SOME REMARKS ABOUT THE NEW GENERATION OF prEN1993-1-1

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Introduction

Since 2015, the Eurocode standards of the series EN 1990 to EN 1999 have been revised in the framework of the mandate M515 of the European Commission, which should incorporate the experience of practice from the first decade of application and the latest scientific knowledge. In the first phase of this revision, the general rules for the design of components and connections in building construction were revised - in steel construction, therefore, EN 1993-1-1 and EN 1993-1-8.

In the present paper, the most important innovations for the dimensioning of cross sections and components are presented for EN 1993-1-1. The article focuses on the following points:

- Partial safety factors γ_{M0} und γ_{M1}
- Systematics of the calculation of internal forces
- Cross-sectional design for elastic-plastic cross sections of class 3
- New lateral torsional buckling curves for double symmetric cross sections
- Component design for monosymmetrical cross sections

Material Properties and Partial Safety Factors

A major innovation of prEN 1993-1-1 is the extension to high strength steels up to S690. However, certain ductility requirements apply to restricting the plastic system calculation. Thus, a ratio of tensile strength to yield strength of at least 1.10 and an elongation at failure not less than 15% are required. This means that under certain circumstances for high-strength steels, such as S550, a plastic system calculation is excluded.

With the introduction of EN 1090-2, component straightness tolerances were relaxed and set at $\Delta \leq L/750$. In most European and national standards as well as in the tests and load calculations, which underlie the buckling curves in EN 1993-1-1, values of the geometric imperfections of $e_0 = L/1000$ were assumed. This was also the basis for the original probabilistic definition of the buckling curves. In publications published until 2014 there was also consensus on a partial safety factor of $\gamma_{M1} \sim 1.1$. Additional safety assessment studies [1] show that in some cases the simplified strength gradations for larger sheet thicknesses are on the uncertain side and buckling curves for buckling about z-z axis of S460 rolled sections are not conservative. In such cases, partial safety factors for stability should be set greater than 1.1.

In prEN 1993-1-1, the European recommendations on the partial safety factors γ_{M0} and γ_{M1} of 1.0 are nevertheless to be maintained. The following measures are carried out for this. On the one hand, some buckling curves, concerning flexural buckling of rolled sections about the z-z axis, are adjusted. On the other hand, specifications are to be made for the steel industry with regard to the statistical production values to be observed. This can be explained by the fact that all previous evaluations of the safety factors are based on the assumption that the steels basically have a statistical "overstrength", which has not yet been guaranteed by EN 10025. As a result, a new Annex E is introduced, which predefine scatter bands of material properties, yield strength, tensile strength and modulus of elasticity.

Parameter	Steel grade	Mean value X_m	Coefficient of variation	Upper reference value $X_{5\%}$	Lower reference value $X_{0,12\%}$
Yield strength, f_y	S235, S275	1,25 $R_{eH,min}$ [a]	5,5%	1,14 $R_{eH,min}$ [a]	1,06 $R_{eH,min}$ [a]
	S355, S420	1,20 $R_{eH,min}$ [a]	5,0%	1,11 $R_{eH,min}$ [a]	1,03 $R_{eH,min}$ [a]
	S460	1,15 $R_{eH,min}$ [a]	4,5%	1,07 $R_{eH,min}$ [a]	1,00 $R_{eH,min}$ [a]
	Above S460	1,10 $R_{eH,min}$ [a]	3,5%	1,04 $R_{eH,min}$ [a]	1,00 $R_{eH,min}$ [a]
Ultimate tensile strength, f_u	S235, S275	1,20 $R_{m,min}$ [a]	5,0%	1,11 $R_{m,min}$ [a]	1,03 $R_{m,min}$ [a]
	S355, S420	1,15 $R_{m,min}$ [a]	4,0%	1,08 $R_{m,min}$ [a]	1,02 $R_{m,min}$ [a]
	S460 and above	1,10 $R_{m,min}$ [a]	3,5%	1,04 $R_{m,min}$ [a]	1,00 $R_{m,min}$ [a]
Modulus of elasticity, E	All steel grades	210000 N/mm²	3,0%	200000 N/mm²	192000 N/mm²

[a] $R_{eH,min}$ and $R_{m,min}$ are the minimum yield strength R_{eH} and the lower bound of the ultimate tensile strength R_m, according to the applicable product standard, e.g. of the EN 10025 series.

Fig.1 Example for requirements of Annex E

The basic idea here is the definition of quality classes that must be complied by the steel industry. As a third measure, the simplified Table 3.1 of EN 1993-1-1 on material properties is replaced by the tables of EN 10025. Thus, a refined consideration of different sheet thicknesses is possible.

Systematic of Calculations

Since the introduction of EN 1993-1-1, there have been discussions and different interpretations regarding the approach of influences from second order theory. Common opinion is that the defined a_{cr}-conditions apply to sway modes. Thus, global P-Δ effects may be considered when determining the internal forces. On the other hand, local effects would not necessarily have to be taken into account and would be covered by the equivalent member method according to EN 1993-1-1, 6.3. In the past, the question was which theory to apply for systems where the a_{cr}-criterion is not met but no sway mode is possible, such as non-sway frame systems. For such systems, there are still different interpretations in Europe. To standardize the system calculations, prEN 1993 will integrate a flow chart with recommendations for different calculation methods.

Here, a distinction is made in principle between a_{cr} for buckling (non-sway) and sway modes. The mentioned methods EM and M0 to M5 are descriptions of alternative possibilities for verification of the structural stability on the basis of the required internal forces. Here, EM is the classic equivalent member method with buckling length to be determined and M3 with the system length and internal forces at the member ends according to 2nd order theory. M4 describes the linear-elastic calculation taking into account the influences of theory of 2nd order exclusively in-plane. Thus, additional equivalent member verifications for lateral torsional buckling and buckling out of plane are required. The method M5 comprises the 3-dimensional, linear-elastic calculation according to 2nd-order bending torsion theory (in and out of plane).

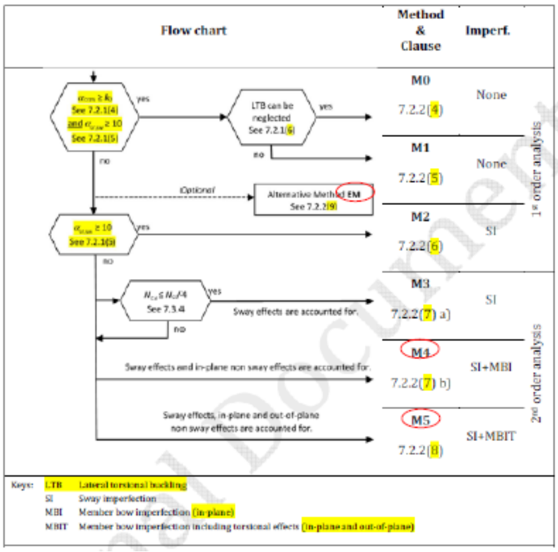

Fig.2 Flow Chart

Cross-section Classes

The load capacity values of the different cross-section classes in EN 1993-1-1 have always had a discontinuity between class 2 and 3 (Fig.3). This is particularly pronounced for bending about the z-z axis and moment interaction [2]. With the introduction of prEN 1993-1-1 this lack should be closed in appendix B. The new methodology relies on a linear interpolation between class 2 and 4 (Fig.3).

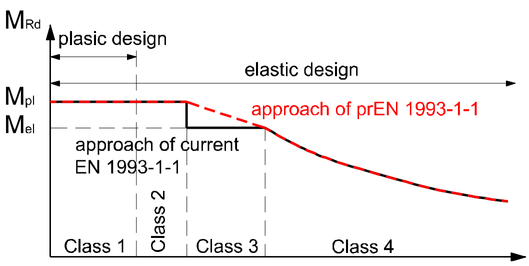

Fig.3 Bending resistance for different cross-section classes (schematic)

In the method according to Annex B, a classification of the cross section is based on the combined stress distribution. Subsequently, the resistance M_{Rd} is interpolated for the respective axis, reduced in the case of an acting normal force and finally taken into account a possible moment interaction by a non-linear relationship.

In addition, the c/t-limits for class 2 are adjusted for internal compression parts, as they were not conservative in all cases. The transition from class 3 to class 4 was not consistent with EN 1993-1-5, which is why the c/t-limits are adjusted in the new prEN 1993-1-1.

Lateral Torsional Buckling

Since the lateral torsional buckling (LTB) curves in EN 1993-1-1 were not derived mechanically "consistently", in the past inaccuracies compared to tests and non-linear FEM calculations could often be determined [3]. In addition, there are still two different sections for the “general case” and “rolled sections”. In order to standardize the design for LTB in the future, new LTB curves will be introduced in prEN 1993-1-1. These are based on GMNIA calculations taking into account imperfection approaches consistent with flexural buckling and the fact that each cross section results in different characteristic reduction curves. Based on the Ayrton-Perry formulation, the design procedure for LTB is adapted. In order to fulfill the safety level required by EN 1990, the α_{LT}-imperfection approaches in prEN 1993-1-1 are adapted for different cross sections. In addition, non-constant moment distributions are taken into account by a factor f_M.

Stability of Monosymmetric Members

The stability of monosymmetric members is not directly covered by the regulations of the current EN 1993-1-1. For such cross sections, a normal force-moment interaction may result in a failure of the smaller tension flange. In prEN 1993-1-1 specific LTB-curves for such I-profiles are introduced. If there is a change of sign in the moment distribution along the member axis, two verifications must be provided. If there is pressure in the smaller flange, the reduction factor χ_z in the interaction equation (flexural buckling and LTB) is to replace by a reduction factor χ_{TF} for torsional flexural buckling.

Summary

The new generation of Eurocode in steel construction is based on the structure of the existing EN 1993-1-1. Significant changes are expected from introduction of high-strength steels up to S690, new LTB curves, an improved method for determining the load-bearing capacity of cross-section class 3 and a verification method for the stability of monosymmetric members. In addition, a flow chart is provided for choosing the system calculation theory.

References

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