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Universal Composite Construction, a New Successful Technology

Construction mixte universelle, nouvelle technologie performante

Die universale Verbundbauweise, eine neue erfolgreiche Technologie

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SUMMARY
The paper deals with a new and powerful approach to fire resistance engineering, which allows full advantage to taken of composite construction based on rolled H-sections mainly concreted between the flanges. This leads to a new functional and aesthetic architecture, reinstating the use of visible steel.

RÉSUMÉ
Cette contribution donne un aperçu sur une nouvelle approche puissante de détermination de la résistance au feu, permettant de profiter pleinement des avantages de la construction mixte à base de profils laminés H bétonnés entre les ailes. Ceci conduit à une nouvelle architecture fonctionnelle et esthétique réhabilitant l'acier visible.

ZUSAMMENFASSUNG
Dieser Text gibt eine Uebersicht über eine neue Methode der Feuerwiderstandsbemessung, welche es gestattet, die Vorteile der auf I-Walzträgern basierenden und zwischen den Flanschen ausbetonierten Verbundkonstruktion voll auszunutzen. Dies wiederum erlaubt eine neue funktionelle und aesthetische Architektur, mit der erneuten Verwendung von sichtbarem Stahl.

1. INTRODUCTION

At the Department Bridges and Structural Engineering of the University of LIEGE (Belgium) new developments have been done on steel and composite structures within a C.E.C. research, under the leadership of ARBED-LUXEMBOURG [1,2]. The first aim of this research was to establish a computer program for the analysis of steel and composite structures under fire conditions. This numerical code is based on the finite element method using beam elements with subdivision of the cross section in a rectangular mesh. The thermal problem is solved by a finite difference method based on the heat balance between adjacent mesh-elements of the cross section.

This programm CEFICOSS-which means "Computer Engineering of the FIre resistance for COmposite and Steel Structures"-has to be considered as a general thermo-mechanical numerical computer code allowing to predict the behaviour under fire conditions of structural building parts such as columns, beams or frames. These structural elements could be composed either of bare steel profiles or of steel sections protected by any insulation, either of any composite cross-section type. In order to verify the simulation results given by CEFICOSS and to estimate with greater accuracy the fundamental physical parameters, it was decided to perform a new series of full scale fire tests based on the ISO-834 heating curve. Thus a better comparison was guaranteed between test and simulation results and most interesting informations got available on a new type of composite structure developed by ARBED.

2. FIRE RESISTANCE ENGINEERING

2.1. Theoretical background

As explained in detail by [2], this numerical code is based first on the finite element method using beam elements. Therefore any frame structure composed of interconnected columns and beams could be discretized as shown in Fig. 1. The chosen beam element has 2 nodes and 3 degrees of freedom at each node. The cross-section itself of this beam element is divided into a rectangular mesh, which allows to know exactly in function of time the stress and strain history of each mesh-element. Furthermore this cross-section subdivision allows to analyse finally any type of column or beam. The same rectangular mesh is directly used when calculating the evolution in function of time of the differential cross-section temperature field. Temperatures are obtained by a finite difference method, the second main numerical procedure used in this computer code.

2.2. Thermo-mechanical analysis

CEFICOSS is a new tool, which at last makes feasible a lot of new investigations, seriously improving our knowledge on the fire safety level of real structures. First of all as internal temperature and stress fields can be established for any cross section, the optimum fire design is provided without paying for excessive fire protection. Steel reinforcements could be foreseen at more convenient places as temperature fields would be known. Internal stress fields could give us the correct physical explanation for certain failure behaviours. Moreover the global deformation of structures can be calculated in order to show either its evolution in function of elapsed time, either the situation just before failure [3].

Most important is of course the prediction of the real failure time. In this respect it is worthwile to underline the perfect duality existing in CEFICOSS between the mathematical failure expression and its physical meaning. Indeed failure is mathematically reached when the value of the Determinant related to the Structure Stiffness Matrix (DSSM) falls zo zero. Physically this means that a static equilibrium can no more be obtained because either the buckling of a column is occuring, either a plastic hinge has formed in a statically determinate beam. In both situations we assist to rapidly growing deformations leading to the collapse of the structural element.

In real structures the failure understanding becomes of course more difficult but failure is still obtained when the value of DSSM falls to zero. Physically the failure of a global frame corresponds to the successive formation of plastic hinges leading with or without a column buckling to a so-called structural mechanism [4].

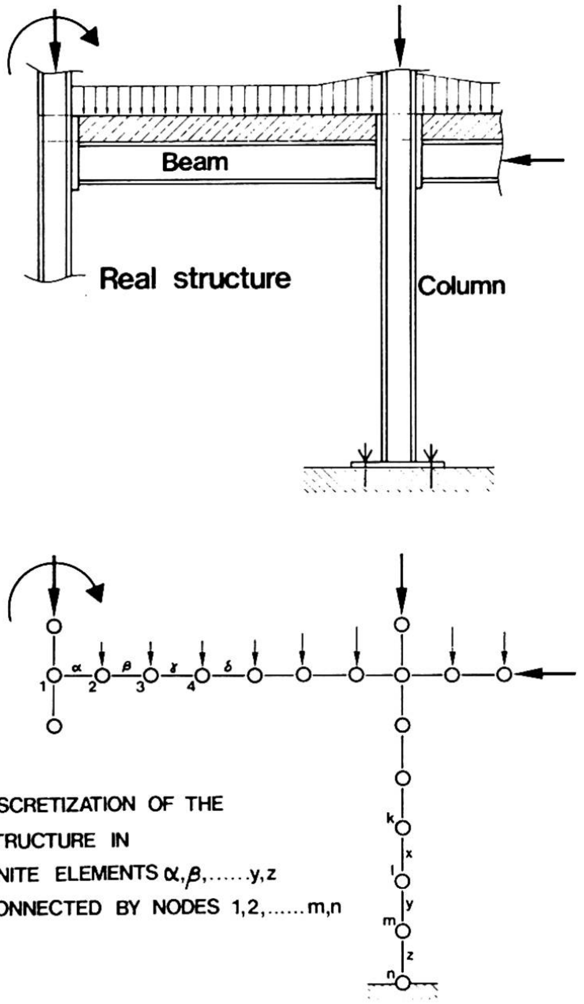

Fig.1 Real structure with finite element division

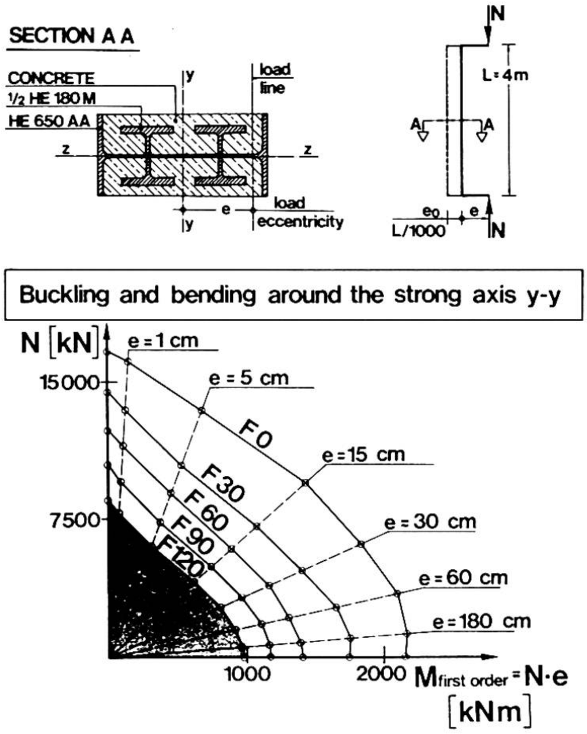

Fig.2 Example of N-M Interaction Failure Diagram for service condition (Fo) and the ISO-fire classes (F30 to F120)

2.3. N-M Interaction Diagrams

For direct use by engineers and architects, practical design tools are being established in case of four different composite column cross-section types [5]. Vertical loads and bending moments are considered simultaneously, allowing to elaborate N-M Interaction Failure Diagrams covering the whole static field from pure axial loads to pure bending moments. It is for the first time that such N-M Interaction Failure Diagrams are elaborated for fire conditions (F30 to F120) while considering the buckling effect (see Fig. 2). Because of the perfectly working failure duality, CEFICOSS gives for the whole N-M field a clear mathematical failure, corresponding either to a Column Buckling in the area of axial loads and up to higher eccentricities (60 to 180 cm), either to a Plastic Hinge Failure in the area of highest eccentricities and pure moments.

2.4. Collapse of Real Structures

Thanks to the powerful numerical tool CEFICOSS, we can at last study the global behaviour of complete structures under local fires. This could be of the highest interest as on one side fires should remain localized through building compartments and as on the other side separately heated structural elements, as parts of a global frame, will probably not induce global collapse at an early fire stage.

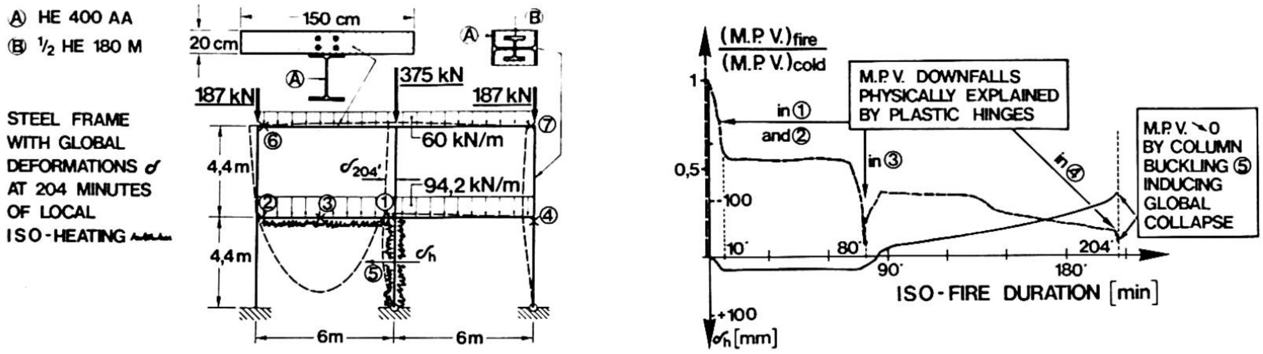

Fig.3 Collapse study of a real structure under a local ISO-influence.

It is for the first time that the effect of a local ISO-fire on a global steel structure has been analysed in a credible and reproducible way. This study shows that even naked, not protected steel beams could have a rather high fire resistance [6]. The analysed frame shown in Fig. 3, designed for cold service conditions with wind and snow loads, is slightly overdesigned as concrete slabs have a thickness of 20 cm. Nevertheless, provided the HE 400 AA not protected steel beams are connected to the concrete slabs by correctly designed shear studs, provided the beams have conveniant connections to the composite columns and provided wind and snow loads are supposed not to act simultaneously during the fire, the heated beam is able to transmit loads to the neighbouring columns up to 204 minutes of fire rage. The physical failure history is doubled up by the mathematical Minimum Proper Value (M.P.V.) evolution, which clearly shows critical downfalls at every physical structural stiffness weakening due to local plastic hinges. As long as these plastic hinges allow equilibrium with a new internal load redistribution, the M.P.V. value remains positive; it falls to zero when equilibrium definitively becomes impossible.

3. ARCHITECTURAL POINT OF VIEW.

Now last but not least this computer code will contribute to improve undoubtedly the image of steel construction. Indeed architects will have the free choice for composite structural sections of any shapes. However above all, construction elements with visible steel surfaces will become available for any fire safety levels. This important aspect is illustrated by Figures 4 to 7 showing some of the possible composite column cross-sections, based on rolled H profiles and normally presenting a systematical alternation from steel to concrete surfaces. This so-called Universal Composite Construction undoubtedly allows the creation of most aesthetic building elements and offers vast architectural possibilities [7,8].
Moreover the following caracteristics make this composite construction system most competitive:

- a very high flexibility is guaranteed as a great number of constructional connection types are available, offering always a feasible practical solution (see Fig. 8),

- an extremely high construction speed can be achieved as complete prefabrication is really possible, thus allowing a by far earlier construction finishing than with pure concrete,

- the smallest possible building element cross-sections are conceivable, thus leading to more slender constructions and offering more space for the practical use of the building.

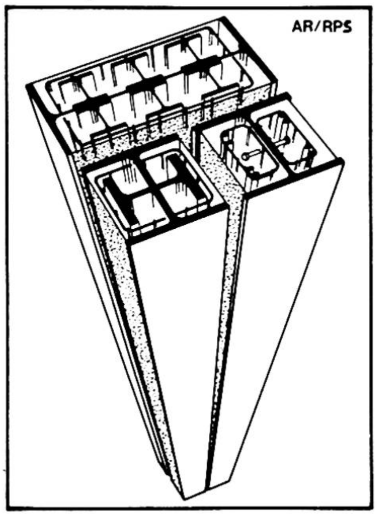

Fig.4

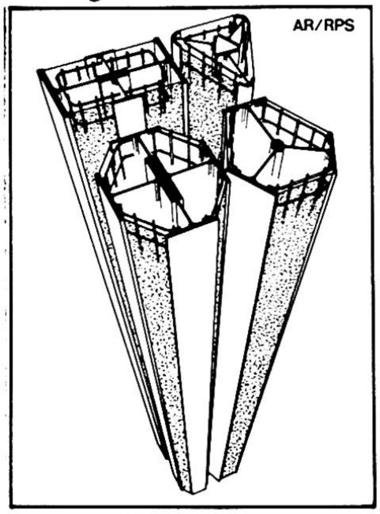

Fig.5

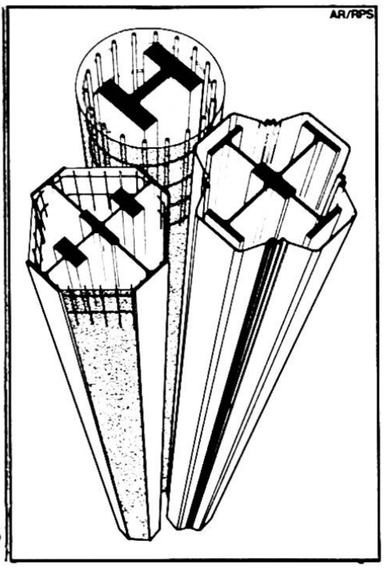

Fig.6

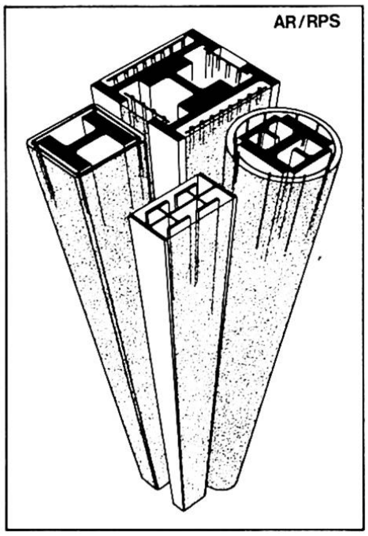

Fig.7

Fig.4,5,6,7 Possible column cross-sections considered by the Universal Composite Construction

Fig.8 Composite beams connected to a composite column

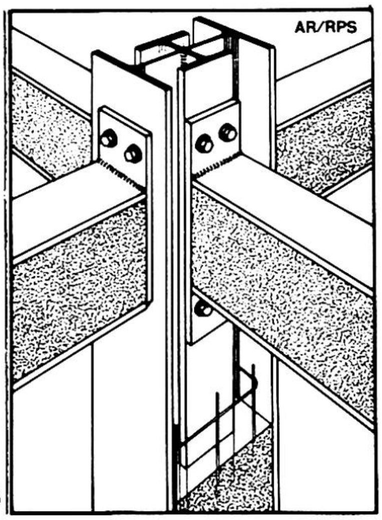

Fig. 8

4. FUTURE DEVELOPMENTS AND CONCLUDING REMARKS

Various studies have been undertaken in order to increase the application field of this Universal Composite Construction. So it could be concluded from first calculations, that composite structures have a very promising behaviour in face of Natural Fires [3]. Indeed it could be demonstrated that the inner part of composite cross-sections is heated up to a rather low maximum temperature and that a Critical Load Level exists below which the structural composite element will not fail any more.

Furthermore a first successful attempt was done to establish for a given structure the equivalent time of ISO-fire exposure, t_{eq}^{ISO} , for which the load bearing capacity under ISO-fire is identical to the minimum load bearing capacity under a given natural fire [3]. This Load Bearing Equivalence is of course by far more accurate and useful than the Temperature Equivalence proposed up to now but which is completely inadequate for composite construction.

Finally credible studies will allow to find out the conditions under which even Unprotected Steel Sections are fire resistant. On one side indeed heavy steel profiles could be classified in the Fire Class F 60 [9], whereas light steel sections as a part of complete structures could even have by far Higher Fire Resistances (see chapter 2.4 and Fig. 9).

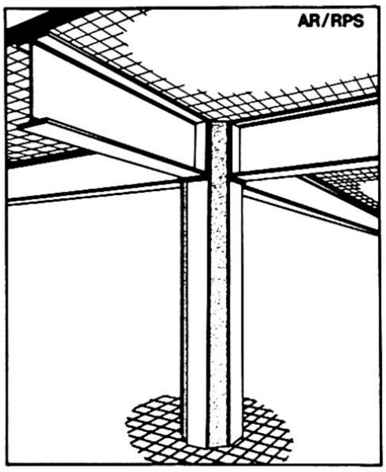

Fig.9 Composite space frame with naked steel beams, fire resistant up to F120 under localized fire.

At last a C.E.C. Research has been started, in order to adapt this Universal Composite Construction to Earthquake Conditions [10]. The idea is to combine the good ductility of rolled sections with the damping qualities of concrete, and to take advantage of the concrete filling between the profile-flanges in order to improve local steel buckling. It will be a challenge to develop beam-column connections with a high Cyclic Bending Moment Capacity and a simultaneous Prefabrication Ability.

5. ACKNOWLEDGEMENTS

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