Composite steel-concrete components: current state of the art and future possibilities

Composite Steel-Concrete Components: Current State of the Art and Future Possibilities

Eléments structuraux mixtes acier-béton: progrès récents et futurs

Stahl-Beton Verbundteile: gegenwärtige Erkenntnisse und Zukunftsaussichten

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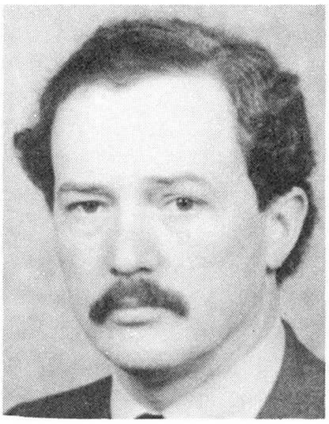

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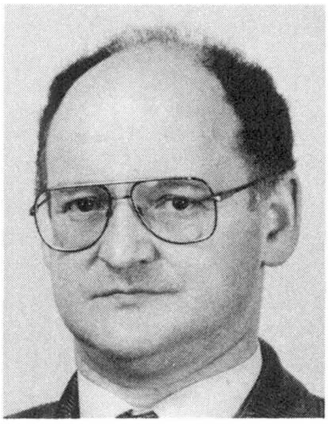


J.B. Schleich, born 1942, got his civil engineering degree at the Univ. of Liège, where he was involved for two years in teaching and research. He then got active for eleven years in the constructional steelwork industry in Luxembourg. He is now responsible for the research on steel construction at ARBED's Research Centre, Luxembourg. President of the ECCS in 1985.

SUMMARY
The paper gives a survey of the most commonly used composite cross-section types, deals with architectural and practical points of view, and shows the future possibilities of the newly developed thermo-mechanical numerical computer codes and of new material technologies.

RÉSUMÉ
Cette contribution donne un aperçu sur les sections mixtes les plus usuelles, traite de points de vue d'architecture et de la pratique, et indique les perspectives d'avenir concernant les nouveaux programmes de calcul thermo-mécaniques et numériques ainsi que les nouvelles technologies à venir dans le domaine des matériaux.

ZUSAMMENFASSUNG
Dieser Text gibt eine Übersicht von den gebräuchlichsten Verbundquerschnitten, behandelt architektonische und praktische Gesichtspunkte, und beleuchtet zusätzlich die Zukunftsaussichten der neuen thermo-mechanischen, numerischen DV-Programme sowie der neu zu erwartenden Materialtechnologien.

1. Introduction

The base principle of composite steel-concrete constructions consists in combining ideally advantageous characteristics of both materials steel and concrete. Ductility, high-tension-strength and easy prefabrication are procured by the steel component; high compressive strength and low thermal diffusibility ($\lambda/c.\rho$) are supplied by the concrete component. In a composite cross section these single parameters don't just add, but activate new additional effects like high stiffness for slender members, high rotation capacity, higher load bearing capacity etc. Therefore composite steel-concrete structural elements are coming into favour for all typical building applications.
The possibility of using visible steel as load bearing component, even for fire resistant structural elements, opens new and trendsetting aspects for architectural design concepts (fig. 1).

2. Present time acquirements

2.1.Slabs

Steel-concrete composite slabs are commonly based on a cold rolled profiled steel sheet supporting the concrete deck. Using special shaped steel sheets, no additional reinforcement is required as well for normal temperature load bearing capacity as under fire load [1]. Quick and easy setting up of such slabs, due to concreting without additional supports, to easy beam connections and to a steel sheet surface ready for use allow very economic applications.

2.2.Beams

Hot rolled steel profils acting as shear connected beams with a concrete or a composite slab are well known structural elements. High load bearing capacity, high bending stiffness, easy prefabrication and a practically always given feasibility explain why this type of composite element is nowadays so largely involved in the field of industrial and office buildings.

A new technology [2,3] for fireproof elements allows to do definitively without cladding of the steel surfaces by concreting between the profile flanges (fig. 2). The lower flange remains as an unprotected visible steel surface. In industrial buildings this is of the highest advantage for making connections by welding at any time not only during the construction procedure but also later for constructional modifications.

Concrete filled beams of this type, but without shear connections to the concrete plate reach higher load bearing capacity than simple steel beams by activating the concrete filling in the compression zone. The same advantage exists for this type of composite beam when used as cantilever, where negative bending moments become the predominant load effect. For fire design the proportional loss of load bearing capacity from the unprotected steel flange, must be compensated by reinforcing bars (fig. 3) or steel strips welded to the web.

These numerous advantages undoubtedly are leading to a dominating application of this type of composite beams in case of fire resistance requirements.

2.3.Columns

Three basic types of cross-section design (fig. 4, 5, 6) lead to the standard steel-concrete composite columns:

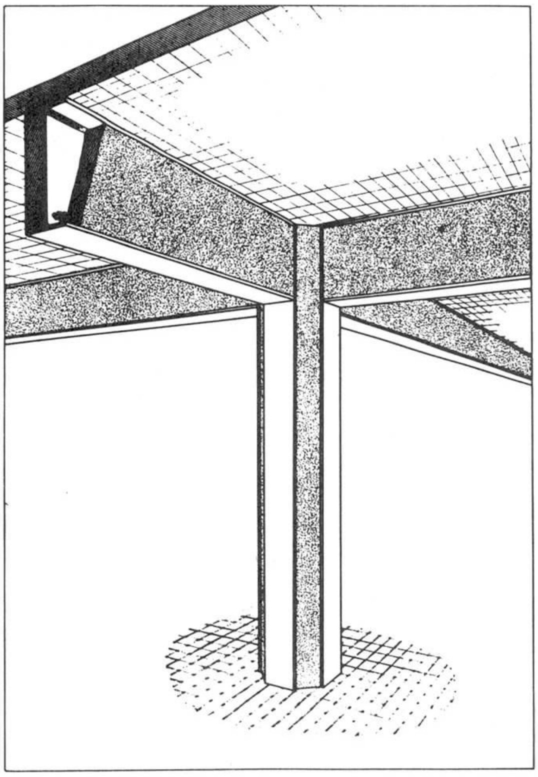
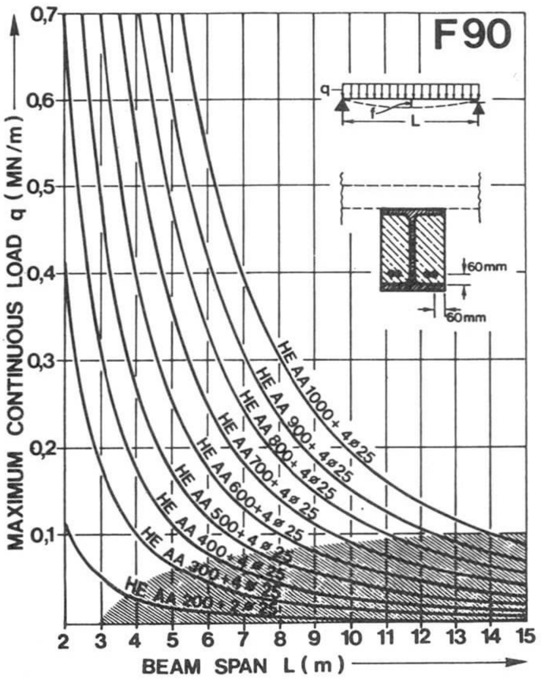


Fig. 1 Octagonal composite column supporting four composite beams, high fire resistance and visible steel

Fig. 3 Design diagram for AF composite beams [7] using HE-AA profiles of ARBED (β_y/β_c = 355/35 N/mm²).(Hatched part: $f_q \leq L/300$ at ambient temperature



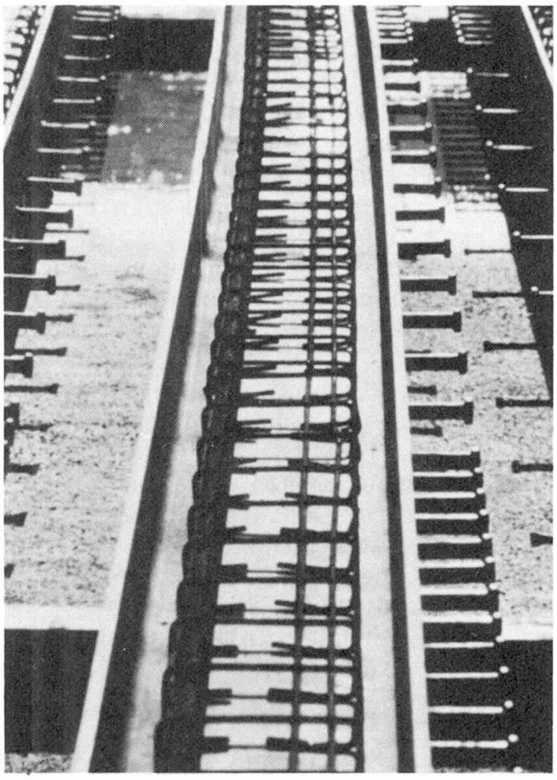
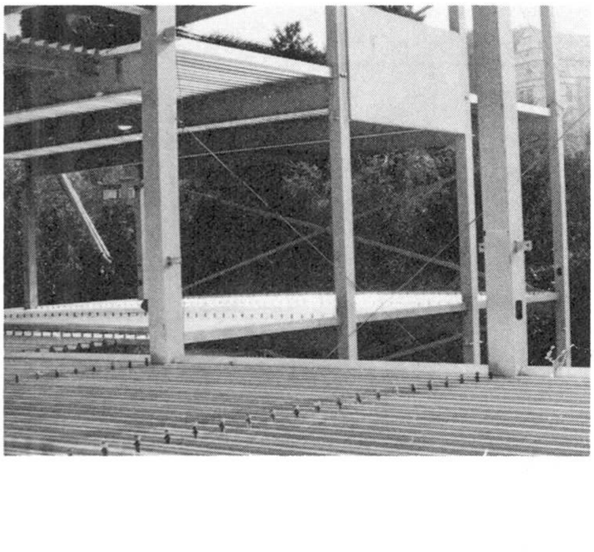


Fig. 2 AF 90 beams before concreting: Office building Magnus Müller, Delmenhorst W-Germany, 1982

Fig. 4 Hollow section composite columns (openings for concrete filling): Office building, Bielefeld, W-Germany, 1980



-hollow sections filled with concrete [4],
-hot rolled profiles concreted between the flanges [2,3],
-hot rolled profiles completely encased in concrete [5].

Under normal temperature conditions load bearing behaviour and hence design procedures are uniform for all these types of composite columns. But every type has different fire behaviour characteristics. The reason is the different location and consequently the different heating behaviour of the steel component. Columns with higher percentage of unprotected steel, show reduction in load bearing capacity sooner than those with steel completely protected by the concrete component.

For fire design the uniform service load calculation concept must be modified and adapted to each different cross section type.

All the mentioned column types can be designed for high fire resistance times [6]. The key for this, is the realistic consideration of the internal interaction between the cross section components. A credible fire design therefore must be based on numerical methods. Service load tables for normal temperature conditions and ultimate load tables attached to fire resistance classes have been calculated in this way (fig. 7,8,9).

2.4. Structures

The creation of complete steel-concrete composite structures indicates a new tendency in building technology, especially in industrial and office buildings. The advantages are numerous: prefabrication, easy fitting (fig. 10), reduced erection time and hence, lower financial costs.

In fire design the step from the single member calculation to the global structural analysis should activate additional economic advantages for instance given by the frame stiffening of columns or the bending moment rearrangement possible with continuous beams. Two options are offered: higher fire safety with the benefit of less fire damage on one hand, or lower building costs for a well defined fire safety on the other hand.

3. Future possibilities

New fields of application for composite structural elements can be expected in the very next future by new developments in material technology and structural analysis [7, 8].

Numerical simulations of the component interaction together with combinations of the well known basic cross-section types lead to improved shapes for beams and columns (fig. 11). Experimental results confirmed the reliability of this new design procedure. This improved cross-section design enhanced as well load bearing capacity as fire resistance.

New developments in material technology open new fields of applications for composite elements. Improved light weight concrete with no tendency towards explosive spalling, promotes the application of composite beams in light frame structures. Consequently industrial halls could be covered by a fire proof composite roof structure with visible steel surfaces and increased load bearing capacity. New high temperature resistant cements will improve the design of hollow section composite columns with unprotected steel surface, high slenderness and high fire resistance. Heat absorbing concrete for encased steel profiles and rolled profiles of the highest steel quality can be combined in order to conceive high load bearing columns for long fire resistance times.

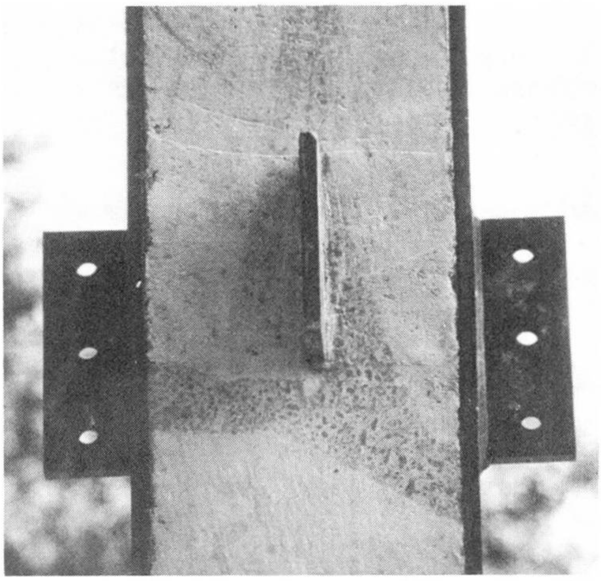


Fig. 5 AF 90 column with gussets for beam connection: Office building TRADE ARBED, Cologne, W-Germany, 1980

Fig. 6 Composite columns with encased hot rolled H-profiles and steel shear heads: Office building LE FOYER, Luxembourg, 1982

Fig. 7 Influence of load level η and cross section size a on failure time t_u of composite columns on concrete filled hollow sections

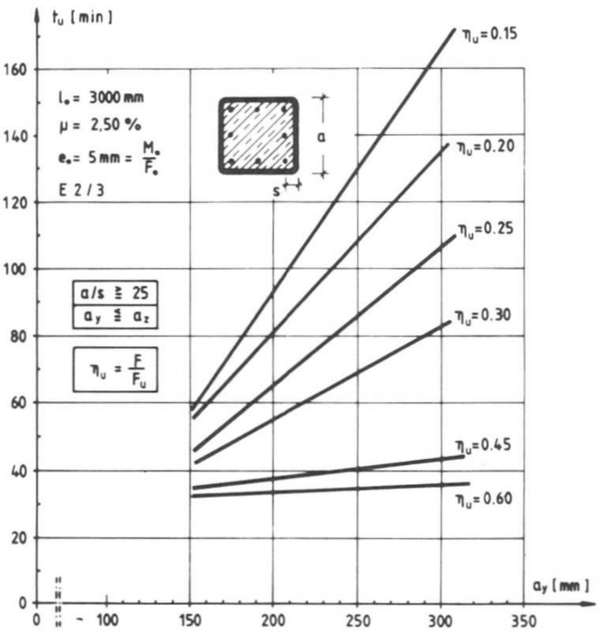
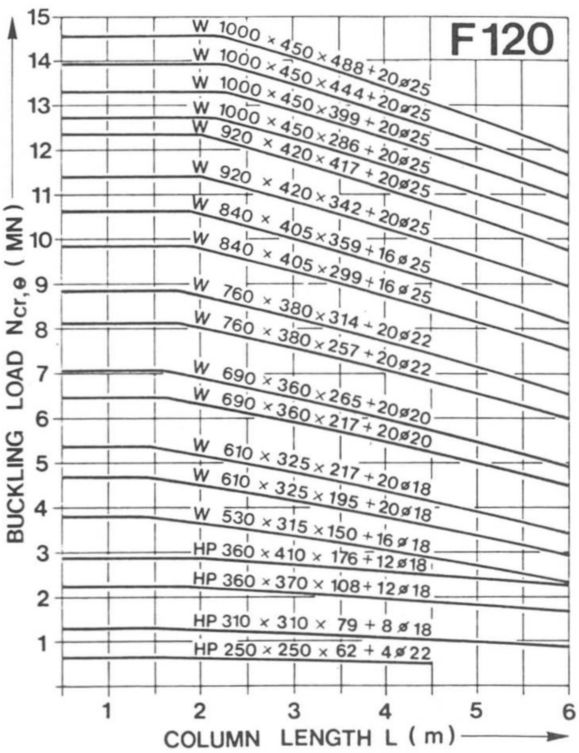


Fig. 8 F 120-design diagram for AF columns, American wide flange shapes W 10''x 10'' to 40''x 18'' concreted between flanges ($ß_y/ß_c$ = 355/45 N/mm²)



Composite structural elements composed of rolled H-profiles either completely embeded in concrete or concreted between the flanges, could be prefabricated in a more economical way by using the adequate steel-fibre concrete technology; by this the high labour cost involving stirrup reinforcement can be dropped.

A wide application of composite construction elements in engineering, presumes the availability of good prepared design tables, graphes - not only for service load design but also for fire engineering. Such informations are already available or will be worked up in function of running research projects (fig. 12). But cross-section improvement discussed above will remain an individual analysis, which cannot be completely solved by practical design tools; for fire design the problems are similar f.i. for columns with normal force and bending moment interaction. It's a new generation of computer programmes developed for computer aided calculation and design and running on micro computers, which will support this tendency of wider application. Using these programmes, calculation and design of single construction members could be done easily by consulting engineers. Complete structures could even be analysed in order to activate the advantage of construction member interaction, so leading to a more economic design of the structural elements. Especially for fire design this is of fundamental importance (fig. 13).

The high rotative capacity of composite steel-concrete beams and columns notifies a high seismic resistance of these structural members.
Japanese investigations in this field clearly indicate wide and important applications in civil engineering. The combination of seismic resistance and fire safety in addition to the well known traditional advantages of composite steel-concrete structural elements, will activate a new trendsetting technology for buildings in seismic areas.
The above mentioned new aspects of prefabrication and material development can support this tendency.

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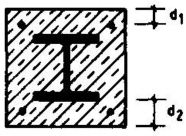
t_u	L_o	PROFILE				remarks
		HE	d_2	HD	d_2	
min	mm					
30	≤6000	≥100A	≥50	≥210 . 210 . 46		
		≥100B	≥40	≥260 . ≥260 . 73		
	≤8000	≥100B	≥40	≥310 . 310 . 97		
60	≤6000	≥100A	≥50	≥360 . 360 . 134		
		≥100B	≥40	≥400 . 400 . 187	≥40	
	≤8000	≥100B	≥40			
90	≤4500	≥100B	≥50	≥210 . 210 . 87		
		≥200B	≥40	≥260 . 260 . 101		
		≥100M	≥40	≥310 . 310 . 130		
	≤6000	≥200B	≥50	≥360 . 360 . 148		
		≥120M	≥50	≥400 . 400 . 187		
	≤8000	≥180M	≥40	≥210 . 210 . 100		
120	≤4000	≥120M	≥50	≥260 . 260 . 149 ≥310 . 310 . 158		
	≤8000	≥180M	≥40	≥360 . 360 . 196 ≥400 . 400 . 187		

Remarks:



cover d_1 according to reinforced concrete column

Reinforcement:

$\mu \leq 3$ % for $t_u \leq 90'$

$\mu \leq 1$ % for tu $\geq 120'$

Fig. 9 Fire design diagram, minimum steel profiles encased in concrete without load reduction (L_o : real column length)

Fig. 10 AF 30/120 construction system composed of composite columns and beams

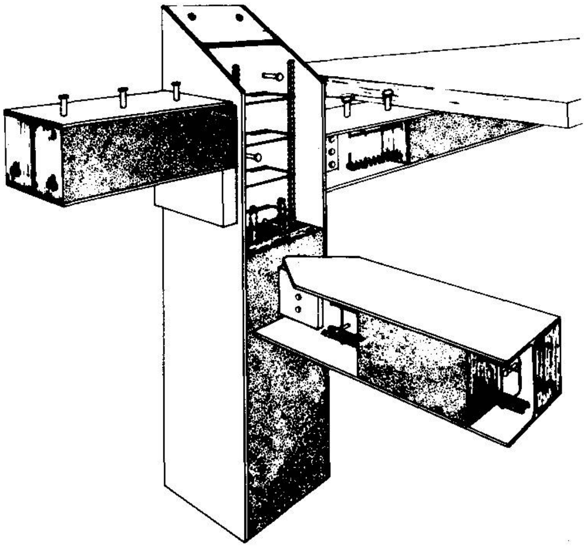
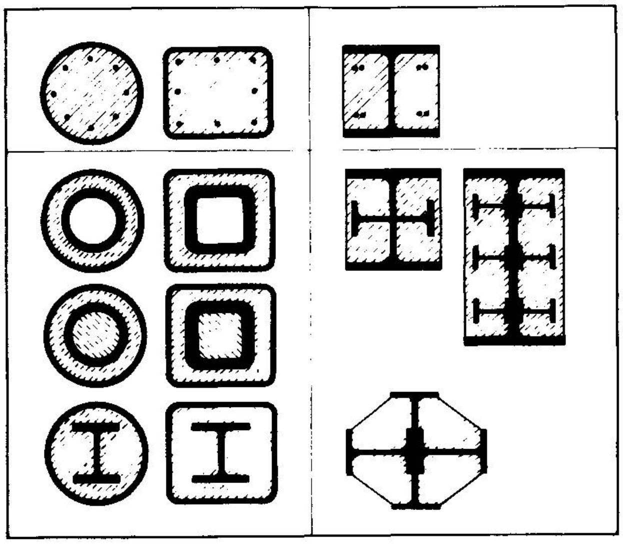


Fig. 11 Special composite cross sections



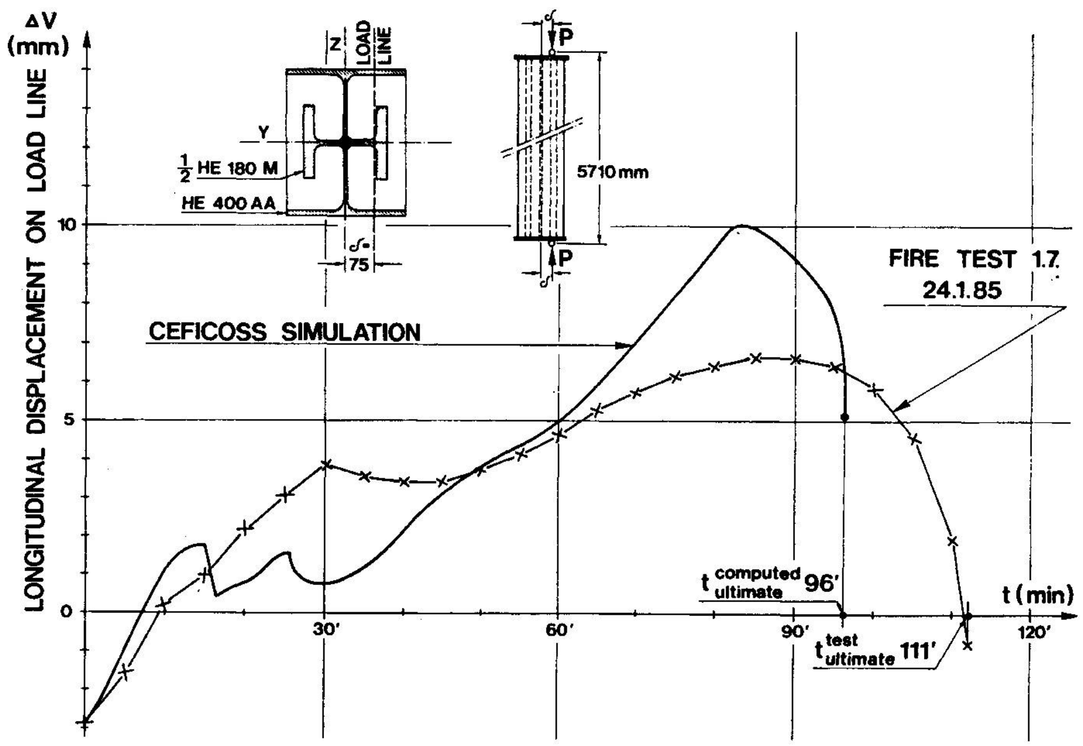


Fig. 12 Calculated [8] and measured longitudinal displacements of a composite AF column, supporting a eccentric load

Fig. 13 Different column-beam interaction possibilities in AF 30/180 construction system: pure shear connection and mixed hear-bending moment connection [8]