Nordic Wood: Reliability of timber structures

Safety principles and levels in the Nordic countries and Eurocode 5

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Introduction

In this note the partial coefficient system and the values of some of the safety elements in EN 1995-1-1, “Design of timber structures, Part 1.1, General rules and rules for buildings” (Eurocode 5, 2001) are described and compared with the systems and values in the existing Nordic Timber codes as a basis for the adoption of the Eurocodes and the assignment of national values for the safety elements.

The member states of the EU and of EFTA/EEA shall adopt the general safety principles, but levels of safety of buildings and civil engineering works, including aspects of durability and economy, remain within the competence of the member states, making it possible to take into account differences in geographical or climatic conditions, or in ways of life, as well as different levels of protection that may prevail.

Conclusions

Notation

G permanent action
Q variable action
R resistance, strength
S action effect
k factor
k_{mod} modification factor for service and load-duration classes
γ partial coefficient

Subscripts
k characteristic

Load cases

Only the simple case with permanent actions *G* and 1 variable action *(Q)* is covered and it is assumed that permanent actions are not dominating.

Safety format

The Eurocodes and the Nordic codes are based on the following format, where γ are partial coefficients:

$$S(\gamma_G G_k + \gamma_Q Q_k) = S_d < R_d = k_{mod} R_k / \gamma_m \qquad (1)$$

γ_m depends on the coefficient of variation for the characteristic material property, the accuracy of the design model and the uncertainty in the determination of the material parameter in the structure from standard tests. In some Nordic countries it also depends on the safety class (comparable to the Consequences Class, see below), the failure type and the control on site. In the following a structure belonging to normal safety class (Consequences Class 2), with ductile failure and normal model accuracy and uncertainty is discussed.

k_{mod} is a factor taking into account the influence of the load duration and the moisture history and is treated in the chapter “Effect on load duration on timber structures in Denmark”.

For limit states where (1) applies it is possible freely to transfer part of the safety elements from one side to the other, i.e. (1) is identical to:

$$S(k \cdot \gamma_G G_k + k \cdot \gamma_Q Q_k) = k \cdot S_d < k \cdot R_d = k_{mod} R_k / (k \cdot \gamma_m) \quad (2)$$

To make comparisons easier, a value of $(k \cdot \gamma_G) = 1$ has been chosen.

Consequences classes and reliability differentiation

The required reliability depends on the consequences of failure or malfunction of the structure. In the Eurocodes a distinction is made between the 3 classes defined in Table 1.

Table 1 - Consequences Classes

Consequences class	Description related to consequences	Examples of building and civil engineering works
CC3	High for loss of human life and/or Very high economic, social or environmental	Grandstands Concert halls and other big and important buildings with many people
CC2	Medium for loss of human life and/or Considerable economic, social or environmental	Residential and office buildings and most other buildings
CC1	Low for loss of human life and Small or negligible economic, social or environmental	Agricultural buildings where people do not normally enter Greenhouses

In the Eurocodes it is proposed to associate the consequences classes with the required reliability as shown in Table 2, expressed either by the reliability index β or the formal probability of failure. The difference from CC2 to CC1 or from CC2 to CC3 corresponds approximately to a variation of the γ-factor on the action side (recommended in the Eurocodes) or on the material side (used in the Nordic codes) by ± 10 %.

Table 2 - Required reliability

	Reference period	Consequences class		
	years	CC1	CC2	CC3
Reliability index	50	3.3	3.8	4.3
	1	4.2	4.7	5.2
Formal probability of failure, approximately	50	10^{-3}	10^{-4}	10^{-5}
	1	10^{-5}	10^{-6}	10^{-7}
Factor to γ_m		0.9	1.0	1.1

Partial coefficients for actions

Two options for the partial coefficients are proposed in Eurocode 1. It is up to the member states to make the choice.

Option 1 is aimed at structures where the ultimate load corresponds to structural failure not involving geotechnical actions or resistances. Option2 can be used for all structures

Option 1

Expression (1) is used with γ_G = 1.35 and γ_Q = 1.50. If a reference value of $(k \cdot \gamma_G)$ = 1 is used, then γ_Q = 1.50/1.35 = 1.11.

Option 2

The less favourable of the following two sets of partial coefficients shall be used:

(a) γ_G = 1.35 and γ_Q = 1.50ψ_0 where ($\psi_0 Q_k$) is the combination value of O_k. For most actions ψ_0 = 0.7[1].

If a reference value of $(k \cdot \gamma_G)$ = 1 is used, then γ_Q = 0.7·1.50/1.35 = 0.78. This option is clearly not realistic for timber structures.

If a value of $(k \cdot \gamma_G)$ = 1.25 is used, then γ_Q = 1.0, and this combination may be appropriate for cases where dead load is dominating.

(b) γ_G = 1.15 and γ_Q = 1.50. If a reference value of $(k \cdot \gamma_G)$ = 1 is used, then γ_Q = 1.50/1.15 = 1.30.

Comparisons of safety elements

The safety elements in Eurocode 5 and the Nordic timber design codes are summarised and compared in Table 3.

Table 3 - Safety elements in Eurocode 5 and the Nordic timber design codes

	Denmark	Finland	Norway	Sweden	Eurocode 5	
					Option 1	Option 2(b)
Actions						
Permanent	1	1	1	1	1	1
Imposed	1.3	1.3	1.25	1.3	1.11	1.3
Wind	1.5	1.3	1.25	1.3	1.11	1.3
Snow	1.5	1.25	1.25	1.3	1.11	1.3
Materials						
Timber	1.64	1.55	1.58	1.38	1.76	1.50
Glulam	1.5	1.55	1.32	1.27	1.69	1.44
LVL	1.5	1.55	1.32	1.27	1.62	1.38
Joints	1.64	1.55	1.58	1.38	1.76	1.50
k_{mod}, timber						
Storage	0.70	0.62	0.80	0.70	0.70	
Imposed actions	0.80	0.77	0.90	0.85	0.80	
Snow	0.90	0.77	0.90	0.85	0.90	
Wind	1.1	1.0	1.1	1.0	0.90	
Global safety						
Imposed actions	2.41	2.38	2.02	1.92	2.35	2.21
Snow	2.37	2.38	2.02	1.92	2.08	1.97

[1] Exceptions are Storage load (ψ_0 = 1.0), snow for sites located at altitudes under 1000 m above mean sea level (ψ_0 = 0.5), and wind loads on buildings (ψ_0 = 0.6).

Wind	1.94	1.78	1.65	1.63	2.08	1.97
Overturning	1.88	1.67	1.67	1.53	1.65	

The k_{mod}-values may be compared to the values determined in the chapter on Effect of load duration on timber structures in Denmark in this report:

Imposed: 0.80 - 0.85
Snow: 0.80 - 0.85
Wind: 1.10

To give an impression of the relative safety in the codes, a global safety factor, n, is calculated for a typical case where $Q_k = 1.5G_k$:

$$n = (G_k + \gamma_Q Q_k)\gamma_m/(k_{mod}(G_k + Q_k)) = 0.4(1 + 1.5\gamma_Q)\,\gamma_m/k_{mod} \quad (3)$$