Eurocode Load Combination Rules and Simplified Safety Formats

Michael Mikoschek, François Colling
University of Applied Science Augsburg
Augsburg, Germany

Michele Baravalle, Jochen Kohler
NTNU
Trondheim, Norway

1 State of the Art – Eurocode Load Combination Rules

The safety assessment of structural elements according to Eurocode 0 (EN 1990, 2002) is based on a comparison of the resistance design value r_{d} with the design value of the effect of actions e_{d} where the former has to be larger than the latter in order to provide appropriate safety $r_{\mathrm{d}} > e_{\mathrm{d}}$. Following the requirements of Eurocode 5 (EN 1995-1-1, 2004) for structural timber design, the resistance design value r_{d} has to be determined for ultimate limit state design as presented in Eq. (1) with the characteristic value of the resistance r_{k}, the partial safety factor γ_{M} and the timber specific modification factor k_{mod}.

$$r_{\mathrm{d}} = k_{\mathrm{mod}} \frac{r_{\mathrm{k}}}{\gamma_{\mathrm{M}}} \tag{1}$$

The modification factor k_{mod} takes the load duration effect and moisture content of timber into account and is influencing the determination of the design load e_{d} or rather the decisive load combination, which will be described herein later. The design load e_{d} for persistent or transient design situations according to Eurocode 0 equation 6.10 can be calculated with

$$e_{\mathrm{d}} = \sum_{j \geq 1} 1.35 \cdot g_{\mathrm{k},j} + 1.5 \cdot q_{\mathrm{k},1} + \sum_{i > 1} 1.5 \cdot \psi_{0,i} \cdot q_{\mathrm{k},i} \tag{2}$$

(or two alternative formulas: equation 6.10a and 6.10b in Eurocode 0 for STR and GEO limit states) where ψ_0 is the load combination factor. For each relevant load case the design effect of action shall be determined by combining the loads that can occur simultaneously.

Due to the linear resistance models of the material property, the design check can be rewritten as in Eq. (3), where the resistance side is independent of k_{mod}.

$$r_{\mathrm{d}} > e_{\mathrm{d}} \rightarrow \frac{r_{\mathrm{k}}}{\gamma_{\mathrm{M}}} > \frac{e_{\mathrm{d}}}{k_{\mathrm{mod}}} \tag{3}$$

As it can be seen, the load case with the highest ratio of $e_{\mathrm{d}}/k_{\mathrm{mod}}$ is decisive for design. The value for k_{mod} has to be chosen as the one corresponding to the load with the shortest duration considered in the combination. This circumstance requires the examination of a larger number of load combinations compared to other construction materials where the combination giving the largest design load is automatically decisive. Thus, the engineering effort is significantly higher, especially when hand calculations are performed, which is often the case for simple structures. For this reason, the following simplified safety formats where discussed and examined within Working Group 1 (basis of design) and a Short-term Scientific Mission in COST Action FP1402.

2 Simplified Safety Format I (SFI)

This simplified safety format is based on these two load combinations from Colling and Mikoschek (2016).

$$e_{\mathrm{d},1} = \gamma_{\mathrm{F}} \cdot \left(\sum_{j \geq 1} g_{\mathrm{k},j} + \sum_{i \geq 1} q_{\mathrm{k},i} \right) \tag{4}$$

$$e_{\mathrm{d},2} = \sum_{j \geq 1} 1.35 \cdot g_{\mathrm{k},j} + 1.5 \cdot q_{\mathrm{k},1} \tag{5}$$

where γ_{F} is a global partial safety factor and $q_{\mathrm{k},1}$ is the leading live load. As usual, the design loads $e_{\mathrm{d},1}, e_{\mathrm{d},2}$ have to be divided with the corresponding values of k_{mod} (with the shortest load duration considered in the combination) in order to determine the decisive design load:

$$\frac{e_{\mathrm{d},1}}{k_{\mathrm{mod}}} > \frac{e_{\mathrm{d},2}}{k_{\mathrm{mod}}} \rightarrow e_{\mathrm{d},1} \text{ is the decisive design load,}$$
$$\frac{e_{\mathrm{d},2}}{k_{\mathrm{mod}}} > \frac{e_{\mathrm{d},1}}{k_{\mathrm{mod}}} \rightarrow e_{\mathrm{d},2} \text{ is the decisive design load.}$$

Generally, this simplified safety format is not thought to replace the current load combination rules according to Eurocode 0. Instead, it could provide an alternative for a quicker and more economic design of simple structures. However, the application should be only permitted for load cases with less than 60% permanent loads and only with imposed loads from categories A, B, C and D (not E with load duration = long).

3 Simplified Safety Format II

The additional effort for finding the decisive load combination in structural timber design is caused by the large number of different modification factors k_{mod}. Therefore, it was proposed in Baravalle et al. (2017) to use a fixed value of k_{mod} (hereinafter referred to as k'_{mod}) for load cases with dominating permanent loads and for

Table 1: Calibrated values of global factor γ_F in SFI and fixed k'_{mod} in SFII.

Case		permanent loads dominating	variable loads dominating
1	γ_F	2.14	1.46
	k'_mod	0.63	0.89
2	γ_F	2.17	1.48
	k'_mod	0.62	0.84
3	γ_F	2.35	1.56
	k'_mod	0.63	0.92
4	γ_F	2.38	1.58
	k'_mod	0.62	0.86

load cases with dominating variable loads. This simplification is leading to a number of load combinations which is equal to the ones considered for any other construction material.

4 Calibration of Reliability Elements

Simplifications have to provide a satisfying level of safety. For this reason, both simplified safety formats needed to be calibrated by established techniques. At first, the reliability indices β associated with the simplified safety formats were calculated and compared with the safety level given by the Eurocodes. Then, the reliability elements (global safety factor γ_F in SFI and k'_mod in SFII) were calibrated in order to satisfy the objective of minimizing the reduction of structural efficiency without compromising the structural safety level.

The calibration was restricted to service class 1 and 2, only three load types (self-weight, snow, wind), two materials (solid timber and glulam) and three failure modes (bending, tension and compression parallel to the grain). For the comparison of climatic cases, four types of climate were regarded by combining snow and wind actions with different characteristics. These cases might represent the climates and load durations of Germany, Austria, Denmark and Norway.

Different load scenarios were included in the study, too. They are characterized by the proportions between the different loads expressed as $\chi_G = g_k/(g_k + q_{1,k} + q_{2,k})$ and $\chi_Q = q_{1,k}/(q_{1,k} + q_{2,k})$. The load scenarios are divided into two domains: dominating permanent loads with $\chi_G \geq 0.6$ and $0 \leq \chi_Q \leq 1$; dominating variable loads with $0 \leq \chi_G \leq 0.6$ and $0 \leq \chi_Q \leq 1$.

The results of the calibration process published in Baravalle et al. (2017) are summarized in Table 1.

5 Conclusion

The load duration factor k_{mod} can cause a large number of load combinations in the design of timber structures. Therefore, two simplified safety formats have been proposed and calibrated. Both proposed safety formats with the calibrated reliability elements meet the requirement of simplifying design without decreasing the level of safety. The question, of which type of simplification is to be preferred, has to be discussed in further investigations or expert groups. More profound and detailed calculations and results are described in Colling and Mikoschek (2016); Baravalle et al. (2017).

References

Baravalle, M., Mikoschek, M., Colling, F., and Köhler, J. (2017). Calibration of simplified safety formats for structural timber design. *Construction and Building Materials*, 152:1051–1058.

Colling, F. and Mikoschek, M. (2016). Vereinfachte Regeln für Lastkombinationen. Project report PRB-4.3. PraxisRegelnBau.

EN 1990 (2002). Eurocode – basis of structural design. European Committee for Standardization, Brussels, Belgium.

EN 1995-1-1 (2004). Eurocode 5: Design of timber structures – Part 1-1: General – Common rules and rules for buildings; German version. European Committee for Standardization, Brussels, Belgium.