HISTORICAL REVIEW
OF
MASONRY STANDARDS
IN NEW ZEALAND

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for the
ROYAL COMMISSION OF INQUIRY
BUILDING FAILURE CAUSED BY THE CANTERBURY EARTHQUAKES

This review of the development of masonry standards in New Zealand has been prepared for the Royal Commission of Inquiry into Building Failure Caused by the Canterbury Earthquakes. The review includes all significant changes that have occurred in masonry standards in the period 1935 to 2010 but does not include all amendments to the standards over the period.

Development of Masonry Standards

The first masonry standard was introduced as NZSS 95 Part X in 1948. The standard was titled "Masonry Construction" and was part of the model building by-law issued by the New Zealand Standards Institute which was established under the Standards Act 1941.

The standard related to masonry construction in stone, units of burned clay, concrete blocks and bricks. The standard included requirements of both reinforced and reinforced masonry structures. The standard also included specification of materials, material quality and enumerated conditions for construction and workmanship.

The standard set out design principles and working stress design and for inspections during construction. For structures with continuity of supervision, significantly increased stresses were permitted in the masonry.

Specific requirements for the masonry components were set out in the following standards;

NZSS 366 Building Bricks
NZSS 595 Concrete Bricks and Blocks
NZSS 781 Building Limes
NZSS 1051 Concrete Materials and Method of Test

As part of the revision of New Zealand standards circa 1964, NZSS 95 Part X was re-titled and published as NZSS 1900: Chapter 9.2: 1964 "Masonry". NZSS 1900: Chapter 9.2 was not a revision of that standard and did not incorporate any new material. However, the minimum requirements for small masonry buildings incorporated in NZSS 95 Part X were removed from the standard and included in NZSS 1900 Chapter 6 "Construction Requirements for Buildings Not Requiring Special Design" Chapter 6.2: 1964 "Masonry".

The masonry design standards remained unchanged until circa 1981 when the masonry standards were significantly revised into limit state format and Standards New Zealand issued the draft for comment DZ 4210.

In 1983 Standards NZ cited the structural designs standard NZS 4210 "Masonry Buildings; Materials and Workmanship" as a means of compliance to NZSS 1900: Chapter 9.2.

As a result of comments received, this Standard was issued as NZS 4230P in 1985 with extensive changes both in format and technical content. Complete technical consensus of Masonry Design and Construction Standards had not been achieved within the industry and the Standard was issued as a Provisional Standard providing industry time to forward arguments of construction supervision and observation, bolt shear loads, seismic zone limitations, and unreinforced veneers.

NZS 4230 was finally issued in 1990 after rewriting of the section on masonry veneers and changes to the reinforcing requirements to align with NZS 3402 which related grades of steel to the lower characteristic strength rather than the minimum yield strength.

NZS 4230 included both reinforced and unreinforced masonry. The Standard introduced the concept of three grades of masonry, Grade A, B and C.

Grade A Masonry requirements included a requirement for a supervisor to be on the job full time or to be present to supervise all critical stages of the work in addition to the periodic inspection by the Design Engineer. Grade A Masonry required all cells to be filled within potential plastic hinge zones with other regions being either all cells filled or partially filled.

Grade B Masonry required construction observation by the Design Engineer or his nominated representative during construction. Grade B Masonry also required all cells to be filled within potential plastic hinge regions. Other regions of masonry could be all cells filled or partially filled.

Grade C Masonry was only permitted in buildings constructed to the requirements of the non-specific design code NZS 4229, where the engineer specifically permited any masonry to be constructed without construction observation by the Design Engineer or his nominated representative.

NZS 4230 required the designer to identify on the drawings the grade of masonry used in a project. NZS 4230 was in limit state format. The code introduced the concepts of ductile structures, structures of limited ductility and elastic responding structures. For ductile structures resisting seismic loading and undergoing inelastic displacements, the Standard required a capacity design approach where the elements of the primary lateral load resisting system were chosen and suitably designed in detail for energy dissipation under severe deformation. All other structural elements were then provided with sufficient strength so that the chosen means of energy dissipation could be maintained.

Structures of limited ductility were assumed to have low inelastic deformation demand and were to be designed to resist seismic loads derived by the use of larger structural type factors, as specified in NZS 4203.

NZS 4230: 2004 finally removed the legal construction of unreinforced masonry.

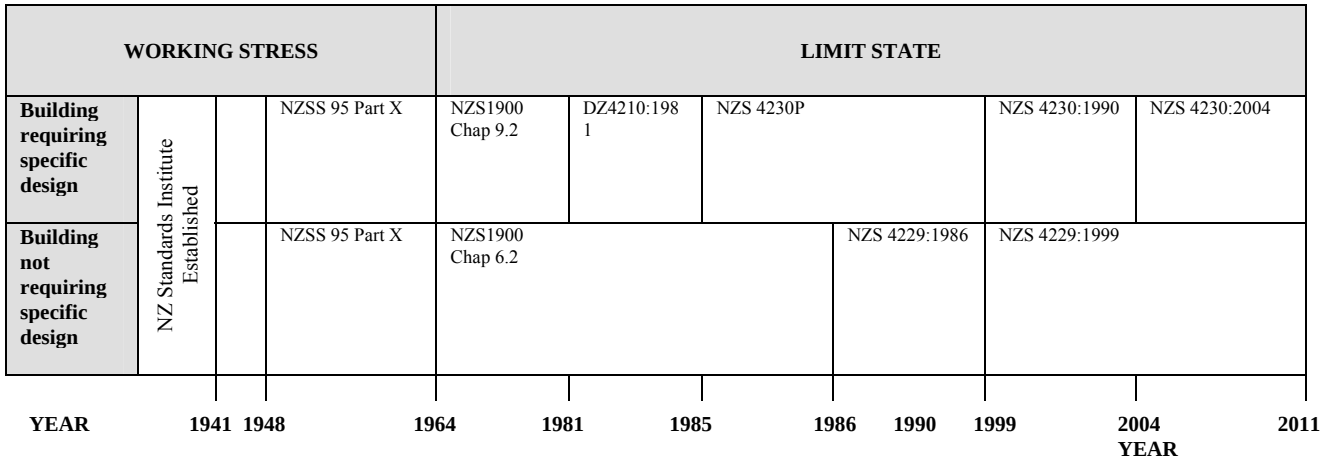

Figure 1 - Historical Implementation of Masonry Standards

Masonry Standards in New Zealand

NZSS 95: Part X : 1948 "Masonry Construction"
First revision July 1959

NZSS 1900: Chapter 6.2: 1964 "Masonry"
Supersedes NZSS 95: Part X

NZSS 1900: Chapter 9.2: 1964 "Masonry"
Supersedes NZSS 95: Part X

NZS 4230P: 1985 "Code of Practice for the Design of Masonry Structures"
Supersedes NZSS 1900: Chapter 9.2: 1964

NZS 4229: 1986 "Code of Practice for Concrete Masonry Buildings not requiring specific design"
Supersedes NZSS 1900: Chapter 6.2: 1964

NZS 4230: 1990 "Code of Practice for the Design of Masonry Structures"
Supersedes NZS 4230P: 1985

NZS 4229: 1999 "Concrete Masonry Buildings Not Requiring Specific Design"
Supersedes NZS 4229: 1986

NZS4230: 2004 "Design of Reinforced Concrete Masonry Structures"
Supersedes NZS 4230: 1990

Constituent Material Properties

Masonry

NZSS 95

Materials are of stone, burned clay, and concrete blocks and bricks.

The minimum quality of masonry units was to conform to NZSS 366 for building bricks and NZSS 595 for concrete bricks and blocks. Grade A or B were generally required to external members, and grade C for partition walls.

NZSS 595: 1966 required minimum compressive strength for;

hollow masonry unit Grade A to be 1000 lb/in^2 (6.9 MPa) and Grade B to be 700 lb/in^2 (4.8 MPa)

solid masonry unit Grade A to be 1800 lb/in^2 (12.4 MPa) and Grade B to be 1200 lb/in^2 (8.3 MPa)

NZSS 366: 1963 required minimum crushing strength for structural bricks to be 3000 lb/in^2 (20.7 MPa)

Natural stone was required to be durable when exposed to the weather and to have physical strength characteristics at least equal to those required for bricks or blocks. Stone from sedimentary geological formations shall be so laid that its natural bedding plane is at right angles to the direction of loading.

NZS 4230P: 1985

Concrete masonry units shall have a 12 MPa minimum compressive strength

Clay masonry units to comply with NZSS 366 and natural stone were still applicable (NZS 4210P: 1981)

NZS 4230: 1990

Concrete masonry units shall have a 12 MPa minimum compressive strength

Clay masonry units to comply with NZSS 366 and natural stone were still applicable (NZS 4210: 1989)

NZS 4230: 2004

Concrete masonry units can be various strengths, however those supplied for NZS 4229 construction shall have a 12.5 MPa minimum compressive strength (NZS 4210: 2001)

Clay masonry units and natural stone were still applicable and subject to specific design, as part of reinforced concrete masonry

Mortar

NZSS 95

Mix No. 1 to be 1800 lb/in^2 (12.4 MPa) minimum compressive strength at 28 days
Mix No. 2 to be 1250 lb/in^2 (8.6 MPa) minimum compressive strength at 28 days

Bond strength of mortar adhering to units to resist a tensile strength of 30 lb/in^2 (207 kPa), cured for 28 days.

NZS 4230P: 1985

Structural masonry 12.5MPa minimum compressive strength at 28 days (NZS 4210P: 1981)
Other masonry 8.5MPa minimum compressive strength at 28 days (NZS 4210P: 1981)

NZS 4230: 1990

12.5MPa minimum compressive strength at 28 days (NZS 4210: 1989)

NZS 4230: 2004

12.5MPa minimum compressive strength at 28 days (NZS 4210: 2001)

Grout (Infilling of masonry)

NZSS 95

The filling of cavities for reinforced masonry should be with concrete consisting of sand and 5mm to 12mm course aggregate. The Standard also provided for reinforced brick masonry consisting of two or more skins of brick between which reinforcing steel is embedded in grout.

Minimum standard to be 1500 lb/in^2 (10.3 MPa) min compressive strength at 28 days
Minimum for cavities exceeding 4" (100mm) to be 2500 lb/in^2 (17.2 MPa) min compressive strength at 28 days

NZS 4230P: 1985

17.5MPa minimum compressive strength at 28 days (NZS 4210P: 1981)

NZS 4230: 1990

17.5MPa minimum compressive strength at 28 days (NZS 4210: 1989)

NZS 4230: 2004

17.5MPa minimum compressive strength at 28 days (NZS 4210: 2001)

Reinforcement Properties

NZSS 95

The stresses permitted in reinforcement were as follows;
Plain round rods 18,000 lb/in^2 (124 MPa)
Deformed bars 20,000 lb/in^2 (138 MPa)

The modulus of elasticity (yield strength 54,000 lb/in^2 at 0.002 strain from NZSS 95 Part V "Reinforced and Plain Concrete Construction") calculates to be 186 GPa.

NZS 4230P: 1985

The tensile strength of the reinforcement was 275 MPa for mild steel, and 380 MPa for high tensile steel.

The modulus of elasticity was 200 GPa.

NZS 4230: 1990

The tensile strength of the reinforcement was 300 MPa for mild steel, and 430 MPa for high tensile steel.

The modulus of elasticity was 200 GPa.

NZS 4230: 2004

The tensile strength of the reinforcement was 300 MPa for mild steel, and 500 MPa for high tensile steel.

The modulus of elasticity was 200 GPa.

Reinforcement Ratio

NZSS 95

Reinforced masonry to have a minimum volume of 0.0025 of reinforcing steel, with not less than 1/3 either horizontal or vertical.

Vertical reinforcement at 40" (1000mm) centres and minimum size 3/8" (9.5mm) diameter rod
Horizontal reinforcement at 32" (800mm) centres and minimum size 3/8" (9.5mm) diameter rod

The general minimum reinforcement requirements for reinforced hollow masonry in NZSS 95 was for at least one ½" (12.5mm) or larger diameter rod or two 3/8" (9.5mm) diameter rods placed at all corners, at sides of and adjacent to every opening exceeding 600mm in dimension, and wall ends of reinforced masonry walls.

Laps were to be a minimum of 40 diameters for plain rods, and 30 diameters for deformed bars

Columns to have 0.008 minimum to 0.04 maximum gross area of column of reinforcing steel

Minimum area of ties to a column to be 0.001 that section area

NZS 4230P: 1985

Reinforced masonry to have minimum reinforcing of 0.0007 of the area of the wall, in each direction. The sum of the horizontal and vertical reinforcement ratios shall be at least 0.002.

The horizontal reinforcement ratio was required to be increased to 0.0015 for stack bonded walls in R = 1.0 and 1.3 walls.

Horizontal and vertical reinforcement at up to 600mm centres for grade A, 800mm for grade B, and 1000mm for grade C masonry. The spacing depends on risk factor and running or stack bond.

Laps were to be a minimum of 40 diameters for grade 275 steel bars, and 54 diameters for grade 380 steel bars

NZS 4230: 1990

Reinforced masonry to have minimum reinforcing of 0.0007 of the area of the wall, in each direction. The sum of the horizontal and vertical reinforcement ratios shall be at least 0.002.

The horizontal reinforcement ratio was required to be increased to 0.0015 for stack bonded walls in R = 1.0 and 1.3 walls.

Horizontal and vertical reinforcement at up to 600mm centres for grade A, 800mm for grade B, and 1000mm for grade C masonry. The spacing depends on risk factor and running or stack bond.

Laps were to be a minimum of 40 diameters for grade 300 steel bars, and 60 diameters for grade 430 steel bars

NZS 4230: 2004

Reinforced masonry to have minimum reinforcing of 0.0007 of the area of the wall, in each direction. The sum of the horizontal and vertical reinforcement ratios shall be at least 0.002.

The horizontal reinforcement ratio was required to be increased to 0.0015 for stack bonded walls for building importance level 3 walls.

For solid filled masonry horizontal reinforcement spacing 1200mm maximum centres and for vertical reinforcement 800mm maximum centres (NZS 4229: 1999).

Laps were to be a minimum of 40 diameters for grade 300 steel bars, and 70 diameters for grade 500 steel bars

Reinforcement	NZSS 95	NZS 4230P:1985	NZS 4230:1990	NZS 4230:2004
Concrete Grout			NZS 4230:1990	NZS 4230:2004
Concrete Infill	NZSS 95	NZS 4230P:1985	NZS 4230:1990	NZS 4230:2004
Mortar	NZSS 95	NZS 4230P:1985	NZS 4230:1990	NZS 4230:2004
Concrete blocks	NZSS 595	NZS 4230P 1985	NZS 4230:1990	NZS 4230:2004
Bricks	NZSS 366	NZS 4210P 1981	NZS 4230:1990	Specific Design
Burnt Clay	NZSS 366	NZS 4210P 1981	NZS 4230:1990	Specific Design
Stone	NZSS 366	NZS 4210P 1981	NZS 4230:1990	Specific Design

YEAR **1948** **1981** **1985** **1990** **2004** **2011** **YEAR**

Figure 2 – Historical Specification of Material Properties

Masonry Material Properties

Modulus of elasticity

NZSS 95

Burned clay, concrete and natural stone modulus of elasticity 1,500,000 lb/in^2 (10.3 GPa)
Burned clay, concrete and natural stone shear modulus of rigidity 600,000 lb/in^2 (4.1 GPa)

NZS 4230P: 1985

The modulus of elasticity for masonry 25 GPa
The bulk modulus for masonry 10 GPa

NZS 4230: 1990

The modulus of elasticity for masonry 25 GPa
The bulk modulus for masonry 10 GPa

NZS 4230: 2004

The modulus of elasticity for masonry 15 GPa

Design Stresses

NZSS 95

This standard was in working stress. The allowable stresses were as follows;

Allowable Stresses in Unreinforced Masonry

Material Grade of Unit	Allowable Stress lb/in^2 (kPa)					
	With Continuous Inspection			Without Continuous Inspection		
	Com-pression	Tension*	Shear	Com-pression	Tension*	Shear
Plain masonry Brick and Solid Concrete Brick	150 (1030)	10 (70)	10 (70)	75 (520)	5 (35)	5 (35)
Hollow unit masonry	60 (410)	10 (70)	10 (70)	40 (275)	5 (35)	5 (35)
Cavity wall masonry Solid units Hollow units	 100 (700) 50 (345)	 8 (55) 8 (55)	 8 (55) 8 (55)	 70 (480) 30 (210)	 4 (28) 4 (28)	 4 (28) 4 (28)
Natural stone	100 (700)	4 (28)	4 (28)	80 (550)	2 (14)	2 (14)

Allowable Stresses in Reinforced Masonry

Material Grade of Unit	Allowable Stress lb/in^2 (kPa)					
	With continuous Inspection			Without Continuous Inspection		
	Axial Com-pression	Flexural Com-pression	Shear	Axial Com-pression	Flexural Com-pression	Shear
Reinforced grouted solid units 2,500 plus lb/in^2 (17.2MPa) 1,500 to 2,500 lb/in^2 (10.3MPa)	 300 (2070) 150 (1035)	 500 (3450) 250 (1725)	 60 (410) 30 (205)	 150 (1030) 150 (1030)	 250 (1725) 150 (1030)	 30 (210) 15 (105)
Reinforced filled cell units	250 (1725)	400 (2760)	50 (345)	125 (860)	200 (1380)	20 (140)
Bond on reinforcement Smooth round rods Deformed bars			 60 (415) 120 (830)			 30 (210) 90 (620)

The Standards allowed the stresses permitted under wind and earthquake to exceed the above values by 33%.

NZS 4230P: 1985

Limit state design strengths;

Type of stress	Grade of masonry		
	C	B	A
Compression	4 MPa	8 MPa	8 MPa
Shear provided by masonry, general conditions	0.12 MPa	0.24 MPa	0.30 MPa
Shear provided by masonry, plastic hinges	-	0	0
Maximum total shear, general conditions	0.67 MPa	1.33 MPa	1.60 MPa
Maximum total shear, plastic hinges	-	1.00 MPa	1.20 MPa

Strength reduction factors ϕ;

Flexure, axial tension $\phi = 0.85$

Axial compression, bearing on masonry $\phi = 0.65$

Shear and shear friction $\phi = 0.80$

When actions are derived from overstrength of adjacent components, in accordance with capacity design principles, a strength reduction factor of $\phi = 1$ shall be adopted.

NZS 4230: 1990

Limit state design strengths;

Type of stress	Grade of masonry		
	C	B	A
Compression	4 MPa	8 MPa	8 MPa
Shear provided by masonry, general conditions	0.15 MPa	0.24 MPa	0.30 MPa
Shear provided by masonry, plastic hinges	-	0	0
Maximum total shear, general conditions	0.80 MPa	1.40 MPa	1.60 MPa
Maximum total shear, plastic hinges	-	1.00 MPa	1.20 MPa

Strength reduction factors ϕ;

Flexure, axial tension $\phi = 0.85$

Axial compression, bearing on masonry $\phi = 0.65$

Shear and shear friction $\phi = 0.80$

When actions are derived from overstrength of adjacent components, in accordance with capacity design principles, a strength reduction factor of $\phi = 1$ shall be adopted.

NZS 4230: 2004

Limit state design strengths;

Type of stress	Grade of masonry		
	C	B	A
Compression	4 MPa	12 MPa	>12 MPa
Basic shear provided by masonry, general conditions	0.30 MPa	0.70 MPa	$0.2\sqrt{f'_m}$
Shear provided by masonry, potential plastic hinges, limited ductile structures	-	0.50 MPa	$0.15\sqrt{f'_m}$
Shear provided by masonry, potential plastic hinges, ductile structures	-	0	0
Maximum total shear, general conditions	0.80 MPa	1.50 MPa	$0.45\sqrt{f'_m}$

Strength reduction factors ϕ;

Flexure, axial tension ϕ = 0.85

Bearing on masonry ϕ = 0.65

Shear and shear friction ϕ = 0.75

When actions are derived from over-strength of adjacent components, in accordance with capacity design principles, a strength reduction factor of $\phi = 1$ shall be adopted.

Design for Structural Actions

Design was to be in working stress format until NZS 4230P: 1985. The allowable stresses within both unreinforced and reinforced masonry are as noted above, and buildings were to be designed as elastic responding buildings.

NZS 4230P: 1985 was the first masonry standard that was in limit state format, and included the concepts of ductility, and capacity design.

The format of NZS4320P followed that of NZS 3101 for concrete, and as such allowed for design of reinforced masonry frames as well as walls for lateral support of buildings with detailling requirements for the appropriate level of ductility.

On drawings, masonry was to be denoted to which grade (A, B or C) it was constructed, and the grades allowed for generally differing ductility as follows (NZS 4203: 1992);

Grade C to be Elastic ($\mu = 1.25$)
Grade B to be Limited ductile ($\mu = 2$)
Grade A to be Ductile ($\mu = 3$ to 6)

NZS 4230: 1990 did allow Grade C face loaded walls to be designed for $\mu = 2$ for seismic loading.

Current design is for the actions of NZS 1170, notably NZS 1170.5: 2004 "Earthquake Actions – New Zealand." Ductility and material strain limits were moved to the material standards at this time.

NZS 4230: 2004 allows for ductility to the grade of masonry as follows;

Grade C to be Elastic ($\mu = 1.0$) or Nominally Ductile ($\mu = 1.25$)
Grade A and B can be Elastic, Nominally Ductile, Limited ductile ($\mu = 2.0$), or Ductile (μ up to 6)

Recommendations for Assessment and Strengthening

Guidelines for the assessment and strengthening of masonry buildings have been published to provide advice for design engineers on how to address buildings designed to previous codes. This is due to concern that the seismic lateral strength of buildings designed to previous codes are likely to be of a lower standard than that required by more modern codes.

In 1968 legislation, which became section 624 of the Local Government Act 1974, defined Earthquake Risk Buildings as those unreinforced masonry buildings with insufficient capacity to resist earthquake forces of 50% of those defined by NZS 1900 Chapter 8: 1965.

Section 66 of the Building Act 1991 similarly defines a building to be earthquake prone if its construction is wholly or substantially of unreinforced concrete or unreinforced masonry and have its capacity exceeded in a moderate earthquake, defined as seismic forces 50% of those defined by NZS 1900 Chapter 8: 1965.

The Building Act 2004 includes provisions whereby each Territorial Authorities are required to adopt a policy on dangerous, earthquake prone and insanitary buildings within its District. Under this legislation an earthquake prone building is defined as a building that will have its ultimate capacity exceeded in a moderate earthquake for a building with commercial use or or larger residential buildings (2 or more stories and 3 or more households).

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

The four common publications providing advice on the assessment and strengthening of masonry buildings have been published by the New Zealand Society for Earthquake Engineering;

"Earthquake Risk Buildings" NZSEE, December 1985 (Red book)

Includes a basic strength evaluation for unreinforced masonry buildings, and provided requirements for interim securing that were based on earthquake forces of 2/3 of those defined by NZS 1900 Chapter 8: 1965. Interim securing was "aimed at reducing the risk of total collapse due to particular hazardous features of a building". Strengthening requirements related to NZS 4203: 1984.

"Draft Guidelines for Assessing and Strengthening Earthquake Risk Buildings" NZSEE, February 1995

Includes an attribute score for buildings being assessed, and specific assessment recommendations for unreinforced masonry buildings, including strength values for materials. Design was to NZS 4203: 1992.

"Assessment and Improvement of the Structural Performance of Buildings in Earthquake" NZSEE Study Group on Earthquake Risk Buildings, June 2006

Includes an Initial Evaluation Procedure to attribute a %NBS (new building standard) to a building, of various types of construction, for seismic loading. The loading code referenced is NZS 1170.5: 2004. Detailled assessment guidelines are included for a most building types, including unreinforced masonry buildings. Reinforced masonry buildings are not specifically included, however the principles of reinforced concrete structures could be adopted.

"Assessment and Improvement of Unreinforced Masonry Buildings for earthquake Resistance" NZSEE and University of Auckland, February 2011

Provides advice on material testing and prediction of properties, and assessment and improvement of building strength for unreinforced masonry buildings.

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