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SIMPLE AND ADVANCED MODELS FOR CONNECTION DESIGN IN STEEL STRUCTURES

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Abstract

The paper refers to current development in design of structural steel and steel and concrete composite connections. Today practice is preferring analytical models which are based on good quality of prediction for standardised structural solutions. For description of full behaviour were analytical models equipped by prediction of stiffness and deformation capacity, which is called Component method. This paper introduces next step of design using finite element method for distribution of internal forces and components to analyse connectors itself, Component based finite element method. The material is modelled on design level as bilinear. The internal forces in connection is analysed procedure by shell elements with adequately accurate meshing. The proper behaviour of components is treated by introducing its behaviour in term of initial stiffness, ultimate resistance and deformation capacity. The internal part of this design procedure is validation and verification including its hierarchy.

Keywords: Steel structures, Connection design, Analytical model, Finite element method, Validation and verification.

1. Introduction

The structural steel connections are designed by experimental, curve fitting, analytical and numerical models. The tests with connections are simple and economical solution for its design. Based on tests were prepared designed tables for standardised connections and published databases of test. Curve fitting models are known from 1930. Mathematical formulas expressing the influence of geometrical and material parameters are reproducing the behaviour of similar connections well, but are not appointing the major parameters for design in particular the resistance. Today is applied in modelling of connections in seismic design. The analytical modelling of components of connections are well developed for all connectors, bolts, welds, anchor bolts etc. Analytical model of connections needs good engineering assumption of internal forces and proper selection of components, which affects the resistance and stiffness. This model prepared for selected types of configuration in known as Component method (CM). CM builds up on standard procedures evaluating the internal forces in connections and their checking. Zoetemeijer [1] was the first who equipped the model for resistance with prediction of stiffness and deformation capacity. The elastic stiffness was improved in the work of Steenhius [2]. Description of components behaviour was prepared by Jaspart for most beam to column connections [3] and by Wald et al for column bases [4]. Method implemented in the current European structural standard for steel and composite connections see [5] and [6] is applied in majority of software for structural steel used in Europe. The model was generalised by da Silva [7] allowing its application for design at elevated temperature during fire, 3D modelling of connections etc. The procedure starts with decomposition of a joint to components followed by their description in terms of normal/shear force deformation behaviour. After that, components are grouped to examine joint moment-rotational behaviour and classification/representation in a spring/shear model and application in global analyses. Advantage of the component model is integration of current experimental and analytical knowledge of connections components behaviour, bolts, welds, end plates, flanges, anchor bolts and base plates. This provides very accurate prediction of behaviour in elastic and ultimate level of loading. Verification of the model is possible using simplified calculation. Disadvantage of component model is that experimental evaluation of internal forces distribution is done only for limited number of joint configurations. Also in temporary scientific papers, description of typical components is either not present or has low validity and description of background materials. Models of hollow section connections are described in Ch. 7 of EN1993-1-8 [8] by curve fitting procedures. The transfer to higher level of analytical modelling by component method is under development. The CM´s is not developed for hand calculation. The analyses of all components in connection and its assembly is focus to preparation of design tables or tools.

Finite element models (FEM) for connections are used from 70s of last century as research-oriented (ROFEM). Their ability to express real behaviour of connections is making them a valid alternative to testing standard and expensive source of knowledge of connection's behaviour. Material model for FEM uses true strain stress-strain diagram. Four decades ago computational analysis of structural connection was treated by some researchers as a non-scientific matter. Two decades later it was already a widely accepted addition or even extension of experimental and theoretical work. Today computational analysis, in particular computational mechanics and fluid dynamics, is commonly used as an indispensable design tool and a catalyst of many relevant research fields. The recommendation for design by advanced modelling in structural steel is already hidden but ready to be used in Chapter 5 and Annex C of EN 1993-1-5:2005, see [8]. Development of modern general-purpose software and decreasing cost of computational resources facilitate this trend. As the computational tools become more readily available and easier to use, even to relatively inexperienced engineers, more scepticism and scrutiny should to be employed when judging one's computational analysis. Native process of computer based design is

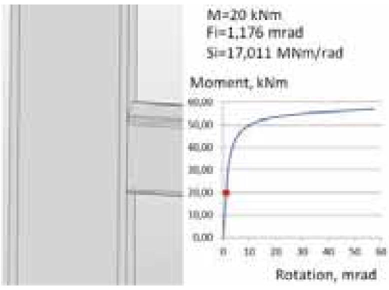
Validation and Verification (V&V) of models, see [9]. Application of V&V to steel connections design is limited to a few published benchmark studies, see [10]. Comparison of V&V to different engineering application is still to be done [11]. Strain is recommended to be limited to 5%, see cl. C.8(1) EN 1993-1-5 [8]. Implementation of safety into advanced design models under ultimate limit state design is summarised in cl. C.9(2) EN1993-1-5 [1]. Standard procedure with partial safety factors for material/connections may be applied. More advanced and accurate solution, which takes into consideration the accuracy of model and material separately, gives more accurate and economical solution of structural connections, see [12] to [15].

However for structural connections with thousands experiments available the validation process may be executed. But even in such situation the verification process performed through benchmark tests gains crucial importance. Seeing the need of making the results of research more transparent to the public, the office of science and technology policy in the United States issued a memorandum stipulating increased access to the results of federally funded scientific research. Such data can be easily verified or used for verification (or benchmarking), of some other work. The trend of making extended data available together with a report or publication persists in order to build confidence in growing number of performed numerical simulations. To achieve this goal it seems even more beneficial at this point to develop a standard set of smaller benchmark tests that can be used as a reference in the verification pro-cess of simulations. The source and the extent of such benchmark tests for the field of structural connections is yet to be established, see [16].

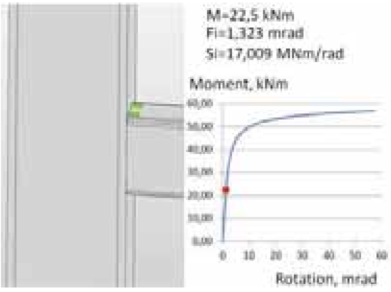
The detailed procedure for verification of proposed method and its application in design tool IDEA RS Connections, see [17], was prepared. The procedure consist of preparation of Benchmark studies for used components, e.g. bolts, welds, slender plates in compression, anchor bolts, and concrete block in compression. Three different types of welded connections were selected for benchmark studies, connections loaded in shear, in bending, and welded to flexible plate. For bolted connections are prepared benchmark studies for T-stub in tension, the splices in shear and the generally loaded end plate connection. For slender plate in compression is studied the triangular haunch in compression, the slender stiffener of column web and the plate in compression between bolts. For hollow section joints are studied the welded joints between CHS members, between RHS and FHR/CHS welded to the open section chords in shape of T, K and TT joints. For column bases are prepared verifications for generally loaded columns of open and hollow sections. Verification of case study consist of description of selected joint, results of CM and CBFEM, differences described in term of global behaviour on the force-deformation/rotation curve, and verification of initial stiffness, resistance, deformation capacity. At the end of each Benchmark study is prepared a Benchmark case to allow the user to check his results. In some cases gives the CBFEM method higher resistance, initial stiffness or deformation capacity. Advanced FEM model from bricks element validated on own experiments or experiments from literature is used in these cases, to get proper results. CBFEM is approved by this procedure.

2. Global and Local Behaviour

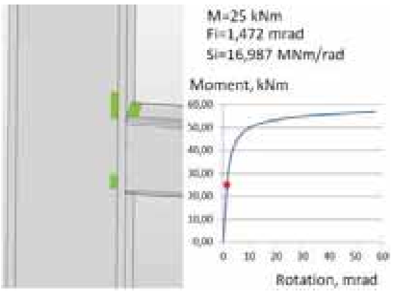
The advantages of CBFEM analyses of steel plates may be documented on study of global and local behaviour of a joint between open section HEA 240 and hollow section RHS 180x100x10 mm loaded by bending moment and shear force. The results of analyses shows in Fig. 1 the development of plastic zones in connection, from first yielding of upper flange of RHS to plastification of the HEA flange till reaching the resistance of the HEA web at 5 % strain.



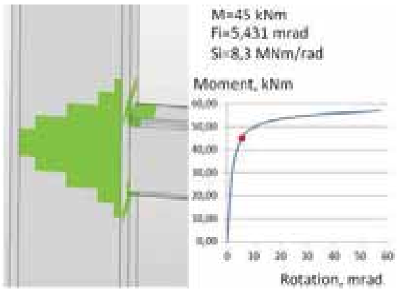
a) Elastic stage



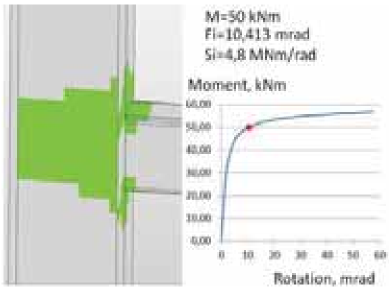
b) Plastification of the RHS upper flange



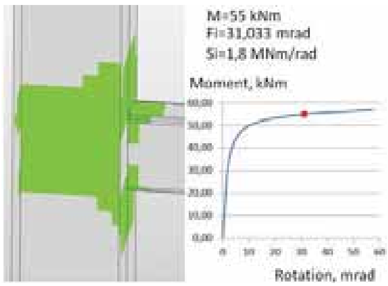
c) Initial plastification in HEA web



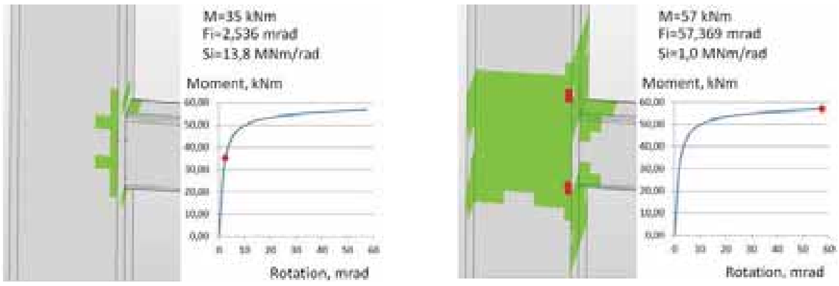
e) Full plastification in the HEA web



f) Initial plastification in the RHS web



g) Plastification of second flange of HEA



d) Initial plastification in the HEA flange **h) The HEA web reaches design strain**

Fig. 1. Development of plastic zones in connection by CBFEM analyses.

3. Prediction of Deformation Capacity

It is commonly known that the end plate connections with bolts under the flange have a limited deformation capacity due to reaching the bolt tensile resistance before a significant plastification of the end plate. This is reflected in design by limiting the bolt resistance of bolt row below the bolts under flange to elastic distribution, see [17]. The CBFEM analyses allows to evaluate the real deformations at individual stages of loading. The procedure also enable to search for possible influence of higher upper values of steel properties and is implemented in IDEA SR code. The composition of the connection geometry of the bolted beam splice connection of two IPE 300 is demonstrated in Fig. 2. The end plates with steel S355 were designed 12 mm thick with bolts M16 4.8. The comparison of CBFEM and CM shows, see Fig. 3, difference in initial stiffness and correspondence in prediction of resistance, which is limited by bolt tensile resistance. The sensitivity analyses shows the influence on prediction of resistance due to changes of the end plate thicknesses, see Fig. 4, bolt sizes, and material property with limited change of geometry, see Fig. 5. The development of plastic zones round the bolts and limited plastification till failure of bolts in tension is shown in Fig. 6.

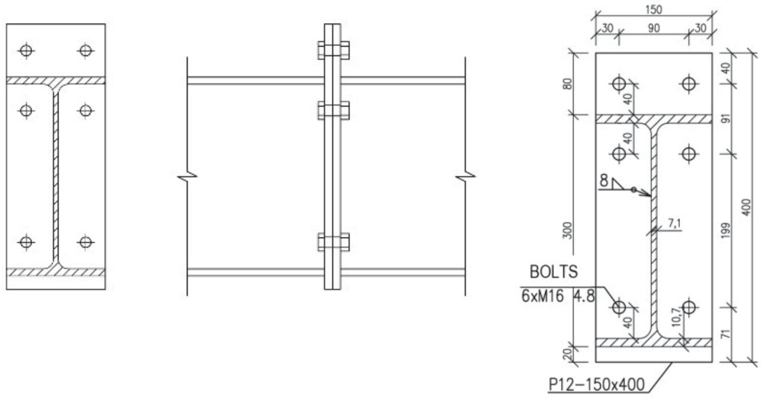


Fig. 2. Geometry of studied joint, IPE 300 S355.

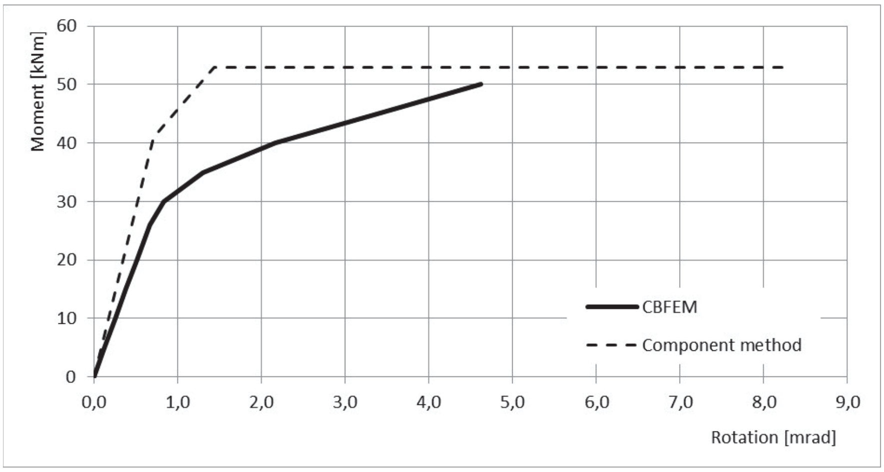


Fig. 3. Moment - rotational diagram for beam splices connection predicted by CBFEM and CM.

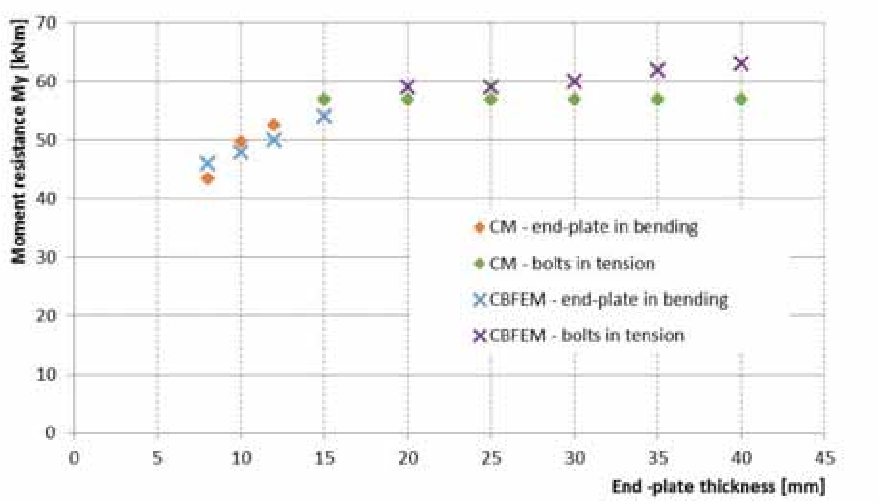


Fig. 4. Comparison of moment resistance predicted by CBFEM and CM for different plate thicknesses.

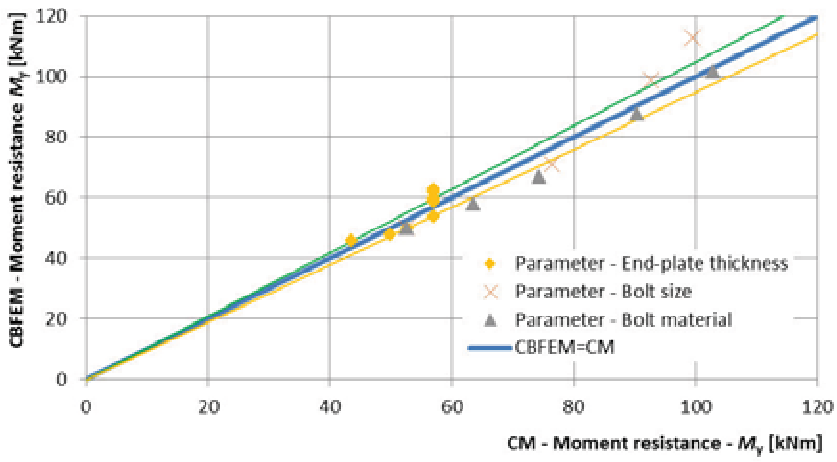
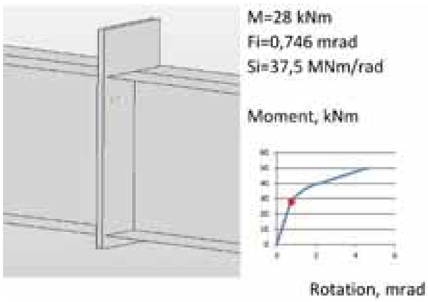
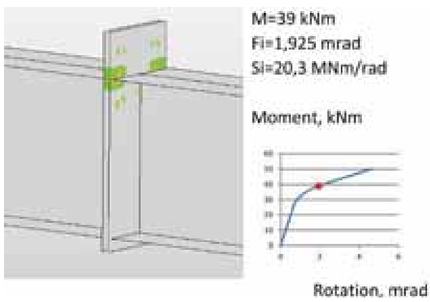


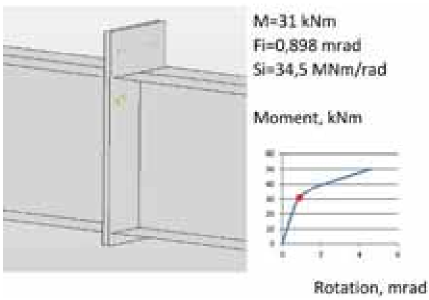
Fig. 5. Comparison of moment resistance predicted by CBFEM and CM for changes of geometrical and material parameter.



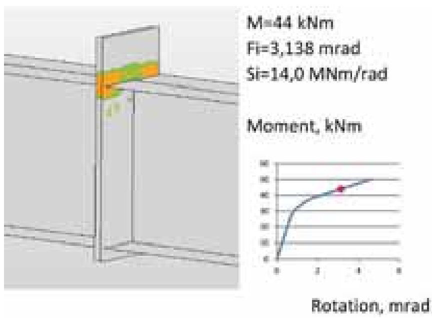
a) Elastic stresses.



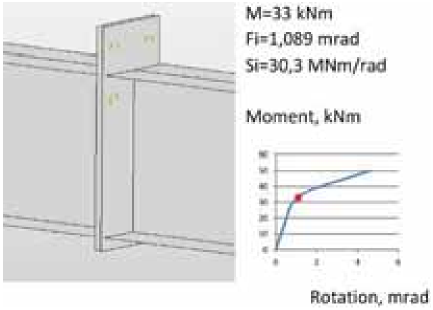
e) Plastification in the web of HEA.



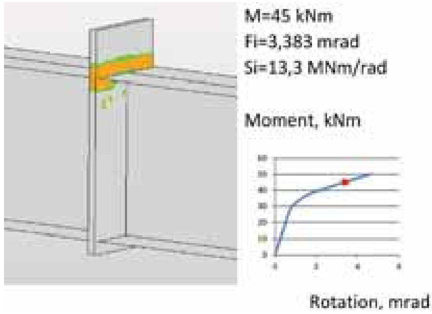
b) Plastification round the lower bolts.



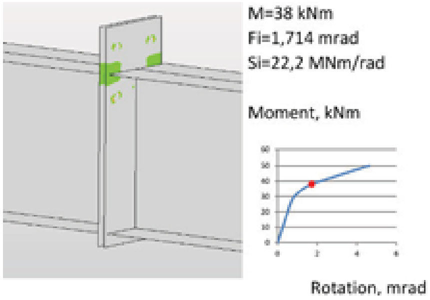
f) Initial plastification in the web of RHS



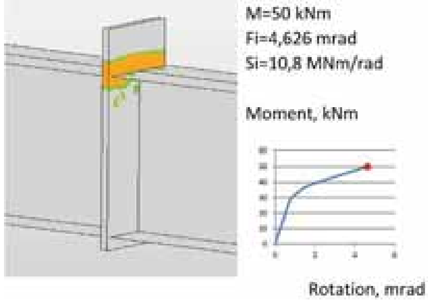
c) Plastification round the upper bolts.



g) Plastification of second flange of HEA



d) Plastification round the flanges



h) HEA web reaches the design strain

Fig. 6. Limited plastification till failure of bolts in tension.

4. Conclusions

The global analyses of steel structures is today carried out by FEM and all the traditional procedures are not used any more (like force method, three moment equation, Cremon´s pattern, the Cross method or the method distribution moments). In current fast development of software ability will be the connections designed very soon by FEM instead of today used curve fitting and CM. The CBFEM is an competitive solution ready to use. Some concluding observations from the investigation are given below.

- For proper use of CBFEM is necessary to develop and standardise a good V&V procedures to allow of its safe use.
- The presented results shows the good accuracy of CBFEM verified to CM.
- In some cases the CBFEM gives higher stiffness / resistance / deformation capacity. Then needs to verify to ROFEM, which is validated to experiments.
- The CB method used in tables and tools limits poor design of structural steel and steel and concrete composite connections by incompetent amateurs. By CBFEM can be properly analysed/checked the complex design solutions complicatedly loaded by well-trained experts.
- The benchmark cases and correct use of V&V limits the improper use of model. The high-quality education will remain the background of design of pretty structural connections.

Acknowledgments

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