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Practical implementation of the General Method according to Chapter 6.3.4 – EC3-1-1 for the verification of the stability of any beam and frame structures out of plane | AiF No.: 20751N

Summary of the research project AiF No.: 20751N

The stability design of steel frameworks is regulated in DIN EN 1993-1-1. Chapter 6.3.4 of DIN-EN 1993-1-1 (8.3.4 in prEN1993-1-1) deals with the “General Method” for the verification of stability problems in frames or beams loaded in plane. For the general case of a combined moment and normal force load, the method offers two different approaches to determine the reduction factor x_op for bending out of plane. A distinction is made between the special cases of lateral-torsional buckling („LTB“ - i.e. only with moment) and flexural buckling („FB“ - i.e. only with normal force). However, this usually leads to inconsistencies with the intended generality of the formulation and ultimately to flawed results. The individually combined effects of moment and normal force on the structure, using a mode-affine imperfection approach, are the cause of out-of-plane instability. In this context, moment and normal force, along with the resulting buckling mode, must be considered as a whole and can no longer be separated into individual stress components. The instability phenomenon requires a reduction of the component resistance taking into account the combined loads.

The aim of this research project was to find solutions to this problem in order to summarize the impacts in plane and out of plane in a general approach. With the solution approach presented in this research report - the so-called “General Method” (short: “GenMeth”) - a general buckling curve is derived for the case of a combined moment and normal force, which agrees with the buckling curves of the special cases (pure flexural buckling or pure lateral-torsional buckling). This allows the general procedure to be formulated in an improved form. The standardization results in a general and consistent solution that allows the stability analysis of, for example, an entire frame system to be carried out directly using a modified buckling curve and without interaction factors (as in the equivalent member method). Furthermore, the method allows for the omission of non-linear spatial load capacity calculations, so only one calculation in plane and a determination of the bifurcation load out of plane are necessary, which can be solved with common framework models.

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Within the framework of this research project, the project results of the previous project “ALLVER” (ICR project no. 17943 N) were initially processed. An analytical method was developed to derive equivalent geometric imperfections based on component tests: the so-called “advanced Southwell methodology”. Furthermore, the replacement imperfections obtained in this way were transferred to the “GenMeth” solution approach and tested. This made it possible to test the performance of “GenMeth” using experimental data. In a separate step, the imperfection approach according to DIN-EN 1993-1-1 Section 5.3.2 [1] was extended so that it can also be applied to an interaction of normal force and moment as well as for non-prismatic cross-sections.

Since, in its original sense, “GenMeth” is intended for the design case with loads in plane, a particular challenge was the extension of the “GenMeth” to include loads out of plane (i.e., affine to the buckling mode) in the verification format. For this purpose, a method for differentiating displacement vectors was presented, which then allows to define the effective planes in order to enable a division between in plane and out of plane again. This division of the displacement vectors is the basis for the determination of section forces or stresses in different planes, which are incorporated into the verification format at the corresponding points. It was shown that this methodology enables loads to be implemented out of plane and comparative calculations with geometrically nonlinear calculations using imperfections and material nonlinearity (GNMIA) confirm the results. The procedure and application of “GenMeth” were prepared in a design guideline.

With the help of subroutines, “GenMeth” could also be extended to include shell and volume elements, meaning that more complex structures could be investigated in the future. Before extensive comparative calculations were carried out, various preliminary studies were carried out to test the capability of “GenMeth”. Various influences were identified that have an effect on the GNMIA and lead to a stiffer load deformation behavior compared to the initial system. Any deviations that occur between the “GenMeth” and the GNMIA usually have their origin here. Furthermore, extensive numerical studies and comparative calculations were carried out. Various support types, such as constrained rotational axes and elastically flexible lateral restraints, were examined and validated through comparative calculations.

Furthermore, the application of “GenMeth” to non-prismatic and monosymmetric cross-sections as well as Class 4 cross-sections was also examined. It was also shown here that using “GenMeth” offers potential solutions for proving the stability of spatial systems. In principle, the same analysis scheme was always used. Investigations conducted with “GenMeth” were always followed by geometric nonlinear imperfection analyses (GNIA/GNMIA). In all comparisons, there was very good agreement between GNIA/GNMIA and the “GenMeth” solution approach.

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In a final step, two design examples were prepared in detail and the stability verification was carried out using "GenMeth". This involved the verification of a special construction with variable cross-sections, which is mainly subjected to compression loads, and the verification of a hall frame with haunched column and beam profiles.

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