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Light-frame timber construction — Comparison of four national design documents

Construction à ossature légère de bois — Comparaison de quatre documents nationaux pour la conception

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

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Introduction

Light-frame timber construction is the dominant construction practice for housing and other types of buildings in some countries. In these countries, it has gained widespread acceptance due to its many benefits, including ease of construction, cost-effectiveness, adaptation to energy efficient buildings and proven performance. This Technical Report is intended to provide an overview of the common elements in existing national structural design documents on light-frame timber construction.

The comparison chart (see Annex A) is intended to assist in that process. This Technical Report draws attention to several common themes and identifies some differences in the documents reviewed.

Light-frame timber construction — Comparison of four national design documents

1 Scope

This Technical Report provides an introduction and synopsis of comparisons among the following four national design documents on light-frame timber (wood)[1] construction:

a) AS 1684-1 (including AS 1684-1:1999/Amd.1:2002), AS 1684-2 and AS 1684-3;

b) the *Engineering guide for wood-frame construction*;

c) NZS 3604;

d) the *Wood Frame Construction Manual (WFCM) for One- and Two-Family Dwellings* (Chapter 1: General information, Chapter 2: Engineered design and Chapter 3: Prescriptive design).

Each of the four light-frame texts compared in this Technical Report is based on a national timber design standard that includes provisions for assemblies and systems, which go beyond single-member design methodology. Other jurisdictions also have similar design documents on light-frame timber construction. Although not all jurisdictions have design documents on light-frame timber construction, timber design standards typically address assemblies and systems (See 6.2).

2 Document design principles

2.1 Basic principles

AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual* each comply with a national code, which defines the higher level building design principles and conditions that need to be met for light-frame timber buildings, including strength and serviceability criteria, specified loads and material design performance.

In general, AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual* (design documents) share basic principles related to demonstrating how light-frame timber construction can comply with structural requirements, particularly how it can resist high-wind and/or seismic loading conditions and provide additional guidance concerning system design and construction methods.

At the same time, AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual* do not all seek to have the same coverage or topics (see Clause 3). Some deal with housing only, others with housing and small buildings; a few with wood structural design only and others with other structural components or design aspects of the building. These differences complicate direct comparisons of the documents on a detailed level.

The following are some observations on general principles found.

1) The terms “wood” and “timber” are used interchangeably in this Technical Report.

2.2 Compliance through pre-engineered solutions

To demonstrate how to comply with national code requirements for light-frame wood construction, pre-engineered solutions and tables to accompany engineering design methods are included in AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual*. This approach can be more conservative in some cases, but can also facilitate design and regulatory checking, particularly in areas less familiar with the construction system.

The following are examples.

— AU: AS 1684-1, AS 1684-2 and AS 1684-3 cover design of timber-framed construction conforming to loading and performance requirements for Class 1 (housing or hostels) and Class 10 (non-habitable structures) buildings as defined by the national code; less conservative designs can be permitted by other building regulations or standards.

— CA: The *Engineering guide for wood-frame construction* covers a subset of the national code — Part 9 (Housing and small buildings). Part 9 typically permits less conservative measures for housing and small buildings, particularly for buildings subjected to significant lateral loading.

— NZ: NZS 3604 provides acceptable "non-specific" design solutions to the performance-based national code, including many detailed construction provisions.

— US: The *Wood Frame Construction Manual* is referenced in US national codes for design of wood-frame construction, particularly in higher wind and seismic conditions; other provisions permit less conservative conventional construction or engineered designs.

2.3 Design requirements matched to risk level

2.3.1 General

AS 1684-1, AS 1684-2 and AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual* all, in one way or another, match design provisions to the type and intensity of loading as well as vulnerability of the building structure. This can in some cases lead to design discontinuities where special solutions are specified only for high- or low-risk areas, but also helps to provide a better fit to the scale of the problem.

2.3.2 Examples

— AU: Separate cyclonic and non-cyclonic documents deal with high- or low-risk cyclonic events. AS 1684-1, AS 1684-2 and AS 1684-3 increase requirements for higher risk areas, with up to half of racking force permitted to be resisted by nominal wall bracing; AS 1684-2 is published for simplified design in non-cyclonic areas.

— CA: Part C of the *Engineering guide for wood-frame construction* advises on applicability of solutions under lateral loading conditions, based on spacing and location of braced walls; national codes permit prescriptive construction that are more liberal than Part C of the *Engineering guide for wood-frame construction*.

— NZ: Prescriptive provisions include restrictions on bracing elements in terms of spacing, minimum capacity and location; if spacing of bracing lines not evenly distributed, spacing is reduced to coincide with a line of supporting members.

— US: Separate "prescriptive design" document in tabular format is based on engineering principles; national codes permit conventional construction in lower risk situations.

2.4 Relationship to engineering design

AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual* share the objective of maintaining continuous load paths, but it is recognized that they cannot fully replace the design process. Common themes include agreement that not all aspects of the complete structure are fully addressed and conservative assumptions are made to present efficient design aids. The documents are intended to be used principally by engineers or other competent designers.

The following are examples.

— AU: Intended to provide building industry with design procedures and details for use in cyclonic and non-cyclonic areas; another simplified version (AS 1684-4) was published for non-designers.

— CA: Intended to be used in conjunction with competent engineering design, as well as to provide guidance to a wide range of the building community (e.g. builders, code officials).

— NZ: Intended to be used by a wide range of the building industry, while recognizing that due to national code requirements, users would be mainly fulfilling the role of a designer.

— US: Intended to be used in conjunction with competent engineering design, providing guidance and saving time for the design professional.

2.5 Evolving understanding of load-resistance interaction

There is widespread recognition of the complexity of load and resistance distribution and interaction in light-frame construction systems under gravity and lateral loading patterns. AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual* include varying approaches to incorporating system action provisions and calibrating to the long performance history of these systems. These provisions are likely to evolve to include more advanced design tools as knowledge grows.

The following are examples.

— AU: Load distribution and strength-sharing effects are included in design methods for framing members, including rafter, studs and joists.

— CA: Design of rafters, studs, joists, headers and beams includes consideration of system action and strength sharing; shearwall design is a mechanics-based approach with additional consideration of shearwalls without hold-downs where sheathing is used to resist overturning and/or uplift.

— NZ: Nominal bracing systems are provided with prescribed bracing capacities; performance-based design (national code) permits use of alternative design solutions.

— US: Wall stud design includes system factors, load-sharing increase factors provided for joists, rafters and other members; shearwall design includes a mechanics-based approach for shearwalls with hold-downs with additional consideration of the empirical based perforated shearwall model (without hold-downs).

3 Coverage and limitations

3.1 General

The light-frame construction documents are limited in terms of building size, loads and other parameters. These limits are dictated largely by national codes, yet committees also make many decisions on what to include within the scope and limitations of light-frame construction documents.

3.2 Definition of light-frame construction

AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual* all address small light-frame buildings constructed primarily of closely-spaced repetitive wood-framing members connected together in roof, wall and floor systems. Construction details are based on traditional domestic methods, and consequently, they differ to some extent on restrictions on building height, width, size and occupancy. The differences are less significant than common elements of structural design interest.

The following are examples.

— AU: Maximum building of two stories above substructure, maximum 8,5 m height; storey height up to 3,0 m, except up to 3,6 m where increased loads considered in design.

— CA: Building height not greater than three stories and maximum storey height not greater than 3,5 m.

— NZ: Timber-framed buildings up to three stories high, total height not more than 10 m.

— US: Building not more than three stories or a mean roof height of 10 m, maximum story height of 3,6 m for engineered design or 3,0 m for prescriptive design.

3.3 Prescriptive and performance-based approaches

Design documents are formulated on the basis of either prescriptive or performance-based designs, or combinations of both. Both approaches can take the form of pre-engineered solutions and it is sometimes difficult to disentangle them in a standard. In general, one would expect prescriptive measures to be more limited in application or more conservative than a fully engineered approach, but this is not always so.

The following are examples.

— AU: Bracing walls with minimum shear capacity require nominal fixing only and prescriptive fixings are provided for such cases; design criteria include system-based assumptions.

— CA: Mechanics-based lateral design method supplemented by tables; prescriptive bracing provisions, including consideration of non-structural elements included in Part C of the *Engeneering guide for wood-frame construction*.

— NZ: Prescriptive measures are based on tabulated bracing units equivalent to shear force (kN) per unit length or unit area; detailed provisions depend on building location and climatic data.

— US: Engineering lateral design method supplemented by prescriptive tables and specific framing details based on engineering assumptions and calculations.

3.4 Integration of national code provisions

National building codes vary from country to country and can include other sections related to light-frame construction, such as conventional construction provisions, loading and load factors, design principles and methods. On the other hand, national codes cannot cover all that is needed to fully address light-frame construction. Therefore, the documents either duplicate some of the national code provisions or make reference to them. Duplication is more complete, but can also lead to errors, revisions and national code interpretation questions.

The following are examples.

— AU: AS 1684-1, AS 1684-2 and AS 1684-3 include many prescriptive and engineering design and loading provisions, as well as reference to other documents forming part of the criteria for residential timber-framed construction to show conformance to national code requirements.

— CA: National code includes separate provisions for both fully-engineered and prescriptive design of wood buildings, therefore the *Engineering guide for wood-frame construction* includes selective provisions on loads and design assumptions to ensure understanding of which are applicable it.

— NZ: National code is a high-level performance-based document without specific provisions for light-frame construction, therefore NZ 3604 includes all aspects of design for these types of buildings, but does not include all load and design provisions.

— US: National codes include specific provisions for prescriptive braced walls which may be used for conventional construction, but these provisions are not included in the *Wood Frame Construction Manual*; the *Wood Frame Construction Manual* includes design provisions with reference to the national code for further load information.

3.5 Scope of structural design

Structural design of light-frame construction can include design of foundations, components, ancillary buildings, hybrid concrete-wood construction and other types of structures. Some of the documents include provisions for design aspects of these non-wood structures, while others are limited to the basic wood-frame construction system. AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual* stress the need for load path continuity throughout the structure.

The following are examples.

— AU: AS 1684-1, AS 1684-2 and AS 1684-3 include detailed provisions for concrete foundations, piers, stumps, columns and slabs; AS 1684-1, AS 1684-2 and AS 1684-3 also includes building practice and procedures to assist in correct specification and construction procedures.

— CA: The *Engineering guide for wood-frame construction* does not cover specific foundation design, but includes forces and design provisions for attachment of walls to foundation and anchor bolt capacities; it also contains detailed prescriptive provisions for connecting braced walls to foundation.

— NZ: Includes detailed provisions for site requirements, foundations, expansive soils, slabs, piles, lintels, claddings, linings and ceilings; concrete masonry walls included as part of framing system; some design aspects covered by reference to other standards.

— US: Does not cover specific foundation design, but includes forces and connection design provisions for attachment of walls to foundation or crawl spaces, and anchor bolt capacities.

3.6 Beyond structural requirements, such as durability

Regulation of wood-frame construction does not end with structural requirements. Durability issues are of equal concern and can also be linked to structural issues resulting from high-wind and seismic events, e.g. corrosion, decay, mould and ventilation. Some of these documents are limited to structural design, while some cover other aspects of national code requirements.

The following are examples.

— AU: Includes durability provisions for timber, hardware, service conditions by reference to other standards and informative appendices on durability classes and timber properties.

— CA: Addresses structural requirements only; durability is outside scope, other than a general requirement to consider decay resistance in design of the structure.

— NZ: Includes section on durability covering timber, hardware, service conditions, claddings, underlay, sheathing, concrete, sealants and flashings; it does not include full details related to protection of the building envelope.

— US: Addresses structural requirements only; it is not applicable to durability.

4 Loads and load factors

4.1 General

Because loading is dictated largely by national codes, there are load differences between AS 1684-1, AS 1684-2, AS 1684-3, the Engineering guide for wood-frame construction, NZS 3604 and the Wood Frame Construction Manual. However, these differences are not so large as to change the nature of the light-frame construction system or the demands placed on the system.

4.2 Basic design framework and philosophy

All except the *Wood Frame Construction Manual* are based on factored load and resistance Limit states design format. While the *Wood Frame Construction Manual* is in unfactored or Working stress design format in accordance with general US practice, the referenced US wood design standard is available in dual (factored and unfactored) format. Another framework choice relates to decisions about design for load combinations, including the probability of simultaneous occurrence of maximum design loads.

The following are examples.

— AU: Loads and capacities based on Limit states design; calculations include consideration of various combinations and patterns of permanent and transient loads for single span, continuous and cantilevered spans.

— CA: Loads and capacities based on Limit states design; primary members designed for single spans under uniform loading with point loads as appropriate; reductions apply where multiple transient loads are considered together.

— NZ: Loads and capacities based on Limit states design; national code requires compliance but does not stipulate how to comply; intent of NZS 3604 is to provide acceptable “non-specific” pre-engineered solutions; some design capacities are referenced to test results.

— US: Loads and capacities based on Working stress design, although multi-level load combination factors based on factored load approach; primary members designed for single spans under uniform or unbalanced (snow) loading with point loads as appropriate.

4.3 Load comparisons

Comparison of load levels in AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual* is not straightforward because of the many load and resistance adjustments forming part of the design methods in different countries. In some cases, cross-boundary comparisons are misleading due to offsetting load and resistance modifications. National committees make many different decisions about how to characterize loads, e.g. return period, statistical parameters and modification factors.

The following are examples.

— AU: Permanent and transient loads are listed as specified loads along with associated load factors; loads are modified by additional load distribution factors depending on construction variables.

— CA: Live loads, F_{L}, snow loads, F_{snow}, rain loads, F_{rain}, wind loads, F_{wind}, earthquake loads and dead loads, F_{D}, are listed as specified loads, along with associated load factors; wind load calculations involve many additional gust factors.

— NZ: Live loads, F_{L}, are listed in the standard without identified modification factors and adjustments.

— US: Live, snow, wind, earthquake loads and dead loads are specified; loads are based on unfactored Working stress design, and wind calculations involve many additional load modifications.

5 Material specifications

5.1 General

AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual* address material specifications and resistances for standard and non-standard products, including engineered wood and connections.

5.2 Product standards

Each document includes domestic material references and specifications accepted by the authority having jurisdiction. While these references tend to be limited to national standards and other documents, there is some provision for acceptance of other specifications as needed.

The following are examples.

— AU: References to applicable standards and supplements; alternative seasoned and unseasoned timber sizes also provided.

— CA: References to applicable material and design standards provided.

— NZ: Materials limited to two species, specific sizes and grades; other specifications require alternative solutions.

— US: References to applicable material and design standards provided.

5.3 Proprietary wood products

Proprietary wood products, such as I-joists and structural composite lumber, expand wood-frame construction through increased spans or load-carrying capacities. AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual* have sought to integrate these products as much as possible, although their proprietary nature makes it impossible to include complete design information.

The following are examples.

— AU: Proprietary engineered wood product use subject to approval of building authority and manufacturer's recommendations.

— CA: Proprietary engineered wood product use in accordance with QA programme supervised by independent third party certification organization and as stated in the manufacturer's report.

— NZ: Proprietary products subject to approval of authorities, with testing standards referenced for evaluating proprietary products.

— US: Proprietary engineered wood product use according to the national code and the manufacturer's report.

6 Member design

6.1 General

In accordance with the relevant national code, members are designed to meet specific strength and serviceability limits. At the same time, AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual* are useful in helping set those limits because performance levels are complex and calculated or prescribed solutions are only approximations of actual performance. Light-frame wood systems have a long performance history that is also considered in developing AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual*. Calculations, partial calculations or prescriptive determinations of roof, floor and wall provisions are included.

6.2 Member vs. system design

AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual* are based on a national material design standard that covers design of wood or timber members and their connections, including provisions for structural components or systems which go beyond single member design methodology, adding greater efficiency or accuracy to specified end uses. System design is typically referenced to other standard documents, based on full-sized tests, models or historical experience or a combination of these.

The following are examples.

— AU: Design criteria include system-based assumptions to recognize the interaction between structural and other elements of the construction assembly; any changes to materials or methods can invalidate these assumptions.

— CA: Design criteria for framing members include system action, strength sharing and special short-term load duration; built-up members also have system factors.

— NZ: Design criteria include bracing system capacities which are based on test results.

— US: Design criteria for framing members include factors for composite action and load sharing.

— Other jurisdictions also have design standards which address timber assemblies and systems. For example EN 1995-1-1 and EN 1995-1-2 include design provisions for trusses, shearwalls, diaphragms and system design.

6.3 Roofs

Roof design is typically simplified for light-frame construction, taking into account the complexity of roof shapes and systems. As a result, AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame construction*, NZS 3604 and the *Wood Frame Construction Manual* do not always require consideration of roof live or snow load patterns and can permit reduced gravity loads. Roof trusses tend to have more complete engineering solutions than rafter systems, but can also be calibrated up to limits of span and building size. Wind uplift on roofs is a different matter (see Clause 7).

The following are examples.

— AU: Roof members designed as sloped bending member under uniform and point live loads, coupled or uncoupled with ceiling joists; deflection calculated on basis of span along axis.

— CA: Roof members designed as sloped bending member under gravity and wind loads, F_{wind}, supported at top and bottom or as rafter connected to ridge board at top and ceiling joist at bottom; deflection on horizontal projection.

— NZ: Roof members designed to resist vertical wind and roofing loads, with rafters either coupled with ceilings or supported by ridge beam.

— US: Roof members designed as sloped bending member under gravity and wind loads, supported at top and bottom or as roof rafter connected to ridge board at top and ceiling joist at bottom; deflection on horizontal projection.

6.4 Walls

For light-frame walls up to 3 m in height, stud design tends to be governed more by practical constraints, such as the spacing of interior lining attachment, rather than by structural requirements. Where they are engineered, wall studs are designed to resist axial and lateral loads, alone or in combination. Where open spaces or vaulted ceilings require taller studs, special tables or designs are provided.

The following are examples.

— AU: Wall studs designed for axial forces from supported floors or roofs, as well as for horizontal bending loads.

— CA: Wall studs designed for bending, axial and axial-bending cases; bending-axial design has lower wind pressure coefficients than bending design alone.

— NZ: Wall studs designed to resist vertical loads as well as to resist horizontal loads separately.

— US: Wall studs designed for bending, axial and axial-bending cases; bending-axial design has lower wind pressure coefficients than bending design alone.

6.5 Floors

Floor design solutions are based on National performance criteria, and serviceability criteria—more than strength criteria — typically limit joist spans. Proprietary engineered wood members provide acceptable alternative solutions, but can also achieve longer spans and involve special design considerations, therefore member design and documentation in accordance with specified procedures and reports are required.

The following are examples.

— AU: Floor joists designed as bending members under permanent, transient and point loading: single span, continuous or cantilevered spans; serviceability includes deflection and dynamic criteria.

— CA: Floor joists designed for gravity loads and, in the case of diaphragms, designed for lateral loads; serviceability criteria include deflection and vibration performance.

— NZ: Floor joists pre-engineered for tabulated spans and loads.

— US: Floor joists designed for gravity loads and, in the case of diaphragms, designed for lateral loads; serviceability criteria includes deflection performance.

7 Lateral load systems design

7.1 General

Most questions about structural performance of light-frame construction systems arise from lateral load design, including shear, uplift and overturning. This is a topic of interest to national code bodies and an active area of research, so it's not surprising that the various documents provide different solutions. Each committee has had to decide whether lateral load resistance provisions were to be calculated, partially calculated or determined prescriptively in specific cases.

7.2 Linking lateral design to analysis models

In general, structural analysis methodology is not the principal subject of AS 1684-1, AS 1684-2, AS 1684-3, the *Engineering guide for wood-frame constructio*n, NZS 3604 or the *Wood Frame Construction Manual*. Nevertheless, design of the lateral load system can be predicated on assumptions about structural models in accordance with codes or general practice, and it is not always possible to separate analysis from design.

