16. ON THE WAY TO AN UNIFIED DESIGN APPROACH FOR JOINTS IN STRUCTURAL SYSTEMS

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Present paper first briefly describes the past and ongoing activities of the Technical Committee 10 "Connections" of the European Convention for Constructional Steelwork (ECCS TC10).
The Committee has been deeply involved in the recent years in the development of Eurocode 3, and more especially in that part of the code which deals with connections (Chapter 6 and related annexes, ...). Beam-to-column joints and beam splices required much efforts, and to cover all the needed configurations, an unified design approach based on the so-called component method has been developed. This joint characterisation process is described in detail in the second part of the paper.
Lastly, topics for further investigations and developments are pointed out and, amongst them, those presented, in the session 8 on "Connections" of the present conference, by Prof. Nethercot and Prof. Stark.

16.1. PAST AND PRESENT ACTIVITIES OF ECCS TC10

The Technical Committee TC10 of ECCS is constituted of three working groups dealing respectively with :

- TC10.3/4 : Bolted Connections;
- TC10.2 : Semi-Rigid Joints;
- TC10.5 : Welded Connections and High Strength Steel (HSS).

The name of each of these working groups does not reflect always exactly the activities carried out by their members. From that point of view, some clarification is required :

- TC10.3/4 concentrates on the study of connectors and of "basic connections".
  Connectors represent means to connect steel elements together and amongst them, bolts appear nowadays as a quite usual solution. But new products are regularly developed and their use in actual structures requires the preparation of appropriate design rules for strength evaluation.
  Examples of such new products may be given : Huck-Fit bolts, flowdrill systems, welded studs, shot nails, ...
  Besides these activities on connectors, TC10.3/4 has developed efforts to provide designers with adequate rules for the design of "basic connections" where two connected plates are subjected to tension or shear forces. As far as bolts are concerned, the level of bolt prestressing - this topic has been widely discussed in TC10.3/4 to supply the European Normalisation Committee (CEN) with agreed recommendations - is a governing parameter as it may influence significantly the collapse mode and the collapse load of the connections. In this study, collapse modes such as bolt fracture, excess of bearing, shear block failure, ... are to be considered.
- In TC10.2, focus is made on structural joints such as beam-to-column joints, beam or column splices and column bases. The mechanical behaviour of these ones is characterized by a design resistance, but also by a rotational stiffness and a rotation capacity. The development and the validation of formulae for the evaluation - the proper word to be used is "characterisation" - of these

three mechanical properties has constituted one of the major objectives of the working group in the last years. The activities of TC10.2 have been closely linked in this period to those of the CEN project team (European Normalisation Committee) in charge of the preparation of the revised Annex J of Eurocode 3 devoted to "Joints in Steel Building Frames". At this occasion, an unified approach for the design of joints in structural systems has been established. It is based on the so-called component method which is described in the next chapter. As explained later in this paper, present activities within TC10.2 are aimed at extending the application of the component method, initially proposed for welded joints and bolted end-plate joints to a wider range of joint configurations.

- TC10.5 deals with the behaviour of welds in connections and the application of higher steel grades in joint and connection design.

In the next chapter, the basis of the component method is described and the possibilities for further extensions of its range of application within T10.2 are identified.

16.2. COMPONENT METHOD

16.2.1.GENERALS ON THE CHARACTERIZATION

In the present chapter, a general analytical procedure for the prediction of the mechanical properties of structural joints is introduced. This so-called component method, the name of which originates from the period where the Annex J on "Joints in Steel Building Frames" of Eurocode 3 [1] has been revised, appears as the outcome of several years of studies on joint characterisation throughout Europe and North America. Its great advantage, contrary to other approaches proposed in the past, is the possibility to be applied to any steel or composite beam-to-column joint, to beam splice or to column base.

Before describing the principles of the component method, and in view of a better understanding of its different levels of refinement, it appears quite interesting to present hereafter an overview of the other characterisation procedures by particularly highlighting their advantages and drawbacks.
The more accurate but also expensive way to characterise the deformability and the resistance of joints is the experimentation in laboratory. The use of this technique - which requires much money and much time - is basically limited to research activities and can consequently not be recommended for daily practice.

The existence of numerous test results for a large variety of joint configurations and connection types led progressively some researchers to develop computerised databanks. The low probability for the designer to find information for the specific joint he is studying and the risk to misinterpretate the results listed in the databank - no standardised procedure for the testing of joint exists at present - limit considerably the practical interest of these tools. On the other hand, it appears now clearly that the databanks have to be considered as quite valuable tools for the validation of mathematical models aimed at predicting the joint response on the basis of the geometrical and mechanical joint properties.

Most of the well-known mathematical models available in the literature are described in [2] by Nethercot and Zandonini. They can be classified in four main categories :
A - curve fitting;
B - simplified analytical models;
C - mechanical models;
D - finite element analysis.

In [3], the differences and similarities between these categories are presented through four tables focusing for each category, on :
- the definition;
- the advantages and disadvantages (practical interest, field of application, etc).

The description of a specific model belonging to each category as well as a list of available models complete also the information given in each table.
This synthetic presentation is aimed at helping the researchers who intend to develop mathematical predicting tools for joints - whatever is the material used - to choose on good grounds the type of modelling to which he will refer.

From the four tables, it is concluded in [3] that :
1. The finite element analysis is not yet likely to be used to predict the semi-rigid response for any type of connection detailing and that its use is still reserved to research activities.
2. The simplified analytical models and the mechanical models are characterised by a wider field of application than curve fitting; this results from the theoretical background of these two kinds of modelling.
   They have however to be extended to other types of connections in order to cover the main needs of the designers.
3. The simplified analytical models are the only ones - with the formulae resulting from curve fitting - to be suitable for hand calculations.

16.2.2.PRINCIPLES OF THE COMPONENT METHOD

The component method may be presented as the application of the well-known finite element method to the calculation of structural joints.
In the traditional characterisation procedures, a joint is generally considered as a whole and is studied accordingly; the originality of the component method is to consider any joint as a set of "individual basic components". In the particular case of figure 16.1. (joint with an extended end-plate connection subject to bending), the relevant components are the following :
- compression zone :
  - column web in compression;
  - beam flange and web in compression;
- tension zone :
  - column web in tension;
  - column flange in bending;
  - bolts in tension;
  - end-plate in bending;
  - beam web in tension;
- in shear zone :
  - in column web panel in shear.

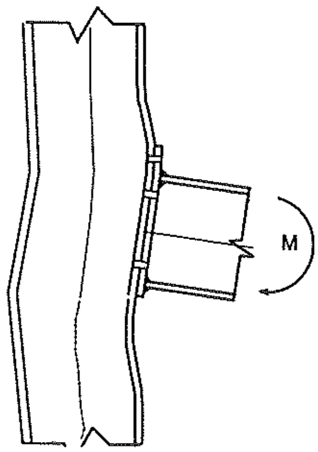


Fig. 16.1 Joint in bending with an extended end plate.

Each of these basic components possesses its own level of strength and stiffness in tension, compression or shear. The coexistence of several components within the same joint element - for instance, the column web which is simultaneously subjected to compression (or tension) and shear - can obviously lead to stress interactions that are likely to decrease the strength and the stiffness of each individual basic component; this interaction affects the shape of the deformability curve of the related components but does not call the principles of the component method in question again.

The application of the component method requires the following steps :

a) definition of the active components within the studied joint;
b) evaluation of the stiffness and/or strength characteristics of each individual basic component (specific characteristics - initial stiffness, design strength, ... - or the whole deformability curve);
c) "assembly" of the components in view of the evaluation of the stiffness and/or strength characteristics of the whole joint (specific characteristics - initial stiffness, design resistance, ... - or the whole deformability curve).

These three steps are schematically illustrated in figure 16.2. in the particular and simple case of a beam-to-column steel joint with a welded connection.

As specified here above, the parallelism with the finite element method is obvious. To "component" and "joint" may then be substituted the words "finite element" and "structure".

The assembly is based on a distribution of the internal forces within the joint. As a matter of fact, the external loads applied to the joint distribute, at each loading step, between the individual components according to the instantaneous stiffness and resistance of each component. But in practice simplified distributions of internal forces may be obtained through different ways; one of these is suggested in the revised Annex J of Eurocode 3 [1] for joints subjected to bending moments.

The application of the component method requires a sufficient knowledge of the behaviour of the basic components. Figure 16.3. gives an overview of the steel components covered by the revised Annex J of Eurocode 3. In the recently drafted Annex J of Eurocode 4 [4], a new component is added : the reinforcement bars in tension; the stiffening and the strengthening of the column web panel in shear and of the column web in compression by means of encased concrete are also made available.

The combination of these components allows to cover a wide range of joint configurations, what should largely be sufficient to satisfy the needs of practitioners as far as beam-to-column joints and beam splices in bending are concerned.

Research works have recently allowed to investigate these different aspects; they have brought some first answers to these last questions which prevent the general use of the component method to any structural joint.

16.2.3.LEVELS OF REFINEMENT

The framework of the component method is sufficiently general to allow the use of various techniques of component characterisation and joint assembly.
In particular, the stiffness and strength characteristics of the components may result from experimentation in laboratory, numerical simulations by means of finite element programs or analytical models based on theory. Experimentation and numerical simulations can also be used as references when developing and validating analytical models. These ones may be developed with different levels of sophistication according to the persons to whom they are devoted :

- expressions resulting from deep scientific investigations cover the influence of all the parameters which affect significantly the component behaviour (strain hardening, bolt head and nut dimensions, bolt prestressing, ...) from the beginning of the loading to collapse and fit therefore well with scientific publications;
- the rules which have been introduced in Annex J of Eurocode 3 [1] are more simple and are therefore more suitable for hand calculations.
- Simplified design sheets as those prepared in the SPRINT European project [5] constitute an ultimate step in the simplification process; the procedures for stiffness and strength evaluation are reduced to the essentials and allow a quick and nevertheless accurate prediction of the main joint properties.

Similar levels of sophistication exist also for what regards the joint assembly.

16.2.4. FURTHER DEVELOPMENTS

As already said, the extension of the component method to composite joints has been recently achieved and design rules for Eurocode 4 have been included in an Annex J on "Joints in Composite Building Frames".

But some fields of application are however not yet covered by the codes :

- Weak axis joints where the beam is connected to the web of a H or I column profile are characterised by an out-of-plane deformability of the column web under the tension and compression forces carried over by the beam. The "column web in transverse compression and tension" component still requires specific studies to be performed in view of the development of reliable

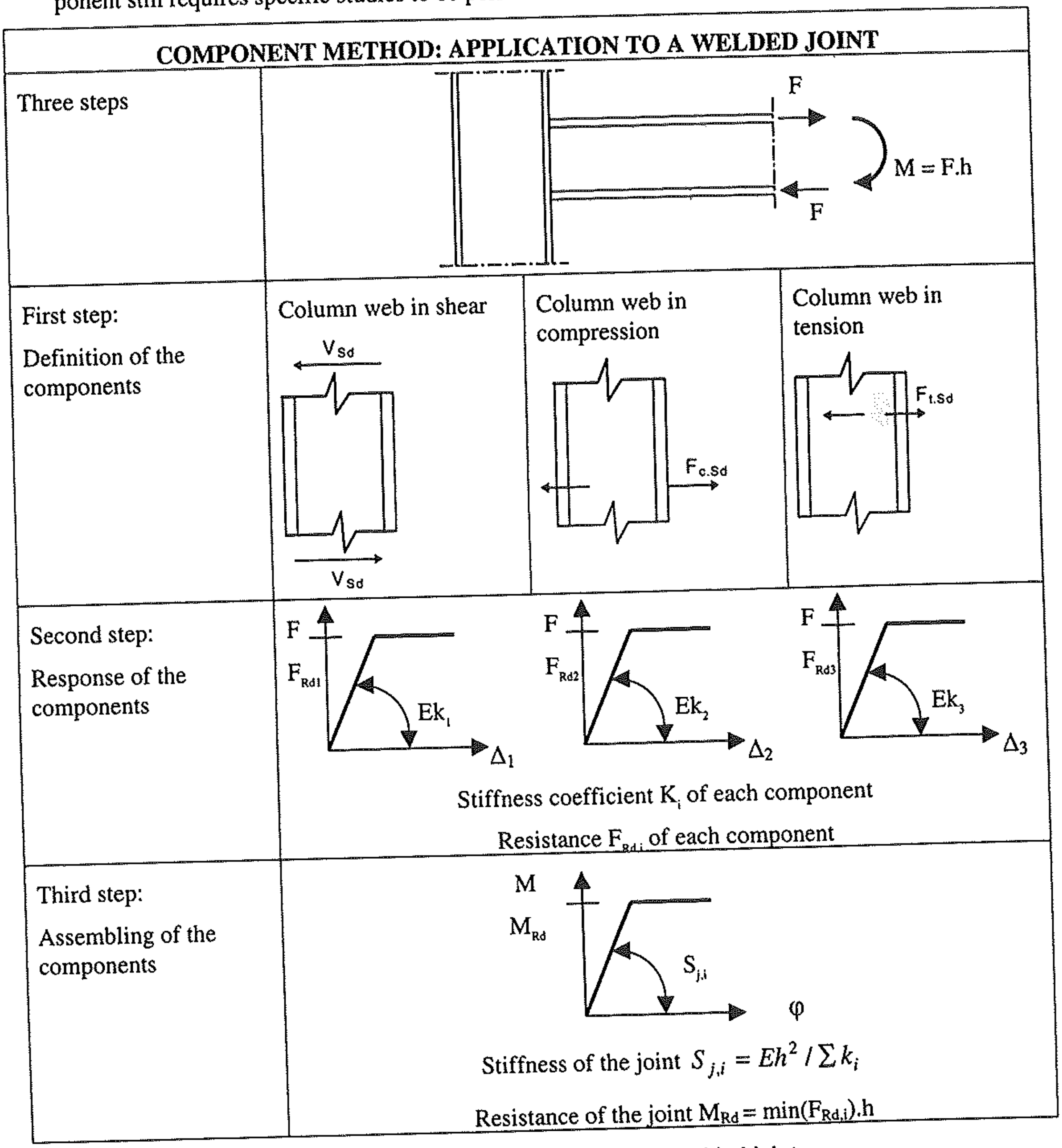


Fig. 16.2 Application of the component method to a steel welded joint.

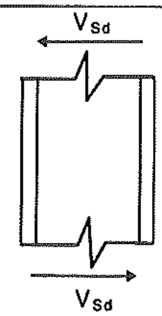
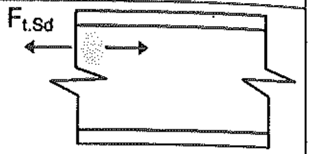
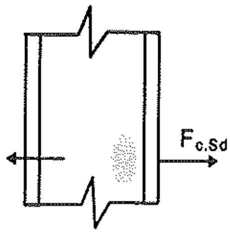
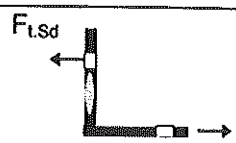
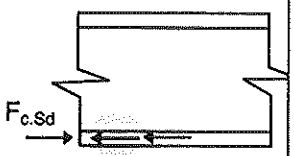
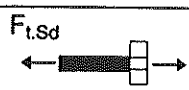
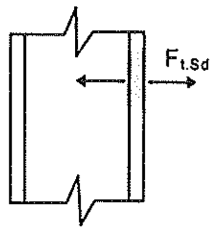
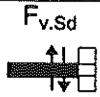
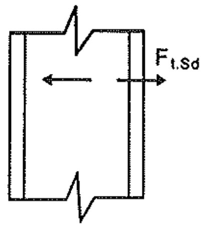
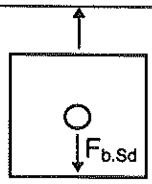
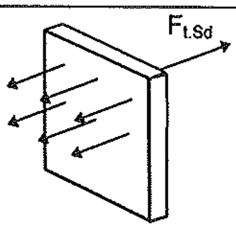
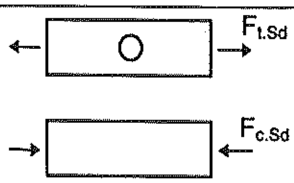
N°	Component		N°	Component	
1	Column web panel in shear		7	Beam web in tension	
2	Column web in compression		8	Flange cleat in bending	
3	Beam flange and web in compression		9	Bolts in tension	
4	Column flange in bending		10	Bolts in shear	
5	Column web in tension		11	Bolts in bearing (on beam flange, column flange, end-plate or cleat)	
6	End-plate in bending		12	Plate in tension or compression	

Fig. 16.3 Components available in Eurocode 3.

stiffness and strength characterisation tools. Knowledge about this component would directly allow the extension of the component method to joints where tubular columns with rectangular hollow sections are used, as shown in [6]. As a matter of fact, similar phenomena occur in the face of the hollow section where the beam is connected.

- Joints subject to bending moment (and shear) and axial compression or tension forces have been less studied and, in particular, the way to distribute the internal forces for stiffness and strength calculations, the stiffness and strength component properties remaining unchanged whatever is the type of loading.
- Column bases are subjected to combinations of bending moments and axial forces and possess specific components which are not yet fully well-known. For instance :
  - concrete block in compression;
  - end-plates with specific geometries;
  - anchorages in tension;
  - contact between soil and foundation;
  - ...
- An improvement of the mechanical properties of the joints may be achieved through the use of beam haunches or end-plate stiffeners. These aspects are not yet covered in the codes.
- In pitch-roof portal frames, connected beams and columns form an angle higher than 90°. This requires specific amendments to be made to the existing characterisation procedures.
- When columns with rather slender webs are used, the usual rules for "column web panels in shear" are no more valid because of the apparition of shear buckling and post-critical phenomena. Few recommendations are available in this field.
- The rules contained in Eurocode 3 revised Annex J are valid for steels up to S355. The possible extension to steels up to S460 requires further investigations.

16.3. FUTURE ACTIVITIES OF ECCS TC10

Three main fields of activities for future may be pointed out :
- Synthesis of new findings from research.
- Support to codification.
- Practical guidelines for designers.

Each of them may be described in short words.

16.3.1. SYNTHESIS OF NEW FINDING FROM RESEARCH

In the last years, numerous research works have been carried out in the field of structural joints between H or I rolled or built-up profiles and other ones between H or I beam profiles and tubular columns. Reference can be made to the works performed within the European COST C1 project on "Control of the Semi-Rigid Behaviour of Civil Engineering Structural Connections" where scientific solutions have been suggested for weak-axis joints, joints with slender profiles, joints in tubular construction, ... An intensive activity also developed on column bases, within an ECCS TC10/COST C1 ad-hoc working group, on the basis of extensive researches recently carried out in different European countries.

This material, usually referring to the principles of the component method, is rough from research, what often prevents a simple and easy use in design practice. One of the activities of TC10 will therefore consists in extracting the essentials of these research works and presenting them in an appropriate format so as to complement and extend the scope of the presently available design rules contained in the normative documents.

16.3.2. SUPPORT TO CODIFICATION

ECCS is involved in the conversion of the Eurocodes from ENV to EN (from an European prenorm to an actual norm) through the so-called "ECCS Validation Group", the role of which is to provide CEN (European Normalisation Committee) with appropriate technical rules and guidelines for inclusion in the European Norm (EN).

For what regards connections, a complete reorganisation of the related material contained in Chapter 6 of Eurocode 3 and different annexes is planned. This work will develop in TC10; besides the reorganisation of the material, an update of the technical content is also foreseen.

Finally, a tendency in the construction industry is to move from solution driven specifications towards performance requirements. In the standards first steps have been set to introduce performance requirements but further developments are necessary. This aspect will be considered by Prof. STARK in his paper entitled "Towards performance requirements for structural connections".

16.3.3. PRACTICAL GUIDELINES FOR DESIGNERS

New concepts for joint design have been progressively introduced in design codes. However their use can, in some situations, lead to slight modifications in the usual frame and connection design procedure; the objective is to get an economical benefit by reducing the fabrication and erection costs for joints.

In other words, an "integrated design for economy" has nowadays to be usually preferred to traditional design procedures where joint and frame designs appear as two separate and quasi-independent tasks. This topic is treated extensively in the selected paper of Prof. Nethercot entitled "The integration of Connection Design". To facilitate the use of modern design concepts and calculation procedures, it is imperative to produce practical recommendations for practitioners and to organise seminars where these ones could be presented and explained.

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