EXPERIMENTAL STUDY OF THE NON-LINEAR BEHAVIOUR OF BEAM-TO-COLUMN BOLTED JOINTS

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ABSTRACT

The paper is aimed to compare the behaviour of several types strong axis of beam-to-column bolted joints, which are commonly used in practice.

INTRODUCTION

An experimental investigation was recently performed at the University of Liège, with the financial support of IRSIA and ARBED [1]. Three types of connections between a beam and a column flange (strong axis connection) were considered : i) end plates, ii) double web cleat, and iii) flange cleats (fig. 1). All the connections are bolted ones with bolts of quality 10.9 (H.S. bolts), preloaded to 0.8 times the material yield stress or, in some cases, with a lower torque moment (controlled hand tightening). The basic data are listed in table 1 ; all the mechanical and geometrical properties of specimens were measured but are not listed here. The testing arrangement is shown in figure 2. The load P is increased step by step either up to collapse of the connection, or up to a maximum deflection (20 cm) of the cantilever end. The deflections are measured at the ends of the column and cantilever beam, as well as the slopes of beam and column axis in the joint. From these measurements, the relative rotations of the connection, of the joint and that due to the shear flexibility of the column web are deduced (fig. 3).

Test n°	Column C	Beam B	Relative Stiffness B/C	Connection (fig. 2)	Loading	Axial force N	Bolt tight.	Clearance d (mm)
01	HEB160	IPE200	0,78	a	S	300kN	C	-
02	HEB160	IPE200	0,78	b	S	-	C	0
03	HEB160	IPE200	0,78	c	S	-	C	15
04	HEB160	IPE200	0,78	a	S	700kN	C	-
05	HEB160	IPE200	0,78	b	S	-	C	15
06	HEB160	IPE200	0,78	c	S	-	M	15
07	HEB160	IPE200	0,78	a	S	-	C	-
08	HEB160	IPE200	0,78	b	Cyc	-	C	0
09	HEB160	IPE200	0,78	c	S	-	C	15
010	HEB160	IPE300	3,35	a	S	-	C	-
011	HEB160	IPE300	3,35	b	S	-	C	15
012	HEB160	IPE300	3,35	c	S	-	C	15
013	IPE240	IPE200	0,50	a	S	-	C	-
014	IPE300	IPE200	0,23	a	S	-	C	-
015	HEB160	IPE200	0,78	a	Cyc	-	C	-
016	HEB160	IPE200	0,78	b	S	-	M	15
017	HEB160	IPE200	0,78	c	Cyc	-	C	15
018	HEB160	IPE300	3,35	a	Cyc	-	C	-
019	HEB160	IPE300	3,35	b	Cyc	-	C	0
020	HEB160	IPE300	3,35	c	Cyc	-	C	15
021	IPE240	IPE200	0,50	a	Cyc	-	C	-
022	IPE300	IPE200	0,23	a	Cyc	-	C	-

-: The axial force is negligible or d has no meaning
S : static loading ; Cyc : cyclic loading
C : preloading to 0.8 f_y ; M : controlled hand tightening

Table 1 - Basic data for the test specimens

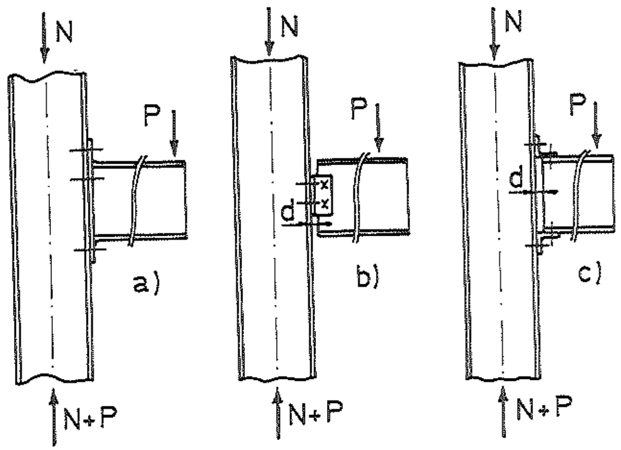


Figure 1 - Types of joints

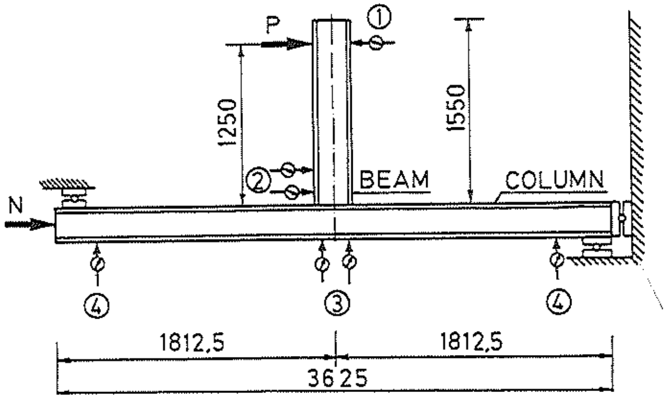
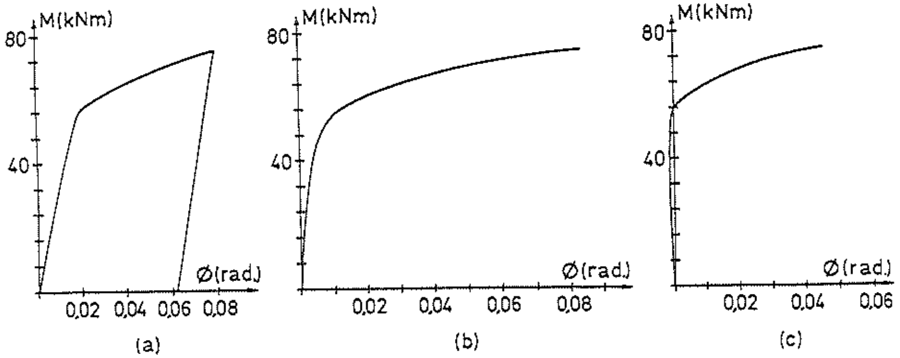


Figure 2 - Testing arrangement



(a) (b) (c)

Figure 3 - M-ϕ Curve : a) of the connection ; b) of the joint ; c) of the web column - (end plates).

RESULTS OF THE STATIC TESTS

Connections with end plates.

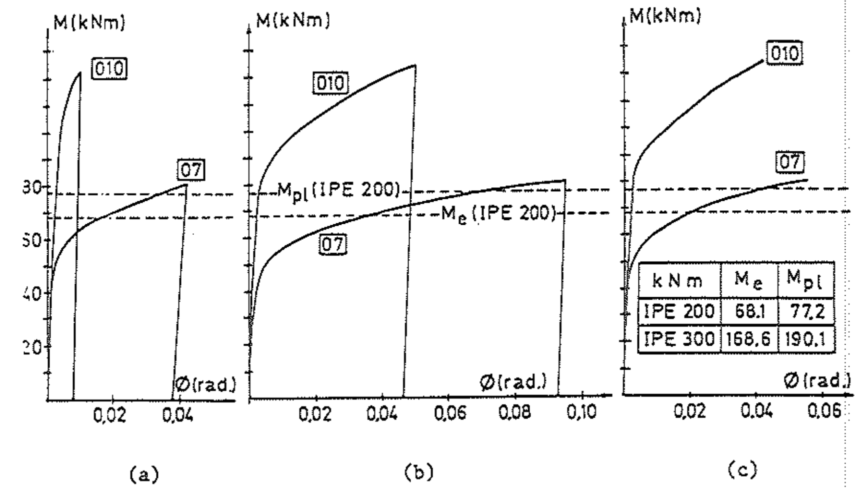
The relative rotations of the connection and of the joint are nearly linear at the beginning of the loading (fig. 3.a,b). Then occurs yielding, which is followed by a strain hardening of quasi constant stiffness. The column web behaviour is different at all; the web is first nearly infinitely rigid, then yields rather suddenly (fig. 3c). From the test results

the influence of the main parameters can be summarized as follows :

a) The axial force has no sensible effect on the yield shear force in the range $\sigma < 130$ MPa , i.e. $\sigma = 0.5\ f_y$, while the yielding moment of the column flange is affected so that the linear portion of the M-ϕ curve is reduced ; this observation is in accordance with Packer's and Morris' conclusions [2] but in contradiction with Zoetemeijer' and Munter' ones [3];

b) The initial stiffness of the joint seems just be little influenced by the axial force ;

c) It is necessary to distinguish between both behaviours of the column web and of the connection and to modelize them separately, as it appears clearly from figures 4. a-c. In test 07, the column web and the connection contribute the rotation in similar proportions, while, in test 010, the deformation is mainly due to the shear flexibility of the column web, which is weaker than the connection. It can also be observed that the use of the full elastic strength of the beam would imply a marked non linear behaviour of the joint.



(a) (b) (c)

Figure 4 - M-ϕ Curve : a) of the connection ; b) of the joint ; c) of the web column - (end plates).

d) The initial stiffness intests 07 and 014 - specimens fitted with same end plates - is shown dependent on the dimensions of the column flange (fig. 5). The more marked non linear behaviour of specimen 014 is due to a weaker column flange and to the yielding of the compressed zone of the web column. With respect to similar stiffness, specimen 013 benefits from the stronger rigidity of IPE240 column flange. Unlike test 07, the collapse of the connections 013 and 014 is reached, due to yielding in the compressed part of the column web, and the associated rigidity becomes nearly zero.

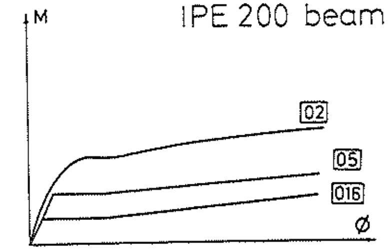
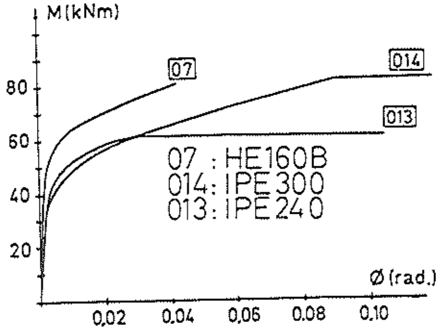


Fig.6-Effect of bolt tightening and of beam depth on connection M-ϕ curves (double web cleat)



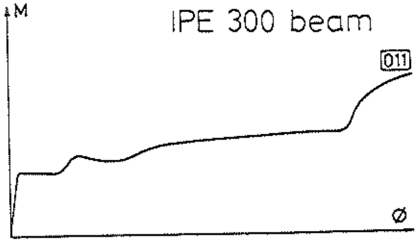


Fig.5- Connection M-ϕ curves for tests 07 - 013 - 014.

Fig.7- Connection M-ϕ curve for test 011 (double web cleat).

Connections with double web cleat.

The response of the tests carried out on such connections is quite different from the previous one. The linear behaviour with a nearly constant stiffness is followed by successive slips of the bolts due to hole clearance. When all the bolts are bearing, the holes are ovalized and the cleats distort and yield. Following conclusions can be drawn :

a) The curves corresponding to similar specimens 05 and 016 (d = 15 mm) are plotted in figure 6. Only the bolt tightening is different : preload to 0.8 f_y for specimen 05 and controlled hand tightening for specimen 016. The level of tightening does not alterate neither the initial stiffness, nor the behaviour after slip ; only the bending moment associated to the first slip varies and does it proportionnally to the preload in the bolts (fig. 6).

b) By reducing the clearance d (fig. 1) from 15 mm to zero (specimen 02), the transmission of the applied bending moment is modified with the result of a much higher initial stiffness (fig. 6). Indeed compression is transmitted by direct bearing between beam-and column flanges, while tension is supported by friction, then by shear after slip occurs, and last by bearing pressure. The non linearity before slip is due to distorsion and yielding of the angles in the tensile zone, and last by the slip initiation in the upper bolts in the beam.

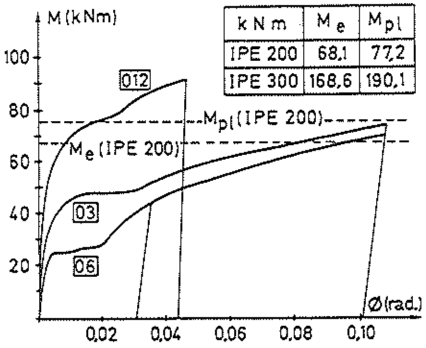
c) A deeper beam (IPE300) allows the use of deeper angles with four bolts (specimen 011), with the result of an initial stiffness nearly equal to that of specimen 010 (connection with end plates). The clearance d=15mm allows the beam-and column flanges bearing and explains the increase of rigidity at the end of the test (fig. 7).

Connections with flange cleats.

The M-ϕ curves dealing with tests n° 03 - 06 - 012 are shown in figure 8. It can observed that :

a) The initial stiffness of tests 03 and 06 is not affected by the level of tightening and that the ultimate strength is quasi independent of this level. However, the slip is initiated earlier for test 06.

b) With a deeper beam, (test 012), the initial stiffness does not change significantly ; so for the overall shape of the M-ϕ curve.



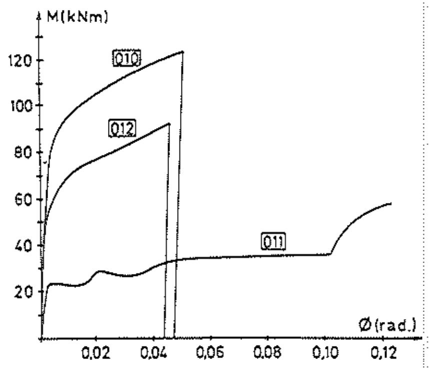


Fig. 8 - M-ϕ curves for tests 03 - 06 - 012 (flange cleats).

Fig. 9 - Comparison of M-ϕ curves for 3 types of connections.

Comparison between different types of connections.

Figure 9 shows for instance the M-ϕ curves associated respectively to the three types of connections for a joint between a HE160B column and an IPE300 beam.

CYCLIC TESTS

The cyclic tests were performed in accordance with a standard procedure [5]. At the present time, the results have not yet been fully investigated. Therefore only a cyclic test is compared to a static one, both being carried out on identical specimens (fig. 10).

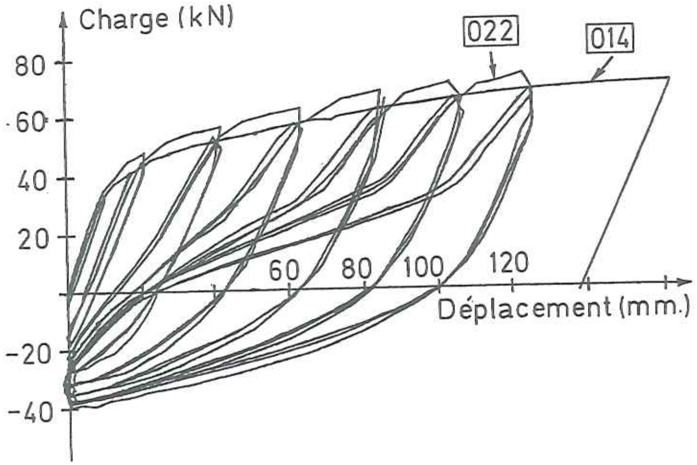


Figure 10 - Comparison between static and cyclic tests.

MODELLING OF M-ϕ CURVES

An ambitious goal would be to define the M-ϕ curve of a joint from the whole geometry and the mechanical properties of the connection and of the connected elements. Such an attempt was made for connections with end plates [4] but has to be somewhat modified [6] and improved in order to be in a quite satisfactory agreement with experimental results. The authors are intended to contribute such improvements and extend the procedure to other kinds of connections and to shear column webs.

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PREDICTION OF MOMENT-ROTATION BEHAVIOR OF SEMI-RIGID BEAM-TO-COLUMN CONNECTIONS

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ABSTRACT

This paper presents the results of a study of the static behavior of semi-rigid steel beam-to-column connections. From the experimental investigation, the geometric parameters which most significantly affect the moment-rotation performance of the connections have been evaluated. An analytical model was developed to predict the complete non-linear static moment-rotation behavior of the connections. The model was found to compare reasonably well with the test data for the range of connection stiffnesses examined.

INTRODUCTION

The analysis of steel frame building structures with fully rigid beam-to-column connections is a straightforward one, and buildings utilizing such framing systems have been used extensively in design practice. More recently, increasing interest has been expressed in the use of semi-rigid (partially restrained) connections for building frames, spurred by potential economies that may be realized from simpler connection details, and by "tuning" the connections (i.e., adjusting connection stiffnesses) to optimize the distribution of moments in the connected members.

Semi-rigid connections are characterized by a decidedly non-linear moment-rotation (M-ϕ) behavior which, in turn, can contribute significantly to the performance of the complete structure, including strength limits and drift considerations [1-4]. In certain instances, definition of the complete M-ϕ relationship may not be necessary, and an estimate of the initial stiffness of the connection (initial slope of the M-ϕ curve) will suffice. For example, under service gravity live load and wind load fluctuations, corresponding to a nominally elastic response of the structure, frame analyses using linearized connection stiffnesses may be adequate [5,6]. Under extreme loading conditions, however, such as those imposed in a seismic event, use of the full non-linear M-ϕ curve (complete hysteresis loop) is required to assess structural performance.

In the study reported herein, the static moment-rotation behavior of connections consisting of bolted top and seat flange angles, and double web angles, was investigated. The objectives of the study have been to experimentally determine the geometric parameters which most significantly affect connection performance, and, from these data, to develop analytical models to predict the static M-ϕ behavior. Models used to predict the