VERIFICATION METHODS FOR STRUCTURAL PERFORMANCE

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ABSTRACT: *The Australian National Construction Code (NCC) has recently introduced a verification method for strength BV1 and a verification method for robustness BV2. BV1 requires the reliability indices established for permanent, imposed, wind, snow and earthquake to be equal to a set of target indices provided for in the NCC. BV2 introduces the 'notional removal of structural elements' as a verification method for robustness. The paper reports on issues encountered in actual applications. The stringency levels of acceptability are high for some applications and there are some issues with the interpretation of the rules in their present forms. The verification methods are capable of wide range of usage and their stringency should be set at appropriate levels depending on applications.*

KEYWORDS: reliability, robustness, structural engineering, performance verification

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1 INTRODUCTION

Two basic performance attributes that any structure must have are *reliability* and *robustness*:

Reliability is the ability of the structure to cope with all *predictable* events such as usage, high wind, earthquake, flood etc. Structures must function as intended under *normal* events and must not collapse under *extreme* events. *Predictable* events can be defined (usually by statistical methods) and are prescribed in standards and regulations.

Robustness is the ability to cope with all *unpredictable* events such as accidents, human errors etc. *Unpredictable events* cannot be defined or prescribed by their very nature.

Reliability and robustness are abstract concepts, intuitively understood by the practitioners who are more concerned with *how* to achieve them rather than defining *what* they are. Past and existing standards and regulations are mainly prescriptive in the sense that they prescribe the processes of 'how' to achieve certain levels of reliability and robustness that found to be satisfactory from past experience without quantifying them in any way. With the development of 'performance-based' standards and regulations, that are more concerned with the outcomes than how to achieve them, there is an increasing need to have these concepts defined and processes developed for their verifications.

The Australian National Construction Code (NCC) has introduced a verification method for strength and a verification method for robustness for its structural performance requirements [1]. This paper reports some issues associated with the applications of these verification methods in practice.

2 VERIFICATION METHOD FOR STRENGTH

2.1 DESCRIPTION OF THE METHOD

Reliability is about uncertainties involved in the design and construction processes including loadings, material properties, fabrication, design theories etc. These parameters can be quantified and their characteristics can be statistically assessed. Benchmark reliability indices can be developed, requiring all structures to achieve certain level of reliability.

The verification method for strength BV1 is based on structural reliability theory, i.e. probabilistic modelling of structural actions and resistance from which a probability of failure (or reliability index) can be computed. The method is established in ISO 2394 [2]. Probabilistic models for known types of actions such as permanent, imposed, wind, snow and earthquake are established based on standard specifications for these actions. A probabilistic model for resistance is required to be established by the user. From these models, a reliability index can be computed. The NCC verification method requires the reliability indices thus established for permanent, imposed, wind, snow and earthquake to be at least equal to a set of target indices provided for in the NCC. More complete description of the method can be found in ABCB Structural Reliability Handbook [3].

Features of the method BV1 that are to be noted include:

- BV1 provides a closed form solution for the calculation of the reliability indices. The formulae appear to be complicated compared with those used earlier (e.g. Ravindra and Galambos[4]) because of the need to cater for large coefficients of variation of live and wind loads and possibly of the resistance. The reliability indices are annual values thus avoiding the need for assuming a 50 year life.
- The target indices provide in the NCC are the results of calibration with existing practice. They represent the average values of the indices with a fairly wide spread of results (±1).
- The NCC makes the distinction between 'primary' and 'other' structural components (i.e. members and connections). 'Primary' components are defined as components 'whose failure could result in the collapse of the building'. Targets for 'primary' components are higher than for 'other' components.

2.2 ISSUES WITH ITS APPLICATION

BV1 is provided as an option for demonstrating conformance with NCC performance requirement. It needs to be used only if there are no NCC referenced documents that can be used to obtain the necessary information for design. It has been used to derive the capacity factor (ϕ factor) for new structural products that there is no applicable ϕ from NCC referenced documents. It has also been used in the conversion of overseas standards or design procedures for used in Australia. Issues associated with these applications include:

- Table 1 shows typical results for an anchor system [5]. The capacity factors required to achieve the NCC target reliability indices are

tabulated. Thus a capacity factor of 0.67 will be satisfactory for all cases except non-cyclonic wind action. Similar outcomes have been reported for other cases, indicating that either non-cyclonic wind action is the most critical or there are some problems with the setting of the non-cyclonic wind design wind speed.

Table 1: *Capacity factors to achieve target indices*

Load type	Importance Level	Capacity factor to achieve target reliability indices	
		As 'primary'	As 'other'
Permanent action	1 - 4	0.77	0.81
Imposed action	1 - 4	0.68	0.77
Non cyclonic wind action	1	0.58	0.68
	2	0.64	0.74
	3	0.61	0.71
	4	0.59	0.68
Cyclonic wind action	1	0.68	0.84
	2	0.68	0.85
	3	0.67	0.83
	4	0.66	0.82

- The NCC distinction of 'primary' and 'other' members and connections could be a problem when BV1 is used for the determination of φ factors for design standards as most current design standards do not make this distinction with the exception of the timber design standard AS1720. It is therefore proposed that this distinction should not be made for standard application and only a single set of target is to be used. Whether the reliability should be increased for critical members whose failures could result in the collapse of the structures is a judgement call and should be left at the discretion of the designers.
- The current NCC acceptance criteria must be interpreted as 'minimum criteria' and do not reflect their origin as an average value from calibration with existing practice. This is again a problem when single value of ϕ is selected for a particular load effect as in standards. This problem can be overcome by setting an average and a minimum reliability target as shown in Table 2. The ϕ value is then the average of the ϕ's obtained with the average reliability targets and the resulting reliability when using this φ shall be greater than the minimum reliability targets.

  It is understandable that the NCC is more conservative when dealing with new innovative products. The new proposed revised target however will align more closely with existing practice enabling the new product to be competitive with existing ones.

Table 2: *Proposed revised reliability targets*

Load type	Importance level	Average targets	Minimum targets
Permanent and imposed action	1-4	3.5 (3.8)	3.2 (3.5)
Wind, Snow and Earthquake	1	2.9 (3.2)	2.6 (2.9)
	2	3.1 (3.4)	2.8 (3.1)
	3	3.3 (3.6)	3.0 (3.3)
	4	3.5 (3.8)	3.2 (3.5)

Note: The values in ( ) are for cases when failure of a component could cause the collapse of the structure (average and minimum reliability targets increased by 0.3)

For the example as given in Table 1 above, this procedure will yield an average ϕ of 0.66 for primary components and 0.77 for 'other' components. The corresponding reliability indices are above the minimum targets for in both cases.

3 VERIFICATION METHOD FOR ROBUSTNESS

3.1 DESCRIPTION OF THE METHOD

Robustness is about how to cope with unpredictable events to ensure that the consequential damages are proportional to the magnitudes of the events, i.e. no progressive or disproportionate collapses. Because the magnitudes of the events cannot be specified, the problem is one of risk management. There have been many rules incorporated in regulations and standards to ensure robustness of structures. Most of the rules are prescriptive, i.e. they describe how to achieve certain level of unspecified robustness

without quantifying the concept. These include provisions for minimum requirements, for vertical and horizontal ties, for notional horizontal forces etc.
The verification method for robustness BV2 is based on the concept of 'notional element removal'. Structural elements such as a column, a beam or a wall segment are hypothetically removed from the structure one at a time and the resulting damages must be within NCC defined limits. More complete description of the method can be found in ABCB Structural Robustness Handbook [6].

Features of the method BV2 that are to be noted include:

- Notional element removal is one of many techniques that have been used to improve the robustness of structure. It is the only technique that fits the criteria as a performance verification method i.e. non prescriptive and generic.
- The defined acceptable limits for damages are the same as those used in UK building regulation but without any limits on its applications.
- The risk assessment is offered as the 'way out' when it is not possible to comply with the requirement.

3.2 ISSUES WITH ITS APPLICATION

BV2 is provided as an option for demonstrating conformance with NCC performance requirement. It needs to be used only if there are no NCC referenced documents that can be used to obtain the necessary information for design.

Australian loading and design standards have include many explicit and implicit requirements designed to improve the robustness of structures. It is interesting to note that with the exception of the masonry design standard [7] robustness is not mentioned in any other material design standards.

Issues associated with the application of BV2 include:

- No clear guidance on when BV2 should be used. While it its use is not mandatory, some advice on areas for its application could be quite useful, e.g. robustness should be examined for structures of Importance Level 3 and 4.

- The criterion for acceptable damage is quite severe and it is doubtful that current design practice satisfies the requirement. A less stringent criterion such as damage should be limited to areas that the element is designed to support could be more practical and feasible.

- Different materials of construction and forms of structures have different problems with robustness, guidance on specific applications for each materials of construction such as steel, concrete, timber etc. could be useful.

4 CONCLUSIONS

The introduction of BV1 and BV2 in the NCC is a good thing as it is long overdue. The stringency levels of acceptability however are probably a bit too high and there are some issues with the application of the rules in their present forms. While it is understandable and acceptable that the NCC is and should be more conservative when dealing with new innovative products, the verification methods are capable of wider usage and their stringency should be set at appropriate levels depending on applications.

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