The Software Used as Design Application for Composite Steel-Concrete Columns

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Abstract: - This paper studies the resistance of composite steel-concrete cross-section of columns at the ultimate limit state. The recommended design procedure is focused on solving the problem with the aid of the normal force vs. bending moment diagram, whose construction is time-consuming. This makes economical design difficult. Therefore a user-friendly application (a simple program on VBA platform) was developed for everyday use. The practical solution and some derivations are explained in this paper.

Key-Words: -composite steel and concrete; ULS; interaction; normal force – bending moment diagram; design

1 Introduction

The subject of this paper is the creation of a computer program to simplify design and evaluation of different types of steel-concrete cross-section of columns. The principle of evaluation is based on the fundamental formulas derived from structural mechanics. The usual cross-section shapes of columns were considered. The plastic resistance of each cross-section shape is determined with the aid of a simplified method. There are variable parameters, dimensions and materials for each type of column under assessment. The cross-section shapes are evaluated in accordance with both general and simplified interaction diagrams of normal forces and bending moments according to the recommendations given in the EN 1994-1-1 Standard.

2 Carrying capacity of composite steel-concrete columns [1]

Two methods mentioned in [1] can be used when evaluating the carrying capacity of steel-concrete columns. The general method is, among others, suitable for solving special non-symmetric cross-section shapes and columns with variable cross sections. The procedure and all requirements for its application are explained in [1]. Although it is necessary when preparing and calibrating the Standards, the general method is hardly ever used in practice because it is time consuming. The simplified method, allowed for bi-axially symmetric columns, is widespread. Therefore this method was used when creating a computer program for evaluating the usual types of bi-axially symmetric steel-concrete columns – cf. Fig. 4

The conditions under which the simplified method (and consequently our program) can be applied are:

- the cross section shape is symmetric with respect to two mutually perpendicular axes;
- the cross-section shape is constant along the entire length of the column;
- the value of relative slenderness is smaller than 2.0;
- the steel structure must not consist of several independent elements – it must be a single (continuous) cross-section shape; this condition ensures sufficient interaction between the steel and concrete parts and prevents the structure from undesirable slippage;
- for steel structures fully covered with concrete the coverage must comply with the requirements stated in [1] – those requirements are based on the types of the tested columns, from which theoretical formulas were derived to calculate the carrying capacity using the simplified method;
- the area size of the additional reinforcement must not be larger than 6% of the concrete part – if the percentage were higher, adverse effects on the interaction and load transmission would be implied;
- the ratio between the height and width of the cross section must not fall outside the limits 0.2 ~ 5.0 – this condition ensures that tilting effects in the calculations can be neglect.

ISBN: 978-960-474-352-0

2.1 Interaction Diagram

Under the conditions stated above the carrying capacity of a column with respect to pressure and bending loads with the aid of an interaction diagram (a chart of the carrying capacity as it depends on the plasticity limit when combining the normal forces and bending moments) can be determined. Tension impulses of rectangular shapes are assumed, which corresponds to the full plastic use of the cross section – cf. Fig. 1. The shape of the interaction diagram depends on the cross-section type, the materials used and the ratios between the components' carrying capacities, cf., e.g., Fig. 5. In order to improve readability of the diagrams, the bending moment values on the horizontal axis are divided by the limit value of plastic moment $M_{pl,Rd}$. The values on the vertical axis are ratios of the design value of the plastic resistance of the composite section $N_{pl,Rd}$ to compressive normal forces. The resulting interaction diagram thus passes through points |1,0| and |0,1|. Such adaptations enable us to compare the interaction curves for columns with different parameters, as shown in Fig. 5. The shape of the curve is specifically affected by the distribution of steel components within the cross-section shape, or rather, the steel contribution ratio, Eq. 1.

$$\delta = \frac{A_a \cdot f_{yd}}{N_{pl,Rd}} \qquad (1)$$

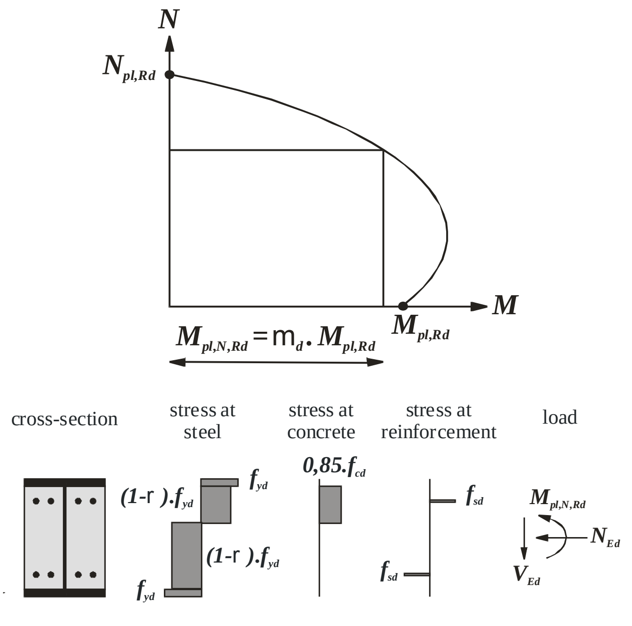

Fig.1: (a) Example of typical interaction diagram.
(b) Example of typical stress distribution across the cross-section.

For design purposes, the interaction diagram is usually displayed only in the first quadrant (pressure & bending) but it also touches on the fourth quadrant (tension & bending) of the coordinate system. Creating the interaction diagrams is demanding and time-consuming if calculated manually. Hence, simplified interaction diagrams are considered, cf. Fig. 2. Such diagrams go through four key points, *A*, *B*, *C*, and *D*, which correspond to the general interaction diagram. In Fig. 2 the limit position of the vertical axis corresponding to each of these points it can be seen. Point *A* represents the situation when only the cross section is under pressure, and the normal force corresponds to the design value of the plastic resistance of the composite section $N_{pl,Rd}$. At point *B*, pure bending occurs without any effects of the normal force. Point *D* corresponds to *B* in that the bending moment has the same size here, but with an additional normal force of value $N_{pm,Rd}$, which expresses the design value of the resistance of the concrete to compressive normal force. At point C, the normal force's value is $N_{pm,Rd}$ / 2 and the maximum design value of the resistance moment in the presence of a compressive normal force, $M_{max,Rd}$, is achieved.

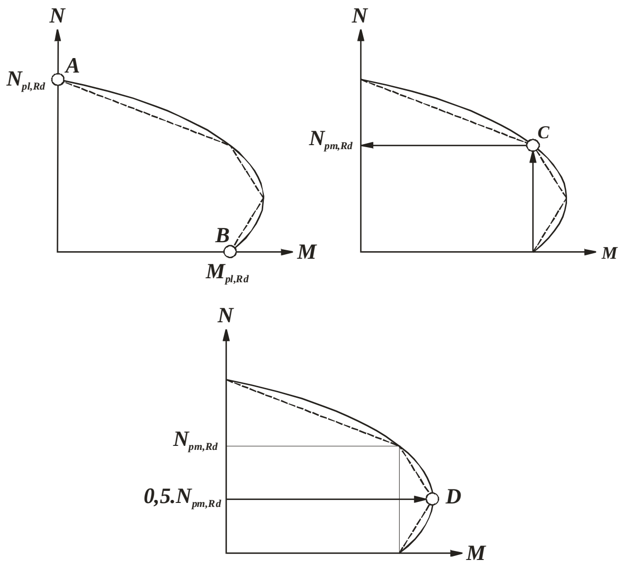

Fig.2: Simplified interaction diagram (dashed), definition of marginal points *A*, *B*,*C* and *D*.

2.2 Design capacity of composite steel-concrete columns

The procedure recommended in [1] mainly allows for manual calculations, based on the values looked up in interaction diagrams given, e.g., in [2] or [3]. A disadvantage of this approach is a limitation on the cross-section types: only those for which the corresponding interaction diagrams have been created can be used. In [4] such diagrams are

ISBN: 978-960-474-352-0

shown, and an example is in Fig. 5. This type of diagrams is more detailed and includes more cross-section types than those considered in [2] and[3]. When evaluating the carrying capacity values in the main planes, the inequalities given in Eq. 2 must be fulfilled. Coefficient αM depends on the steel used. For steel classes S235 and S355, the value of αM is 0.9; for other classes it is 0.8. When evaluating the resistance for combinations of normal force and biaxial bending moments, the inequality given in Eq. 3 have to be fulfilled.

$$\frac{M_{y,Ed}}{\mu_{dy} \cdot M_{pl,y,Rd}} \leq \alpha_{M,y} \quad or \quad \frac{M_{z,Ed}}{\mu_{dz} \cdot M_{pl,z,Rd}} \leq \alpha_{M,z} \qquad (2)$$

$$\frac{M_{y,Ed}}{\mu_{dy} \cdot M_{pl,y,Rd}} + \frac{M_{z,Ed}}{\mu_{dz} \cdot M_{pl,z,Rd}} \leq 1{,}0 \qquad (3)$$

Values μ_{dy} and μ_{dz} can be read in interaction diagrams (Fig. 3.) or numerically computed from the derived interaction curve. Values of $\mu_d < 1.0$ are usually taken. Values $\mu_d > 1.0$ should only be used where the bending moment M_{Ed} depends directly on the action of the normal force N_{Ed}, for example where the moment M_{Ed} results from an eccentricity of the normal force N_{Ed}.

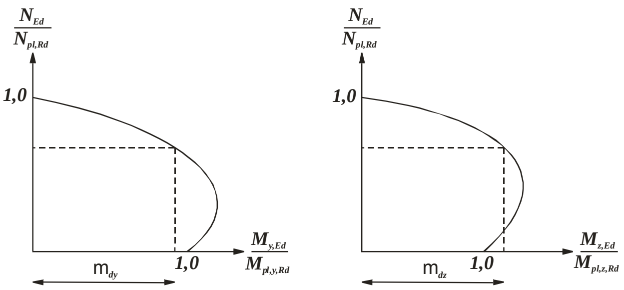

Fig.3: Definition of coefficients μ_d according to the corresponding stress.

3 Automatic calculation program

As already mentioned above, the procedure described in Section 1 is too laborious and time-consuming for manual calculations. Specifically, curves for determination of μ coefficient values are far from efficient for practical purposes. Certain simplification can be achieved by using the already known interaction curves for selected cross-section shapes as given in, e.g., [2] or for some other cross-sections in Fig. 7. However, those are only known for some cross-section shapes and with restricted properties. Such simplifications also lead to an unknown degree of inaccuracy – for example, the effects of reinforcement are usually outside the scope of our knowledge.

The purpose of our program is to simplify and make more efficient the process of evaluating steel-concrete columns. It enables us to create the required interaction curve for a selected cross-section shape with set dimensions and materials. It also evaluates the resistance for predefined cross-section types. The evaluation follows the procedure described in [1]. Another outcome, interesting from the design viewpoint, is a listing of possible reserve margins in the resistant values. The program is written in Visual Basic for Applications in Microsoft Excel; hence it does not require any specific software platform to be used. The formulas were first created and verified in Matlab and then converted to VBA, in which functions for evaluating and checking the input data were included. The user interface is a "normal" window in MS Excel. The application is set for such behavior using code. User orientation in the program is easy. Fig. 4 shows examples of cross-section shapes for which the program will work. The current language version of the program is Czech only; the English translation is on the progress.

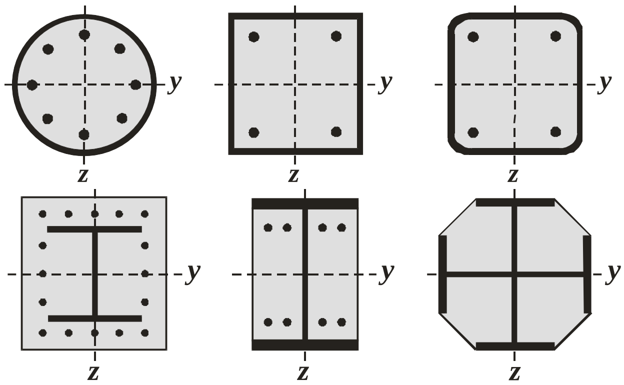

Fig.4: Basic types of cross-section shapes contained in the calculation program.

The section of the program that calculates the interaction diagrams is subdivided into modules. VBA uses modules for definitions of larger procedures and functions [5]. The program contains twelve modules for calculations of interaction curves. Each cross-section shape needs two modules: one for calculations without reinforcement, and another which takes additional reinforcement into account. The resulting coordinates of interaction diagrams are listed as Excel tables, from which the diagrams are generated. On input of each module there are dimensions and carrying-capacity parameters of the materials used. On output the interaction curves or, alternatively, evaluations of the set cross-section

ISBN: 978-960-474-352-0

types are plotted. Another example of a multiple output is a sum-up chart of interaction curves for variable ratios of the carrying capacities δ, cf. Fig. 7.

Each module also contains code for finding the maximum values of the moments and forces for the corresponding loading. These values are also listed for further use within the evaluation. The intersection between the applied internal forces and the interaction diagram must be looked up for evaluation, Fig. 5. For this purpose, special modules are included in the program, which make use of a simple algorithm to determine the coordinates of such an intersection, Fig. 6.

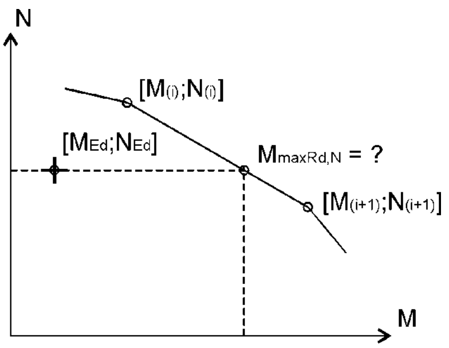

Fig.5: Intersection between the applied internal forces and the interaction diagram.

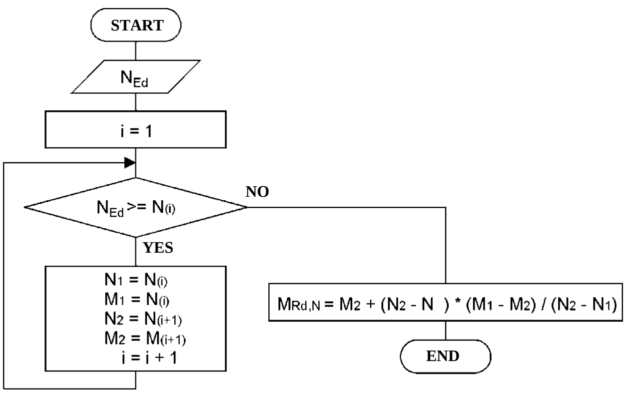

Fig.6: Intersection between the applied internal forces and the interaction diagram.

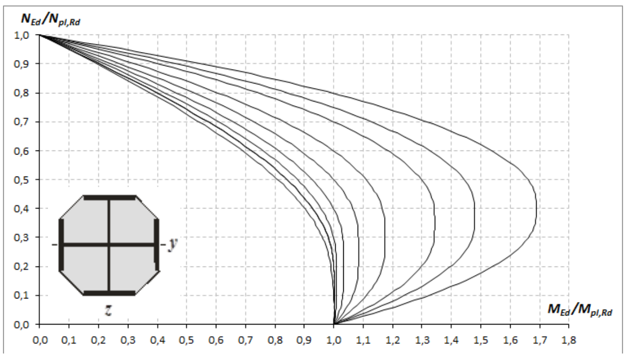

Fig.7: Interaction diagrams for one of the typical cross-section shapes.

4 Conclusion

The paper introduces a program for automatized efficient evaluation and design of composite steel-concrete columns of the usual cross-section shapes in compliance with currently applicable Standards [1]. The main contribution is considerable simplification of the time-consuming evaluation process and elimination of manual derivations of characteristics of the cross-section shapes. Using the program a quick and efficient design of the usual types of composite steel-concrete cross-section columns can be done. In the future, this program can be extended to include more user-friendly functions, such as automatized evaluation of axial-stress bending and effects of imperfections according to the second-order theory, assessment of fire performance, printing reports of calculations, etc. Only part of the related issues is addressed in the paper: more details can be found in [4] – e.g., detailed diagrams for resistance values of individual cross-section types, examples of solutions, general tables for the basic characteristics of cross-section shapes, etc. Program works in Czech currently, the English translation is on progress.

The program will be available online at http://www.fast.vsb.cz/221/cs/okruhy/studijni-materialy/. The access to the program is free for non-commercial use.

Acknowledgements:
This paper was created within the project "The creation and internationalization of top teams and enhancing their excellence in the Faculty of Civil Engineering VŠB – TUO" by members of the „Structural“ research group.

References:

[1] *EN 1994-1-1*, Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings.

[2] R. P. Johnson, *Composite Structures of Steel and Concrete*, Third edition,Oxford, UK,2004, ISBN: 1-4051-0035-4.

[3] A. Duricova, M. Rovnak,*Design of Composite Steel and Concrete Structuresaccording to STN EN 1994-1-1*, Bratislava, VEDA, 2008. [in Slovak]

[4] P. Pařenica, *Design Capacity of Composite Steel and Concrete Structures*, Bachelor thesis, VŠB-TUO, Fac. of Civil Eng., 2012. [in Czech]

[5] R. Jurecek, *Useful applications for program Excel*, [online, in Czech], Available WWW:http://www.rjurecek.cz/navody/TextBox-cisla.html