Improved Robustness of Performance Solutions – Structure examples calculations

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NCC 2025/Volume One

Example calculations following the proposed NCC 2025 B1V1 method

The following examples demonstrate the main steps to determine the level of reliability of structural components, using the proposed NCC 2025 B1V1 method.

It is assumed that all the resistance values are based on actual test data.

The focus of this example is NCC Volume One, however a similar process applies for NCC Volume Two.

These examples demonstrate how the Verification Method can be applied in a project specific application. When this method is used to develop capacity tables for products additional consideration is needed for a range of possible load combinations and scenarios.

Practical designs must consider other aspects (e.g. serviceability, robustness) which often result in structural reliability that is higher than the proposed minimum reliability indices in the NCC.

Summary of main steps and two worked-out examples

Main Steps:

1. Establish the resistance R
2. Work out the mean, standard deviation and coefficent of variation for R, therefore C_R
3. Determine all the actions
4. Work out the mean and standard deviation for each action. Work out the load combinations S, and V_s for the combined actions,therefore C_s
5. Work out the reliability index β, refer to B1V1. Compare with the corresponding minimum values of β in Tables B1P1a, B1P1b and B1P1c.

Step 1: Establish resistance model

The resistance model is a function of the variation in the structural resistance (standard deviation / coefficient of variation). The resistance model can be based on prototype testing of the component, in situ proof load testing, or material property and strength testing combined with analytical methods.

Where analytical methods are used, it is recommended that peer reviewed or established authoritative guidance or standards are used to determine the model wherever possible. Expressions may be established to calculate resistance from structural mechanics first principles for a particular design situation.

Step 2: Determine structural resistance

Strength testing is required as an input parameter in the resistance model. The extent of testing undertaken must be adequate to establish confidence in the resistance model for the situation. Tests carried out during the product development stage, must be interpreted to reflect the mean and coefficient of variation of actual construction, rather than a limited number of laboratory tests.

Analytical methods – Tested material strengths and properties are used as inputs to the structural first principles expressions. Testing should be undertaken on an appropriate number of samples to ensure that the design resistance is representative of the real resistance, with regard to material strength variability and quality assurance.

Proof load testing – Post-construction testing is undertaken of the component to demonstrate that it can resist the required actions. This testing is non-destructive to ensure that the testing does not compromise future in-service strength.

Prototype testing - For components which are manufactured as a production run, it is recommended that multiple units are tested to establish confidence in the resistance model for the population of components. If the unit / element is being manufactured on a regular basis, it is recommended that random testing be undertaken in a periodic manner.

Step 3: Determine nominal actions

Nominal actions must be established through reference to the AS1170 series of standards where possible. Actions not covered by the above series of standards must be determined on a case-by-case basis.

Step 4: Establish annual action models

The annual action models are established with the 'ratio of mean to nominal' and 'coefficient of variation' set out in Table B1V1a for each type of actions. For actions not listed, the ratio of mean to nominal and coefficient of variation of the specific action must be determined through statistical analysis.

Step 5: Determine reliability index

Determine the reliability index for the element using the formula given in B1V1(5)(b) and ensure this is equal to or greater than the minimum reliability indices given in Tables B1P1a, b and c.

Example 1: Glass Fibre Reinforced Concrete (GFRC)

This is an example calculation for glass-fibre reinforced concrete (GFRC) anchorages to demonstrate the process of the proposed NCC2025 Volume One B1V1 method. It should not be treated as a design guide for determining adequacy comprehensively.

This example determines the level of reliability of anchorages for GFRC panels used in an external soffit arrangement loaded in tension (pullout) on a specific project. The anchors are cast-in to the GFRC panels during manufacture and have been designed with appropriate degrees of freedom to avoid moment transfer into the GFRC panel. As there are no Deemed-to-Satisfy NCC Referenced Standards available for use for design of GFRC elements, the designer has opted to utilise the B1V1 Verification Method to determine that the design meets the minimum reliability levels set out in B1P1. This example considers only the tension loads which will act on the anchorage, however other loads may be applicable which would also need to be assessed.

The building for which this design case applies, is classified as Importance Level 2 and is located in wind region A.

In order to establish a resistance model, several sample anchorages have been tested in tension, in an identical manner to which they will be loaded in their designed configuration. These can be treated as prototype testing. The tests were performed on samples which were representative of the overall population which will be used on the project with a sample size adequate to provide confidence that results are representative of the population. Due to the sensitivity of GFRC material properties across various batches, the fabricator has tailored their quality control (QC) procedures to ensure the manufacturing is replicable and will also follow up with random quality assurance (QA) testing throughout the fabrication process. Adequate testing and QA processes are in place to ensure that in-service and time dependent effects such as fatigue, and weathering do not reduce the long-term performance of the anchorages.

RESISTANCE

Test results (pullout / tension):

Mean failure load: $\boldsymbol{\bar{R} = 2.02kN}$

Standard deviation: $\sigma_R = 0.195kN$

Coefficient of variation: $V_R = 0.097 = 9.7\%$

As the resistance coefficient of variation is less than 40%, the B1V1 method can be used as per B1V1(1).

As the resistance coefficient of variation is also less than 0.1, we adopt a $V_R = 0.10$ in accordance with B1V1(2); therefore:

Correction factor for resistance: $\boldsymbol{C_R = 1 + 0.1^2 = 1.01}$

ACTIONS

The anchorages for the GFRC panels will support both permanent actions (dead load) and wind actions in tension.

Permanent Action (G)

These panels are 1200mm wide, 1500mm in length and 30mm thick, and have 4 anchorages equally spaced near the panel corners. The unit weight of the GRC material is controlled by the fabricator through their in-house QC processes to not exceed 2200kg/m^3, however it is possible for a statistical model to be established if there is known, measurable variation in the weight of the GFRC panels. Considering an upper bound value is conservative in this instance.

Nominal permanent action: $G = \frac{1.2m \times 1.5m}{4} \times 0.03m \times 2200kg \cdot m^{-3} \times g = 0.291kN$

Ratio of mean action to nominal: $\frac{\bar{G}}{G} = 1.05$ (Table B1V1a)

Coefficient of variation of action: $V_G = 0.10$ (Table B1V1a)

Using these values, the mean and standard deviation of the permanent action can be established:

Mean permanent action: $\boldsymbol{\bar{G} = 1.05 \times 0.291kN = 0.306kN}$

Standard deviation, permanent action: $\boldsymbol{\sigma_G = 0.10 \times 0.306kN = 0.031kN}$

Wind Action

The wind action on the soffit is determined using AS/NZS 1170.2 to be 2kPa (suction), based on an average probability of exceedance of 1/500 (Importance Level 2). Therefore:

Nominal wind action: $W = \frac{1.2m \times 1.5m}{4} \times 2kPa = 0.90kN$

Ratio of mean action to nominal: $\frac{\bar{W}}{W} = 0.31$ (Table B1V1a)

Coefficient of variation of action: $V_W = 0.47$ (Table B1V1a)

Using these values, the mean and standard deviation of the permanent action can be established:

Mean wind action: $\boldsymbol{\bar{W} = 0.31 \times 0.9kN = 0.279kN}$

Standard deviation, wind action: $\boldsymbol{\sigma_W = 0.47 \times 0.279kN = 0.131kN}$

Combined actions

Gravity action only

Mean combined action: $\bar{S} = \bar{G} = 0.306kN$

Standard deviation, combined actions: $\sigma_S = \sigma_G = 0.031kN$

Coefficient of variation, comb. Actions: $V_S = V_G = 0.10$

Correction factor for action: $C_S = 1 + V_S^2 = 1 + 0.10^2 = 1.01$

Gravity action in combination with wind load

Mean combined action: $\bar{S} = \bar{G} + \bar{W} = 0.306kN + 0.279kN = 0.585kN$

Standard deviation, combined actions: $\sigma_S^2 = \sigma_G^2 + \sigma_W^2 = (0.031kN)^2 + (0.131kN)^2 = 0.018$

therefore: $\sigma_S = 0.135kN$

Coefficient of variation, comb. Actions: $V_S = \frac{0.135kN}{0.585kN} = 0.23$

Correction factor for action: $C_S = 1 + V_S^2 = 1 + 0.23^2 = 1.053$

RELIABILITY

Gravity action only

Reliability index: $\boldsymbol{\beta = \frac{\ln\left(\frac{R}{S} \cdot \sqrt{\frac{C_S}{C_R}}\right)}{\sqrt{\ln(C_S \cdot C_R)}}}$ (B1V1(5)(b))

$$\beta = \frac{\ln\left(\frac{2.02kN}{0.306kN}\sqrt{\frac{1.01}{1.01}}\right)}{\sqrt{\ln(1.01 \times 1.01)}}$$

$$\beta = \frac{1.887}{0.141} = 13.38$$

Minimum annual reliability index for gravity actions only: $\beta_{min} = 4.30$ (Table B1P1a)

Gravity action in combination with wind load

Reliability index: $$\boldsymbol{\beta} = \frac{\ln\left(\frac{\bar{R}}{\bar{S}} \cdot \sqrt{\frac{C_S}{C_R}}\right)}{\sqrt{\ln(C_S \cdot C_R)}}$$ (B1V1(5)(b))

$$\beta = \frac{\ln\left(\frac{2.02kN}{0.585kN}\sqrt{\frac{1.053}{1.01}}\right)}{\sqrt{\ln(1.053 \times 1.01)}}$$

$$\beta = \frac{1.260}{0.248} = 5.07$$

Minimum annual reliability index for combined actions: $\beta_{min} = 3.70$ (Table B1P1b)

The results of this assessment show that the GFRC anchorages can withstand the design permanent actions and combination of wind and permanent actions to a level of reliability greater than that required by clause B1P1(2).

Note this example only relates to the performance of the anchorages in tension (pullout) for the purposes of demonstrating the process of Verification Method B1V1. Further assessments which may be required to finalise the design of the GRC panel assembly include, but are not limited to:

- Anchorages loaded in shear due to horizontal loads, such as seismic actions or thermal effects.
- Any additional actions which have not been considered in the able example.
- Assessment for the overall structural performance of the GFRC panel.
- Assessment of the structural performance of the framing & fixings of the framing to the building structure.

Example 2: Mass Timber Beam in Bending

This is an example calculation for an engineered mass timber beam to demonstrate the process of the proposed NCC2025 Volume One B1V1 method. In this case, the manufactured beam is beyond the scope of NCC Deemed-to-Satisfy standards, therefore a Performance Solution is required. It should not be treated as a design guide for determining adequacy comprehensively.

This example determines the structural capacity of the beam in flexural bending used to support the top floor roof terrace of a multi-storey office building on a specific project. The building is an Importance Level 3 building, located in wind region B1, and is classified as Earthquake Design Category II (EDC II). For the purposes of this example, it is assumed that access to the roof terrace is restricted during extreme weather and that wind actions and imposed actions do not occur simultaneously.

The resistance is based on data provided by the manufacturer (random testing undertaken for each n units produced), and variability is controlled by their in-house quality control processes. There is variability both in the beam strength as well as in the geometry of the beam; both are taken into account in the overall resistance model using an analytical method from first principles. Adequate testing and QA processes are in place to ensure that in-service and time dependent effects such as fatigue, and environmental exposure do not reduce the long-term performance of the beams.

The beam size is 250mm width x 600mm height, the beams are spaced at 6m centres, and span 9m between supports. The beams are simply-supported (i.e. the end connections do not develop moment).

RESISTANCE

Mean flexural bending strength: $\overline{f_b} = 32MPa$

Standard deviation of bending strength: $\sigma_f = 4.6MPa$

Mean elastic section modulus: $\bar{Z} = \frac{0.25m \times (0.6m)^2}{6} = 0.015\ m^3$

Standard deviation of section modulus: $\sigma_z = 0.00075\ m^3$

Mean resistance – additive load combinations: $\boldsymbol{\overline{R} = \overline{f_b} \times \overline{Z} = 32MPa \times 0.015\ m^3 = 480kNm}$

Standard deviation of resistance: $\sigma_R^2 = (32MPa \cdot 0.75\mathrm{e}^{-3}m^3)^2 + (15\mathrm{e}^{-3}m^3 \cdot 4.6MPa)^2 + (4.6MPa \cdot 0.75\mathrm{e}^{-3}m^3)^2$

$\sigma_R = 73.1kNm$

Resistance coefficient of variation: $V_R = \frac{73.1kNm}{480kNm} = 15.2\%$

The resistance coefficient of variation is not more than 40%, therefore B1V1 method can be used as per B1V1(1).

Correction factor for resistance: $\boldsymbol{C_R = 1 + 0.152^2 = 1.023}$

Mean resistance – action reversal and stability load combinations: $\boldsymbol{\overline{R} = \overline{R_b} + \overline{G} = 480kNm + 138.3kNm = 618.3kNm}$

Note, in this combination the permanent action has a stabilising effect, therefore is considered as part of the resistance. The limit state function is: (R_B+G)-W in which R_B denotes the resistance of the beam. Therefore, the total resistance, R, of the structure is R= R_B+G. For determination of G and the standard deviation of G, refer further on where it is calculated under Actions – Permanent Action.

Standard deviation of resistance: $\sigma_R^2 = (73.1kNm)^2 + (13.8kNm)^2$

$\sigma_R = 74.39kNm$

Resistance coefficient of variation: $V_R = \frac{74.39kNm}{618.3kNm} = 12.03\%$

The resistance coefficient of variation is not more than 40%, therefore B1V1 method can be used as per B1V1(1).

Correction factor for resistance: $C_R = 1 + 0.1203^2 = 1.014$

ACTIONS

Permanent Action

The nominal weight of the structural floor slab plus superimposed dead load is taken as $G = 2.0kPa$ (floor slab, ceilings, partitions, floor coverings, etc). The unit weight of the timber is $6.7kN/m^3$. To make the comparison to the resistance easier, the actions are converted to design action effects (i.e. kNm bending moment in beam).

Self-weight of beam: $G_{beam} = 6.7kN/m^3 \cdot 0.6m \cdot 0.25m = 1kN/m$

Nominal permanent action effect: $G = (6m \cdot 2kPa + 1kN/m) \times \frac{(9\text{m})^2}{8} = 131.7\ kNm$

Ratio of mean action to nominal: $\frac{\bar{G}}{G} = 1.05$ (Table B1V1a)

Coefficient of variation of action: $V_G = 0.10$ (Table B1V1a)

Using these values, the mean and standard deviation of the permanent action can be established:

Mean permanent action effect: $\bar{G} = 1.05 \times 131.7kNm = 138.3\ kNm$

Standard deviation, permanent action: $\sigma_G = 0.10 \times 138.3kNm = 13.8\ kNm$

Imposed Action

The nominal imposed actions are taken from AS/NZS1170.1-2002 Table 3.1 as for Offices for general use.

Nominal imposed action effect: $Q = (3.0kPa \cdot 6m) \times \frac{(9\text{m})^2}{8} = 182.3\ kNm$

Annual maximum imposed action

Ratio of mean action to nominal: $\frac{\bar{Q}}{Q} = 0.35$ (Table B1V1a)

Coefficient of variation of action: $V_Q = 0.45$ (Table B1V1a)

Using these values, the mean and standard deviation of the imposed action can be established:

Mean imposed action effect: $\bar{Q} = 0.35 \times 182.3kNm = 63.8\ kNm$

Standard deviation, imposed action: $\sigma_Q = 0.45 \times 63.8kNm = 28.7\ kNm$

Arbitrary-point-in-time imposed action (for combination with earthquake actions)

Arbitrary-point-in-time (APT) factor is taken from AS/ZS1170.0-2002 Section 4.2.2(f), as $\psi_E = 0.3$.

APT imposed action effect: $Q_{apt} = (3.0kPa \cdot 6m \cdot 0.3) \times \frac{(9\text{m})^2}{8} = 54.7\ kNm$

Ratio of mean action to nominal: $\frac{\overline{Q_{apt}}}{Q_{apt}} = 0.25$ (Table B1V1a)

Coefficient of variation of action: $V_{Q.apt} = 0.78$ (Table B1V1a)

Using these values, the mean and standard deviation of the APT imposed action can be established:

Mean APT imposed action effect: $\overline{Q_{apt}} = 0.25 \times 54.7kNm = 13.7\ kNm$

Standard deviation, APT imposed action: $\boldsymbol{\sigma_{Q.apt} = 0.78 \times 13.7kNm = 10.7\ kNm}$

Earthquake Action

The earthquake actions are established by AS1170.4 method. The vertical component of the earthquake action is calculated as 0.1G. For the purposes of this example, the beam is considered to be well braced against lateral loads, so no consideration of biaxial bending is considered.

Nominal earthquake action effect: $E = (0.1 \cdot 6m \cdot 2kPa) \times \frac{(9m)^2}{8} = 12.2\ kNm$

Ratio of mean action to nominal: $\frac{\bar{E}}{E} = 0.12$ (Table B1V1a – Importance Level 3)

Coefficient of variation of action: $V_E = 0.90$ (Table B1V1a – Importance Level 3)

Using these values, the mean and standard deviation of the earthquake action can be established:

Mean earthquake action effect: $\boldsymbol{\bar{E} = 0.12 \times 12.2kNm = 1.46\ kNm}$

Standard deviation, earthquake action: $\boldsymbol{\sigma_E = 0.90 \times 1.46kNm = 1.31\ kNm}$

Wind Action

The wind actions are established in accordance with AS/NZS 1170.2 to be 0.75kPa ULS (maximum differential pressure across two floors). This wind action can act either upwards (action reversal) or downwards (additive).

Nominal wind action effect: $W = (6m \cdot 0.75kPa) \times \frac{(9m)^2}{8} = 45.6\ kNm$

Ratio of mean action to nominal: $\frac{\bar{W}}{W} = 0.29$ (Table B1V1a – Importance Level 3)

Coefficient of variation of action: $V_W = 0.47$ (Table B1V1a – Importance Level 3)

Using these values, the mean and standard deviation of the wind action can be established:

Mean wind action effect: $\boldsymbol{\overline{W} = 0.29 \times 45.6kNm = 13.2\ kNm}$

Standard deviation, wind action: $\boldsymbol{\sigma_W = 0.47 \times 1.46kNm = 6.21\ kNm}$

Combined actions

Permanent action only (gravity actions only)

Mean action effect: $\boldsymbol{\overline{S} = \overline{G} = 138.3kNm}$

Standard deviation, gravity actions: $\sigma_S = \sigma_G = 13.8\ kNm$

Coefficient of variation, comb. actions: $V_S = V_G = 0.1$

Correction factor for action: $\boldsymbol{C_S = 1 + V_S^2 = 1 + 0.1^2 = 1.01}$

Permanent action in combination with wind action (additive)

Mean combined action effect: $\boldsymbol{\overline{S} = \overline{G} + \overline{W} = 138.3kNm + 13.2kNm = 151.5\ kNm}$

Standard deviation, combined actions: $\sigma_S^2 = \sigma_G^2 + \sigma_Q^2$

$\sigma_S^2 = (13.8kNm)^2 + (6.21kNm)^2$

$\sigma_S^2 = 229 \cdot (kNm)^2$

therefore: $\sigma_S = 15.1\ kNm$

Coefficient of variation, comb. actions: $V_S = \frac{15.1kNm}{151.5kNm} = 0.1$

Correction factor for action: $\boldsymbol{C_S = 1 + V_S^2 = 1 + 0.1^2 = 1.01}$

Permanent action in combination with wind action (action reversal)

In this load combination the permanent action has a stabilising effect, therefore is considered as part of the resistance.

Mean combined action effect: $\boldsymbol{\overline{S} = \overline{W} = 13.2kNm}$

Coefficient of variation, comb. Actions: $Vs = Vw = 0.47$

Correction factor for action: $\boldsymbol{C_S = 1 + V_S^2 = 1 + 0.47^2 = 1.2209}$

Permanent action in combination with imposed action (additive)

Mean combined action effect: $\boldsymbol{\overline{S} = \overline{G} + \overline{Q} = 138.3kNm + 63.8kNm = 202.0\ kNm}$

Standard deviation, combined actions: $\sigma_S^2 = \sigma_G^2 + \sigma_Q^2$

$\sigma_S^2 = (13.8kNm)^2 + (28.7kNm)^2$

$\sigma_S^2 = 1015.1 \cdot (kNm)^2$

therefore: $\sigma_S = 31.9\ kNm$

Coefficient of variation, comb. actions: $V_S = \frac{31.9kNm}{202.0kNm} = 0.158$

Correction factor for action: $\boldsymbol{C_S = 1 + V_S^2 = 1 + 0.158^2 = 1.025}$

Permanent action in combination with earthquake action and arbitrary-point-in-time imposed action (additive)

Mean combined action effect: $\boldsymbol{\overline{S} = \overline{G} + \overline{E} + \overline{Q_{apt}}}$

$\boldsymbol{\overline{S} = 138.3kNm + 1.46kNm + 13.7kNm = 153.3\ kNm}$

Standard deviation, combined actions: $\sigma_S^2 = \sigma_G^2 + \sigma_E^2 + \sigma_{Q.apt}^2$

$\sigma_S^2 = (13.8kNm)^2 + (1.31kNm)^2 + (10.7kNm)^2$

$\sigma_S^2 = 306.6 \cdot (kNm)^2$

therefore: $\sigma_S = 17.5\ kNm$

Coefficient of variation, comb. actions: $V_S = \frac{17.5kNm}{153.3kNm} = 0.114$

Correction factor for action: $\boldsymbol{C_S = 1 + V_S^2 = 1 + 0.114^2 = 1.013}$

RELIABILITY

Permanent action only

Reliability index: $\boldsymbol{\beta = \frac{\ln\left(\frac{\overline{R}}{\overline{S}} \cdot \sqrt{\frac{C_S}{C_R}}\right)}{\sqrt{\ln(C_S \cdot C_R)}}}$ (B1V1(5)(b))

$\beta = \frac{\ln\left(\frac{480kNm}{138.3kN/m}\sqrt{\frac{1.01}{1.023}}\right)}{\sqrt{\ln(1.01 \times 1.023)}}$

$\boldsymbol{\beta = \frac{1.238}{0.181} = 6.85}$

Minimum annual reliability index for gravity actions: $\beta_{\min} = 4.30$ (Table B1P1a)

Permanent action in combination with wind action (additive)

Reliability index: $\boldsymbol{\beta = \frac{\ln\left(\frac{\overline{R}}{\overline{S}} \cdot \sqrt{\frac{C_S}{C_R}}\right)}{\sqrt{\ln(C_S \cdot C_R)}}}$ (B1V1(5)(b))

$\beta = \frac{\ln\left(\frac{480kNm}{151.5kN/m}\sqrt{\frac{1.01}{1.023}}\right)}{\sqrt{\ln(1.01 \times 1.023)}}$

$\boldsymbol{\beta = \frac{1.146}{0.181} = 6.34}$

Minimum annual reliability index for combined actions: $\beta_{\min} = 3.85$ (Table B1P1b)

Permanent action in combination with wind action (action reversal)

Reliability index: $\boldsymbol{\beta = \frac{\ln\left(\frac{\overline{R}}{\overline{S}} \cdot \sqrt{\frac{C_S}{C_R}}\right)}{\sqrt{\ln(C_S \cdot C_R)}}}$ (B1V1(5)(b))

$$\beta = \frac{\ln\left(\frac{618.3kNm}{13.2kN/m}\sqrt{\frac{1.2209}{1.014}}\right)}{\sqrt{\ln(1.2209 \times 1.014)}}$$

$$\boldsymbol{\beta} = \frac{\mathbf{3.940}}{\mathbf{0.462}} = \mathbf{8.53}$$

Minimum annual reliability index for combined actions: $\beta_{\min} = 3.85$ (Table B1P1b)

Permanent action in combination with imposed action (additive)

Reliability index: $$\boldsymbol{\beta} = \frac{\ln\left(\frac{\bar{R}}{\bar{S}} \cdot \sqrt{\frac{C_S}{C_R}}\right)}{\sqrt{\ln(C_S \cdot C_R)}}$$ (B1V1(5)(b))

$$\beta = \frac{\ln\left(\frac{480kNm}{202kN/m}\sqrt{\frac{1.025}{1.023}}\right)}{\sqrt{\ln(1.025 \times 1.023)}}$$

$$\boldsymbol{\beta} = \frac{\mathbf{0.866}}{\mathbf{0.218}} = \mathbf{3.97}$$

Minimum annual reliability index for gravity actions: $\beta_{\min} = 4.30$ (Table B1P1a)

Permanent action in combination with earthquake action and arbitrary-point-in-time imposed action (additive)

Reliability index: $$\boldsymbol{\beta} = \frac{\ln\left(\frac{\bar{R}}{\bar{S}} \cdot \sqrt{\frac{C_S}{C_R}}\right)}{\sqrt{\ln(C_S \cdot C_R)}}$$ (B1V1(5)(b))

$$\beta = \frac{\ln\left(\frac{480kNm}{153.4kN/m}\sqrt{\frac{1.013}{1.023}}\right)}{\sqrt{\ln(1.013 \times 1.023)}}$$

$$\boldsymbol{\beta} = \frac{\mathbf{1.136}}{\mathbf{0.189}} = \mathbf{6.00}$$

Minimum annual reliability index for combined actions: $\beta_{\min} = 3.85$ (Table B1P1b)

As the calculated reliability index, β, for the combined permanent and imposed action load case is less than the minimum reliability index for gravity actions, the Performance Requirement B1P1 is not satisfied for the mass timber beam under flexural bending.

The designer will need to revise the design to increase the structural resistance (e.g. by increasing the beam section size) and/or reduce the imposed action effect (e.g. by decreasing the beam span or spacing between beams) until the reliability index satisfies those required in the Performance Requirements.

Note, this example only relates to the performance of the timber beam in overall flexural bending for the purposes of demonstrating the process of Verification Method B1V1. Further assessments which may be required to finalise the design of the mass timber beam include but are not limited to:

- Potential for lateral or lateral-torsional buckling.
- Design of end connections.
- Design of beam under lateral loads or any foreseeable load not considered above.