HIGH TEMPERATURE TESTS ON PARTIALLY ENCASED BEAMS

Paulo A. G. Piloto*, Ana B. R. Gavilán, Luís M. R. Mesquita* and Carlos Gonçalves***

*** IDMEC, Polytechnic Institute of Bragança, Portugal**

**** University of Salamanca, Spain**

7th International Conference on Structures in Fire, Swiss Federal Institute of Technology, Zurich, 6 - 8 June 2012

KEYWORDS

- Partially Encased Beams (PEB).
- Bending resistance.
- High temperature.
- Experimental tests.

1- INTRODUCTION

- Partially Encased Beams (PEB) are often defined from a steel profile, usually I-Shape or H-shape cross section, using reinforced concrete between flanges.
- Concrete between flanges increases fire resistance, load bearing and stiffness, without enlarging the overall size of bare steel cross sections.
- These advantages outweigh the increasing self-weight of the partially encased solution.

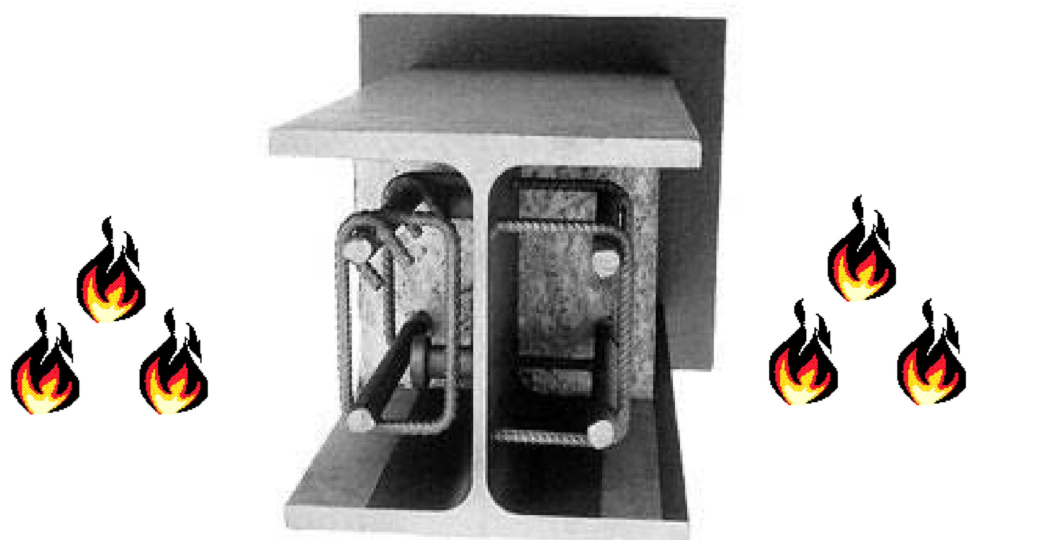


Figure 1 – PEB . Different configurations for stirrups.

2- STATE-OF-THE-ART

PEB have been widely tested at room temperature, but only a small number of testes are reported under fire or under high temperature:

- Kindmann et al, proved the importance of the reinforced concrete between flanges for bending resistance. Caused the revision of Eurocode 4 (pre-standard) for the design of partially encased composite beams;
- Lindner and Budassis in 2000, developed a new design proposal for lateral torsional buckling, taking into consideration the torsional stiffness of concrete;
- Maquoi et al, improved the knowledge on the elastic critical moment and on the lateral torsional buckling resistant moment;
- Makamura et al., concluded that bending strength of the PEB girders was almost two times higher than conventional bare steel girders. Specimens with rebar not welded (NW) to flanges presented a decrease of 15 % for maximum load bearing when compared to the welded rebar (W) specimens;
- Akio Kodaira et al., showed that reinforcement is effective during fire.
- Piloto et al., developed fire resistance tests (small series).

3- RESEARCH MOTIVATION / OBJECTIVES

- From the start of this research (2005), only a small number of experiments under fire conditions were reported.
- Fire design calculation method (EC4, Part 1.2) is based on tabulated data and on simple calculation models for composite beams.
- Understand the ultimate limit state of PEB under fire conditions and quantify the ability of an element to withstand load when exposure to elevated temperatures.
- Our research will provide essential data to the calibration / validation of new simplified design methods and advanced numerical methods.

- Compare structural behaviour between PEB and Bare steel beam.
- Analyse the effect of shear condition between stirrups and web steel.

Figure 2 Comparison between PEB and are steel beam at room temperature.

Figure 3 PEB at elevated temperature, before and after removing thermal insulation.

4- SPECIMENS

PEB (Partially Encased Beams):

- W (welded stirrups)
- NW (not welded stirrups)

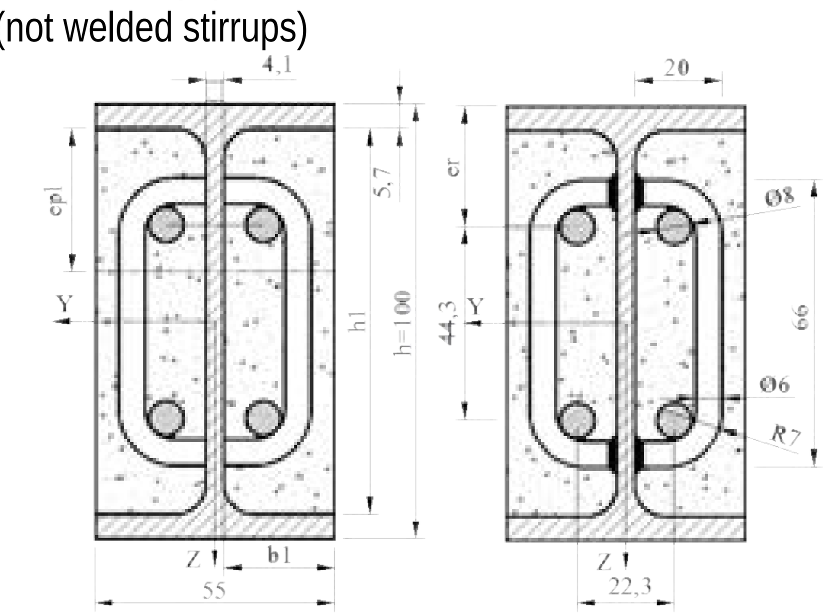


Figure 4 – Cross section of specimens (NW and W).

Plastic Moment (M_{Pl}):

$$M_{pl} = W_{pl,y}.f_{yk} - 2.f_{yk}.t_w.\left(0.5h_1 - e_{pl}\right)^2/2 + f_{ck}.2.b_1.e_{pl}\left(0.5h_1 - 0.5e_{pl}\right) + 2.A_r.\left(f_{sk} - f_{ck}\right)\left(h - 2.e_r\right)$$

Materials:

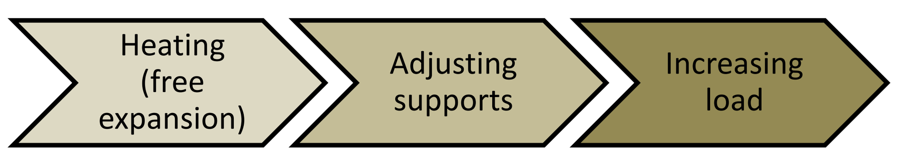
PROPERTY	(f_{yk}) [MPa]	(f_{sk}) [MPa]	$f_{ck,cube}$ [MPa]	f_{ck} [MPa]
VALUE	302.47	531.51	21.45	20.36

List of partially encased beams (22 specimens):

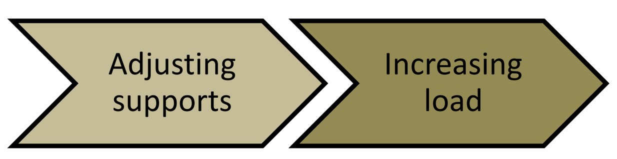
SERIES	SPECIMEN	LENGTH LS [m]	STIRRUPS [W/NW]	TEMP. [ºC]	MAX. IMP. [mm]
1	B/2.4-01	2.4	W	400	2
	B/2.4-02				2
	B/2.4-03				2
2	B/2.4-04	2.4	W	200	1
	B/2.4-05				2
	B/2.4-06				1
3	B/2.4-07	2.4	NW	400	1
	B/2.4-08				1
	B/2.4-09				1
4	B/3.9-01	3.9	W	400	2
	B/3.9-02				5
	B/3.9-03				3
5	B/3.9-04	3.9	W	600	2
	B/3.9-05				2
	B/3.9-06				5
6	B/3.9-07	3.9	NW	400	5
	B/3.9-08				5
	B/3.9-09				2
7	B/3.9-11	3.9	W	room	2
	B/3.9-12				5
8	B/3.9-11A	3.9	-	room	1
	B/3.9-12A				3

5- EXPERIMENTS

Elevated temperature:



Room temperature:



Reference lengths:

SPECIMEN	TOTAL LENGTH Lt [M]	LENGTH LOAD Lf [M]	HEATING LENGTH Lf [M]
B/2.4	2.5	1.5	1.3
B/3.9	4.0	3.0	2.8

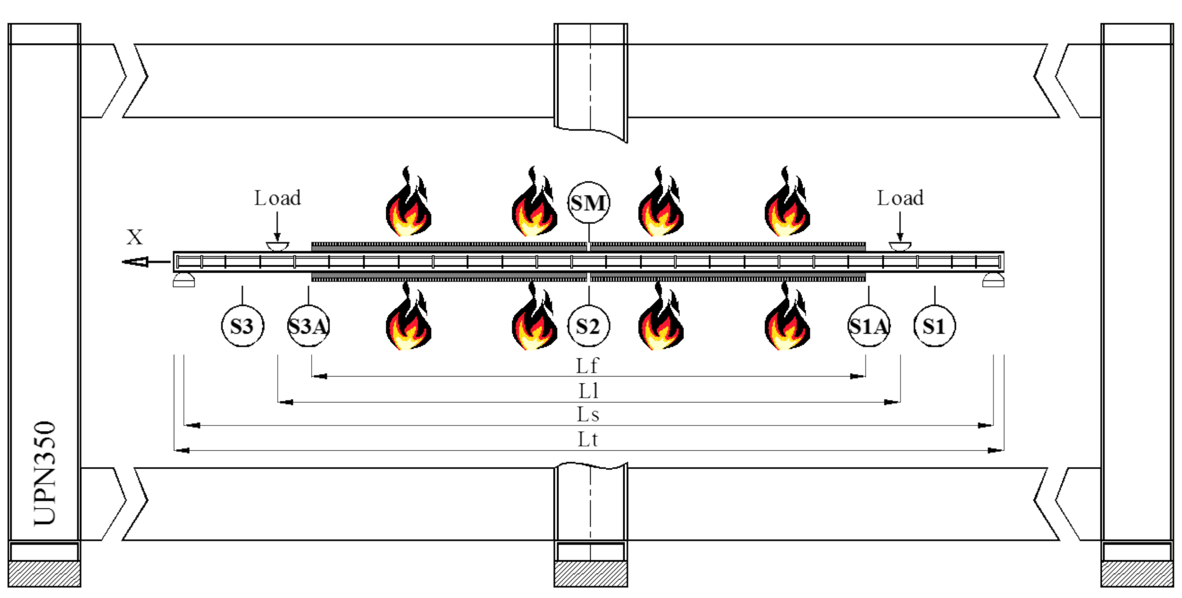


Figure 5 - Four point bending tests. Main cross sections.

ACKNOWLEDGEMENT

6- RESULTS

Medium series: Bending resistance.

SERIES	SPECIMEN	F_{MPL} [N]	$F_{L/30}$ [N]	F_U [N]
1	B/2.4-01	18890	24932	38864
	B/2.4-02	21760	26583	31533
	B/2.4-03	19920	24878	33568
2	B/2.4-04	31430	34060	36875
	B/2.4-05	30350	32953	39042
	B/2.4-06	31380	33930	34712
3	B/2.4-07	20610	24898	29000
	B/2.4-08	19270	25135	40861
	B/2.4-09	20850	25722	33246

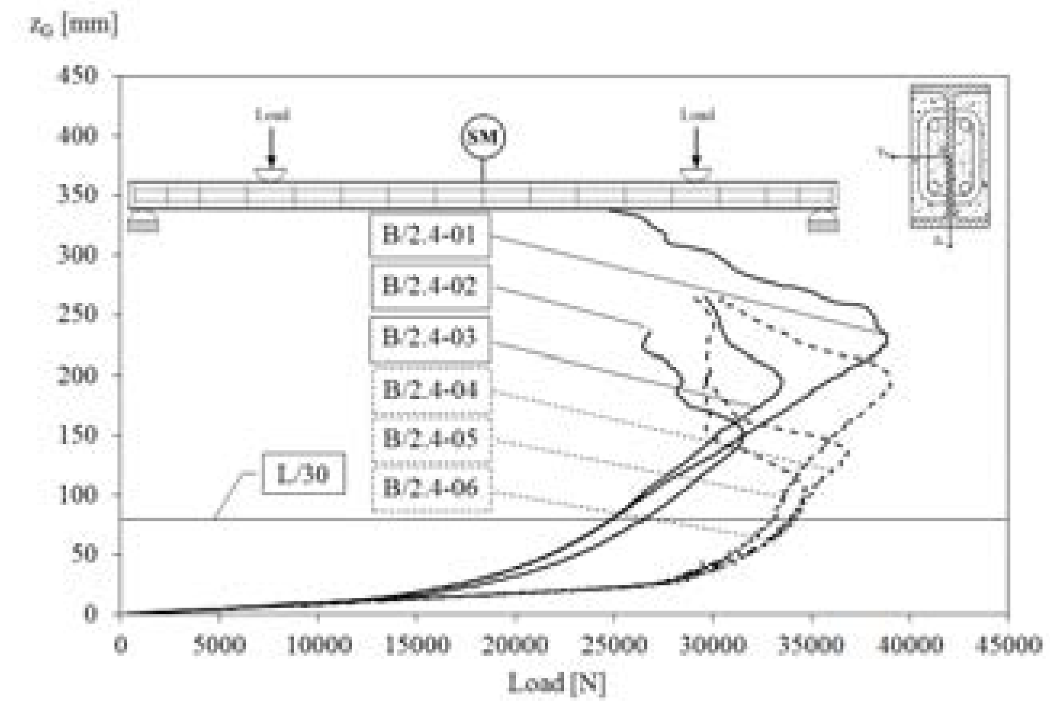


Figure 6 - Vertical deflection for series 1 and 2.

Large series: Bending resistance.

SERIES	SPECIMEN	F_{MPL} [N]	$F_{L/30}$ [N]	F_U [N]
4	B/3.9-01	16370	22126	30204
	B/3.9-02	16360	22715	27290
	B/3.9-03	14850	22573	28337
5	B/3.9-04	9620	12641	22456
	B/3.9-05	9750	12996	21662
	B/3.9-06	9110	12025	22770
6	B/3.9-07	15000	22665	23591
	B/3.9-08	15600	24237	32642
	B/3.9-09	15100	23207	24816
7	B/3.9-11	31600	35428	38718
	B/3.9-12	32100	36161	36380
8	B/3.9-11A	-	-	19436
	B/3.9-12A	-	-	21272

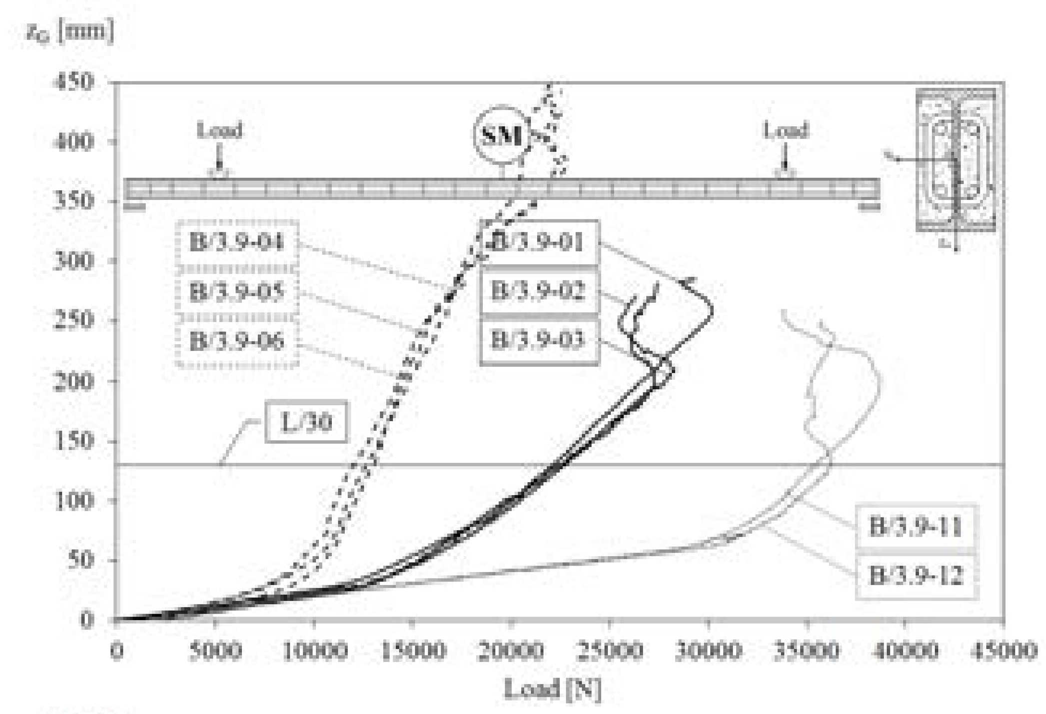


Figure 7 - Vertical deflection for series 4, 5 and 7.

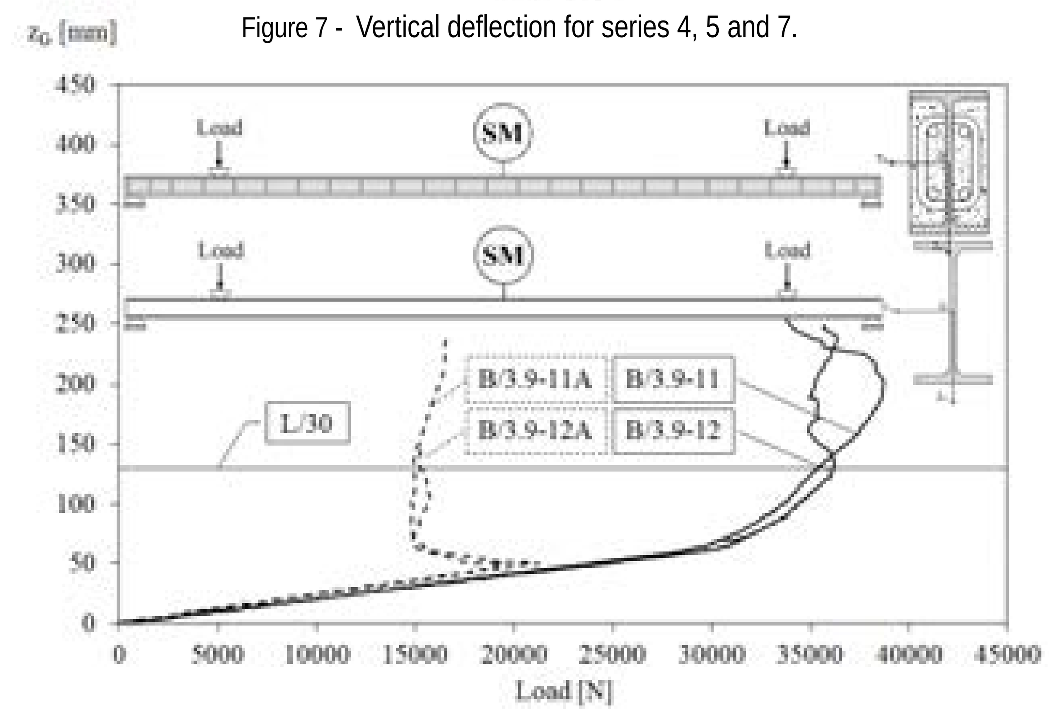


Figure 8 - Vertical deflection for series 7 and 8.

7- CONCLUSIONS

- The bending strength of the PEB (room) is almost two times the bending resistance of bare steel beam.
- The reduction on bending resistance of PEB is not directly proportional to the increase of temperature. An increase of temperature from 200ºC to 400 ºC leads to a reduction of 24 % on $F_{L/30}$ for medium series, while an increase from room to 400ºC, 600ºC leads to a reduction of 37 % and 64% on $F_{L/30}$, respectively.
- The deformed shape mode was LTB for all tested PEB and bare steel beams, with exception to those tested at 600 ºC.
- The deformation of large bare steel beams is completely different from PEB. The former series attained the ultimate limit state in the elastic range of the material.
- The bending stiffness of PEB is 15% higher than the bending stiffness of bare steel beam, at room temperature.

7th International Conference on Structures in Fire, Swiss Federal Institute of Technology, Zurich, 6 - 8 June 2012