Simplification of basic design rules

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1. Introduction and Motivation

Even for simple structures the rules of EUROCODE 0 (EC 0) for combining loads lead to a great number of load cases to be considered. Furthermore the load transmission to the bearing structures below increases the amount of load cases. This is also valid for other building materials. Therefore simplifications in relation with the load combinations could be useful.

Whereas for other building materials the load combination with the maximum load is automatically decisive for the design, this is not the case for timber structures according to EUROCODE 5 (EC 5). Due to the influence of load duration, service class and the corresponding values for k_{mod} the decisive load combination could also be giving a lower sum of load. For many engineers the consideration of this effect is still unusual, even if other materials seem to introduce such a factor too. Therefore simplifications for finding the decisive load combination are needed.

Further arguments for introducing simplifications in EC 0 and EC 5 are:

- Engineers can generally benefit from simplifications e.g. for designing small constructions. Especially those engineers with little experience in timber construction are advantaged.
- In the area of teaching, such complicated subjects could be better grasped by students when “alternative” ways of calculation are offered.
- Software for calculating all possible load combinations (and choosing the decisive one) is not available in all construction bureaus and for all construction. Moreover, software for timber structures are by far not as sophisticated as software for other building materials.
- Even if suitable software is in use, there should be possibilities to easily check the results.

This paper gives an idea how such simplifications could look like. In the first place it should be understood as a basis for discussion. The intention of these proposals is to simplify the design of timber structures in order to increase the use of timber. This is a basic request because it’s a question of using timber or not: if the design of timber structures is considered to be too complicated, the engineer will prefer other building materials.

It is pointed out that simplifications should not be obligatory for all design calculations (more accurate calculations should furthermore be allowed). However, they could be adequate in approx. 80% of cases (“ease of use”).

2. General - State of the Art

The design value e_d of actions is normally calculated according to EUROCODE 0 as follows:

$$e_d = 1,35 \cdot g_k + 1,5 \cdot q_{k,1} + 1,5 \cdot \sum_{i>1} \psi_{0,i} \cdot q_{k,i} \qquad \text{Eq. (1)}$$

with

e_d = design value
g_k = characteristic dead load
$q_{k,1}$ = live load 1
$q_{k,i}$ = further live loads
$\psi_{0,i}$ = load combination factors

In case of a structure being loaded by 3 different live loads the maximum design value max e_d is calculated to the maximum of the following load cases (LC):

LC 1: g+1+2+3 (= g+1+3+2)
LC 2: g+2+1+3 (= g+2+3+1)
LC 3: g+3+1+2 (= g+3+2+1)

Normally the load case in which the "leading" live load is fully considered (i.e. without load combination factor ψ_0) will give the maximum load e_d.

By transmitting the loads to the bearing structures below, new calculations are necessary. Therefore simplifications in relation with the load combinations are desirable.

In timber structures the number of load combinations is considerably higher due to the effects of load duration and service class in use (→ k_{mod}). Here a load combination with a design load lower than the maximum design load may be decisive! Therefore the following load combinations have to be checked in case of timber structures:

LC 1: g
LC 2a: g+1
LC 2b: g+2
LC 2c: g+3
LC 3a: g+1+2
LC 3b: g+1+3
LC 3c: g+2+1
LC 3d: g+2+3
LC 3e: g+3+1
LC 3f: g+3+2
LC 4a: g+1+2+3 (= g+1+3+2)
LC 4b: g+2+1+3 (= g+2+3+1)
LC 4c: g+3+1+2 (= g+3+2+1)

The design-controlling load case will be the one giving the maximum value of e_d/k_{mod} (in case of loads acting in the same direction, vertical loads for instance).

The listing above shows that the finding of the controlling load case with the corresponding design load is much more time consuming and complicated than for other building materials. Taking into account that many construction bureaus are in fact well familiar with structures made of concrete and steel, but not experienced in the design of timber structures, simplifications in how to find the decisive load combination are needed.

In the further sections the following simplifications are proposed as a basis of discussion:

- Simplified method to find the maximum load according to EC 0,
- Simplified method to find the decisive load according to EC 5.

3. Simplification for finding the maximum load

In Germany an initiative “PraxisRegelnBau (PRB)” including all building materials tries to find ways to simplify the design of building structures. One task group (PG 1) deals with the basis of design, namely EUROCODE 0.

Based on comparative calculations they proposed to omit the load combination factors ψ_0 and to calculate the maximum design load e_d as follows:

$$e_{d,PRB} = 1,35 \cdot g_k + 1,5 \cdot q_{k,1} + \sum_{i>1} q_{k,i} \qquad \text{Eq. (2)}$$

with

$e_{d,PRB}$ = maximum design load
g_k = characteristic dead load
$q_{k,1}$ = “leading” live load
$q_{k,i}$ = further live loads

In case of live loads of building category E (load duration = long) this simplification is unsafe: here a more detailed calculation is needed.

Another proposal could be to increase all loads by one global load factor γ_F = 1,4:

$$e_{d,1.4} = \gamma_F \cdot \left(g_k + \sum q_{k,i}\right) = 1,4 \cdot \left(g_k + \sum q_{k,i}\right) \qquad \text{Eq. (3)}$$

This proposal simplifies the load transmission to bearing elements below and the occurrence of further loads.

Within several trial calculations dead loads (g), snow loads (s), wind loads (w) and service loads (p) were combined (in each case two live loads at maximum) considering different circumstances (metres above sea level, building categories). The ψ_0-values were chosen in accordance with the German national annex of EUROCODE 0.

In the following graphs these proposals are compared with the “exact” values determined according to EUROCODE 0 (see Eq. (1)).

The blue squares represent all values without building category E. Values which were calculated with building category E are marked with a red X.

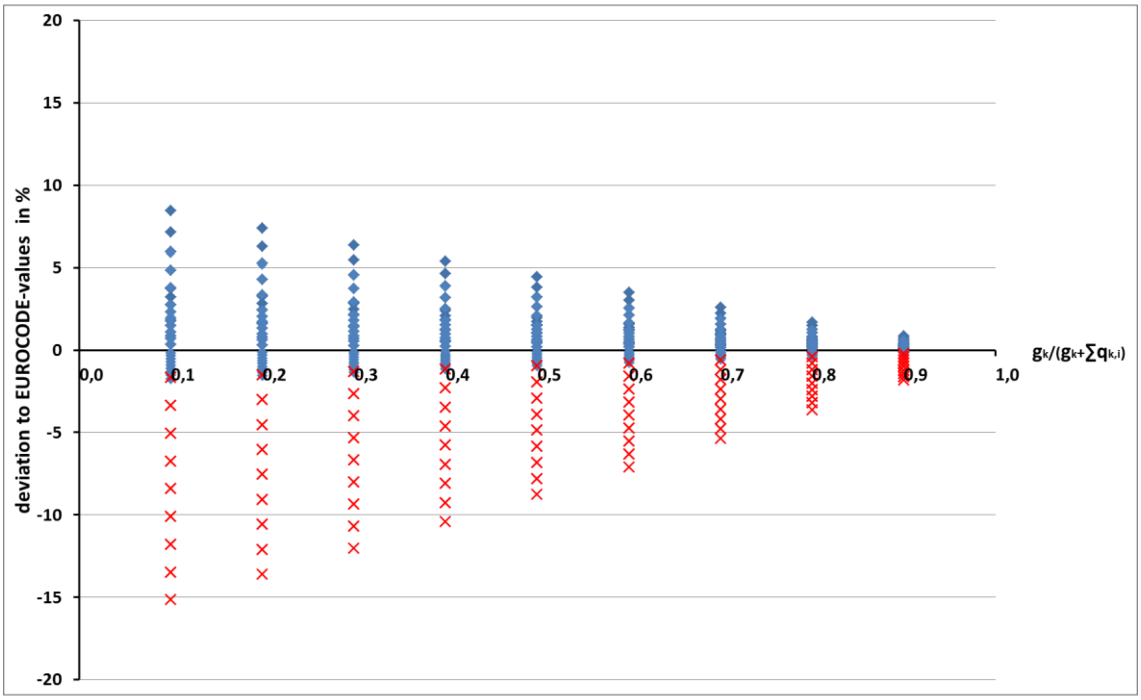

Figure 1: Graph with the deviations of PRB-values to EUROCODE-values

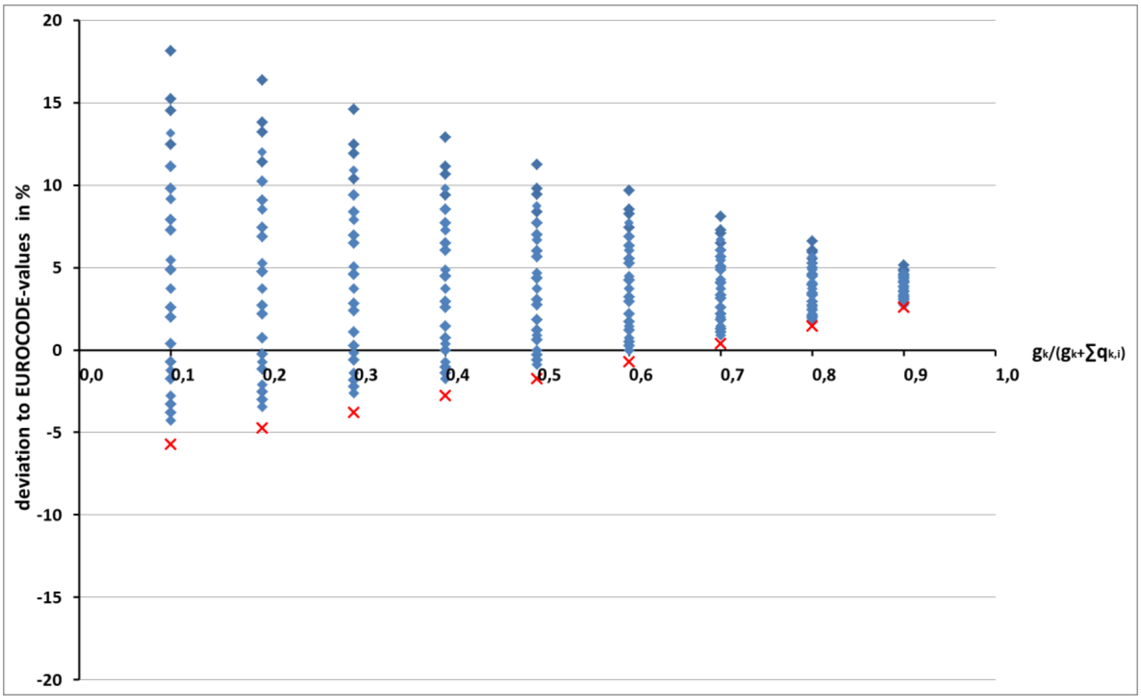

Figure 2: Graph with the deviations of Factor1,4-values to EUROCODE-values

Discussion:

- The PRB-values are close to the values of EC 0 (when building category E is disregarded)
- The proposal with global load factor gives values differing -6 **%** and +18 % at maximum from the values of EC 0.
- In case of PRB-proposal, the load transmission to the bearing elements below, the leading live load has to be checked again when new loads occur. This is not the case for the other proposal with global load factor.

4. Simplification for finding the decisive load

For timber structures the design-controlling load combination is not necessary the one giving the maximum load but could also be one giving a lower sum of load. This is influenced by:

- The amount of load with shorter load duration:
  If the load with shorter load duration is rather negligible (for instance 5% of the total load), the load combination without this load will be decisive.
- The difference between the k_{mod}-values of the different loads:
  - if wind is classified as short , its effect will be similar to that of other live loads (mostly medium or short term);
  - if wind is classified as very short, the possibility of a load combination excluding wind being decisive, increases.

Finding the accurate design load is time consuming and often unnecessary regarding the (small) differences in the resulting values. Therefore the following simplification will be suggested for loads acting in the same direction.

Firstly the two design loads $e_{d,1}$ and $e_{d,2}$ have to be calculated by using the equations

$$e_{d,1} = 1,35 \cdot g_k + 1,5 \cdot q_{k,1} \qquad \text{Eq. (4)}$$

and

$$e_{d,2} = 1,4 \cdot \left(g_k + \sum q_{k,i}\right) \qquad \text{Eq. (5)}$$

with

g_k = characteristic dead load
$q_{k,1}$ = “leading” live load
$q_{k,i}$ = further live loads.

The maximum value of the design load divided by the respective k_{mod}-value shows which one of those two loads is decisive:

$e_{d,1} / k_{mod,1}$ > $e_{d,2} / k_{mod,2}$ → $e_{d,1}$ is decisive!

$e_{d,2} / k_{mod,2}$ > $e_{d,1} / k_{mod,1}$ → $e_{d,2}$ is decisive!

The proposed simplification is valid for the following conditions (restrictions):

- Ratio $g_k/(g_k+\Sigma q_{k,i}) \leq 0{,}6$.
- Building categories A, B, C and D (not E with load duration = long).
- Loads acting in the same direction.
- Maximum two live loads (tests with more than two live loads are in progress)

In order to test the proposal, several calculations with dead loads (g), snow loads (s), wind loads (w) and service loads (p) were performed (in each case max. two live loads). Furthermore, different circumstances (load durations and service classes) were considered. The k_{mod}-values were chosen in accordance with the German national annex of EUROCODE 5.

In the following diagrams this proposal is compared with the “exact” values determined according to EUROCODE 5. The blue squares represent all values without building category E (long load duration). Values which were calculated with building category E are marked with a red X.

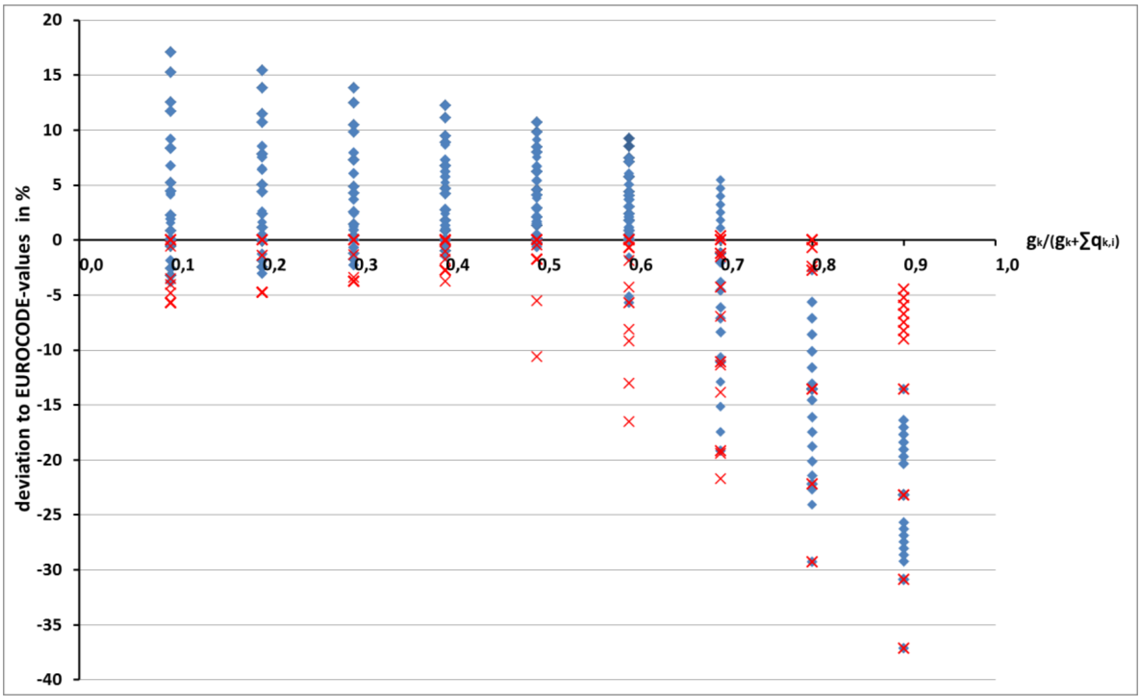

Figure 3: Graph with the deviations of the proposal to EUROCODE-values for service class 1 and 2

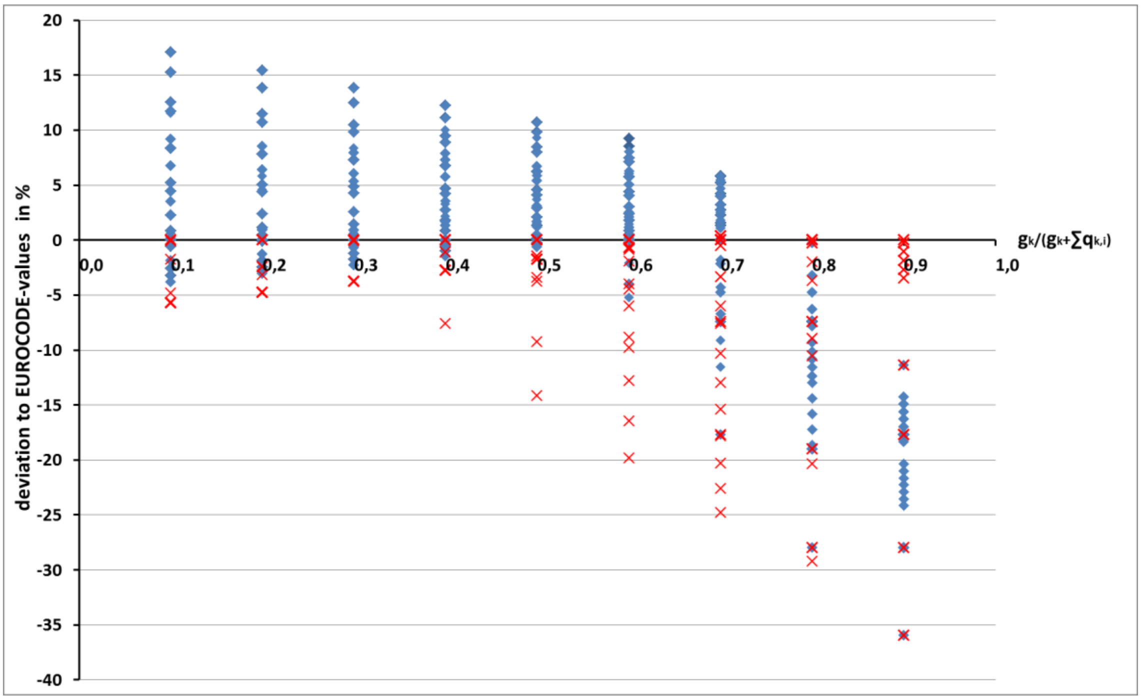

Figure 4: Graph with the deviations of the proposal to EUROCODE-values for service class 3

Discussion:

- Within the Ratio $g_k/(g_k+\Sigma q_{k,i}) \leq 0{,}6$ the deviations are in the range from -6% to +17% (when load duration class "long" is disregarded).
- The effort for finding the decisive load is significantly lower, because only two values have to be compared in all cases.
- The usage of bigger values compared to EC 5 can lead to higher construction costs. However, in the "typical" dead load range between 0,3 and 0,6 for timer constructions the exceedance of the values is mostly below 10%.

5. General Discussion

Apart from the arguments in the introduction of this paper, there might be some points against simplifications. Higher costs due to greater design loads are one of them. Regarding the fact, that the existing rules can be still used for the calculations this argument is invalidated. However, this critical topic has to be discussed further including the following points and questions:

- Are the deviations of the proposals to the values according to EUROCODE too high?
  →Safety issues?
- Could further restrictions for the usage of simplifications improve the results?
  → With an increasing number of restrictions the simplification gets more complicated!
- Several timber specific factors (k_{mod} , k_{def} ,γ_M, etc.) make the design of timber structures unnecessarily complicated. →Are there ways to reduce the effort?
- It seems that specific factors for other materials were derived with higher probabilities of failure. →Is it possible to adopt these values for fixing the timber specific factors?

In particular the last two questions need further discussion in view of more transparency. From the engineering point of view a reduction (and a harmonization) of values for k_{mod} , k_{def} and γ_M is desirable.

6. Summary and Outlook

In this paper simplifications for design calculations have been proposed as basis of discussion. The results from test calculations do not differ much when certain conditions and restrictions are applied. Though there is a need of further verification and development, it offers a perspective to considerably simplify the design of timber structures ensuring an adequate accuracy.

Further simplifications and harmonization are necessary concerning the timber specific factors k_{mod} , k_{def} and γ_M.