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Structural Reliability of Australian Standard AS 2870:2011 *Residential slabs and footings*

Purpose

The purpose of reporting structural reliability is to assist the ABCB[1] (and other organisations involved in building regulations) to determine whether structures designed and constructed in accordance with the documents will satisfy the structural performance requirements of the BCA[2]. In particular, the ABCB Building Codes Committee has expressed interest in reviewing changes in structural reliability resulting from the adoption of new or revised standards or design guides.

Scope

This report provides an estimate of the structural reliability of structures designed and constructed in accordance with AS 2870:2011 *Residential slabs and footings*, and the changes from AS 2870:1996.

Basis of Report

This report is based on the method set out in

> *Protocol - Structural Reliability of BCA Referenced Structural Design Documents, 2008*
> Ref: Q08020301-1

This is based, in turn, on the following report, which is quoted extensively herein.

> Pham, L., *Reliability Analysis of Australian Structural Standards, Report to the Association of Consulting Structural Engineers of NSW*, CSIRO Sustainable Ecosystems, July 2007

Limitations

1. This report deals only with structures that actually comply with AS 2870:2011. It considers the risk associated with failure due to the interaction of variable loads, variable materials and imprecise methods of analysis.
2. The failure to design and build in accordance with established standards 9including AS 2870) is the common cause of structural failure, rather than variability of loads on complying structures. This report does not deal with structures that are incorrectly designed or constructed, thus not complying with AS 2870.
3. The structural reliability of buildings as built depends also on matters that are outside the scope of AS 2970, such as adequate supervision, site control, quality assurance and certification. These are all matters that should be addressed independently.
4. Therefore, this report should be considered as an assessment of the ability of AS 2870:2011to deliver acceptable structural reliability; rather than an assessment of the structural reliability of buildings as built.

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[1] Australian Building Codes Board

[2] Building Code of Australia

5. Rigorous analysis for structural reliability should involve scientifically-based assessment of the variability of loads, deformations, materials properties and interaction of these. Because this report is based only on assumed values of variability, the absolute values for structural reliability must be considered to be approximate.
6. The ABCB Building Codes Committee has expressed interest in any change of structural reliability resulting from the adoption of new or revised standards or design guides. Changes in the design rules do not normally change the variability of the loads, deformations, materials. Therefore, the changes in reliability due to changes in the rules (reported herein) can be use as a meaningful guide for regulators.
7. Although structural reliability may calculated for both serviceability and ultimate limit states, it is often calculated and reported only for the ultimate limit state. This practice is maintained in this report.
8. Most of the considerations in AS 2870 relate to the minimisation and control of cracking (a serviceability limit state), rather than to structural collapse (the ultimate limit state). Therefore this report contains extensive comment on implications for cracking, in addition to a short discourse on the structural reliability for the ultimate limit state.

Forms of Construction

Background
When houses and other small buildings are constructed on clay or similar soils, moisture movements in the soils will lead to expansion and contraction of the soil causing the building to either cantilever beyond a shrinking soil mound or sag between an expanded soil rim.

When AS 2870.1:1988 was first published it was oriented principally towards buildings with clad frame, masonry veneer and full masonry superstructure. This remains the case with AS 2870:2011, although other forms of superstructure are also covered.[3]

AS 2870:2011 *Residential slabs and footings* is intended to replace and expand the provisions of the AS 2870:1996 *Residential slabs and footings - Construction*, for the design and construction of residential slabs and footings for small structures such as detached dwellings

Both versions of AS 2870 provide performance criteria, deemed-to-satisfy construction details and design methods for residential slabs and footings.

Clad Frames, Masonry Veneer and Full Masonry Superstructures
The most common form of new housing in Australia is clad framing of unreinforced masonry walls (either cavity or brick veneer) supported by reinforced concrete strip footings or stiffened raft slabs. As the supporting soil contracts or expands, the cantilevering or spanning concrete footings or rafts are forced by the mass of the supported building to deflect.

Any unreinforced masonry may crack, moving sympathetically with the deflected concrete supporting structures. The design solutions adopted in both versions of AS 2870 cater for this scenario by ensuring that the internal and external concrete beams or footings have sufficient depth to minimize the possible deflection, and articulating the masonry wall at points of weakness so that indiscriminate cracking is minimized. For relatively stable soils, these systems (in conjunction with articulation) will provide effective and economical solutions.

[3] An alternative form of construction is common in northern Australia. Walls consisting of strong panels of reinforced hollow masonry are tied monolithically to the concrete footings or slabs.

Other discreet superstructures, such as precast concrete, AAC panels and the like, are not specifically mentioned in AS 2870, although is reasonable to assume that the same rules could be applied.

Reinforced Masonry Superstructures acting monolithically with Slab/Footing Systems
In this system, the reinforced concrete slab or footing and the reinforced masonry wall are structurally connected via steel starter bars, and may be considered to act compositely to resist the loads when soil movement occurs.

The strong-stiff combination of wall and slab/footing spans discrete distances over expanding or shrinking foundations without cracking.

Both AS 2870:1996 and AS 2870:2011 cater for this form of construction, albeit in a brief way

Serviceability Limit State

Slab and Superstructure Serviceability
AS 2870 is principally concerned with serviceability of houses, in that is seeks (through the specification of concrete slabs and footings) to limit the development of cracks in concrete floor slabs and superstructures, thus minimising rainwater penetration and sticking of doors and windows.[4]

Theoretical Considerations
The purpose of a footing system is:

- Prevention of excessive movement of building components relative to each other; and
- Prevention of unsightly or structurally damaging cracks in masonry walls.

To some extent, these two criteria place different requirements on the footing system. While both will be satisfied by strong-stiff footings, this is not always practical. The footings alone often do not have sufficient stiffness and the designer must either find some means of enhancing their stiffness or, alternatively, arrange the walls in such a way that any movement does not lead to cracks or excessive differential movement.

A crack differs from a movement joint in that it is unintentional and its exact location is often unpredictable. However, not all cracks significantly diminish the structural integrity or aesthetics of a building as demonstrated by the following examples:

- Reinforced concrete slabs and reinforced concrete masonry walls crack under load, but the steel reinforcing bars provide tensile strength to the cracked sections and control the width of the cracks once they have formed.
- A relatively flexible paint may bridge small discontinuous cracks in mortar or masonry units, thus ensuring that these cracks do not detract aesthetically.

The first question is to define permissible crack widths in various combinations of masonry wall and coating type. The second is to predict what foundation movement can be tolerated before cracks exceeding those permissible limits will form.

Performance
The purpose of the "Performance" section not intended to set a level of performance for particular applications, which is the role of the BCA, but rather to define what the designs and details are most likely to achieve. Both versions of AS 2870 include similar definitions of the performance implicit in the design methods and the deemed-to-satisfy details included therein.

[4] This point is not made explicitly, although it is inferred through Clause 1.3.1 (discussed later in this report)

<u>AS 2870:2011</u>
Clause 1.3.1 states:

> **1.3.1 General**
>
> Buildings supported by footing systems designed and constructed in accordance with this Standard on a normal site (see Clause 1.3.2) that is—
>
> (a) not subject to abnormal moisture conditions; and
>
> (b) maintained such that the original site classification remains valid and abnormal moisture conditions do not develop (see Note 1);
>
> are expected to experience usually no damage, a low incidence of damage category 1 and an occasional incidence of damage category 2 (see Note 2).
>
> Classification of damage shall be as defined in Appendix C.
>
> NOTES:
>
> 1 Appendix B provides information and guidance on the maintenance of site foundation conditions.
>
> 2 Class A sites (as defined in Section 2) are not reactive to moisture and may have a lesser risk of damage to buildings constructed thereon.

<u>AS 2870:1996</u>
AS 2870:1996 Amendment 1 Clause 1.3.1 states:

> *The footing systems complying with this Standard are intended to achieve acceptable probabilities of serviceability and safety of the building during its design life. Buildings supported by footing systems designed and constructed in accordance with this Standard on a normal site (see Clause 1.3.2) which is:*
> *(a) not subject to abnormal moisture condition; and*
> *(b) maintained such that the original site classification remains valid and abnormal moisture conditions do not develop (see Note 1);*
> *are expected to experience usually no damage, a low incidence of damage category 1 and an occasional incidence of damage category 2 (see Note 2). Damage categories are defined in Appendix C.*

Serviceability Limit State
There have been some changes in the DTS (deemed-to-satisfy) provisions of AS 3700 Section 3 that imply subtle changes in structural reliability. These changes are relatively minor, and are principally concerned with serviceability considerations.

For example, there have been changes to Figure 3.1 for Stiffened Rafts, including the introduction of new Site Classes. This enables the DTS requirements to be matched more closely with the particular soil properties, and will lead to some savings. This implies a drop in structural reliability. Counter to this, there have been some increases in beam depth and reinforcement, implying and increase in structural reliability.

Whilst changes in the serviceability (cracking of slabs and superstructures, rainwater penetration and sticking doors and windows) are important, they are not critical to structural reliability based on the ability to resist collapse.

Ultimate Load Limit State

No Change in Structural Reliability
The following structural design clauses lead to no change in structural reliability.

- Appendix E – Stump Pads and Braced Stump Horizontal and Vertical Capacities.
  There are no significant changes

Changes that Lead to Increased Structural Reliability

- Fig 3.1 Stiffened Rafts
  There have been increases in the required depth of footing and reinforcement required in some applications covered by Figure 3.1. This represents an increase in structural reliability.

- Fig 3.4 Waffle Pod Rafts
  Provisions have been added full-masonry have been added.

- Clause 3.2.5 - Footings for Reinforced Masonry Superstructures
  The requirement for reinforcement has been increased from 3-L8TM to 3-L11TM. This approximately doubles the bending strength, and therefore represents an increase in structural reliability. The relevant clause is:

  3.2.5 Reinforced masonry

  Where a reinforced single-leaf masonry wall with a continuous reinforced bond beam is constructed directly above and structurally connected to a concrete edge beam, and complies with the minimum requirements for reinforced masonry walls in AS 4773.1, the beam may be 300 mm wide by 300 mm deep with 3-L11TM reinforcement.

- Section 5 (Detailing) and Section 6 (Construction Requirements)
  Improvements in both these sections will lead to subtle (but intangible) small increases in structural reliability.

Changes that Lead to Reduced Structural Reliability
There appear to be no changes leading to reduced structural reliability.

The introduction of additional Site Classes enables the DTS requirements to be matched more closely with the particular soil properties, and will lead to some savings. This implies a drop in structural reliability, although from a level that is already above normal expectations (because the serviceability considerations and the additional design requirements override).

Apparently Low Structural Reliability resulting from Clause 1.4.2

Context
Although there is no significant change in this part of the standard, there are a set of pre-existing circumstances where apparently low structural reliability could result from the use of Clause 1.4.2 for ultimate strength design of some elements.

One practical example is where the ultimate strength design of pad footings supporting the upper storey of two-storey houses is based on load factors specified in AS 2870 Clause 1.4.2, rather than (say) AS/NZS 1170. Such an design assumption is unlikely, but, if made, could compromise the expected safety against collapse.

AS 2870 Clause 1.4.2 "Design action effects"
This clause states:

> *Design for <u>serviceability and safety against structural failure or bearing failure</u> shall be based on design actions due to—*
>
> *(a) permanent action plus 0.5 imposed action; and*
>
> *(b) foundation movement.*
>
> *The permanent and imposed actions to be resisted shall be in accordance with AS/NZS 1170.1.*
>
> *Foundation movement shall be assessed as the movement that has less than 5% chance of being exceeded in the life of the building, which is taken to be 50 years.*
>
> *Design soil suction profiles shall be based on this concept and the values of soil suction given in Section 2 are deemed to comply with this requirement.*
>
> *Design for uplift shall be based on design action effects due to 0.9 permanent action plus wind action.*
>
> > *NOTE: For the wind actions to be resisted, see AS/NZS 1170.2 or AS 4055. Reactive soil movements and soil settlements shall be determined from permanent action plus 0.5 imposed action. Soil parameters shall be taken as mean values for each soil stratum. Design bearing capacity, including uplift, shall be not more than 0.33 multiplied by the ultimate bearing pressure. Design bearing capacity shall take into consideration both the site conditions and the ability of the building system to accommodate load-related settlement.*

From the point of view of structural reliability, the critical parts of AS 2870 Clause 1.4.2 are:

…..structural failure or bearing failure

- *permanent action (AS/NZS 1170.1)*
- ***0.5** imposed action (AS/NZS 1170.1)*
- *foundation movement - less than 5% chance of being exceeded in 50 years*

Probability of failure
The probability of a failure occurring is given by the following:

$p_F = \Pr\{ R < Q \} = \int F_R(x).\ f_Q(x).\ dx$

Where:

F_R =Cumulative Distribution Function of R (resistance)

f_Q = Probability Density Function of Q (load)

Calculation of Structural Reliability Index
A Structural Reliability Index is recognised as a more convenient means of expressing and comparing the probabilities of failure of buildings and components.

The Structural Reliability Index for lognormal distributions of load and resistance is given by to following[5]:

$$\text{Structural Reliability Index, } \beta = \frac{\{ (R_{mean} / S_{mean}) [(1 + V_{system}^2) / (1 + V_R^2)]^{0.5} \}}{\{\ln[(1 + V_{system}^2)(1 + V_R^2)]\}^{0.5}}$$

Where:

R and Q assumed log-normal distributions

R_m , Q_m are mean values

V_R , V_Q are coefficients of variation

3.2 Use of Reliability Indices
Reliability indices may be used as a guide when setting the load factors and resistance factors in design standards, although caution is suggested when determining and applying the criteria. As a guide, the following recommendations from ISO 2394 Table E1 have been included in this paper.

ISO 2394 Table E1 Target β-values (life-time, examples)				
Relative costs of safety measures	*Consequences of failure*			
	small	*some*	*moderate*	*Great*
High	*0*	*A 1.5*	*2.3*	*B 3.1*
Moderate	***1.3***	***2.3***	***3.1***	*C 3.8*
Low	*2.3*	*3.1*	*3.8*	*4.3*

Some suggestions are:

A: for serviceability limit states, use β = 0 for reversible and β = 1.5 for irreversible limit states.

B: for fatigue limit states, use β = 2.3 to β = 3.1, depending on the possibility of inspection.

C: for ultimate limit states, use the safety classes β = 3.1, 3.8 and 4.3.

The choice of target reliability indices should depends upon calibration of the reliability model. The values given in ISO 2394 are predicated on the use of the same or similar reliability models for various building systems

[5] For a comprehensive explanation, refer to the Report tot the Association of Consulting Structural Engineers (NSW) by Lam Pham (2007)

Assumed Target Reliability Indices
It is preferable that similar structures constructed of various building materials yield similar reliability indices for collapse, when subjected to the same loads.

The setting of criteria for the Reliability Indices of buildings is the responsibility of the Australian Building Codes Board.

In order to permit the sensible comparisons of various wall systems, it has been necessary to select some values for Structural Reliability Index for use in this paper. In the absence of clear guidelines, the following Reliability Indices have been adopted for purposes of examining the apparent reliability of the structures analyzed in this paper.

Type of Structure	Reason for selecting the particular Target Structural Reliability Index, β	Target Structural Reliability Index, β
Concrete slab-on-ground and concrete footings, which support only the ground floor and roof structure	The ultimate rupture of a concrete slab-on-ground or concrete footing, which supports only the ground floor and roof of single-storey structures, would lead to some small amount of damage of the structure, but is unlikely to cause injury or death. Therefore the consequence of failure is considered to be “small”. The relative costs of safety measures may be considered to be “moderate”.	1.3
Concrete slab-on-ground and concrete footing, which support the suspended storey and roof of two-storey structures	The ultimate rupture of a concrete slab-on-ground or concrete footing, which supports the suspended storey and roof of two-storey structures, would lead to some damage of the structure, but is unlikely to cause injury or death. Therefore the consequence of failure is considered to be “moderate”. The relative costs of safety measures may be considered to be “moderate”.	3.1

Comparison of Target, AS 2870 and AS/NZS 1170.0 Structural Reliability Indices

Structure	Justification	Target Structural Reliability, β	Calculated Structural Reliability, β, using AS 2870	Calculated Structural Reliability, β, using AS/NZS 1170.0
Concrete slab-on-ground & footings, supporting only ground floor & roof	Consequence of failure: small Relative costs: moderate	1.3	1.6	2.7
Concrete slab-on-ground & footings, supporting suspended storey and roof of two-storey structures	Consequence of failure: some Relative costs: moderate	3.1	1.0	3.0

Conclusion

Structural Reliability does not represent a problem for AS 2870, because it is concerned with concrete slabs and footings, constructed on ground that slowly moves with the foundations around them. i.e. no catastrophic failures of tall structures.

On this basis, one could argue for a quite low structural reliability requirement. Instead of the normal 3.1 or more, target Structural Reliability Indices could be as low as:

- 1.3 (for concrete slab-on-ground & footings, supporting only ground floor and roof); or
- 3.1 (for concrete slab-on-ground & footings, supporting suspended storey and roof of two-storey structures).

Calculating a theoretical Structural Reliability Index demonstrates the AS 2870 problem associated with the Imposed Load factor of 0.5 (instead of the normal 1.5, which leads to a relatively low index.

For the strength design of structural members

- In single storey houses, there may be reasonable structural reliability implicit in AS 2870.
- In two storey houses, AS /NZS 1170.0 should be used to calculate and combine the loads.

In summary, deformations and cracking should be based on the relatively long term imposed load application (i.e. load factor of 0.5 as per AS 2870 is appropriate), provided the short term ultimate strength is sufficient to prevent rupture (i.e. 1.5 as per AS/NZS 1170.0). This may require clarification in AS 2870.

Recommendations

It is recommended that:

- AS 2870:2011 be referenced in BCA:2011 Volume 2; and
- Standards Australia be requested to issue a clarification and/or amendment, which describes the appropriate approach to factoring imposed loads for purposes of strength design of footings and associated components.

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Appendix 1
Assumed Loads, Combinations and Material Properties

Load Case			2 storey γL 0.5 AS 2870	2 storey γL 1.5 AS/NZS 1170.0	1 storey γL 0.5 AS 2870	1 storey γL 1.5 AS/NZS 1170.0
Permanent Action Effect						
Is the load acting?			Yes	Yes	Yes	Yes
Load caused by			Concrete slab	Concrete slab	Roof	Roof
Design Input						
Thickness		mm	125	125	0	0
Density		kN/m^3	25	25	25	25
Slab load		kPa	3.125	3.125	0	0
Partition load		kPa	1.00	1.00	1.00	1.00
Nominal load	G_n	kPa	4.13	4.13	1.00	1.00
Properties						
Mean / Nominal	G_m / G_n	-	1.00	1.00	1.00	1.00
COV		%	10%	10%	10%	10%
Mean	G_m	kPa	4.13	4.13	1.00	1.00
Design Values						
Characteristic (Nominal)		kPa	4.13	4.13	1.00	1.00
Load factor		-	1.00	1.20	1.00	1.20
Design load		kPa	4.13	4.95	1.00	1.20
Imposed Action Effect						
Is the load acting?			Yes	Yes	Yes	Yes
Load caused by			Residential	Residential	Residential	Residential
Design Input						
Floor distributed load		kPa	2.00	2.00	0.25	0.25
Other load		kPa	0.00	0.00	0.00	0.00
Nominal load	Q_n	kPa	2.00	2.00	0.25	0.25
Properties						
Mean / Nominal	G_m / G_n	-	0.74	0.74	0.74	0.74
COV		%	25%	25%	25%	25%
Mean	Q_{pm}	kPa	1.48	1.48	0.19	0.19
Design Values						
Characteristic (Nominal)		kPa	2.00	2.00	0.25	0.25
Load factor		-	0.50	1.50	0.50	1.50
Design load		kPa	1.00	3.00	0.13	0.38
Resistances						
Material and application			0.80	0.80	0.80	0.80
Standard			AS 3600	AS 3600	AS 3600	AS 3600
Capacity reduction factor	?	-	0.80	0.80	0.80	0.80
Design resistance	R_d		6.41	9.94	1.41	1.97
COV Material	$V_{R\ mat}$	%	15.0%	NA	15.0%	15.0%
COV Construction	$V_{R\ con}$	%	5.0%	NA	5.0%	5.0%
COV Analysis	$V_{R\ ana}$	%	5.0%	NA	5.0%	5.0%
Means and Coefficients of Variation						
COV Action effects	V_Q	%	26.9%	26.9%	26.9%	26.9%
Mean Action effect	Q_m	kPa	5.61	5.61	1.19	1.19
COV Resistance	V_R	%	15.0%	15.0%	16.6%	16.6%
Mean Resistance	R_m	kPa	7.37	13.71	1.94	2.71
Structural Reliability						
Structural reliability index	β	-	0.98	3.02	1.64	2.72

Reliability Index, $\beta = \{(R_m / Q_m)\ [(1+V_Q^2)/(1+V_R^2)]^{0.5}\} / \{\ln\ [(1+V_Q^2)\ (1+V_R^2)]\}^{0.5}$

Where

- R and Q are assumed to have log-normal distributions
- R_m , Q_m are the mean values of R and Q respectively
- V_R , V_Q are the coefficients of variation of R and Q respectively

Appendix 2
Target Structural Reliability

BCA Requirements
The BCA does not mandate a quantitative level of Structural Reliability to be achieved for buildings or structural components. However, the performance requirements create a qualitative expectation that structures will not be prone to collapse. The implied degree of required structural reliability may be gauged from the commonly available structural standards.

Calculation of Structural Reliability[6]
The probability of failure, p_F, = Pr { R < Q } = $\int F_R(x).\ f_Q(x).\ dx$

Where

- F_R is the Cumulative Distribution Function (CDF) of R
- f_Q is the Probability Density Function (PDF) of Q.

Reliability Index, $\beta = \{(R_m / Q_m)\ [(1+V_Q^2)/(1+V_R^2)]^{0.5}\} / \{\ln [(1+V_Q^2)\ (1+V_R^2)]\}^{0.5}$

Where

- R and Q are assumed to have log-normal distributions
- R_m , Q_m are the mean values of R and Q respectively
- V_R , V_Q are the coefficients of variation of R and Q respectively

Limitations
Structural Reliability calculations rely on adequate data to construct probability models for action combinations, individual action effects and resistance of structural components. In general, only the means and (to some extent) coefficients of variation are known with any confidence. Therefore one should not place too much confidence in the reliability calculation. However it is a useful comparative measure to evaluate the relative reliability of various materials.

Target Reliability
Structural reliability indices may be used as a guide when setting the load factors and resistance factors in design standards, although caution is suggested when determining and applying the criteria. The choice of target reliability indices should depend upon calibration of the reliability model. The values given in ISO 2394 are predicated on the use of the same or similar reliability models for various building systems.

Target Reliability from ISO 2394
As a guide, the following recommendations from ISO 2394 Table E1 have been included.

ISO 2394 Table E1 Target β-values (life-time, examples)				
Relative costs of safety measures	Consequences of failure			
	small	some	moderate	Great
High	0	A 1.5	2.3	B 3.1
Moderate	**1.3**	**2.3**	**3.1**	C 3.8
Low	2.3	3.1	3.8	4.3

Some suggestions are:

A: for serviceability limit states, use β = 0 for reversible and β = 1.5 for irreversible limit states.
B: for fatigue limit states, use β = 2.3 to β = 3.1, depending on the possibility of inspection.
C: for ultimate limit states, use the safety classes β = 3.1, 3.8 and 4.3.”

Calculated Reliability from Various Australian Standards
Set out below are the structural reliability indices that result from design in accordance with the BCA and various Australian Standards.[7]

[6] For a comprehensive explanation, refer to Pham (2007)

[7] For the method of derivation of these indices, see Pham, L., *Reliability Analysis of Australian Structural Standards, Report to the Association of Consulting Structural Engineers of NSW*, CSIRO Sustainable Ecosystems, July 2007.

Metal Structures		
Component	Loading	Reliability Index, □□□[1]
Beam segments with full lateral support (φ = 0.9)	1.25 G 1.5 Q	3.0 4.2
Beam segments without full lateral support (φ = 0.9)	1.25 G 1.5 Q	2.4 3.9
Axially load columns (φ = 0.9)	1.25 G 1.5 Q	2.9 4.1
Bolted connections: 8.8 bolts in shear or tension(φ = 0.85)	1.25 G 1.5 Q	4.1 4.8
Ply in bearing: e/d>3.5 (φ = 0.85)	1.25 G 1.5 Q	4.0 4.8
Ply in bearing: e/d<3.5 (φ = 0.85)	1.25 G 1.5 Q	3.1 4.3
Fillet welds (φ = 0.9)	1.25 G 1.5 Q	4.2 5.2
Notes: 1. Calculated in accordance with the General Method 2. Reference Pham, L. 2007		

Concrete and Composite Structures		
Component	Load	Reliability Index, □□□[1]
Column sections (light r/f) (φ = 0.7)	1.5 G 1.8 Q	3.5 4.5
Short columns with small eccentricity (φ = 0.6)	1.25 G 1.5 Q	3.4 - 3.8 4.6 - 4.9
Short columns with large eccentricity (φ = 0.6)	1.25 G 1.5 Q	2.2 - 2.5 3.7 - 4.0
Long columns with small eccentricity (φ = 0.6)	1.25 G 1.5 Q	5.2 - 6.9 6.1 - 7.3
Long columns with large eccentricity (φ = 0.6)	1.25 G 1.5 Q	2.6 - 3.6 3.8 - 4.7
Composite beam (steel beam concrete slab) (φ = 0.8)	1.25 G 1.5 Q	3.6 4.7
Notes: 1. Calculated in accordance with the General Method 2. Reference Pham, L. 2007		

Timber Structures

Component	Loading	Reliability Index, □□□[1]
Bending strength (φ = 0.85)	1.25 G 1.5 Q	2.3 3.6
Connector strength (φ = 0.75)	1.25 G 1.5 Q	3.1 4.4

Notes:
1. Calculated in accordance with the General Method.
2. Reference Pham, L. 2007

Masonry Structures

Component	Loading	Reliability Index, □□□[1]
Wall under lateral wind - one way bending (φ = 0.6)	W_u	2.5[2a] 4.9[2b] 6.0[2c]

Notes:
1. Calculated in accordance with the mean value method
2. Values for the baseline case of a wall height 2.7m, width of 15 units (3.6m), non cyclonic wind using general method of reliability analysis with the following hypotheses for strength calculation: (a) weakest link, (b) parallel-brittle, (c) averaging
3. Reference Pham, L. 2007

Appendix 3
Definitions & Symbols

Limit states
States beyond which a structure no longer satisfies the design criteria [ISO 8930]
The boundaries between desired and undesired performance of the structure are often represented mathematically by ‘limit state functions’.

Structural reliability
Ability of a structure or structural element to fulfil the specified requirements, including the working life, for which it has been designed [ISO 2394]

Resistance (structural)
Ability to withstand actions including strength (e.g. bending strength, tension strength, buckling strength etc) and static equilibrium (or overall stability i.e. resistance to overturning, sliding etc.).

Ultimate limit states
A state associated with collapse, or with other similar forms of structural failure [ISO 2394]. They generally correspond to the maximum action-carrying resistance of a structure or structural element but in some cases to the maximum applicable strain or deformation.

Symbols

Φ = cumulative distribution function of a standardized unit normal variate.

φ = capacity factor

γ = action (load) factor

β = reliability index

p_F = probability of failure

α = a numerical constant

Q = a general symbol for action (load) effect

R = a general symbol for resistance