STRENGTH AND BEHAVIOUR OF IN-PLANE WEAK AXIS JOINTS AND OF 3-D JOINTS

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ABSTRACT

A limited number of tests have been carried out on weak axis - and on 3-D beam-to-column connections. On base of the first results obtained, some conclusions are drawn.

INTRODUCTION

The behaviour of plane- or space frames may be analysed by means of computer programs. Some of the latter can account for the semi-rigidity of the beam-to-column joints. For beams (fig. 1.a) that are connected to the column flanges (strong axis connection), the information regarding the behaviour of the joints is available. It is largely missing when the beam (fig. 1.b) is connected to the column web (weak axis connection) [1] [2]. The question is still more intricate when 3-D joints (fig. 1.c) because of the interaction in the column web between both strong- and weak axis connections [3]. With a view to collect some data on weak axis - and 3-D connections, some tests were carried out at the University of Liège. It is only reported on those, the results of which have already been fully investigated.

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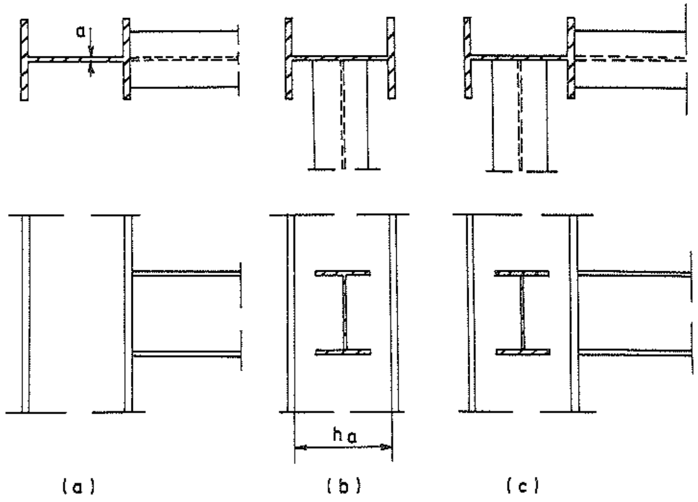


Figure 1 - Types of beam-to-column joints : (a) strong axis connection ; (b) weak axis connection ; (c) 3-D connection.

WEAK AXIS CONNECTIONS.

When defining the test specimens, three main parameters were accounte for : the type of connection, the relative beam-to-column stiffness and the slenderness h_a/a of the column web.

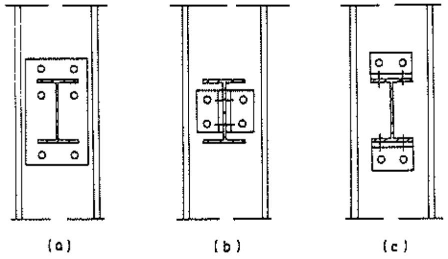


Figure 2 - Types of connections: (a) end plates ; (b) double web cleat (c) flange cleats

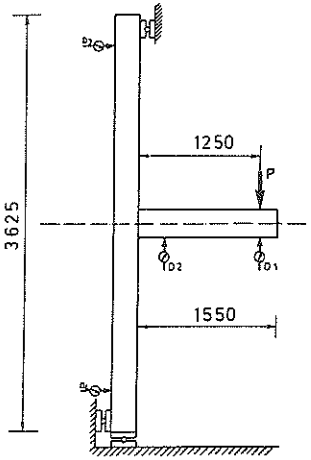


Figure 3 - Test arrangement.

Three kinds of bolted connections were considered because of their current use in practice : end plates, double web cleat and flange cleats (figure 2). In order to exhaust the carrying capacity of the column web and to assess the behaviour of the latter, rather thick angles or end plates and preloaded high strength bolts (quality 10.9) were used. All the mechanical and geometrical properties of columns, beams and connections were measured.

The basic data describing the set of test specimens are summarized in table 1. For each type of joint, four beam-to-column stiffness ratios are examined ; that allows also to change the slenderness ratio h_a/a of the column web, that is obviously a governing parameter. It will be noticed that HE180A and HE160B sections have a same weak axis inertia, while a very different web slenderness.

Test	Column C	Beam B	Column Web-slenderness h_a/a	Relative stiffness B/C	Type of connection (fig. 2)
A1	IPE240	IPE160	35,5	0,33	a)
A2	IPE240	IPE160	35,5	0,33	b)
A3	IPE240	IPE160	35,5	0,33	c)
A4	IPE300	IPE160	39,2	0,70	a)
A5	IPE300	IPE160	39,2	0,70	b)
A6	IPE300	IPE160	39,2	0,70	c)
A7	HEA180	IPE160	25,3	1,06	a)
A8	HEA180	IPE160	25,3	1,06	b)
A9	HEA180	IPE160	25,3	1,06	c)
A10	HEB160	IPE160	16,8	1,02	a)
A11	HEB160	IPE160	16,8	1,02	b)
A12	HEB160	IPE160	16,8	1,02	c)

Table 1 - Basic data for test specimens with weak axis connections

The test arrangement is illustrated in figure 3. The load is applied at the cantilever beam and is increased progressively either up to collapse of the connection, or up to a limiting vertical deflection (40 cm) of the cantilever due to requirements of the testing facilities. The depth of the column is similar to an usual storey height in a multi-storey frame while the beam length allows to emphasize the bending moment with regard to the shear force.

The vertical displacements at both ends of the cantilever beam and the transverse displacements of the column are measured during the tests. With the geometrical and mechanical properties of the sections used, these deflections allow for the computation of the relative joint rotation. This rotation is composed of the rotation of the connection proper (slip, distorsion of connecting elements, elongation of bolt shanks,...) and of the rotation due to the shear flexibility of the column web. Dedicated measurement set-ups allow to distinguish between both rotation components. For instance, figures 4 to 7 are dealing with the double web cleat connection A2; the rotation of the connection itself is divided into one part due to slip and another one resulting from the distorsion of angles.

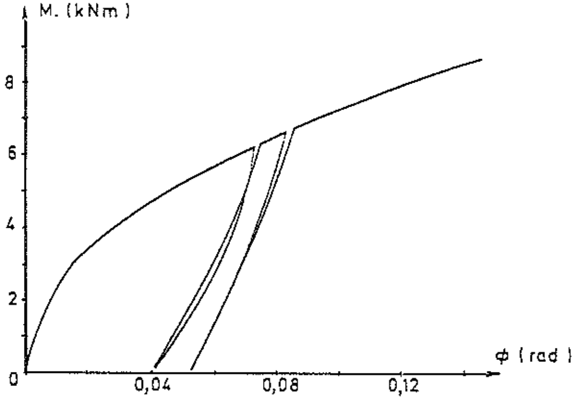


Figure 4 - Test A2: Joint Curve M-φ

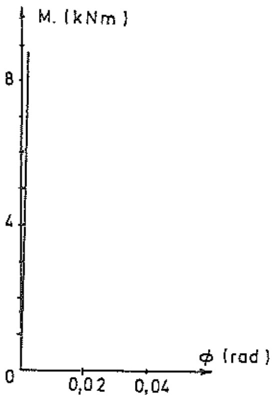


Figure 5-Test A2: Curve M-φ due to slip

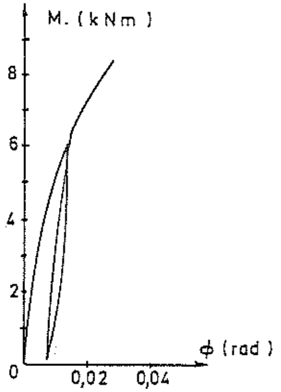


Figure 6 - Test A2: Curve M-φ due to angles distorsion

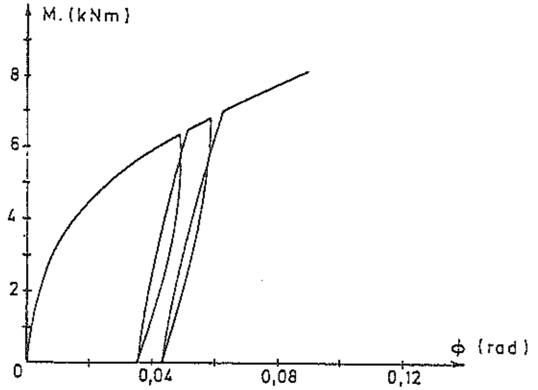
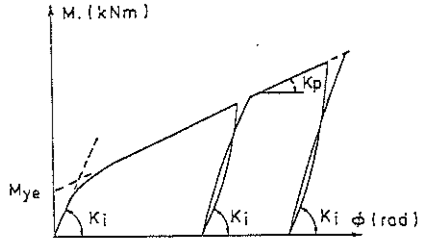


Figure 7 - Test A2: Curve M-φ due to the flexibility of the column web

The assessment of the results will be limited to the tests on joints with end plates, that are the sole to have been investigated in deep at the present time. A complete report will be prepared by the end of 1987 [5]. Because of their thickness (30 mm), the end plates are so stiff that they may be considered as not deformable. In addition, at the loading levels reached at collapse, the effect of the elongation of bolt shanks can be disregarded with respect to that of column web yielding. Thus the joint rotation is nearly due exclusively to the flexibility of the column web, especially as soon as the onset of yielding. For this type of connection an obvious similarity of the M-ϕ curve of the joint and of that dealing with the flexibility of the column web is observable (fig. 8). At the first beginning of the loading, the behaviour remains linear elastic and exhibits an initial stiffness K_i, that is reproduced and recovered when the test specimen will be unloaded and then loaded again, whichever the loading level reached. Then occurs a rather fast yielding of the column web, that is last followed by a strain hardening range, the stiffness K_p of which is quasi constant. According to Yee and Melchers [4], the yield bending moment M_{ye} will be defined as the one given by the intercept of the strain hardening slope with the ordinate axis (fig. 8).



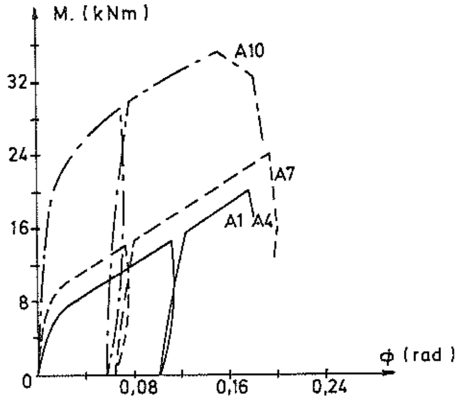


Fig.8-Definition of the initial stiffness K_i, strain-hardening K_p stiffness and yield bending moment M_{ye}.

Fig.9-Comparison of web behaviour of different connections with end plates.

The M-ϕ curves related to four tests on bolted joints with end plates are shown in figure 9. Both tests A1 and A4 (using IPE sections as column) are represented by two nearly identical curves ; they provide a same value of the initial stiffness K_i, of the strain hardening stiffness K_p and of the yield bending moment M_{ye}. The strain hardening stiffness K_p looks like approximately constant for the four tests, i.e. whichever the slenderness h_a/a of the column web in the range 16-36. The initial stiffness K_i and the yield moment M_{ye} are shown to increase rapidly when the slenderness h_a/a decreases. The experimental values of M_{ye} are plotted in figure 10 against the web slenderness.

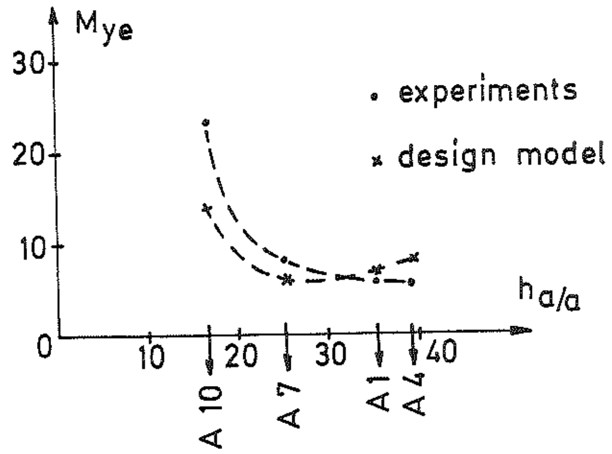


Fig.10 - Yield bending moment vs. slenderness of the column web.

Unlike for strong axis connections, no design model exists - at the authors' knowledge - for weak axis connections, which would provide the ultimate carrying capacity of the joint. By observing the yield lines in the column web, an attempt of establishing such a design model was made (fig.11). Though the effect of the web slenderness is qualitatively well reflected (fig. 10), some improvements of the model are shown necessary with a view to a better quantitative agreement. The consideration of more sophisticated yield lines patterns in the column web as well as the account of membrane force - due to the out-of-plane deflection of this web - in the yield criterion are in progress, so that a realistic design model can be hopefully expected soon.

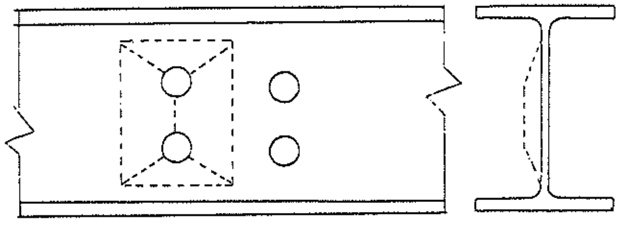


Figure 11 - Test A10 : Yield lines pattern

3-D CONNECTIONS

The results of tests on semi-rigid joints with strong axis connections (serie 0) are presented in another paper [6]. It is briefly reported hereabove on those dealing with weak axis connections (serie A). For a specified type of test specimen, both sets of results give two limiting points of an interaction curve (fig. 12), the aim of which is to show the carrying capacity of a column web involved in a 3-D joint. Any other point of the interaction curve would require tests on the associated 3-D specimen. A limited number of such tests were performed at the University of Liège; the web slenderness and the type of connection were selected as the governing parameters. The basic data for the test specimens are listed in table 2.

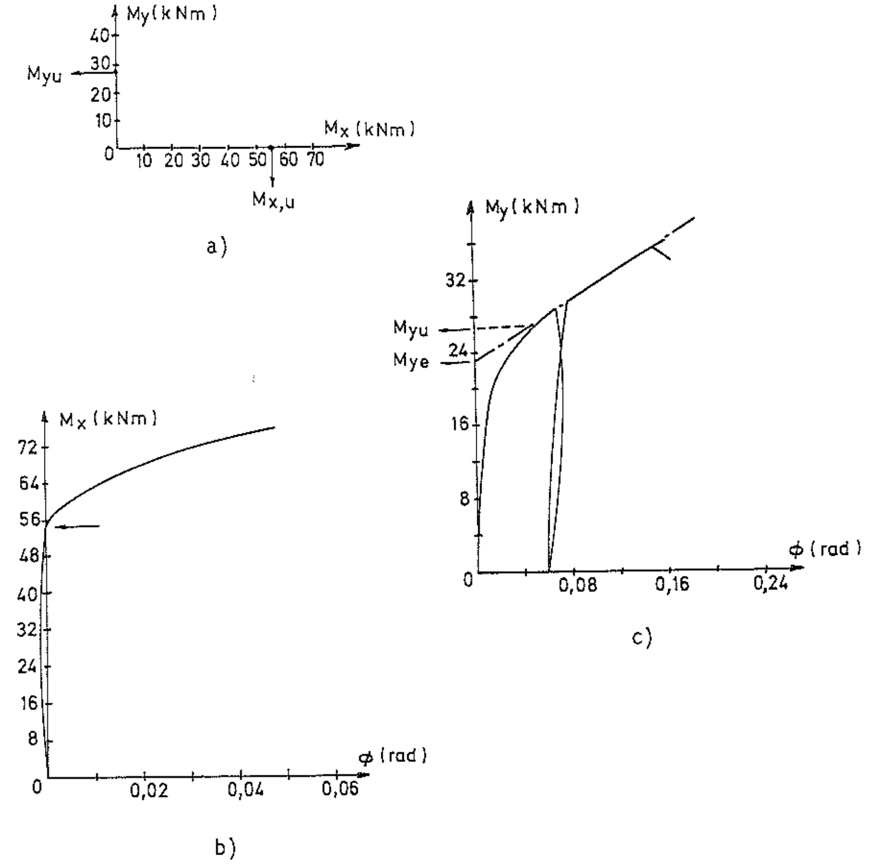


Figure 12 - (a) Test I1: Limiting points of the interaction curve, (b) Curve M-ϕ due to the shear flexibility (Test 04) of the column web ; (c) Curve M-ϕ of the connection (Test A10).

Test	Column	Weak axis beam P_1	Weak axis connection (fig. 2)	Strong axis beam P_2	Strong axis Connection (fig. 2)
I1	HEB160	IPE160	a	IPE200	a
I2	HEB160	IPE160	b	IPE200	a
I3	HEB160	IPE160	c	IPE200	a
I4	IPE300	IPE160	a	IPE200	a
I5	IPE300	IPE160	b	IPE200	a
I6	IPE300	IPE160	c	IPE200	a

Table 2 - Basic data for test specimens with 3-D connections

The test arrangements were quite similar to those used for the tests on joints with weak axis connections. The tests were performed by keeping constant the load P_2 at the end of the weak axis beam while the load P_1 at the end of the strong axis beam is increased progressively. The value of P_2 is associated to the onset of the bending moment M_{ve}, derived from the test on in-plane weak axis connection. Measurements are made similarly to those carried out for the testing of semi-rigid joints with strong axis connections (serie 0) [6].

The behaviour of the column web, when a 3-D connection, can then be compared to that when strong axis connection only. Thus the M-ϕ curves due to the shear flexibility of the column web are plotted in figure 13 for test 07 (strong axis connection) and I1 (3-D connection). It is observable that the rotation remains very small till the onset of yielding in the web of the column fitted with a strong axis connection. The effect of shear deformation is much more marked when an additional loaded weak axis beam exists, because of a more progressive yielding of the web. However the influence of the weak axis beam tends to be masked when approaching the ultimate limit state.

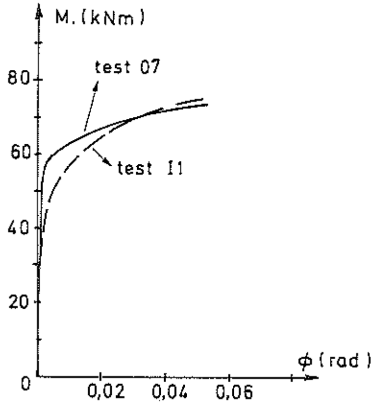


Figure 13 - Comparison of the shear flexibility of the column web between test I1 and test 07.

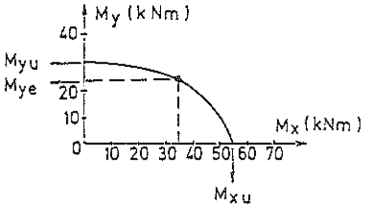


Figure 14 - Interaction curve for a 3-D connection

Such a test on a 3-D joint, carried out as indicated hereabove, enable to determine one additional point of the associated interaction curve and to sketch the shape of this latter (fig. 14). Obviously more experimental points are needed to assess more precisely this interaction curve and to suggest a design model for 3-D joints ; therefore additional tests will be performed soon in order to implement the information.

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ANALYSIS OF JOINTS BETWEEN STRUCTURAL HOLLOW SECTIONS

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ABSTRACT

Structural hollow sections with various shapes are used in various combinations also with open sections. Furthermore, various joint configurations are possible. The large variety in sections, combinations and joint configurations make that many failure modes are observed depending on the geometry variables and loading.

A unified analysis is essential for a uniform presentation of the design rules. In this paper the criteria of failure, failure modes and the analysis are briefly discussed as a background for those not familiar with hollow section joints.

INTRODUCTION

Recent research in Europe, Japan, USA and Canada has added new evidence for the analysis of joints between hollow sections and combinations with open sections. In these programmes various types of axially loaded welded joints have been investigated. The main objective was to enlarge the range of validity of the IIW recommendations [1] and to provide test evidence to check the effective width criteria.

The IIW recommendations cover T, Y, X, N, K and KT joints for various member combinations (figures 1 and 2).

Since research and analyses are carried out in various countries, a major objective is to achieve consistent recommendations. It is important that the designer understands the behaviour, failure modes and the resulting design recommendations. This means also that similar failure modes for different joints should be treated in a similar way. Although there re-