loads will be exceeded in any year. The same probability of excedence over a fifty year period is used for ultimate limit state conditions.

The benefit of applying separate load factors to different load cases is that it should be transparent how differing loads may vary with time and therefore how their effects should be applied for the various limit states.

4.1 SELF WEIGHT (OR DEAD LOAD), G

The self-weight or dead load of the building is always assumed to be present. Such loads are considered to be always present either alone or in combination with one or more other loads.

4.2 OCCUPANCY (OR LIVE LOAD), Q

Basic live loads for different occupancies, Q, are specified in Table 3.4.1 of NZS 4203. The values published are generally similar to those specified in Appendix B of AS 1170 Part 1. These represent the loads imposed on the structure by its contents and occupants. Live loads are specified as both concentrated (or point) loads and equivalent uniformly distributed loads (EUDL). Each is specified for the particular occupancy class and use for which the building is being designed. Certain areas of the floor space may be designated for storage and will be designed to withstand the more intense storage live loads. While the concentrated loads specified attempt to realistically reflect the actual intensity of different applied loads, the basic EUDL published are nominal values only and are modified (increased or reduced) to reflect variation of live load intensity with time and the probable intensity for both serviceability and ultimate loads. Such modifications are achieved by applying a combination of load factors and live load duration factors to the basic EUDL live loads.

Quantification of the long and short term live loads is achieved through the live load duration factors, has been an essential element in permitting a rational basis for serviceability criteria to be developed. The proportion of live load considered as long term or essentially permanent is determined from the product of the basic EUDL and the long term live load duration factor, (L. This proportion represents the intensity of live load present at any arbitrary point in time (or QAPT). The short term live load duration factor, (S, is applied to the basic EUDL to adjust the intensity of load for the shorter return period required. The live load duration factor for concentrated loads is always = 1.0. Live load duration factors are indicated in Table 1.

	ψ_S	ψ_L	Point Loads
Storage	1.0	0.6	1.0
Non-access roofs	0.4	0.0	1.0
Others	0.7	0.4	1.0

TABLE 1 LIVE LOAD DURATION FACTORS

4.3 WIND (W) & EARTHQUAKE (E)

In contrast to the above, wind and earthquake forces are derived by statistically magnifying the intensity of the natural phenomena (ie the design wind speed and the peak ground acceleration respectively). Since these are the basic input parameters from which the design actions are derived, it was more appropriate to modify these directly rather than to apply load factors to the resulting actions. In both cases the target load intensity was nominated as a 10% probability of excedence over the 50 year building life (cf 5% for wind in AS 1170 Part 2). This departure for New Zealand generated considerable debate and resulted in the introduction of a limit state multiplier, Mls,=0.93 being applied to the nominal wind speed for ultimate limit state conditions with Mls=0.75 for serviceability limit state considerations. The resulting return periods for these forces were consistent with those use as the basis for AISI A58.1 (4).

4.4 OTHER LOADS, S

This section considers snow loads, soil loads, ponding effects, ice and contained water.

4.5. LOAD COMBINATIONS

Load factors for the various combinations required to be considered are provided in Table 2. Subscripts S and U are used to differentiate between serviceability and ultimate limit state loads where these vary between load cases.

SLS	ULS
G	1.4G
G & Q_s	1.2G & 1.6Q
G & Q_s & W_s	1.2G & Q_u & W_u
G & Q_s & E_s	0.9G & W_u
G & S_s	1.2G & Q_u & 1.2S_u
	G & Q_u & E_u

TABLE 2 LOAD FACTORS & LOAD COMBINATIONS

5 CODIFYING SERVICEABILITY CRITERIA

When preparing NZS 4203, the committee decided that definitive guidance was essential to enable designers to demonstrate that the requirements of Clause B1.3.2 of the NZBC have been satisfied. The problem remained however that such limits vary widely depending on the particular circumstances in which the element is being assessed. Often deflection limits are a function of the system being supported rather than the element itself. The simple approach of specifying one acceptable deflection limit for all circumstances was obviously flawed, and it was decided to maintain transparency for the designer by ensuring that they consider several inter-related aspects of the system in arriving at the appropriate defection limit. Table 3 details the serviceability criteria as presented in NZS 4203:1992 but with some minor modifications to the limits resulting from more recent work undertaken at BRANZ (King 1995).The following outlines the approach used within this table.

5.1 CONTROL PHENOMENON

Entry into the serviceability table requires the designer to recognise the reason for limiting the deflection of the particular element at all. These were seen as being Sensory (subdivided further into Seen or Felt response); Functionality (being deformations that affect the intended use of the building); and the protection of non-structural elements (where building deformation results in loads being applied to non-structural elements with consequential damage to those members). While the latter two may result in a direct loss of building amenity, occupancy concern and anxiety to occupants caused by 'felt' or 'seen' deformations, they are also considered to be unacceptable by clause B1.3.2 and thus constitute an unserviceable building response.

5.2 ELEMENT CONSIDERED

Lists of structural element to be controlled (i.e., roofs, beams, walls, floors, etc.) are provided within each category. Elements may have several limits prescribed both within a category or between categories. The designer is required to ascertain the reason(s) for applying serviceability controls, and ensure that the limits suggested are not breached by the application of the loading condition specified.

5.3 EXPLANATORY COMMENTS

Explanatory comments accompany most elements and are intended as a guide to the designer to ensure that the limit specified is appropriate for the particular application. Differing limits may be provided for the same element within a category (ie beams where occupants will commonly

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sight along the invert and notice relatively small deflections which would pass un-noticed if viewed from across the soffit from a distance. Thus different acceptable deflection limits are suggested for each case). Where the avoidance of non-structural damage is the reason for imposing element deformation limits, the characteristics of the non-structural element are identified within these explanatory comments. Thus floors supporting brittle masonry walls have tighter deflection controls suggested that those floors supporting walls which are more tolerant to differential movement of their supports.

5.4 DEFLECTION LIMITS

Acceptable limits for each element within each category are listed as an span or height ratio. Previous standards had prescribed deflection limits as a decimalised proportion of the element length or height (ie 0.006L). The committee felt that designers had a better feel for the "span over 360" limits and this was adopted as the format. Reference to the member 'span' for horizontal elements (eg floors, lintels, beams, etc.) and vertical elements (eg columns, walls, windows, etc.) and 'height' for vertical members. Surveys indicate that the designer generally considers the primary reason for limiting deflection was the prevention of damage to secondary elements. The need for consideration of other aspects relating to use and amenity have now been clearly established.

5.5 LOADING REGIMES

Any performance criteria must consist defining a response limit to a prescribed load combination. Thus both the deflection limit and the nature of the applied load are required to fully define the criteria and thus avoid ambiguity. The fifth column within the table specifies the characteristics of the load(s) which are expected to be applied to the element and under which the elemental response (deflection or acceleration) suggested must be met.

The imposed actions are generally serviceability limit state equivalent uniformly distributed loads for horizontal elements and serviceability limit state wind forces for element which support external claddings.

5.6 ACTION CONSIDERED

To avoid ambiguity, the response effect being considered by the criteria (eg sag, ripple, sway ponding, etc.) has been specified for each suggested criteria. There is extensive cross-reference to accompanying notes which elaborate on issues relating to the criteria suggested. These notes are included in the commentary to the standard.

6 CODE ACCEPTANCE OF THE CRITERIA

While the presentational style was considered important to enable a ready understanding and thus acceptance by designers, the real quandary was assigning appropriate limits for each of the elements and for each category suggested.

This process was rather judgemental and, because of the lack of hard data, the committee was reluctant to impose stringent rule for compliance. The criteria table was thus intentionally removed from the body of the standard and presented in the commentary in recognition of the informative nature of the criteria established. Likewise the title was amended from 'Recommended' to 'Suggested Serviceability Limits'. In the event, much of this effort was to no avail in that the NZBC calls up both the Standard and the Commentary as an approved verification method. Indeed both building control authorities and designers required some credible basis to demonstrate that the amenity provisions of B1 of the NZBC had been satisfied.

6.1 CODIFICATION ISSUES

The principles adopted by the committee were

1) Deflection criteria should be unaltered (but for necessary changes to the specified loads) unless there was a sound technical or practical reason for change. A positive effort was made to calibrate the new limits to those previously applied. The lack of hard data upon which to base decisions proved a real constraint. It is expected that these limits will be modified as data becomes available.

2) The limits stated should represent a point where there was a transition from an acceptable to an unacceptable condition. Thus response beyond those limits should yield the onset of an unsatisfactory response (cracking, complaints, etc.) Functionality criteria are more difficult and required collective committee judgement as to what acceptable limits should be. Sensory acceptance was even more judgemental as occupancy and activities being undertaken within the occupied space all contributed to the acceptance levels.

Sensory Conditions

Visual acceptability is by far the most commonly experienced 'serviceability failure' but is generally one of the most difficult to quantify and therefore is generally ignored. Reflective surfaces and the amplification effects that result from movement or irregularities in such surfaces were likewise acknowledged. Different acceptance limits for 'busy' or 'tranquil' environments in regard to sensed deflection or vibration have been acknowledged.

Dynamic Effects

There is a need to provide some reasonable threshhold for dynamic response considerations. Pseudo-static point load controls were therefore introduced for both transient floor vibration effects and assessing impact resistance. These are intended to be trigger values only beyond which more detailed dynamic response analysis should be undertaken. This approach was used to avoid unnecessary design effort in cases where dynamic serviceability effects clearly do not control.

Prevention of Secondary Damage

Generally secondary elements are considerably more tolerant to movement than has previously been thought. Although, hard data is again sparse, work undertaken by King (5) and others indicates that even brittle elements such as windows or gypsum stopped plaster boards are able to withstand moderate movement without damage. Masonry elements, whilst experiencing crack development with very little movement, continue to perform as effective claddings until major cracking is experienced. This does not usually occur until significant movement is present. In-plane and out-of-plane behaviour of such systems differ, this being reflected by different criteria.

The deflection limits placed in portal frame knee-joints relate to spacing between frames. The objective was to limit the shear deformation and thus the potential for damage to the cladding system, particularly where adjacent frames may have considerably different stiffness characteristics(eg in end bays where rigid end wall diaphragms are adjacent to the first bay portal).

7 CONCLUSIONS

Serviceability limit state considerations demands a rational basis for serviceability criteria limits. Sound technical data upon which to arrive at these values is seldom available at this time and soft-conversions to previously acceptable limits often remains the sole alternative. More work is required in this area, particularly where it is practical to specify limits which accompany a distinct change in state.

By demanding that designers consider the reason for controlling deflections or vibrations, considerable relaxation of many arbitrary limits can, and should, be possible.

8 REFERENCES

1. Standard New Zealand (SNZ), "Code of Practice for General Structural Design and Design Loadings for Buildings", NZS 4203, 1992, Wellington

2. NZ Government, "Building Regulations 1992",

3. Standards Association of Australia "SAA Loading Code", AS 1170.1, 1989, Sydney.

4. American National Standard Association "Building Code Requirements for Minimum Design Loads for Buildings and other Structures", AISI A58.1, 1972.

5 King, A.B., "Serviceability Limit State Criteria for Buildings", 1995, SR 57, BRANZ, Judgeford

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Serviceability Limit Considered	Ref id	Element	Phenomenon Controlled	Applied Action	Element Response
Sensory: Seen	S1	Metal Roof Claddings	Indentation	Residual after Qb = 1 kN	Span/600 but <0.5 mm
	S2	Roof members (Trusses, rafters, purlins,	Sag	G & Ψ_SQ	Span/300
	S3	Ceilings with matt or gloss paint finish	Ripple	G	Span/500
	S4	Ceilings with textured finish	Ripple	G	Span/300
	S5	Suspended ceilings	Ripple	G	Span/360*
	S6	Ceiling support framing	Sag	G	Span/360
	S7	Glazing systems	Bowing	Ws	Span/400
	S8	Columns	Side sway	Ws	Height/500
	S9	Flooring*	Ripple	G & Ψ_LQ	Span/300
	S10	Floor Joists/beams*	Sag	G & Ψ_LQ	Span/300*
	S11	Beams where Line-of-sight is along invert	Sag	G & Ψ_LQ	Span/500
	S12	Beams where Line-of-sight is across soffit	Sag	G & Ψ_LQ	Span/250
Sensory: Felt	S13	Walls (face loaded)	Discernable movement	Ws	Height/150
	S14	Walls (Impact)	Neighbours notice	Qb = 1.2 kN*	Height/200 but <12 mm*
	S15	Floors	Vibration	Qb = 1.0 kN	<2 mm*
	S16	Floors -sidesway	Sway	Ws	<0.01 g
Functionality	F1	Flat Roof Systems	Drainage	G & Ψ_LQ	Span/400
	F2	Flat Roof Systems	Ponding	G & Ss	Span/500
	F3	Walls (Face loaded)	Supported elements rattle	Ws	Height/300
	F4	Normal Floor Systems	Noticeable Sag	G & Ψ_SQ	Span/400
	F5	Specialist Floor Systems	Noticeable Sag	G & Ψ_SQ	Span/600
	F6	Lintel beams (Vertical sag)	Doors/Windows Jamming	G & Ψ_SQ	Span/240 but <12 mm
Protection of non-structural elements	D1	Concrete or Ceramic Roof Claddings	Cracking	G & Ψ_SQ	Span/400
	D2*	Metal Roof Claddings	De-coupling	G & Ψ_SQ	Span/120
	D3	Ceilings with plaster finish	Cracking	G & Ψ_SQ	Span/200
	D4	Walls with brittle cladding	Cracking	Ws	Height/500
	D5	Windows, Facades, Curtain walls	Facade damage	Ws; Es	Span/250
	D6	Fixed glazing systems	Glass damage	Ws; Es	2x glass clearance
	D7	Masonry Walls (in plane)	Noticeable Cracking*	Ws; Es	Height/600
	D8	Masonry Walls (face loaded)	Noticeable Cracking	Ws; Es	Height/400
	D9	Plaster/gypsum Walls (in plane)	Lining Damage*	Ws	Height/300*
	D10	Plaster/gypsum Walls (face loaded)	Lining Damage*	Ws; Es	Height/200
	D11	Plaster/gypsum Walls (Equivalent soft body impact)*	Lining Damage*	Qb = 0.7 kN	Height/200
	D12	Movable partitions (Equiv. SB Impact)	System damage	Qb = 0.7 kN	Height/160
	D13	Walls with other linings (face load)	Lining Damage	Ws; Es	Height/300
	D14	Portal Frames (frame racking action)	Roofing damage	Ws; Es	Spacing/200
	D15	Floors - supporting masonry walls*	Wall cracking	G & Ψ_SQ	Span/500
	D16	Floors - supporing plaster lined walls*	Cracks in lining	G & Ψ_SQ	Span/300

TABLE 3: SERVICEABILITY CRITERIA - BASED ON TABLE C2.4.1 OF NZS 4203 MODIFIED FROM MORE RECENT BTL WORK IN BRANZ SR 57

Element	Ref id	Phenomenon Controlled	Applied Action	Element Response
Roof Claddings				
Metal Roof Claddings	S1	Indentation	Residual after Qb = 1 kN	Span/600 but <0.5 mm
	D2*	De-coupling	G & Ψ_sQ	Span/120
Concrete or Ceramic Roof Claddings	D1	Cracking	G & Ψ_sQ	Span/400
Roof Supporting Elements				
Roof members (Trusses, rafters, purlins, etc.)	S2	Sag	G & Ψ_sQ	Span/300
Roof elements supporting brittle claddings	D1	Cracking	G & Ψ_sQ	Span/400
Ceilings & Ceiling Supports				
Ceilings with matt or gloss paint finish	S3	Ripple	G	Span/500
Ceilings with textured finish	S4	Ripple	G	Span/300
Suspended ceilings	S5	Ripple	G	Span/360*
Ceiling support framing	S6	Sag	G	Span/360
Ceilings with plaster finish	D3	Cracking	G & Ψ_sQ	Span/200
Wall Elements				
Columns	S8	Side sway	Ws	Height/500
Portal Frames (frame racking action)	D14	Roofing damage	Ws; Es	Spacing/200
Lintel beams (Vertical sag)	F6	Doors/Windows Jamming	G & Ψ_sQ	Span/240 but <12 mm
Walls (face loaded)	S13	Discernable movement	Ws	Height/150
	S14	Neighbours notice	Qb = 1.2 kN*	Height/200 but <12 mm*
	F3	Supported elements rattle	Ws	Height/300
Walls with brittle cladding	D4	Cracking	Ws	Height/500
Masonry Walls (in plane)	D7	Noticeable Cracking*	Ws; Es	Height/600
	D8	Noticeable Cracking	Ws; Es	Height/400
Plaster/gypsum Walls (in plane)	D9	Lining Damage*	Ws	Height/300*
	D10	Lining Damage*	Ws; Es	Height/200
	D11	Lining Damage*	Qb = 0.7 kN	Height/200
Movable partitions (Equiv. SB Impact)	D12	System damage	Qb = 0.7 kN	Height/160
Walls with other linings (face load)	D13	Lining Damage	Ws; Es	Height/300
Glazing systems	S7	Bowing	Ws	Span/400
Windows, Facades, Curtain walls	D5	Facade damage	Ws; Es	Span/250
Fixed glazing systems	D6	Glass damage	Ws; Es	2x glass clearance
Floors & Floor Supports				
Beams where Line-of-sight is along invert	S11	Sag	G & Ψ_LQ	Span/500
Beams where Line-of-sight is across soffit	S12	Sag	G & Ψ_LQ	Span/250
Flooring*	S9	Ripple	G & Ψ_LQ	Span/300
Floor Joists/beams*	S10	Sag	G & Ψ_LQ	Span/300*
Floors	S15	Vibration	Qb = 1.0 kN	<2 mm*
Floors -sidesway	S16	Sway	Ws	<0.01 g
Normal Floor Systems	F4	Noticeable Sag	G & Ψ_sQ	Span/400
Specialist Floor Systems	F5	Noticeable Sag	G & Ψ_sQ	Span/600
Floors - supporting masonry walls*	D15	Wall cracking	G & Ψ_sQ	Span/500
Floors - supporing plaster lined walls*	D16	Cracks in lining	G & Ψ_sQ	Span/300

TABLE 4: SERVICEABILITY CRITERIA (LINKED TO TABLE 3 BY THE REFERENCE IDS BUT REFORMATTED TO FOCUS ON ELEMENTAL CONTROL)

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