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Introduction

This report describes the safety principles and the safety levels in Denmark, Finland, Norway and Sweden. It is based on national reports prepared by the participantsⁱ in the project "Safety in Timber Structures" supported by the Nordic Industrial Fund under the special Nordic Wood programme, and national industriesⁱⁱ.

Conclusions

Although they have a common basis, the safety rules in the Nordic design codes for timber structures are different on many points. Also the general safety levels differ.

Some of the differences are common to all materials, and a harmonisation requires decisions by the national standardisation bodies. A possibility is to adopt the Eurocode 1 with a common Nordic Application Document.

Other differences are due to decisions made by the timber committees. This applies e.g. to:

- 1. Assumptions regarding the coefficient of variation for material properties.
- 2. The influence of the duration of load.
- 3. The effect of (third party) control.

As for 1 and 2 the differences are to a large extent due to insufficient knowledge. The important factor k_{mod} is generally not fixed on a firm theoretical basis, and the knowledge about the distributions of the material properties is insufficient. For these items the results of this project can lead to harmonisation and a more rational design.

The differences mentioned under 3 are to some extent due to different national approval philosophies, and it should be possible to remove them the when The Construction Products Directive in near future becomes operational.

The general safety levels differ very much. The level is by far the highest in Denmark and lowest in Norway and Sweden. There are no experiences that can support the Danish level.

The Eurocode level is almost the same as the Danish and an uncritical adoption of Eurocode 5 will increase the required dimensions of many well functioning structures.

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

 $\begin{array}{l} \alpha \quad G_k/(G_k+Q_k) \\ Subscripts \end{array}$

k characteristic

Load cases

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

Safety format

All the codes (and also the European design codes: the Eurocodes) are based on the following format, where γ are partial coefficients:

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

 $\gamma_m = \gamma_0 \gamma_1 \gamma_2 \gamma_3 \gamma_4 \gamma_5$

- γ_0 takes account of the safety class
- γ_1 takes account of the **type of failure**
- 2/2 depends on the coefficient of variation for the characteristic material properties which correspond to the 5-percentile for strength parameters and the mean values for stiffness parameters

(2)

- γ_3 takes account of the accuracy of the design model
- γ_4 takes account of the uncertainty in the determination of the material parameter in the structure based on the controlled material parameter. It is assumed that $\gamma_4 = 1$.
- ^{1/5} takes account of the extent of the control of materials and at the building site.

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

$$S(k \gamma_G G_k + k \gamma_O Q_k) = k S_d \le k R_d = k_{mod} R_k / (\gamma_m / k)$$
(3)

It is thus possible to choose $\gamma_G = 1$. During the work with the Eurocodes the Nordic members of CEN in unison have advocated that this value should be used. It makes the calculations easier and makes it possible to use the same format and γ -values for the design of foundations. It is, therefore, surprising that the present Finnish and Norwegian codes are based on $\gamma_G = 1.2$.

To make comparisons easier the Finnish and Norwegian partial coefficients are in accordance with (3) corrected to correspond to $\gamma_G = 1.0$. The partial coefficient γ_2 is also corrected to correspond to $\gamma_G = 1$ for normal safety class, and $\gamma_S = 1$ for normal control class.

Actions

The characteristic permanent actions G_k are defined as the action values that with a probability of 50 % will not be exceeded.

The characteristic variable actions Q_k are with one exception defined as the action values that with a probability of $p_{50} = 0.98$ (return period 50 years) will not be exceeded in one year: The exception is snow load in Finland, where the annual probability of exceeding is $p_{30} = 0.967$ % (return period 30 years) for natural actions like snow and wind.

The ratio S_r/S_{50} between actions corresponding to two return periods (*r* and 50 years) can be calculated from:

$$S_r/S_{50} = (1 - k \ln(-\ln p_r))/(1 - k \ln(-\ln p_{50}))$$
(4)

where k is a parameter taking the values $k \sim 0.20$ for wind load and $k \sim 0.30$ for snow load. For snow load $S_{30}/S_{50} = 0.93$.

The return period for the characteristic snow load in Norway has till now been r = 5 years. In future a return period of 50 years will be prescribed. According to equation (4) this corresponds to an increase in the load by 50 %.

Partial coefficients for actions

The values given in table 1 correspond to $\gamma_G = 1$ and a return period of 50 years.

	Denmark		Finland	Norway	Sweden	Eurocodes	
	old	new					
imposed action	1.3	1.3	1.3	1.25	1.3	1.5/1.35 = 1.11	
wind	1.3	1.5	1.3	1.25	1.3	1.11	
snow	1.3	1.5	1.25	1.25	1.3	1.11	

Table 1 – Partial coefficients γ_Q for variable actions corresponding to $\gamma_G = 1$.

Partial coefficients γ_m

In all countries it is explicitly or implicitly assumed that the failure type is ductile without reserve and that $\gamma_1 = \gamma_2 = 1$.

The use of different safety classes is illustrated in table 2 together with examples on structures assigned to the classes. The factor γ_0 is taken as 1.0 for normal safety class. In Sweden $\gamma_0 = 1.1$ for normal safety class, but the factor as mentioned has been transferred to γ_2 .

	Denmark	Finland	Norway*	Sweden
Safety class				
low	0.9 secondary build- ings, storehouses, barns, many agri- cultural buildings	0.9 roof structures where failure does not cause damage to persons	-	1/1.1 = 0.91 floor structures on ground, roof cover- ing, wall sheathing, light ceiling
normal	1.0	1.0	1.0	1.0
high	1.1 6 storey buildings, arenas for sports and concerts, large road bridges and high masts	_	-	1.2/1.1 = 1.09 structures including stabilising elements, substructures if fail- ure leads to collapse of building

Table 2 – Partial safety factor γ_0 depending on safety class

* In Norway the importance of a structure is taken into account through the prescribed level of control of the design and of execution.

The influence of control is illustrated in table 3. At present only Norway takes into account the influence of third party control. In future the Construction Products Directive prescribes that all products shall be produced under a production control system under third party supervision.

The most important partial coefficient γ_2 is given in table 4.

Control class	Denmark	Finland	Norway	Sweden
reduced	_	_	_	_
normal	1.0	1.0	1.0	1.0
extended	$(0.95)^*$	-	1.0/1.1 = 0.91	-
			for extended control and for simple	
			components (beams, joints,	
			purlins) and pre-manufactured	
			components when a precise	
			installation instruction is available.	

Table 3 – Partial safety factor γ_5 depending on control class

* This value was used in the old code. In the new code normal control class is assumed for all structures.

Table 4 – Partial safety factor γ_2 for timber and wood based materials and in () the assumed coefficient of variation.

	Denmark		Finland	Norway	Sweden	Eurocodes
	old	new				
structural timber	1.5	1.64	1.55	1.58	1.38	1.76
	(0.15)	(0.20)	(0.25)		(0.20)	
glulam, plywood	1.35	1.5	1.55	1.32	1.27	1.76
	(0.10)	(0.15)	(0.25)		(0.15)	
other panels	1.35	1.5	1.55	1.32	1.38	1.76
	(0.10)	(0.15)	(0.25)		(0.20)	
components	1.35*	1.64	1.55	1.32		
	(0.10)	(0.20)	(0.25)			
joints	1.5	1.64	1.55	1.58	1.38	1.76
	(0.15)	(0.20)	(0.25)		(0.20)	

* provided they are produced under third party control.

Modification factor k_{mod}

The modification factor k_{mod} is given in table 5 for structural timber and glulam for indoor climate (Service class 1-2 according to Eurocode 5).

duration	Denmark***	Finland	Norway	Sweden*	Eurocode 5
> 10	0.60/0.50	0.62/0.50	0.70/0.60	0.70	0.60/0.50
years					
0.5**-10	0.70/0.55	0.62/0.50	0.80/0.65	0.70	0.70/0.55
years	storage	storage	storage	storage	storage
				mean snow	
1-26**	0.80/0.65	0.77/0.65	0.90/0.70	0.85	0.80/0.65
weeks	imposed	imposed,	imposed,	imposed	imposed
		snow	snow	char. snow	
				mean wind	
< 1	0.90/0.70		1.0/0.80	1.0	0.90/0.70
week	snow		wind	char. wind	snow, wind
	1.10/0.90	1.0/0.77	1.1/0.90		
	wind,	wind,	accidental		
	accidental	accidental			
	duration > 10 years 0.5**-10 years 1-26** weeks < 1 week	duration Denmark**** > 10 0.60/0.50 years 0.57*-10 0.5**-10 0.70/0.55 years storage 1-26** 0.80/0.65 weeks imposed 0.90/0.70 week snow 1.10/0.90 wind, accidental	duration Denmark*** Finland > 10 0.60/0.50 0.62/0.50 years 0.5**-10 0.70/0.55 0.62/0.50 years storage storage 1-26** 0.80/0.65 0.77/0.65 weeks imposed imposed, snow 0.90/0.70 storage 1.10/0.90 1.0/0.77 wind, accidental accidental	duration Denmark*** Finland Norway > 10 0.60/0.50 0.62/0.50 0.70/0.60 years 0.5**-10 0.70/0.55 0.62/0.50 0.80/0.65 years storage storage storage 1-26** 0.80/0.65 0.77/0.65 0.90/0.70 weeks imposed imposed, snow snow < 1	durationDenmark***FinlandNorwaySweden*> 100.60/0.500.62/0.500.70/0.600.70years0.70/0.550.62/0.500.80/0.650.70yearsstoragestoragestoragestorage1-26**0.80/0.650.77/0.650.90/0.700.85weeksimposedimposed,imposed,imposed<1

Table 5 – Modification factor k_{mod} for structural timber and glulam and indoor/outdoor climate.

* The values depend on the timber quality. The stated values apply for timber C24 (INSTA T2).

** In Finland 6 weeks.

*** New.

Global safety

To compare the safety variation between countries for different loads a "global safety factor" can de determined as $n = R_k/S_k$ provided $R_d/S_d = 1.0$.

$$n = \max \begin{cases} \frac{G_k}{G_k + Q_k} & \frac{\gamma_2}{k_{\text{mod},G}} \\ \frac{G_k + \gamma_Q Q_k}{G_k + Q_k} & \frac{\gamma_2}{k_{\text{mod},Q}} \end{cases} \end{cases}$$
(5)

The variation of *n* is illustrated in figures 1 - 5, where $\alpha = G_k/(G_k + Q_k)$.

Other load cases

Another important case is the one where a variable action – often wind – is counteracted by dead load (uplift, overturning). The total safety for this case varies between the countries as follows: Denmark: 1.5/0.8 = 1.88 – Finland: 1.5/0.9 = 1.67 – Norway: 1.5/0.9 = 1.67 – Sweden: 1.3/0.85 = 1.53.

The Danish value corresponds to the new code DS 413:1999. According to the old code the safety was only 1.3/0.85 = 1.53. The old Danish value was the same as the present Swedish value, and lower than in Finland and Norway– maybe too low, although the number of failures due to overturning/uplift has been extremely low – but Denmark has now by far the "safest" structures.



Figure 1 – Global safety, n, according to the Danish code. The dotted line corresponds to the case with $0.25G_k$ regarded as a free action.



Figure 2 – Global safety, n, for stored load



Figure 3 – Global safety, n, for imposed load



Figure 4 – Global safety, n, for snow load



Figure 5 – Global safety, n, for wind load

Comparisons with steel structures

The material partial coefficient for steel is shown i table 6 together with the assumed coefficient of variation.

Table 6 – I	Partial 3	safety f	factor (α_2 and	coefficient	of val	riation	for steel	l structures.
				-	././	./			

	Denmark		Finland	Norway	Sweden
	old	new			
yield stress	1.28	1.17		1.1*	1.00
ultimate tensile strength	1.42	1.43			1.20
coefficient of variation		< 0.05			(narrow tolerances)

• expected value (code under revision)

ⁱ Denmark: SBI, Norway: NTI, Finland: VTT, Sweden: LTH

ⁱⁱ Denmark: Danish Manufacturers of Wooden Rafters, Danish Manufacturers of Wooden Elements Norway: Nordisk Kartro A/S, MOCON

Sweden: Södra Timber AB

Finland: Finnish Forest Industries Federation, Stora Enso