Actions on Structures: Regulations and Standards

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ABSTRACT: This paper presents an overview of the historical development of Australian loading specifications followed by discussions on the regulatory and policy aspects of the development. These included the historical and rational reasons for the development of each individual standard as well as the state of the current system. It is hoped that practitioners will gain some insights into the background and principles underpinning the system that is currently in place.

1 INTRODUCTION

This paper reviews actions on structures from an Australian regulatory perspective. The purpose is to provide practitioners with some insight into the background and principles underpinning the system currently in place. Discussions on specific actions such as wind and earthquake are covered by other papers. The paper is best read in conjunction with the current Building Code of Australia (BCA) and the Loading Standard Series AS/NZS 1170 and its Commentaries. The information in these documents is not going to be reproduced here.

There were a couple of changes in terminology that will affect the overall discussion in this paper:

a) The first is about the use of the word 'code'. Structural standards used to be referred to as 'codes' meaning 'codes of practice' e.g. loading code, steel code etc. In 1996, the BCA was introduced as the 'Building Code'. To avoid confusion, the word 'Code' is now used to denote the BCA and the word 'Standard' is used for Standards Australia (SA) publication.
b) The second change was introduced by SA itself to the loading terminology to conform to ISO in 2002. The most significant changes are: 'load' is re-placed by 'permanent action', 'live load' is replaced by 'imposed action'.

2 HISTORICAL BACKGROUND

The responsibility for building construction rests with the State and Territory governments. Loading specifications were originally included in State and Territory building regulations. For example, South Australia Building Acts, 1923-1964 Part II specified height restriction, live loads in accordance with types of occupancy and wind loads (South Australian Government 1965).

In 1952, Standard Association of Australia (SAA) published Int. 350 Minimum Design Loads on Buildings (SAA, 1952). It covered dead, live and wind load provisions in a single volume of 20 A5 pages. From that date onwards, the regulatory systems could refer to this document for their loading specifications; thus started the practice of 'referenced documents' in building regulations. For example, South Australian Government introduced this in an amendment in 1958 as an 'Alternative Computation of Loading' (South Australian Government, 1965). The committee responsible for preparing the SAA Loading Code (as it was known) consisted mainly of representatives from Commonwealth and State Public Works Departments. By using SAA, a national loading specification was achieved at a time when a national building regulatory system was out of reach.

In 1969, Int. 350 was revised and issued as AS CA34. It contained two parts. Part II - Wind Forces (SAA, 1971) was published separately; thus starting the process of fragmentation of the loading specification by independent 'expert' sub-committees. Earthquake loading and design was covered in a separate standard AS2121-1979 known as SAA Earthquake Code (SAA, 1979), independent of other loadings. This tradition of treating earthquake loading and design separately from other loading and design considerations still exists in many other countries. The SAA Loading Code specified loads as independent quantities, it was the material design codes (Steel, Concrete, Timber etc.) that decided how these loads are to be used in combinations in design.

In 1971, there was a change in designation to AS1170 which is still in place today. The major change, however, occurred in 1989 with the conversion to Limit States Design (LSD). The loading standard became the 'mother' of all structural standards, driving the whole design process. Major changes introduced with the LSD conversion included:

- Load combinations were specified in the loading code independent of the materials of construction (SA, 1989a).
- A new 'AS1170 - Part 3: Snow loads' was introduced in 1990 to coincide with the removal of all snow load provisions from State and Territory building regulations (SA, 1990).
- A new 'AS1170 - Part 4: Earthquake loads' was introduced in 1993 to supersede AS2121, thus terminating the practice of treating earthquakes separately from other loads (SA, 1993a).

The latest makeover occurred in 2002, when a joint Australian -New Zealand Loading Standard series was introduced. Changes introduced in this edition will be discussed in subsequent sections of this paper.

3 LIMIT STATE DESIGN SYSTEM

The loading specification is best viewed as part of the overall limit state design (LSD) system which was introduced in 1975 (SAA, 1975) but not operational in Australia until 1989 with a new revision of the loading specifications. The basic concept of LSD is that the 'action effects' must not exceed the available 'resistance' at both serviceability and ultimate limit states, i.e.

$$Q \leq R \tag{1}$$

where Q represents the design action effects and R represents the design resistance.

Both Q and R are considered as 'random variables' i.e. quantities that cannot be determined precisely. In design practice, Eq. (1) is replaced by

$$\gamma_Q \,.\, Q_N \leq \Phi\, R_N \tag{2}$$

where

γ_Q is the specified load factor for the nominated action effect Q_N.
Φ is the specified capacity factor for the nominated resistance R_N.
'specified' here means to be specified in an Australian Standard and 'nominated' means to be nominated in the Building Code of Australia or Australian Standard.

The relationship between these quantities is illustrated in Fig. 1.

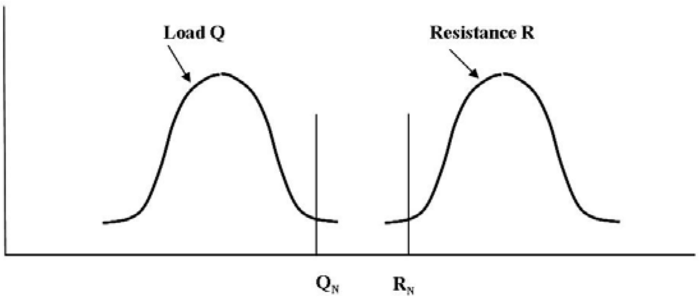

Figure 1: Compliant vertical surface-piercing cylinder

4 ROLES OF BUILDING CODE AND AUSTRALIAN STANDARDS

The specification of the levels of actions and resistance to be used in design is a public policy decision which is best determined by governments while the processes used in calculation can be standardized and published as standards. The separation of policy decisions and standardized processes is relevant for Australia because Australian Standards are produced by voluntary committees for a corporate entity. This is not an issue for countries where national standards are produced by national governments.

Prior to 2002, the Structural Provisions of the BCA consisted mainly of references to Australian Standards (ABCB, 1996). In Amendment 11 (ABCB, 2002), 'public policy matters, with respect to structural adequacy' were transferred from AS1170 to the BCA. At present, the Building Code of Australia (ABCB, 2006) chooses to nominate the following key components for the calculation of actions and resistance:

a) For actions, it specifies the Importance Levels for Buildings and Structures and the annual probabilities of exceedence of the design events for safety for Wind, Snow and Earthquakes.
b) For resistance, it specifies the five percentile characteristic material properties and factors that must be taken into considerations when determining resistance.

All other matters are dealt with in the Australian Standards. The relevant Standards are also referenced in the Building Code as they have become parts of the regulatory system.

It is worth noting that 'Standards' as prepared by SA are 'voluntary' standards. They become mandatory only if they are referenced in government regulations. There might be structures that are not within the jurisdiction of the BCA (e.g. mining structures) where it is advisable to check with the appropriate authorities whether SA publications are approved for use in design.

The act of 'referencing in the BCA' is the only independent checking mechanism available to ensure that the Australian Standards are not in conflict with government policies such as Competition Policy or other regulations such as Trade Practices Act. It is expected that, in the future, the examination of Australian Standards for referencing in the Building Code of Australia will be pursued with more rigor than current practice.

5 RISK MANAGEMENT AND LOADING SPECIFICATIONS

From the building regulatory perspective, loading specifications can be considered as a tool for risk management of buildings against natural or man-made disasters. The Importance Levels (ABCB, 2002) reflect the values and the expectations the community place on these types of buildings. The specification of the design events is the method used to describe the varying building performance expectation for different classes of buildings against extreme events.

The following points should be noted:

a) The design events for different natural phenomena need not be the same. The basic design event for Importance Level 2 buildings and structures, for example, is set at 1:500 for wind and earthquake and 1:150 for snow. The decision should be made based on the consequences of failure caused by a particular phenomenon. In reality, the current requirements were derived from a process called 'code calibration' to match actual practice.

b) While the design events are specified for ultimate limit states, the performance expectation at ultimate limit states was never defined precisely. It is generally accepted that the structure is expected not to collapse but substantially damaged when this condition is reached. The interpretation of the performance expectations for a 1:500 event of wind or earthquake for buildings of different Importance Level might be as follows:

- Buildings of Importance Level 1: not expect to survive
- Buildings of Importance Level 2: expect not to collapse but substantially damaged
- Buildings of Importance Level 3: expect to survive with some damage
- Buildings of Importance Level 4: expect to survive intact and continue to function

This is the rational for specifying lower annual probability of exceedance of the design events for higher level of importance of buildings.

c) The regulatory specified design events are MINIMUM requirements. The levels are not necessarily the most cost effective. The designers can always choose to design for a better level of protection. This may be worth considering if a small increase in cost will result in substantial increase in safety or performance.

6 STRUCTURAL RELIABILITY

There are various ways of defining the reliability of structure using the model of Fig. 1. The most commonly accepted measure is the probability of failure p_F as outlined in ISO2394 - General principles on reliability for structures (ISO, 1998), i.e.

$$p_F = \Pr \{ R < Q \}$$

The results are usually stated in terms of a safety index β defined by

$$p_F = \Phi(-\beta)$$

where $\Phi(\ )$ denotes the cumulative distribution function of a standardized unit normal variate.

The safety implicit in Australian structural standards was based on estimates of p_F for a 50 year period. A fairly extensive collection of these studies was reported in a special publication by the Institution of Engineers Australia (1985). Structural reliability theory had two major applications in the development of Limit State Design. One was to correct any major anomalies in safety within and between different sets of material design rules and the other was in the derivation of a basic set of load combinations for design.

7 LOAD COMBINATIONS

Prior to 1989, load combinations were given separately in each material design standard. The introduction of LSD provided an opportunity to unify different sets of load combinations into a single set to be placed in the Loading Standard. The adopted load combination set was the result of extensive reliability analysis aiming at achieving reasonable consistency in reliability levels for different combinations and material characteristics.

In addition to the use of reliability analysis, the load combinations for ultimate limit states were based on a simple rule for the combination of peak loads that stated the peak combinations of independent loads resulted from the combinations of the peak of one load and the arbitrary point-in-time values of other loads in the combination. This rule acknowledged that the probability of simultaneous occurrences of peak loads is very rare.

For serviceability consideration, load levels for short term and long term effects were proposed as benchmarks. Two sets of loads and load combinations were given to represent the following conditions with five percent chance of being exceeded:

a) Short term actions in which the specified serviceability loads were peak loads in a single year.
b) Long term action in which the specified serviceability loads were average loads over the lifetime of the building.

8 CURRENT AUSTRALIAN LOADING SPECIFICATION SYSTEM

The current Australian loading specification system has three components: AS1170 Series, Derivative Loading Specifications and Loadings on special structures.

8.1 *AS1170 Series*

This is the major Australian loading specification applicable to buildings and other structures. It includes the following parts:

AS/NZS 1170.0 Structural design actions Part 0: General principles (SA/SNZ, 2002a)
AS/NZS 1170.1 Structural design actions Part 1: Permanent, imposed and other actions (SA/SNZ, 2002b)
AS/NZS 1170.2 Structural design actions Part 2: Wind actions (SA/SNZ, 2002c)
AS/NZS 1170.3 Structural design actions Part 3: Snow actions (SA/SNZ, 2003)
AS1170.4 Structural design actions Part 4: Earthquake actions (The current version is still the 1993 version but a new version - Australia only - is expected to be published soon)

These Standards are referenced (or about to be referenced) in the BCA and therefore are part of the building regulatory system.

This series resulted from the effort to produce joint Australia - New Zealand Standards. Two major changes are worth noting:

a) The introduction of Part 0 - General principles where all design requirements and the methods for demonstrating compliance are discussed. These include design events for safety, load combinations, robustness and serviceability.

(i) For the specification of the design events for safety, AS1170.0 refers to the BCA. This arrangement resulted from the separation of ‘social policy’ and ‘standardized processes’ as discussed earlier.

(ii) The only major change to the load combinations from previous editions is the load factor for permanent load when acting in opposition to wind or other loads from 0.8 to 0.9. This revision was made to align the practice with those of New Zealand and the USA.

(iii) The specification for structural robustness is somewhat problematical. The specification of minimum resistance for members and connections is based on current accepted practice but does not address the issue in any meaningful way.

(iv) The serviceability criteria are included as an ‘informative’ appendix. This implies that there is considerable room for ‘engineering judgment’ in serviceability design, as it should be. In regulatory terms, it means that while it is mandatory to consider serviceability conditions, the exact criteria to be used in design are still up to the designer judgment.

b) Earthquake Loading Standard: In contrast to other parts of the AS1170 Series, Part 4 - Earthquake loads contains considerable material design requirements that are further supplemented in material design standards in the form of appendices. Attempts to have a joint standard with New Zealand on earthquake have been unsuccessful; not only because the seismic conditions are fundamentally different but also the design philosophy and practice in the two countries are also radically different. A joint earthquake standard would need a large educational campaign to explain the changes and is considered not to be in the national interest.

8.2 *Derivative Loading Specifications*

There are also derivative loading specifications that give specific interpretations of the actions and action combinations to be used in a particular class of buildings, such as:

AS4055 - Wind load for housing (SA, 2006): The Standard was first introduced in 1992 to facilitate the specification of wind loads for low-rise single family dwelling. It includes a wind classification system for use in conjunction with deemed-to satisfy 'span' tables such as AS1684.2 (SA, 1999). One of the rational for its introduction was to provide a 'simple' interpretation of AS1170.2, which was considered to be too complicated for house designers.

NASH Standard Residential and Low-rise Steel Framing Part 1: Design Criteria (NASH, 2005): This document is to replace AS3623-1993: Domestic metal framing (SA, 1993b). The technical reason for having this Standard is to provide designers with a set of design criteria for steel house framing. This has proven necessary because, unlike timber which has standardized span tables, all steel framing systems are proprietary products and each must have its own span tables. A common set of design criteria, including loads and load combinations, is necessary for public safety as well as the functioning of the market. The publication of this document under the auspices of the National Association of Steel-framed Housing also indicated the Australian Building Codes Board's willingness to reference sources other than Standards Australia as long as they can demonstrate their willingness to comply with the regulatory protocol for referencing which was designed to protect public interest.

These two documents are also referenced in the BCA.

8.3 *Loadings on special structuress*

There are also loading recommendations for special structures, usually published together with design procedures as Australian Standards, such as:

AS3774 - Loads on bulk solid containers
AS3995 - Design of steel lattice tower and masts

These documents are not referenced in the BCA since these special structures are outside its jurisdiction.

9 CONCLUSIONS

A brief overview of the historical development of Australian loading specifications was presented. The paper focused on regulatory and policy aspects of the development. These included the historical and rational reasons for the development of each individual standard as well as the state of the current system. It is hoped that practitioners will gain some insights into the background and principles underpinning the system that is currently in place.

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