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Revision of the General Method for advanced design of Composite Columns in Steel and Concrete

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ABSTRACT: The design of composite columns made of steel and concrete is governed by Eurocode 4 where the General Method is based on a comprehensive numerical analysis, followed by validation of the safety level. However, the current EN 1994-1-1:2004 does not provide detailed information on the application of the General Method, and only limited information is available in literature. As a result, the General Method is often reserved for experts. The new FprEN 1994-1-1:2025 introduces complementary information regarding the General Method, addressing the modelling of geometric imperfections, residual stresses, material resistance, and the application of the method itself. In combination with the development of increasingly powerful software, nonlinear design methods are also expected to gain greater significance in composite construction.

1 INTRODUCTION

The design of composite columns by the simplified method according to FprEN 1994-1-1 is valid only for a limited range of composite cross-sections. This method requires a doubly symmetrical cross-section constant along the entire column length, such as partial concrete encased columns (PCEC), rectangular concrete encased columns (CEC), or concrete filled steel tubes (CFST) with or without an inner steel section, Figure 1. The steel section must consist of a hot-rolled or welded H-section. Additional restrictions apply to the steel contribution factor, the reinforcement ratio, the non-dimensional slenderness, and concrete cover. Further, the concrete compressive strength class is limited to a maximum of C50/60, steel grade up to S460 and reinforcement steel B500.

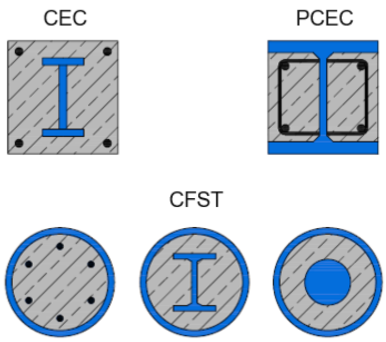

Figure 1. Typical types of Composite Columns cross-sections [1], [2]

Where these conditions are not met, e.g. for composite columns with a massive steel core, laminated steel plates, or CEC with non-rectangular or non-square shape, the design must be performed by the General Method, based on a nonlinear analysis. The structural stability analysis must account for both geometrical and physical nonlinear effects, including residual stresses, geometric imperfections, local instabilities, and the effects of creep and shrinkage of concrete. Physical nonlinearity must consider concrete cracking as well as yielding for structural and reinforcement steel. Compared to the Simplified Method, the sophisticated General Method typically results in a more economical design with increased engineering effort.

2 THE GENERAL METHOD - SUMMARY

The general method is defined by two principal stages. The first involves a global analysis of column behavior through an incremental geometrical and material nonlinear finite element analysis (GMNIA), explicitly incorporating initial imperfections. The second stage entails the evaluation of cross-section resistance via the N-M interaction curve (NM-IA), enabling the determination of an overall factor γ_0. This methodology is applicable to any type of composite cross-section and any material combination permitted under Eurocode 4. The GMNIA must capture all relevant failure modes. Nonlinear effects shall be incorporated in all directions where they may significantly influence structural stability. The design shall verify that instability is prevented under the most unfavorable combination of loading at the ultimate limit state, and that the resistance of individual cross-sections subjected to bending moments, axial forces, and longitudinal/shear forces is not exceeded. Full composite action between steel and concrete components may be assumed up to failure, provided that no important slip effects occur, and sufficient shear connection is ensured. The GMNIA must consider both geometrical initial imperfections and residual stress. FprEN 1994-1-1 specifies recommended initial bow imperfection magnitudes w_0 for various column types as a National Determined Parameter (NDP), while references to prEN 1993-1-14:2023 provide guidance for the incorporation of residual stresses. The outcome of the GMNIA, conducted using mean material strength values and the appropriate nonlinear material stress-strain relationships, is the resistance R_m of the compression member, Figure 2.

The NM-IA defines the envelope of a cross-section failure subjected to combined axial force and bending moment. In accordance with FprEN 1994-1-1, the overall factor γ_0 is determined as the quotient of the resistance vectors $R_{cs,m}$, derived from the NM-IA based on mean material properties, and $R_{cs,d}$, determined based on design material characteristics. The system impact is considered by the direction of the vector E_d, resulting by the normal force N_{Ed} and the second-order moment $M_{Ed,II}$ computed based on the outcomes of the GMNIA, Figure 2. FprEN 1994-1-1 specifies that the NM-IA may be conducted using either plastic or nonlinear cross-sectional resistance.

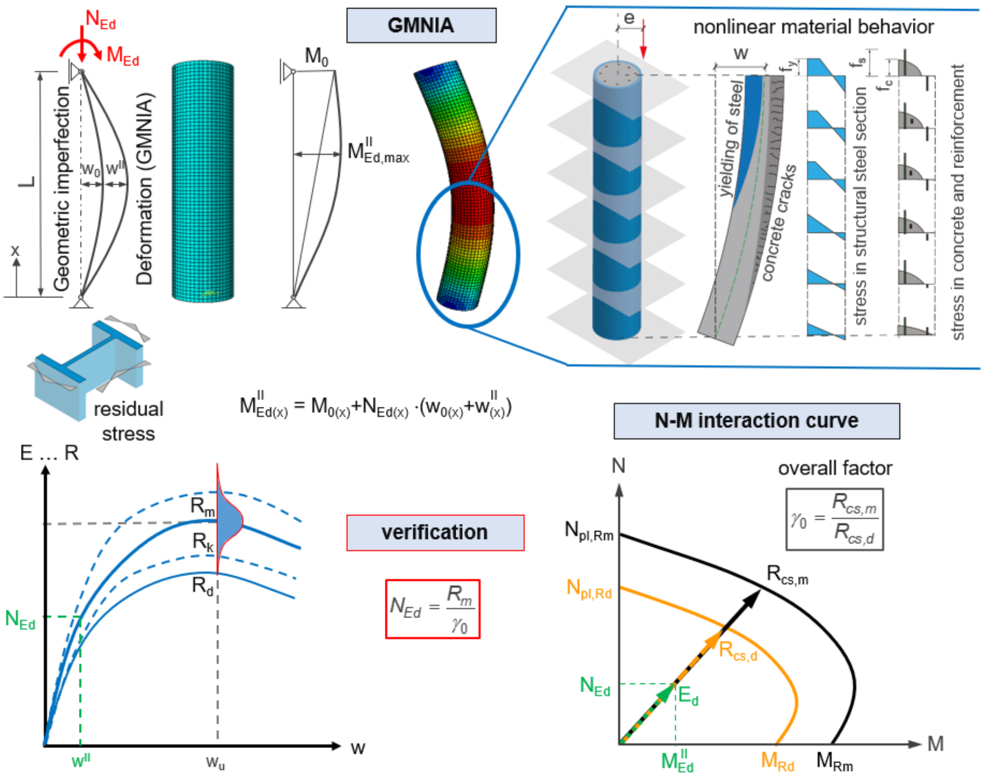

Figure 2. Design concept for the General Method [1], [2]

[1] Schäfer, M., Zogu, P., Zhang, Q., et al. (2021) CavaEurocode, final report, EU-funded Erasmus+ strategic partnerships program.

[2] Hanswille, G., Schäfer, M., Bergmann, M.: Eurocode 4 - DIN EN 1994-1-1 Bemessung und Konstruktion von Verbundtragwerken aus Stahl und Beton, Beuth + Ernst & Sohn (2020)

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