LOAD-INTRODUCTION DEFORMABILITY OF COLUMN WEBS IN STRONG AXIS BEAM-TO-COLUMN JOINTS AND STRUCTURAL STABILITY OF FRAMES

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INTRODUCTION

Present paper is a continuation of another one presented in these Proceedings [1] and entitled "Shear deformability of column web panels in strong axis beam-to-column joints and structural stability of frames".

It is aimed at presenting a mathematical approach that is likely to provide the M-θ curves associated to the load-introduction deformability of unstiffened column webs. This model is demonstrated to give results in close agreement with numerical simulations.

JOINT DEFORMABILITY COMPONENTS

The two following sources of deformability of a strong axis beam-to-column joint have been distinguished in [1] :

a) the deformation of the connection associated to the deformation of the connection elements (end plate, angles, bolts,...), to the slip, to the column flange deformation and to the local deformation of the column web in the tension and compression zones ;

b) the deformation of the column web under shear associated mostly to the common presence of forces, equal and opposite, in tension and compression, carried over by the beam(s) and acting on the column web at the level of the joint.

The load-introduction deformability of a column web panel is defined as the component of the connection deformability relative to the local deformation of the column web in the tension and compression zones of the joint (respectively a lengthening and a shortening).

Figure 1 illustrates schematically these definitions in the particular case of a joint between one beam and one column. The deformation of the ABCD column web panel (figure 1.a) has to be divided into two parts :

- the transversal effect of the beam flange forces F_b (statically equivalent to the beam moment M_b) results in a relative rotation ϕ between the beam and the column axes; this rotation concentrates mainly along edge CD (figure 1.b) and provides a first deformability curve M_b-ϕ ;

- the shear effect due to the shear force V_n [1] results in a relative rotation γ between the beam and the column axes (figure 1.c); this rotation occurs mainly along edges BC and AD and makes it possible to establish a second deformability curve $V_n - \gamma$.

It is important to know that the load-introduction deformability of a column web is only due to the forces carried over by the flanges of the beam(s), while the shear is the result of the combined action of these equal and opposite forces and of the shear forces in the column at the level of the beam flanges [1].
This difference of loading leads to take account separately of both deformability sources.

NUMERICAL INVESTIGATIONS

Numerous numerical simulations with the non linear F-E program FINELG [2] of the loading up to failure of welded "T" (one column, one beam) and "cross" (one column, two beams) beam-to-column joints (figure 2) have been performed recently at the Polytechnic Federal School of Lausanne and at the University of Liège. This parametric study has been shortly presented in [1]. Any interested people will find more details about these numerical simulations, as well as the complete results, the conclusions and the related theoretical developments in [3].
The moment-rotation curves characterizing the shear deformability (V_n-γ curve) and the load-introduction deformability (M_b-ϕ curve) of the column web panel have been reported for every simulation.

The following parameters have been taken into consideration :
- the type of the beam(s) ;
- the type of the column ;
- the loading of the joint ;
- the transversal initial deformation of the column web ;
- the presence or not of transversal stiffeners on the column web.

Only the conclusions relative to the load-introduction behaviour of the unstiffened column web panels are presented here.

a) The M_b-ϕ curve for a given joint depends on the actual loading of the joint.
   Let us suppose that the two unstiffened welded joints of figure 3 are submitted to different types of loading (figure 4) and let us report, for each joint, the characteristic M_b-ϕ curve in a common diagram (figures 5 and 6). A similarity exists only in the elastic range of the web panel behaviour.
   The differences between the M_b-ϕ curves in the non linear range of the panel behaviour can not be neglected.
   In reality an unstiffened column web panel is submitted to three types of stresses in its most stressed zone (figure 7) :
   - the shear stresses σ ;
   - the normal stresses σ_n resulting from the compression force and the bending moment in the column ;

- the normal stresses σ_i resulting from the introduction of beam loads in the column web.

The load-introduction behaviour of a web panel will obviously be affected, excepted in the elastic range, by the relative importance of each of these stresses according to the type of joint loading.

b) The load-introduction behaviour associated to the studied column web panels (HE rolled sections) may be divided into four successive stages (see $M_b-\phi$ curves on figures 5 and 6).
   - an elastic linear zone ;
   - a knee linked up to the progressive yielding of the column web and to the formation of concentrated plastic hinges in the column flange at the level of the beam flanges ;
   - an almost linear strain-hardening zone ;
   - the attainment of the maximum capacity associated to the excessive shear or to the load-introduction resistance of the web (web crippling, web buckling), according to the relative importance of σ_i stresses (figure 7).

c) The comparison (figure 8) of $M_b-\phi$ curves relative to a "T" joint (figure 2.a) and to the corresponding (same column and same type of beam) cruciform joint (figure 2.b) shows clearly the similarity of both web behaviours in the elastic range (it is not possible to compare the curves in the non elastic range on account of the different stresses interacting in the column webs).
   This leads to the conclusion that the introduction of transversal loads in a column web constitutes a local phenomena limited to the vicinity of the column flanges, as far as HE rolled sections are used.

THEORETICAL DEVELOPMENTS

The mathematical approach adopted for the prediction of the load-introduction deformability of column webs is that of an elasto-plastic beam lying on a elasto-plastic foundation : the beam represents the column flange, the radii of fillet and the part of the web between these radii; the independant springs constituting the foundation simulate the action of the column web (figure 9).

In the case of the welded joints envisaged in the numerical study :
- the beam is submitted to two equal and opposite transversal forces;
- the distance between these forces corresponds to the beam depth ;
- the beam is stiffened by the beam web between both forces and may be considered as rigid in this region (figure 10).

These hypothesis may be modified to satisfy other connection conditions.

At the beginning of the loading, the foundation and the beam have an elastic behaviour.

The second stage of loading is the progressive yielding of the foundation springs in the web region located under the transversal loads. The third and last stage corresponds to the development of concentrated plastic hinges in the beam under the loads.

It is obviously accounted for the influence of the interaction between σ_i, σ_n and τ stresses (figure 7) on the yielding of the foundation springs.
The steel strain-hardening is not introduced into the model.

Mathematical equations relative to the behaviour of the chosen model and theoretical expressions of the elasto-plastic characteristics of the springs and of the beam have been established [3] but are not given here because of the lack of space

Examples of application (nodes defined on figures 3 and 4) are presented on figures 11 and 12.
It may be seen that the agreement between the model and the numerical simulations are more than satisfactory excepted in the strain-hardening range of the behaviour (strain-hardening has not been accounted for in the model).

The supplementary resistance due to the steel strain-hardening is small contrary to what is noted for the shear resistance of web panels [1]. This has led us to neglect this factor :

- the first advantage consists in the simplification of the model equations ;
- the second advantage requires more explanation: when the collapse of the column web in the compressive zone of the joint is due to web crippling or to web buckling, it may be noted that the numerically obtained resistance (for example in the case of nodes B) is always greater than the corresponding load evaluated on the ground of the simplified model (HE rolled sections).

This modelisation which seems to give accurate and safe (but not excessively safe) results may be used to predict the load-introduction deformability of the column webs.

CONCLUSIONS

A parametric study based on numerical simulations of welded beam-to-column joints has enabled to enlarge the knowledge of the physical behaviour of the joints up to failure.

A mathematical approach for the prediction of the load-introduction deformability of column webs has been then developed in the case of unstiffened joints with welded connections. Its accuracy has been demonstrated by comparison with the results of numerical simulations. Its validity in the case of steel or composite bolted joints will be checked in a near future by comparison with the results of numerous laboratory tests actually performed at the University of Liège in the frame of a ECSC Research (contract N° 7210-SA/507) with ARBED-Recherches (Luxembourg).

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1. JASPART, J.P. and ATAMAZ SIBAI, W., "Shear deformability of column web panels in strong axis beam-to-column joints and structural stability of frames", Proceedings of the Fourth International Colloquium on Structural Stability, Assian Session (ICSSAS'89), Beijing, People's Republic of China, October 10-12, 1989.

2. FREY, F., LEMAIRE, E., de VILLE de GOYET, V., JETTEUR, P., STUDER, M. and ATAMAZ SIBAI, W., "FINELG, non linear finite element analysis program", M.S.M., University of Liège, IREM, Polytechnic Federal School of Lausanne, July 1986.

3. ATAMAZ SIBAI, W. and JASPART, J.P., "Etude du comportement jusqu'à la ruine des noeuds complètement soudés", Internal Report IREM, Polytechnic Federal School of Lausanne, in preparation.

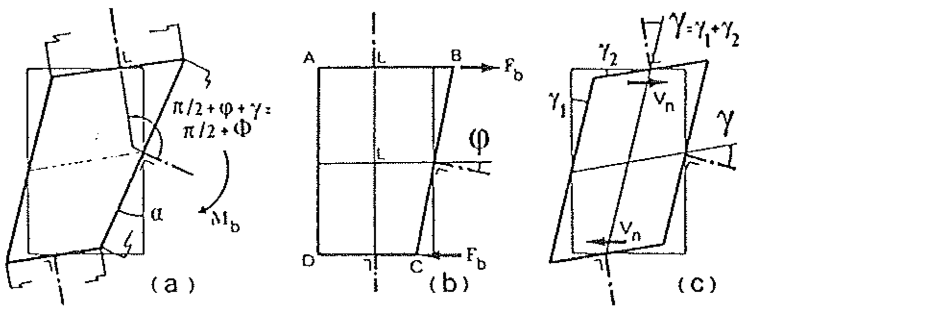


Figure 1 - Global deformation of the column web (a) decomposed into the load-introduction effect (b) and the shear effect (b).

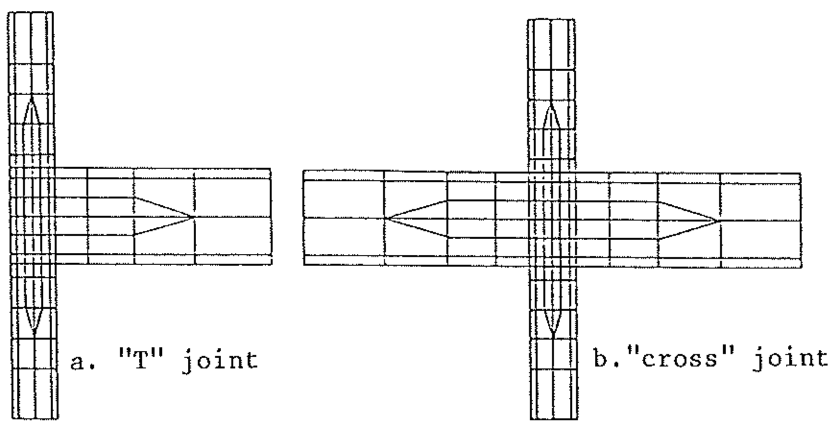
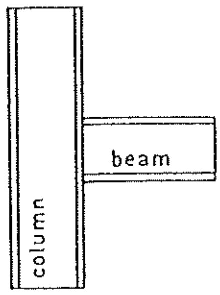
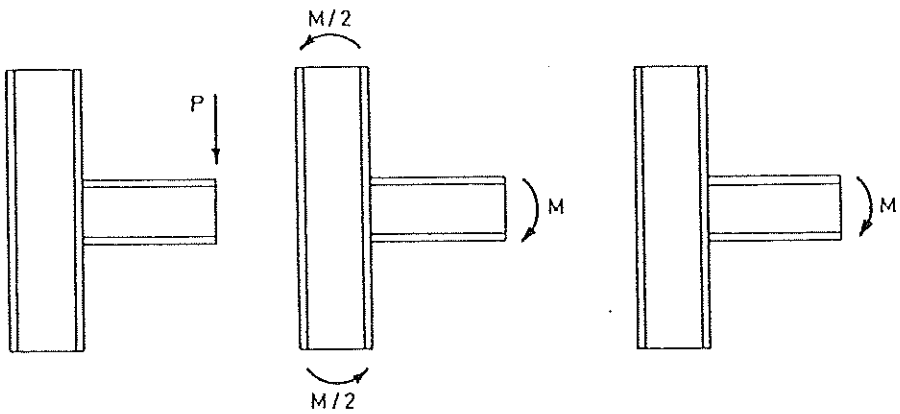


Figure 2 - Types of beam-to-column joints studied numerically.



	Beam	Column
A	IPE 300	HE 160 B
B	HE 500 B	HE 300 B

Figure 3 - Definition of two welded joints("T" arrangement)



Simple bending (FS) Pure bending (FP) Pure bending in the beam (MP)

Figure 4 - Different types of loading

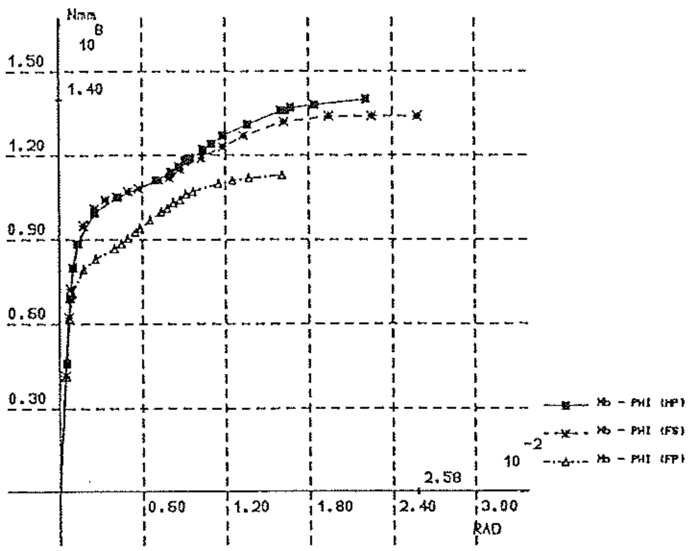


Figure 5 - Characteristic M_b - ϕ curves (joint A)

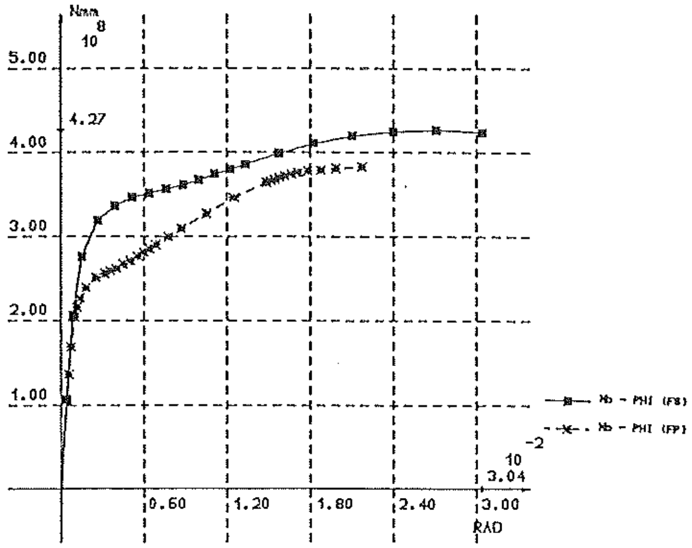


Figure 6 - Characteristic M_b - ϕ curves (joint B)

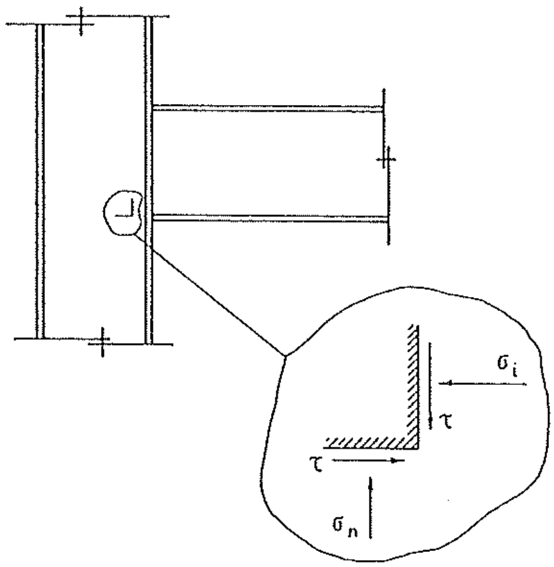


Figure 7 - Different types of stresses in a web panel

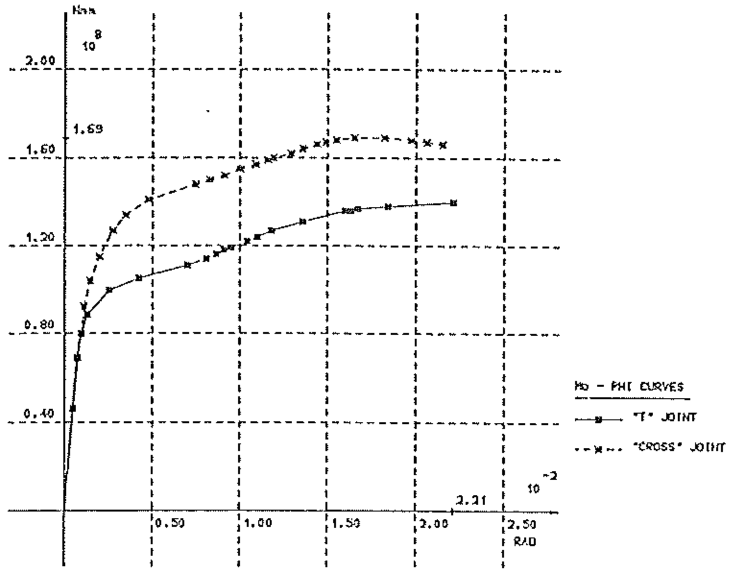


Figure 8 - Comparison between "T" and "cross" joint behaviour

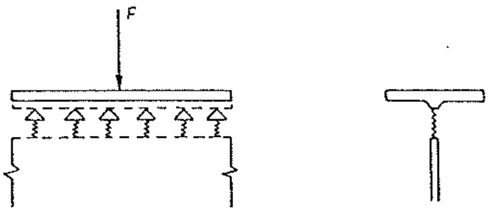


Figure 9 - Definition of beam and foundation

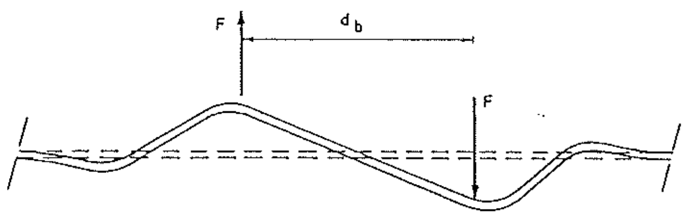
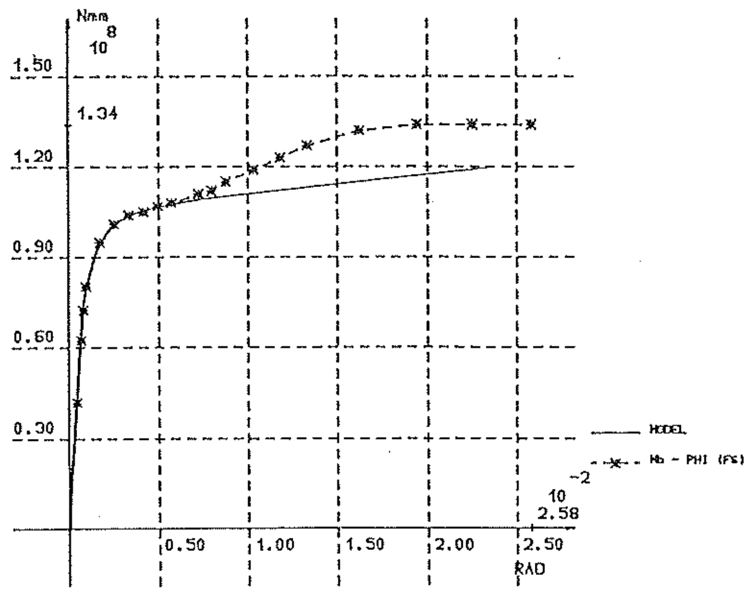
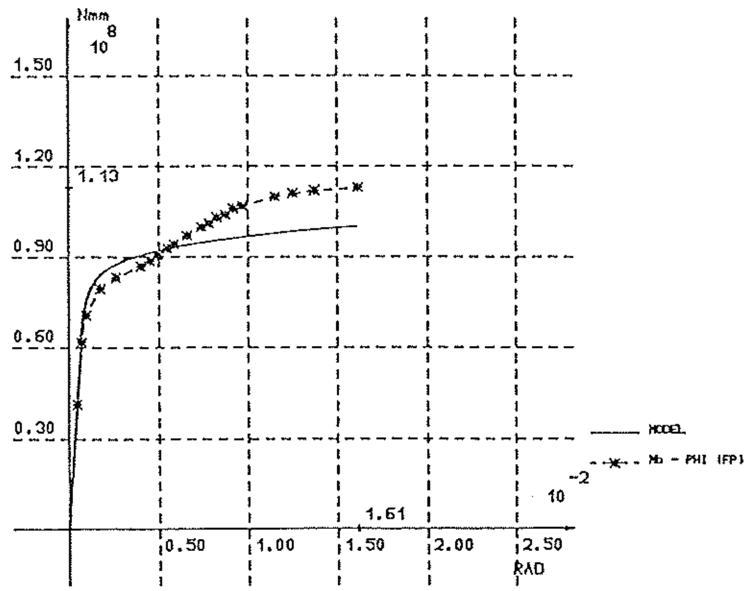


Figure 10 - Deformed shape of the beam

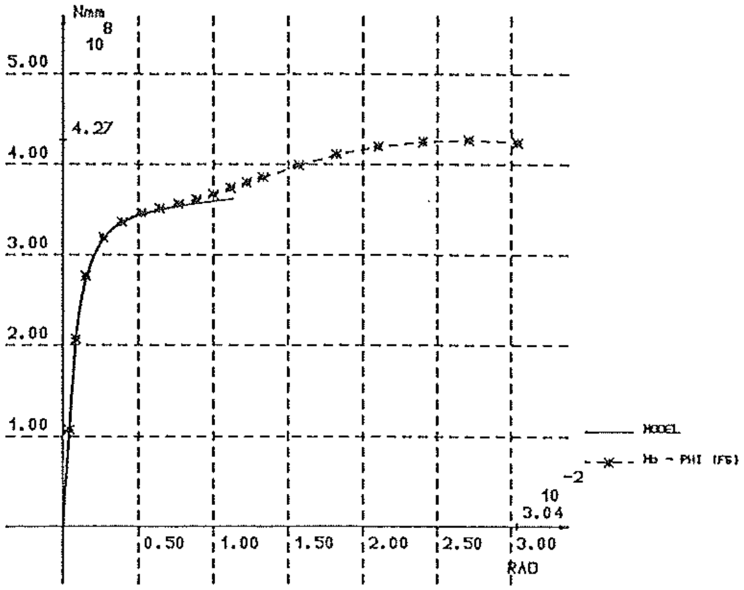


a - FS

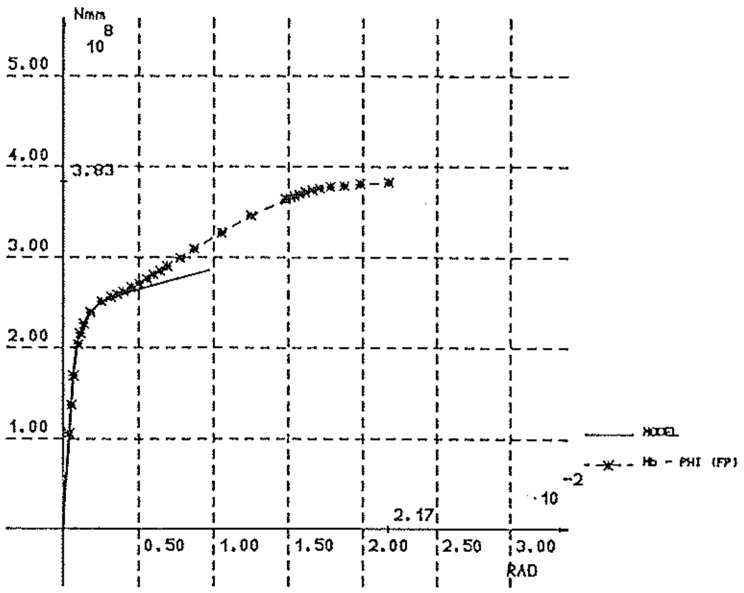


b - FP

Figure 11 - Comparison between numerical simulations and model (joint A)



a - FS



b - FP

Figure 12 - Comparison between numerical simulations and model (joint B)