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Research on connections in Europe
The COST C1 action

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Summary

The basic principles of COST organization are presented as well as the specific topics of COST C1 action which is devoted to civil engineering structural connections. The interest of a large research programme at the european level is demonstrated, in terms of knowledge and in terms of education. The various subgroups, materials oriented and methods oriented are described as well as the common and transversal subjects of research. The resulting european network allows fruitful exchanges for researchers, scientific and design concepts.

1. Introduction

The semi rigidity concept for connections was introduced in an european regulation code, Eurocode 3, in the 1984 version. At this time, there was no indication on the way to use this concept in a practical form. Several theoretical papers [1] or reports had been published [2] but it was not possible to make a full structural design, from this available material, due the lack of knowledge regarding one ore more piece of information (stiffness, local strength, global strength, size and location of the joint, structural effects, ...) for a given connection.

In 1987 the ECCS (European Convention for Constructional Steelwork) established a specific technical subgroup (TWG 8-2) more especially devoted to study the response of the whole structures (sway and nonsway) taking the behaviour of joints into account [3]. Outside of this topics this group of researchers produced the first document on a classification system, which was immediatly implemented in EC3, and pointed out the necessity of deapest studies on the local strenght and local deformability of the joints. So a new technical working group was set up (TWG 10-2) in the relevant technical committee of ECCS, dedicated to connections. Most of the EC3 implementations and annexes are coming from some members of this subgroup [4] who proposed several improvments to the well known T-stub approach [5]. Despite these progresses, regarding the knowledge and the contents of EC3, a lot of people were reluctant to use semi rigid concepts and much criticisms were expressed.

It appeared clearly that the potential users were afraid by the calculations, mostly because they were not educated with these new concepts in the field of structural analysis. By the same time in others fields of building construction - timber, precast concrete - there were the first "tremors" for looking to partial strength or partial rigidity. Thus, in 1990, the idea to set up a wide european programme was born in order to broaden the number of involved researchers, to disseminate more efficiently the results already obtained, to create the necessary new knowledege and most of all to offer the relevant material to the teachers in the frame analysis field in view of the implementation of semi rigid concepts at the earliest stages of education. The idea was that greater will be the number of materials involved greater will be the interest for these new concepts.

After two years of discussion and preliminary meetings in Brussels, the COST C1 action was officially launched in 1991. Very quickly about ten countries were participating in the first organizationnal meetings and two years later more than twenty were involved. To day, twenty three countries are participating : Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom. The european community is involved through the Ispra Center, and the University of Timisoara - Romania - as individual institute.

2. The basic principles of COST

The aim of COST cooperation is to coordinate precompetitive or fundamental research financed at national level. The COST member countries may choose and participate in the various COST actions "à la carte". In each country one ore several institute can participate in the action.

2.1. Financing

The research work itself (testing, researchers salaries ...) has to be financed at national level from public or private funds. The money given by the european community is devoted only to the organization of the scientific coordination through meetings, workshops, publications, missions, travels and subsistance ...

The individuals are directly reimbursed for their own expanses. The institutes can be involved through specific contracts for workshop organization or publication works.

The annual budget of the COST C1 action is about 100 000 ECUS. It is one of the more important budget among all the COST actions. This is due to the very large number of participating countries.

2.2. The administrative organization

The main body is the managment committee. Each participating country has two representatives in this committee. The managment committee, presided by the action chairman, is in charge of all the decisions regarding the action :

- preparation and approvment of the budget
- organization of meetings and workshops

- setting up of working groups
- assignment of individual tasks
- attribution of specific travels and missions
- contents of publications
- examination and decision regarding individual institute applications.

The managment committee has to meet at least two times a year to ensure continuous activities. The permanent relation between the managment committee and the european commission is carried out by the technical secretary.

3. The internal COST C1 organization

Due to the large number of participating countries and the diversity of the materials and problems involved it was decided, in 1992, to set up different working groups in order to be more efficient. Nevertheless the main activities, and more especially the decisional activities, remind at the common level.

3.1. The seven subgroups

Four working groups are materials oriented, and three working groups are methods oriented.

WG1 Concrete structures
WG2 Steel and composite structures
WG3 Timber structures
WG4 Data base
WG5 Seismic design
WG6 Numerical methods
WG7 Polymeric materials.

It was necessary to share the various material fileds because the level of research was quite different from one to another material. As an exemple the semi-rigid concept was already included in EC3, whereas it was nearly ignored for other materials. Furthermore the group coming from steel and composite was already more or less homogeneous while there was no real community for timber and composite. So, it was important to set up consistent groups of researchers. However several common meetings or workshops are organized to ensure full benefit from one group to another and to allow for development of common concepts and methods.

The subgroups meet two times a year, each time in a different location, laboratory, university, in order to allow for every body to know the various equipements and facilities of the colleagues.

Very often, for the two last years more especially, different subgroups meet in sequence at the same location in order to allow a crossed attendance to the meetings. This is an efficient way for technology transfer from one field to another. The youngest group, devoted to polymeric material, was set up in 1994.

The methods oriented subgroups are of transversal interest regarding the different materials and in most of the cases the researchers belong to one material oriented group and to one method oriented group. Of course the purpose of these subgroups is to developp common tools for any kind of structures.

3.2. The bi-annual workshops

In order to melt the various opinions and to allow every body to know each other a common workshop is organized each two years (Strasbourg 1992, Prague 1994). All the written contributions of the members are gathered in a book, but the number of oral presentations is limited in view to spend a long time to discussions starting from one or two specific lectures. It was recognized, from the participants, that this kind of exchange is for first interest for the well experimented and less experimented teams.

3.3. The short term missions

This new financial opportunity appeared in 1994. It allows to reimburse travel and subsistance expanses. These grants are more especially dedicated to young researchers starting a research in the connections field. The duration could be of one, two or three weeks. They allow to attend an experimental campaign, or to participate in a numerical benchmark. The decision regarding the application is made by the managment committee itself, which is of best interest regarding other procedures of exchange of researchers where the decisions are made within anonymous committees. The average number of short term missions is around twelve per year.

4. The main subjects of activity

The general objective of the COST C1 action is a better knowledge of the connections behaviour in order to improve structural design in terms of safety and economy and to developp a unified approach for structural design.

All the materials used in civil engineering are concerned : concrete, steel, composite, timber and polymers in combination with all fasteners like welds, bolts, pins, rivets, nails, plates, angles, rebars and adhesives.

Although the action is devoted to unified approach for structural design it is not looked as prenormative research. The widest objective of the research is to increase the knowledge of the actual behavior and its modeling by developing the relevant tools and setting up the basic concepts. These tools and concepts can be used later in sequence by standards committees, regulation committees, professional organizations...

Because the level of knowledge and the technological background, in terms of traditions and customs, were very different from one country to another, a long time was necessary, at the beginning of the action, for mutual exchanges in order to get a form of homogeneity among the groups. Nevertheless all the members agread quickly on the idea that most of the works had to converge on predictable models, more or less complicated, to help the designers at the earliest stages of the structural design process. Predictable means that from the lay-out of the joint the engineer is able to predict, or to know, its mechanical behavior. Thus, global frame analysis is feasible and the interactive process of optimization between joint design and frame design can start.

The three main characteristics of the mechanical behavior of a joint - initial stiffness, ultimate strength, deformation capacity - were wideley agreed as major subjects of interest. Nevertheless most of the researchers concentrated their activities on the two first one, sometimes, for timber joints for example, only on ultimate strength because the other items are so complicated. Deformation capacity is now on the table, starting 1995, due to seismic requirements but also because knowledge (new team of researchers) and new tools (components method) are available.

From a very rough point of view, at the beginning of the action, ultimate strength was directly related to local approach and local detailing (design of the joint itself and design of the various part of the connections : bolts, plates ...) while stiffness was more especially related to global analysis. Then progressively the various concepts merged at every level, more or less for each material types.

So, we can observe the activity of the group from the point of view of the nature of the works of from the point of view of each working group.

4.1. The activity by the nature of the works

Whatever his working group membership, each individual researcher has to work within one or more of the following activities.

4.1.1. Inventory of existing technological systems

The purpose of this activity is to make an inventory of the existing solutions in each country or group of countries. This was typically the activity of the working group "Concrete" at the beginning of the action because the technical systems for joining precast members (beams, columns, slabs) are very different from one country to another. So it was necessary for each participant to know the technical background of the other participants. One can think that there was a form of technology transfert through the various participating countries. Finally, it can be observed that for each country the choice of one technological principle or solution has been definitively done for precast concrete structure. Of course one can imagine that other technological principles will be developped in the future, but it is necessary to concentrate the activity on one single subject in order to be sure to get progress in the research.

The inventory was easier to do in the field of steel structures because the number of technical solutions is more limited compared to concrete area. Most of the researchers are working on the end plate connection, which is very common, but which is probably the most complicated form of connection due to the wide variety of problems and questions inside the joint itself (bolt elongation and bending, plate bending, flange bending, panel shear, compression zone, tension zone, friction ...). It has to be underligned that the top and seat angle connection which was not very common in Europe has been widely studied and could be now frequently used because calculation methods are available and the economic interest has been demonstrated [6].

In a certain way it has to be noted that, for the future, the component method (which will be presented later as an innovative calculation method) avoids to make an inventory because only the individual components have to be identified. As an exemple we can look to the connections between composite members for which the studies started later and for which there was no inventory of various technological solutions.

The question of inventory is a very tricky question for timber connections due to several problems :

- the variety, and size, of companies using timber technology is very wide, starting from very small, that means that customs and traditions are completely different from one country to another,

- the number of connecting devices is very wide (nails, plates, connectors, bolts, screws, adhesives ...)

- the shape of timber structures is very different from one to another, so the shape of the joints are quite different

- the mechanical properties of the basic material (timber) are strongly dependant on external conditions (temperature, moisture, ...).

All these difficulties make a kind of "heavy fog" which make difficult a single approach.

Regarding polymeric materials, which is a very new group, the inventorv is presently under construction. Because this material is a new one in the civil engineering ... it is necessary to look carefully where the common question with other materials are.

4.1.2. Experimental works

For most of the researchers this field is one of the basic items of research, so it is not necessary to speak too much about this aspect. Nevertheless we can say that most of the experimental works are done by testing full scale substructures. Substructure means that the specimen includes the joint itself and parts of the structure like part of beams and part of columns. A very few number of whole structures has been tested [7], probably due to the lack of equipment and due to the high cost of such experimentation. Nevertheless the teams involved in seismic research try to take the opportunity of every full scale and whole structure test to include joint behavior as a parameter among all the other testing parameters.

The tests on single elements like fasteners and immediate surroundings are, of course, widely developped. They were taking place every where before COST C1 action. Nevertheless they are fully necessary, at the moment, for timber connections in order to judge on the availability of component method in that case.

Otherwise, it has to be mentioned that there is a strong relation between the experimental works and the data base working group, because setting up an experimental data collection needs a very clear definition of the testing parameters (dimension, geometrical and mechanical properties, location of actuators, location of measurement devices, calculation methods for interpretation ...). So, one can say that experimental approaches are now more organized in view of readibility and operation.

4.1.3. Analytical works

This aspect was developped by several teams at the beginning of the action. Its importance is decreasing now, essentially due to the success of the numerical approaches which are more and more powerful.

The greatest difficulty with the analytical models resides in the necessity to use some unknown parameters, curve fitting parameters, which are difficult to justify, more especially for the designers. These unknown parameters are coming from the very high complexity of some internal mechanical phenomenons, like residual stresses, local yieldings ...

At this stage the interest of analytical models is to give some milestones or to blaze a trail for modeling the interaction between internal forces like bending moment, normal force and shear force for example.

In any case analytical models will stay in the research field. At the practical level of design offices, simplified approaches have to be developped.

4.1.4. Numerical works

The progresses in this area are certainly one of the main successes of the action. This is due mainly to the advanced works on the finite element packages that are now available.

Contact problems and friction conditions, which are by nature specific items for connections, can now be taken into account, as well as local yieldings, concrete damage, bonding evolution around rebars, ... [8].

Due to the decreasing cost of computing time, it is now possible to make frequently 3D calculations. Of course 3D analysis will not be used in a near future in design offices but one can easily imagine that tables and catalogues could be prepared from sophisticated softwares packages.

The components method, that can be used from the computer side or from the hand calculation side will probably know a large developpment from the numerical point of view as far as individual components will be widely investigated and stored in numerical data bases.

By the same time single frame analysis programme (finite element methods with beam elements only) have been reinforced in view of utilization in design offices for structural design purpose.

4.1.5. Works devoted to cyclic loading

The seismic group is mainly involved in these works. Experimental, analytical and numerical simulations studies are conducted in order to investigate the part of the joints in the seismic resistance of the whole structures.

It appeared, very recently, that simplified approaches will be able to give relevant values of the q-factors for several categories of buildings without making full dynamic analysis [9]. Such a result is of first importance regarding the benefit that could be obtained in terms of design procedures.

Otherwise, it has to be noted that several results regarding dynamic analysis have been obtained for timber structures even though the modelization of the joints for this building material is not yet well established. Finally cyclic loading studies require more information regarding the deformation capacities of the joints. So it will be necessary to launch new experimental campains on this subject, but numerical simulations, based on the components method, will probably be able to help greatly in this task. Kinematical parameters have to be introduced in the components method for this purpose.

4.1.6. Classification system

The Eurocode 3 classification system was already available at the beginning of the COST C1 action. During two or three years the other material groups tried to use the same concepts for themselves and finally a lot of discussions are now taking place. Some researchers propose an absolute system of classification ignoring the member rigidity, the member resistance and the structural system itself. Others propose to refer only on stability concepts for the whole structure.

This question of classification is certainly the most challenging question for the future as far as the design customs and traditions are based on binary reflexes which require simple responses.

4.1.7. Economic studies

In order to convince the designers on the interest to use new concepts in the field of connections design, several economic studies have been undertaken. Whatever the material, the benefits, in terms of saving, are situated between 5 % and 20 % of the full price of the structure.

Beyond the savings, in terms of money, the use of new connection concepts could lead to innovative solutions or could make avalaible some solutions which were rejected until now due to a lack of knowledge regarding various well established, but non official, requirements.

4.1.8. Data base organization

At the moment it is certainly one of the most challenging domain, because the computer systems and the network systems allow very fruitful and powerful exchanges as soon as the relevant information is on the net. A lot of efforts are done in order to use only one data bank system for all material types. The main difficulty resides in the difference of parameters that characterize the joint behavior. Thus, it is difficult to design only one kind of "information sheet" in order to store the experimental results. At the beginning, the data base organization was thought for experimental results only, now it is thought to extend it to numerical results and calculation methods [10].

Of course the opportunity to use the world wide web (www) system for circulating all kind of information regarding COST C1 is used. The corresponding various "server" are under construction.

4.2. The activity for each working group

The type and the level of activity is somewhat different from one group to another depending on the state of the art of the subject and depending on the number of participants.

4.2.1. Concrete structures : Chairman K.S. ELLIOT. University of Nottingham

In this working group the main activity is to study the behavior of beam to column connections in precast concrete and cast insitu frames. On precast connections the work is focusing on improvments in the design of the frame obtainded from semi rigid connections, while the work on cast insitu connections is concentrated on post-elastic behavior and detailing. Nevertheless in both cases high non linear geometric and material behavior ; leading to crushing, splitting, fracturing, debonding ; are taken into account.

In the field of design rules, limited to static loading at the moment, the following design criteria are aimed :

- continuity of moments at supports
- lateral frame stiffness and sway deflections
- column buckling, load capacity and effective length factors.

All this subjects need the knowledge of moment-roation curves which are proposed from experimental or numerical ways or both [11]. One team [12] is developping a computerised system for the full design process of corner joints.

Regarding cast in situ joints, static behavior and cyclic behavior are aimed for modeling in a numerical way. More or less sophisticated local constitutive equations (cumulative damage, plasticity ...) are introduced in view to get the global behavior of the joints and more especially to model the pinching effect of the cycles and to compute the energy dissipation.

4.2.2. Steel and composite structures : Chairman J.P. JASPART. University of Liege

The activity of this working group is oriented towards :

- steel connections
- composite connections
- column bases

subjected to static loading.

As indicated earlier, steel connections have been much more studied in the past that the others, so the work is focused on innovative connections and allows to test new concepts or new calculation methods like "component method". By the same time simplified methods are proposed since the actual behavior is now well understood [13].

The research work on composite connections started later, due to the complexity of the joints, to the smaller number of researchers, and to the lack of experimental results... Nevertheless the activity is now fully efficient because there is a strong need of basic knowledge from Eurocode 4 writting and because the "component method" seems to be the appropriated tool for this specific connection type.

From the economic point of view it appears that the benefits for using semi-connections in composite construction will be greater compared to the benefits for skeletal steel structures.

The number of researchers working on the column bases subject is more limited. It has to keep in mind that from a formal point of view this question requires the investigation of the steel column - to-concrete block connection and the concrete block - to - soil connection. Only the first one is investigated in this working group (see § 4.3. for the second type).

A wide study [14] have been produced which represents a first step for understanding the mechanical "functionning" of these connections in terms of ultimate strength and initial stiffness. Nevertheless the "component methods" seems to be able to bring some new advantages as soon as the interaction between the various components will be well understood.

4.2.3. Timber structures : Chairman P. HALLER. University of Dresden

While timber is certainly the oldest building material it is by the same time the less throughly known. As for the connections. A specific keynote lecture is devoted to this subject during the conference.

4.2.4. Data base : Chairman K. WEYNAND. University of Aachen

The general objective is to establish a data base which should contain all relevant test parameters and test results as geometry, material properties and moment-rotation characteristics of the joints. This work needs harmonized documentation of the data.

At the beginning of the action several data bases projects were under construction, of course the related teams are continuing their own work, keeping in mind that the final goal is a unique and unified data base.

The SERICON data base, devoted to steel and composite connections, started at the University of Aachen and is now implemented in collaboration with the Universities of Innsbruck, Liège and Sheffield. The CODABAT data base, dedicated to column base joints, is developped in the University of Prage [14]. The SERIPC data base prepared at the University of Southampton collects the information regarding joints for precast concrete frames.

Some "cultural" problems have to be solved for reaching a real and unified data base because each team wishes to keep his own identity, which is not always compatible with the common objective. Furthermore, for economic reasons, many test results ordered by private companies are confidential.

Nevertheless there is a strong will, from the participants, to succeed.

4.2.5. Seismic design : A. PINTO. CEC. Ispra Italy

Some aspects of the works of this group have been discussed in § 4.1.5. Special attention is devoted to experimental activity because it will constitute the basis for the calibration for appropriate analytical models able to represent the seismic behavior of structures during the subsequent parametric studies.

The following areas are presently investigated :

- Strengthening of R/C joints using adhesively bonded steel plates. This is a collaborative project between the University of Bogazici and ELSA laboratory.

- Modelling of bridges with semi rigid connections at the University of Madrid. The various connections in bridges are now looked at the light of the semi rigid concepts.

- Testing of full scale structures at ELSA laboratory and numerical simulations in collaboration with the University of Ljubljana.

- Timber structures at the University of Florence.

- Analytical studies for steel frames at the Universities of Naples and Salerno more especially devoted to simplified models for getting the q-factors. Experimental and numerical works are also on going in Lisbon, Trento and Nantes.

- Sandwich panel connections at the University of Naples in order to assert the diaphragm effect in the interaction between the frame and the cladding panels.

4.2.6. Numerical simulation : K.S. VIRDI. City University

The aim of the numerical simulation process is to describe the joints behavior in term of deflection patterns, failure modes and ultimate strength. Finite element methods are the basic tools of this group. Various phenomena involved in the overall behavior, like realistic constitutive equation including concrete curshing and cracking, yielding of steel, embedding of metal connectors in timber, bond-slip, contact-gap, friction ... are taken into account.

After a large investigation of the various F.E packages and their utilization, it was decided to make benmark tests for a form of "calibration" of the models themselves.

At the moment, each team involved in numerical simulation knowns exactly what is "the right tool for a given problem".

Beyond the numerical results themselves it is interesting to remember that any numerical calculation is able to produce graphic visualation in terms of curves but also in terms of deformed shapes of the structures. This is of first interest for educational purpose but certainly also for design purpose.

4.2.7. Polymeric materials : Chairman T. MOTTRAM. University of Warwick

This group started three years after the beginning of the action. Few people in the world are involved in such a research. Nevertheless the connections behavior of polymeric elements is typically and strongly semi-rigid. Due to the low value of the Young modulus of the basic materials it is quite impossible to get rigid connections. So semi rigid framework is the only one relevant for connections design and subsequently for frame design.

The range of structural forms is larger than with other civil engineering materials due to the flexibility of composites to tailor properties to meet the desired performance. In addition to polymeric composite to polymeric composite connections, the working group will consider connections made between polymeric composite and conventionnal materials. The connections elements, angles, fasteners involve steel and polymeric composites too.

At this stage the inventory of technical solutions is going one as well as the first experimental investigations and interpretations. All the others typical subjects of semi-rigid framework like classification, design detailing, mechanical properties, ultimate limit states, will be investigated in the future as well as the background information for code writers.

4.3. Relations with other groups

Most of the researchers, at the beginning of the action, were members of other research groups, so fruitful exchanges are possible around the world. Of course, the input from COST C1 is always concentrated on connections behavior and design.

- ECCS : European Communitiy for Constructionnal Steelwork
  - . Technical committee 11 : Composite construction
  - . Technical committee 13 : Seismic
  - . Technical committee 10 : Connections

- SSRC : Structured Stability Research Council
  - . Task working group 25 : Semi rigid connections

- FIP : Fédération Internationale de la Précontrainte
  - . Connection group.

Otherwise, the COST C1 action contributed to the creation of the COST C7 action which is devoted to the soil-fundation interaction. Early, inside the COST C1 group it appeared that the specific connection between the soil and the structure was of first interest. But such investigations require competences and ability in the geotechnics field. So it was proposed a separated action which will keep permanent contact with COST C1. Several members of COST C1 will be members of COST C7 too.

5. The most significative results for educational purpose

A wide part of the scientific and technological results will be used for practical methods, standards, regulations, codes and design procedures in the corresponding area of the related materials. However some general results are already available in the field of frame analysis, whatever the material. These results make possible the education of engineers with semi-rigid concepts in order to give them the necessary background knowledge.

The various stages described in figure 1 summarize the various level of modeling [15] which can be teached in any frame analysis course.

- Stage 1 : The connection is described as it is, there is no simplification in the modelling. If the designer wishes to make a calculation, he has to make a local and very fine meshing. The working group 6 is doing benchmarks on such calculations in order to check the capabilities of the sophisticated elements that are necessary (friction and contact elements, specific meshing for bolts,...). Anyway, it is now demonstrated that there is a good level of reliability for such numerical simulation [16].

- Stage 2 : the connection zone is considered as a macroelement or a "black box". This level of modeling is used for analytical purpose [17] and allows more especially the description of interaction effects between internal forces in the joint (normal force, bending moment) for example). But it is too much complicated for direct design purpose. Nevertheless it can be used to produce more or less simplificated constitutive equations which can be introduced in the frame analysis process at the stages 4, 5 or 6.

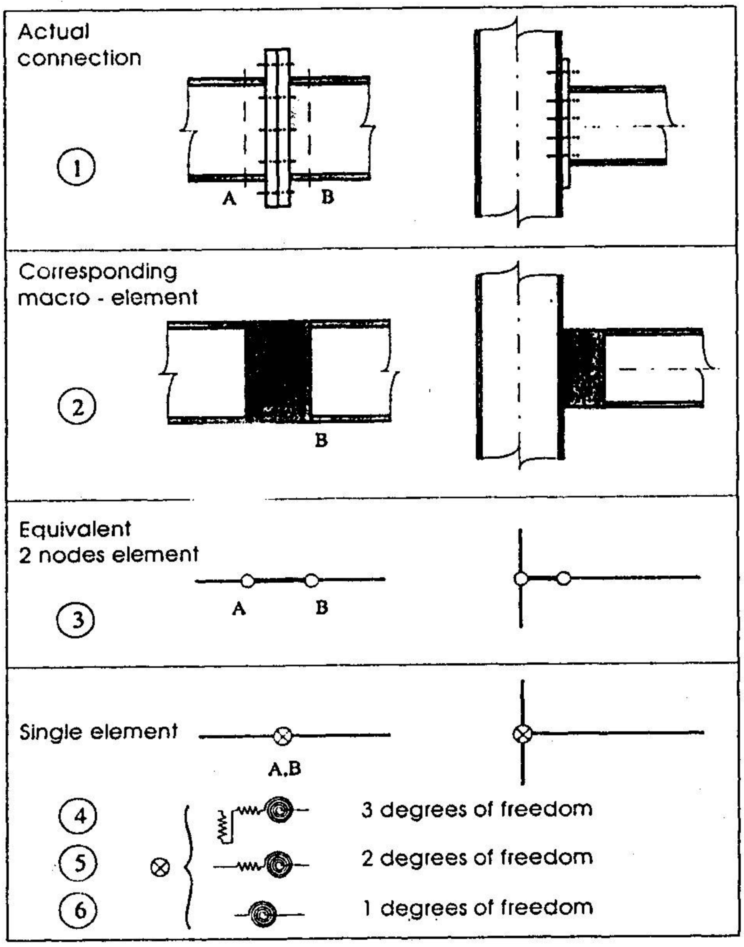

Figure 1

- Stage 2 bis : The "component method" : It is exactly the same level of description than in stage 2, but in that case the connection is not considered as a whole but devided in the various and necessary "components". In figure 2 the typical T-stub component is shown for an end plate beam-to-beam connection. Of course several T-stub components are necessary inside a connection. The assembly of the various components is now well known [18]. In figure 3, a column footing connection, the individual components are quite different : component 1 is the steel part, the anchorage bolt is the component 2 including a steel part and a concrete part and finally the component 3 is the compressive zone of the connection including steel and concrete too [19].

- Stage 3 : The level of modeling is the "beam" level. The connection is modeled with a two nodes beam element with a given length (AB). This level of modeling is familiar with most of the design offices. Nevertheless it requires a constitutive equation for the connection-beam element which could be obtained from the stages 1 or 2 or from experimental way.

- Stage 6 : This is the most popular model for design purpose because it fits very well with the well known frame analysis softwares where the joints are considered as single geometrical point situated at the neutral axis intersection of the elements. The joint is modeled by a single element, a rotational spring, (one degree of freedom), endowed with the relevant constitutive equation obtained from stages 1 or 2 or from experimental way. The Eurocode 3 is presently written with this concept of modeling.

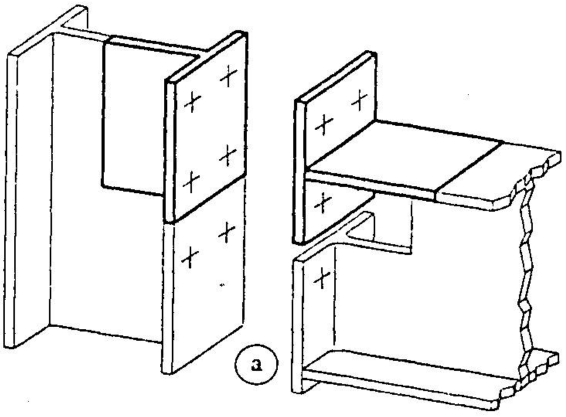

Figure 2

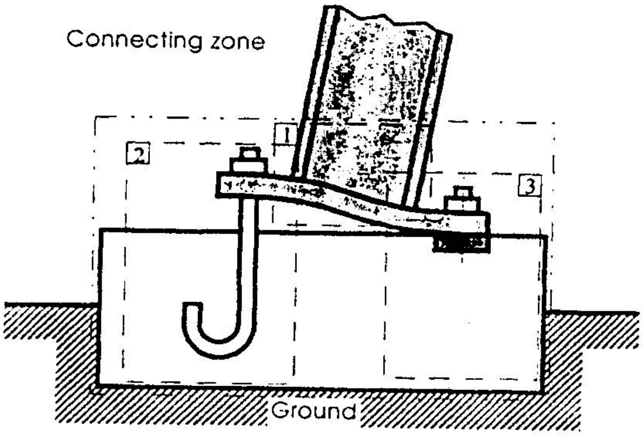

Figure 3

- Stage 5 : This level, including two degrees of freedom, is the immediate level of complexity above stage 6. It is necessary when interaction effects between internal forces (normal force and bending moment) have to be taken into account. This is for example the typical case of the column footing connections [19].

- Stage 4 : Three degrees of freedom characterize this level of modeling. More complex interactions can be described with this model (normal force, shear force, bending moment). This is necessary when important secondary internal forces (shear forces for example) exist and modify the single constitutive equation (one degree of freddom) of the joint. This requirement should not be missed when inertia effects (seismic loading) induce secondary internal forces.

6. Conclusion

A lot of various studies are presently going on through the different countries. The previous chapters gave the main ideas that are developped in the action but are certainly not exhaustive, due to the great number of individual actions. Nevertheless the following subjects or ideas have to be considered as the main success of the COST C1 action :

- the inventory of the various technological solutions for connections across the different european countries,
- the setting up of the "component method",
- the development of the semi-rigid concept as one of the main component for frame analysis process,
- the human success for gathering people from different countries and different cultures, more especially for the participation of young researchers who will be able to work closely together in the future in order to facilitate european collaboration through the various constructionnal processes and to pursue the very good user-friendliness.

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