The 1st INTERNATIONAL WORKSHOP RISQUE "FEU" 2015
April 7th & 8th 2015, Hassiba Benbouali University of Chlef, Chlef, Algeria

Laboratory Structures, Geotechnic and Risks (LSGR)

In association with/ En association avec
IPB Portugal and UBP (IP) France

FIRE SAFETY ENGINEERING: A DESIGN TOOL AT THE DISPOSAL OF CODES OF PRACTICE AND REGULATIONS

INGENIERIE DE LA SECURITE-INCENDIE: UN OUTIL DE CONCEPTION AU SERVICE DE LA REGLEMENTATION

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OBJECTIFS

Le workshop international risque « feu » vise à rassembler des universitaires, des chercheurs et des ingénieurs pour discuter des règlements, des bonnes pratiques et de derniers développements dans la conception des structures en acier, bois, béton et composites contre le feu. C'est une occasion pour focaliser l'attention sur l'apport des connaissances de l'ingénierie de la sécurité incendie et de son intégration dans la conception des structures.

*La première édition du workshop du laboratoire LSGR est sous le thème: «***INGENIERIE DE LA SECURITE-INCENDIE : UN OUTIL DE CONCEPTION AU SERVICE DE LA REGLEMENTATION***». Les expériences vécues et les leçons tirées des évènements passés au niveau international, constituent un apport appréciable dont il faut tenir compte dans toute action s'inscrivant dans la stratégie de protection des infrastructures contre le risque incendie : C'est là l'objectif technique et scientifique de ce workshop international.*

OBJECTIVES

The Workshop aims to bringing together academics, researchers and engineers to discuss buildings regulations, best practices and latest developments in the field design of steel, timber, concrete and composite structures against fire. It is an opportunity to focalise on what fire safety engineering knowledge and new advances in the field can provide to the design of building structures and infrastructures.

*The first edition of the workshop is under the heading: «***FIRE SAFETY ENGINEERING: A DESIGN TOOL AT THE DISPOSAL OF CODES OF PRACTICE AND REGULATIONS***». Experiences drawn from past events and lessons learned from international fire accidents is an added value to include in any fire protection strategy: it is actually one of the main goals of the workshop*

Programme du Workshop /WorkShop Program

Mardi 7 Avril /Tuesday, April 7th 2015

Matin/Morning

8h30-9h : Accueil et Inscriptions des participants / Registration

9h – 9h 30 : Cérémonie d'Ouverture du Workshop / Ceremonial Opening of the WorkShop

9h30 - 10h : Lieutenant-Colonel F. NECHAB, Directeur de la prévention, Protection Civile
PREVENTION ET SECURITE INCENDIE EN ALGERIE

10h-10h30 : PILOTO P., IPB Portugal
FIRE ENGINEERING OVERVIEW: THE EUROCODES AND THE PORTUGUESE FIRE SAFETY REGULATIONS IN BUILDINGS

Pause-café /Coffee break (Posters)

11h-11h30: BOUCHAIR A., UBP, IP France
ASSEMBLAGES ACIER-BOIS SOUS INCENDIE : MODELISATION ET EXPERIMENTATION

11h30-12h: MESQUITA L., IPB Portugal
FIRE PROTECTION OF STEEL MEMBERS WITH INTUMESCENT COATINGS

12h - 12h30 : LAMRI B., UHBC, Chlef
L'INGENIERIE INCENDIE : UNE NECESSITE POUR LA CONCEPTION MAIS PAS UN OBSTACLE

Déjeuner / Lunch

Après-midi/Afternoon

14h 30 - 15h PILOTO P. (IPB Portugal)
BENDING RESISTANCE OF PARTIALLY ENCASED BEAMS: EXPERIMENTAL TESTS AT ELEVATED TEMPERATURE

15h - 15h20 : HACHEMI S., OUNIS A. (UMK Biskra, Algérie)
EVALUATING RESIDUAL MECHANICAL AND PHYSICAL PROPERTIES OF THERMALLY DAMAGED CONCRETE

15h20 - 15h40 : BENLAKEHAL N., LAMRI B., KADA A., MESQUITA L., BOUCHAIR A. (UHB Chlef, Algérie)
NUMERICAL MODELLING OF INDUSTRIAL PORTAL STEEL FRAMES UNDER FIRE CONDITIONS

15h40 – 16h : GUENDOUZ M., DEBIEB F., KADRI E. H. (U. Médéa, Algérie)
EFFETS DE L'ELEVATION DE LA TEMPERATURE SUR LES CARACTERISTIQUES DU BETON DE SABLE A BASE DE DECHETS PLASTIQUES

Pause-café /Coffee break (Posters)

16h30-16h50: KADA A., LAMRI B., BENLAKEHAL N., MESQUITA L., BOUCHAIR A. (UHB Chlef, Algérie)
FINITE ELEMENT INVESTIGATION ON THE BEHAVIOUR OF STRUCTURAL STEEL BEAMS SUBJECTED TO STANDARD & PARAMETRIQUE FIRE

16h50-17h10: AGRED S. , BAROUS A., LOUKARFI L., NAJI H. (UHB Chlef, Algérie)
UN PROGICIEL POUR L'ANALYSE DE LA COUCHE DE FUMEES LORS D'UN INCENDIE DE COMPARTIMENT

17h10-17h30 : SERIKMA M., MITICHE-KETTAB R. (ENP Alger)
LE BÂTIMENT POMPIER

17h30 : **CLÔTURE ET RECOMMANDATIONS / CLOSING THE WORKSHOP-RECOMMANDATIONS**

Diner / Dinner

Le workshop portera sur les thèmes suivants /The workshop topics are:

TOPICS TO BE COVERED

- Fire resistance of structures and elements: Buildings, industrial structures, exceptional infrastructures (tunnels and chemical plants);
- Fire behaviour and fire reaction of materials at elevated temperatures (steel, concrete, composite, wood, masonry, other materials);
- Fire protection of structures (active and passive protection) and case of study on exceptional projects, tunnels or other infrastructures;
- Fire testing (standard and nonstandard);
- Fire regulations and national code aspects;
- Fire risk analysis.

THEMES À COUVRIR

- Résistance au feu de structures et des éléments : Bâtiments, structures industrielles, infrastructures exceptionnelles (tunnels et usines chimiques);
- Comportement et réaction au feu des matériaux à des températures élevées (acier, béton, composite, bois, maçonnerie, autres matériaux) ;
- Protection des structures contre le feu (protection active et passive) et étude de cas sur des projets exceptionnels, tunnels ou d'autres infrastructures ;
- Test d'incendie (standard et non standard) ;
- Règlements d'incendie de et aspects de codes nationaux;
- Analyse du risque incendie.

RISQUE FEU 2015, UHBC

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Plénières
Plenary talks

BENDING RESISTANCE OF PARTIALLY ENCASED BEAMS: EXPERIMENTAL TESTS AT ELEVATED TEMPERATURE

PILOTO, Paulo [1*]; GAVILÁN, Ana B. R. [2]; MESQUITA Luís M. R. [1]

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Résumé : *La performance de 27 poutres partiellement enrobée (PEB) est comparée à différents niveaux de température en utilisant la configuration de test flexion aux quatre points. Tests considèrent une seule section composite, deux longueurs de poutres et deux conditions de cisaillement différentes pour étriers. La performance du PEB est aussi comparée à poutres de l'acier en I (IPE). Des mesures expérimentales ont confirmé que la température n'est pas parfaitement constante sur toute la longueur des poutres chauffées, présentant de forts gradients à extrémités. Détérioration progressive du béton est produite au cours des expériences. La résistance à la flexion de PEB à température ambiante est beaucoup plus élevée que pour les poutres en acier et la rigidité en flexion est d'environ 15% plus élevé, soit la déformation après flambage tout à fait différente. La réduction de la résistance à la flexion de PEB à température élevée n'est pas inversement proportionnelle à l'augmentation de la température. Toutes les poutres testées atteints du déversement pour le mode déformée, à l'exception de ceux testés à 600 °C.*

Abstract: *The bending performance of 27 Partially Encased Beams (PEB) is compared at different temperature levels using the four-point bending test setup. Tests consider only one composite cross section, two beam lengths and two different shear conditions for stirrups. The performance of PEB is also compared to bare steel I beams (IPE). Experimental measurements confirmed that temperature is not perfectly constant over the length of the heated beams, presenting strong gradients at extremities. Progressive damage of concrete occurred during experiments. The bending resistance of PEB at room temperature is much higher than bare steel beams and the bending stiffness is approximately 15% higher, being the post buckling deformation quite different. The reduction of the bending resistance of PEB at elevated temperature is not inversely proportional to the increase of the temperature. All tested beams attained lateral torsional buckling for deformed shape mode, with exception to those tested at 600 °C.*

Mots-clés: *Poutres partiellement enrobées; Section composite acier et béton; Résistance à la flexion; Température élevé et Température ambiante, Essais expérimentaux.*
Key-Words: *Partially encased beams; Composite steel and concrete section; Bending resistance; Elevated temperature and Room temperature, Experimental tests.*

1- Introduction

Partially Encased Beams (PEB) are composite steel and concrete elements that present several advantages with respect to bare steel beams. They are usually built with hot rolled sections with encased concrete between flanges. There are different design possible solutions, considering the arrangement of longitudinal reinforcement of concrete, stirrup configuration and material strength. The reinforced concrete between flanges increases fire resistance, corrosion resistance, load bearing, bending stiffness, without enlarging the overall size of bare steel cross section. Fire design, according to European standard EN1994-1-2 [1], is valid for composite beams, based on tabulated methods (considering simple supporting conditions and standard fire exposure) based on prescriptive geometry to achieve specific fire rating (time domain). The simple calculation method may also be applied to PEB, using fire resistance on load domain, assuming no mechanical resistance of the reinforced concrete slab (considering simple supporting conditions and standard heating from three sides). The effect of fire on the material characteristics is taken into account, either by reducing the dimensions of the parts or by reducing the characteristic mechanical properties of materials.
Partially Encased Beams (PEB) and Columns (PEC) have been widely tested at room temperature, but only a small number of experiments under fire and elevated temperature conditions have been reported.

importance of the reinforced concrete between flanges in determining the ultimate bending moment. Hosser et al. [3], carried out four experimental tests on simply supported composite PEB, connected to reinforced concrete slabs, under fire conditions. Temperature changes were registered at different locations, including the PEB cross section. Authors concluded that the effective width of the slab depends on the transversal longitudinal shear reinforcement. Lindner and Budassis [4], tested lateral instability at room temperature using twenty two full-scale PEB with two different steel sections under three-point bending test. A new design proposal for lateral torsional buckling was proposed, taking into consideration the torsional stiffness of concrete. Maquoi et al. [5], improved and implemented knowledge on lateral torsional buckling of beams, including PEB, and prepared design rules that were not satisfactorily covered by the existing standards. Assi et al. [6], developed a theoretical and experimental study on the ultimate moment capacity of PEB, performing twelve bending tests on specimens with four different IPE cross sections, to investigate the contribution of different types of concrete. Makamura et al. [7], tested three partially encased girders with longitudinal rebars and transversal rebars (welded (W) and not welded (NW) to flanges). The bending strength of the partially encased girder was almost two times higher than conventional bare steel girders. Authors concluded that the specimen with rebar not welded (NW) to flanges presented a decrease of 15 % for maximum load bearing when compared to the welded rebar (W) specimen. More recently, Kodaira et al. [8], decided to determine fire resistance of eight PEB, with and without concrete slabs. Authors demonstrated that reinforcement is effective during fire. In 2008, Elghazouli and Treadway [9], performed ten full scale tests on PEB. The experimental analysis was focused on inelastic performance, considering major and minor-axis bending tests. Authors discussed several parameters related with the capacity and ductility with relevance to design and assessment procedures. Nardin and El Debs [10], studied the static behaviour of three composite PEB under flexural loading at room temperature, testing some alternative positions for shear studs, using one type of mono-symmetric steel section. Experimental results confirmed that studs are responsible for the composite action and increase bending resistance, especially when the studs are vertically welded on the bottom flange. A. Correia and João P. Rodrigues [11], studied the effect of load level and thermal elongation restraint on PEC, built with two different cross sections, under fire conditions. They concluded that the surrounding stiffness had a major influence on fire element behaviour for lower load levels. The increasing of the surrounding stiffness was responsible for reducing critical time. Critical time remained practically unchanged for higher load levels. In 2013, Kvočák and Drab [12], decided to test the bending resistance of partially encased beams with slender web (class 4), using different shear stirrups and web stiffeners and concluded that the stability of slender web increased with the concrete. Recently, Paulo Piloto et al [13], tested fifteen PEB under fire conditions (small series) using three-point bending test to determine fire resistance. Results revealed the dependence of fire resistance on load level. Particular emphasis was given to the critical temperature on the composite section.

The experimental tests presented in this paper aim to analyse the bending performance of partially encased beams using four point bending test set-up, heated from two sides (top and bottom flanges), for four temperature levels (20, 200, 400 and 600 °C). The bending resistance of PEB is also compared with bare steel beams at room temperature. Two different beam lengths were considered (medium and large series), using one cross section type (IPE100) with two different shear conditions between stirrups and the web of the steel profile (W- welded and NW- not welded).

2- Experimental tests

Four point bending tests were developed to determine the bending resistance of lateral unrestrained beams. Twenty seven tests were grouped in ten series according to the conditions defined in table 1. All tested beams used simple supporting conditions. The maximum geometric imperfection was identified for each specimen. The bending resistance was determined in load domain, defining five load events to characterize five stages of the deformed shape of the beams. The proportional limit force (F_p) with respect to the vertical displacement, the force (F_y) resulting from the intersection method between two straight lines drawn from linear and non-linear interaction of the vertical displacement; the load event for the vertical displacement limit of L/30 ($F_{L/30}$); and the maximum load level for the asymptotic behaviour of lateral displacement (F_u).

Table 1: List of tested beams (specimens) and main force events.

Series	Specimen	Length Ls [m]	Length Ll [m]	Stirrups [W/NW]	Temp. [°C]	Max. Imp[mm]	F_{Mpl} [N]	F_p [N]	F_y [N]	$F_{L/30}$ [N]	F_u [N]
1	B/2.4-01	2,4	1,5	W	400	2	32191	11910	18890	24932	38864
	B/2.4-02					2		13627	21760	26583	31533
	B/2.4-03					2		12540	19920	24878	33568
2	B/2.4-04	2,4	1,5	W	200	1	32877	24770	31430	34060	36875
	B/2.4-05					2		26030	30350	32953	39042
	B/2.4-06					1		26580	31380	33930	34712
3	B/2.4-07	2,4	1,5	NW	400	1	32191	13050	20610	24898	29000
	B/2.4-08					1		12960	19270	25135	40861
	B/2.4-09					1		11920	20850	25722	33246
4	B/2.4-10	2,4	1,5	W	room	2	32968	27050	34966	35000	35015
	B/2.4-11					0,5		25960	35410	36360	37624
	B/2.4-12					3		26600	34600	35962	39246
5	B/2.4-11A	2,4	1,5	-	room	1	26271	16107	-	-	29627
	B/2.4-12A					2		15530	-	-	28477
6	B/3.9-01	3,9	3,0	W	400	2	32191	11190	16370	22126	30204
	B/3.9-02					5		11920	16360	22715	27290
	B/3.9-03					3		11700	14850	22573	28337
7	B/3.9-04	3,9	3,0	W	600	2	15086	4110	9620	12641	22456
	B/3.9-05					2		4360	9750	12996	21662
	B/3.9-06					5		4090	9110	12025	22770
8	B/3.9-07	3,9	3,0	NW	400	5	32191	11170	15260	22665	23591
	B/3.9-08					5		13160	16540	24237	32642
	B/3.9-09					2		10720	15400	23200	24815
9	B/3.9-11	3,9	3,0	W	room	2	32968	26500	31350	35405	38718
	B/3.9-12					5		29020	32010	36159	36264
10	B/3.9-11A	3,9	3,0	-	room	1	26271	15023	-	-	19436
	B/3.9-12A					3		15331	-	-	21272

Two or three tests were considered for repeatability in each series and the results agree very well. Specimens were tested using a steel reaction portal frame, using two fork supports, see figure 1. Room temperature tests were carried out in one single stage, using small increments of load, while elevated temperature tests were carried out in two stages. The first stage was used to heat the beam along the length "Lf", using a constant heating rate of 800 °C/h and a specific dwell time to achieve constant temperature. During the second stage, temperature was kept constant using small increments of load. Tests developed at elevated temperature used electro-ceramic resistances to increase and sustain temperature during the incremental loading. Five different cross sections were defined to evaluate temperature (S1, S1A, S2, S3A and S3), and one cross section (SM) was defined to measure strain, displacements (vertical ZG, lateral YG) and cross section rotation.

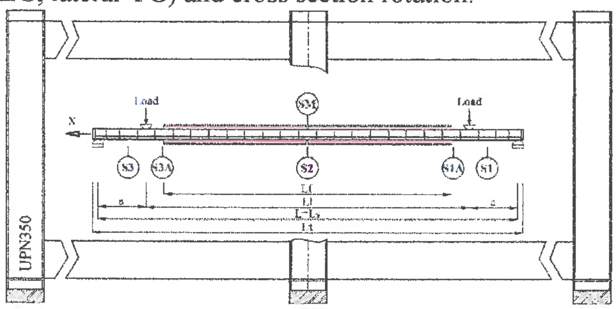


Figure 1: Testing conditions and main cross sections to be monitored.

2.1- Specimens and instrumentation

PEB were prepared by filling the space between the flanges of a steel IPE100 profile, using reinforced concrete (RC). Partially encased sections achieve higher fire resistance when compared to bare steel sections [13]. The increase in fire resistance is mainly due to the concrete encased in the section, reducing the exposed steel surface area to fire and consequently reducing the section factor, introducing concrete which has a low thermal conductivity. Higher fire resistance can also be achieved by increasing the amount of reinforcement to compensate for the reduction of steel strength in case of fire. Two different shear conditions for stirrups were tested (W and NW), both represented in figure 2. According to EN1994-1-1 [14], this composite steel and concrete section is classified as class 1.

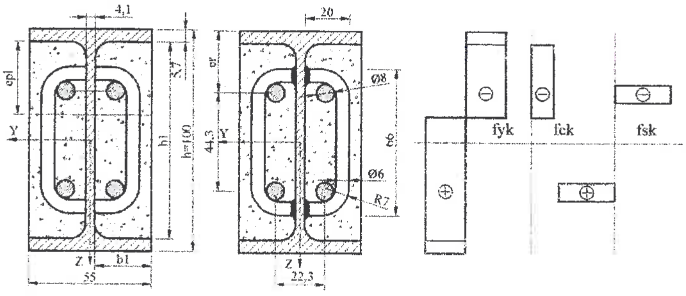


Figure 2: Cross section geometry and plastic stress distribution.

PEB were made of IPE100 with steel S275 JR, using encased concrete with siliceous aggregates. Four longitudinal steel B500 rebar were applied with diameter of 8 mm. Stirrups were designed with B500 rebar with a diameter of 6 mm, spaced every 167 mm. Stirrups were also partially welded to the longitudinal steel reinforcement, as represented in figure 2. The plastic neutral axis is referred by "epl", reinforced concrete block dimensions are represented by "b1" and "h1", while "er" represents the relative position of reinforcement.

PEB had been prepared with sensors to be tested at room temperature, measuring strain in central section (SM), over steel flange and web, in hot rolled section (SM-WS and SM-FS) and over concrete (SM-RS1 and SM-RS2). Whereas perfect bond was considered between concrete and reinforcement, concrete strain was measured on steel reinforcement. For the latter measurement, rebars were machined 1 mm in depth and 15 mm in length, in respect to the dimensions of the electrical strain gauge. Five strain gauges were used. All strain gauges were protected with gloss and special viscous putty against moisture, water and mechanical damage. PEB were also prepared to be tested at elevated temperatures, using thermocouples type K positioned in five sections along the length of the beam. For the concrete temperature measurements, positions Si-IC and Si-OC, thermocouples were welded to a small steel washer, wrapped in concrete, see figure 3.

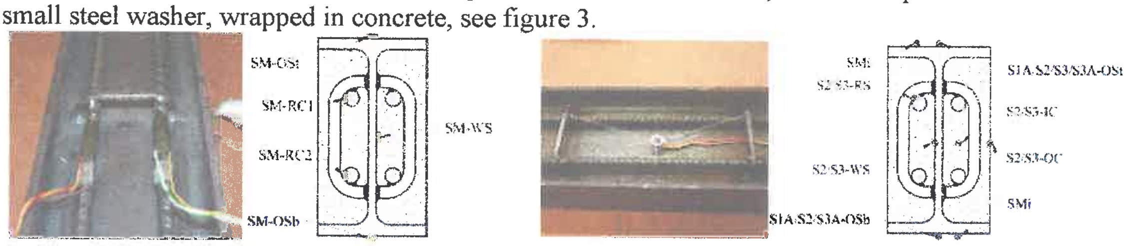


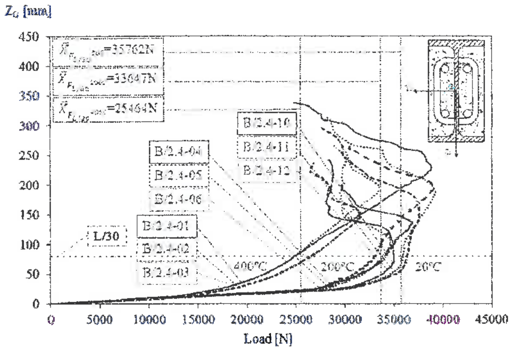
Figure 3: Instrumentation with strain gauges (left) and thermocouples (right).

Each steel material was characterized according to international standards [15] for hot rolled and cold formed steel. Three samples were collected from the web of steel hot rolled profile and two more samples were collected from steel reinforcement. The average value for the elastic modulus of the steel profile was 197.9 GPa and the average values for the ReH- upper yield strength (fyk) was 302 MPa. The values for the cold formed steel (reinforcement) were respectively 203 GPa and 531 MPa.

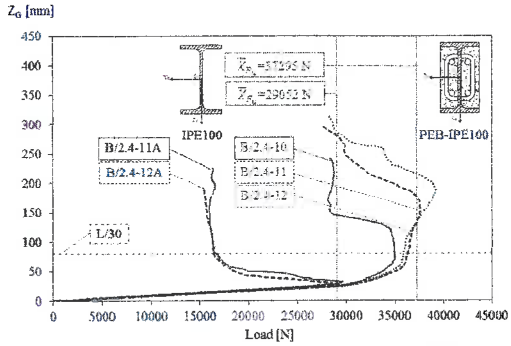
Concrete was made with Portland cement, sand and siliceous aggregates. The concrete mixture was prepared for one cubic meter of concrete with sand mass equal to 1322.7 [kg], aggregate mass equal to 451.1 [kg], water equal to 198 [l] and cement equal to 466.7 [kg]. The ratio water/cement was 45 %. Aggregates were characterized by the sieving method and tested according to European standard [16] to determine particle size dimension. Due to the small size of the steel section and considering the space available to cover the stirrups, small-sized aggregates were used. The percentage of aggregates with diameters between 4-6 mm was 90%, while the percentage of sand with diameters between 0.063-0.5 mm was 80%. The aggregate dimensions limit the value of the compressive resistance of concrete [17] ($f_{ck,cube}$ =21.45 [MPa] and f_{ck} =20.36 [MPa]), as concluded by [18]. The high level of permeability at elevated temperature was responsible to decrease pore pressure. This fact justifies the absence of explosive spalling during experiments.

2.2- EXPERIMENTAL RESULTS ON THE BENDING PERFORMANCE

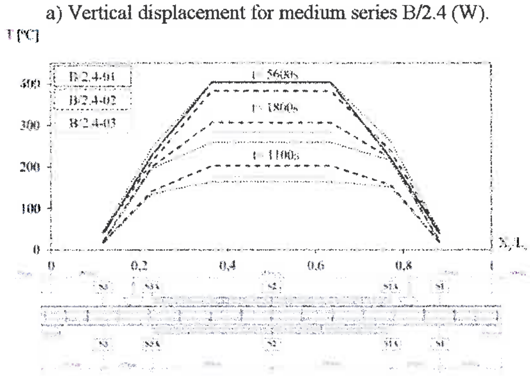
Figure 4 presents the results for the medium B/2.4 and large series B/3.9, showing the temperature effect on bending resistance, using welded stirrups (W) and the comparison between the bending performance of PEB and IPE.



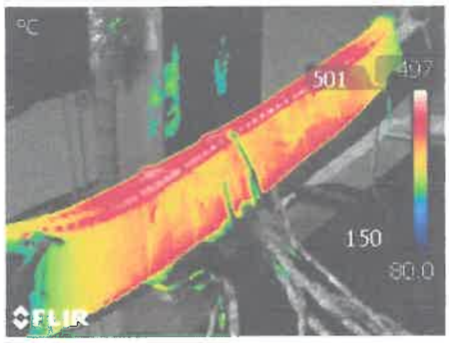
a) Vertical displacement for medium series B/2.4 (W).



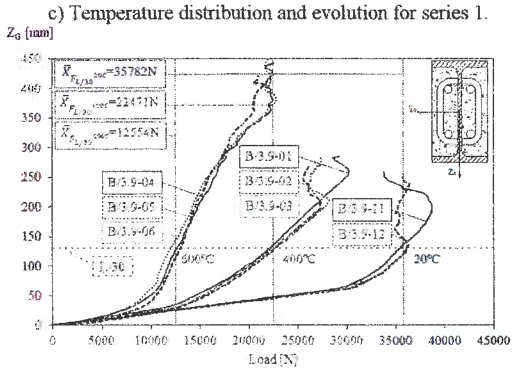
b) Vertical displacement for series 4 and 5 (IPE).



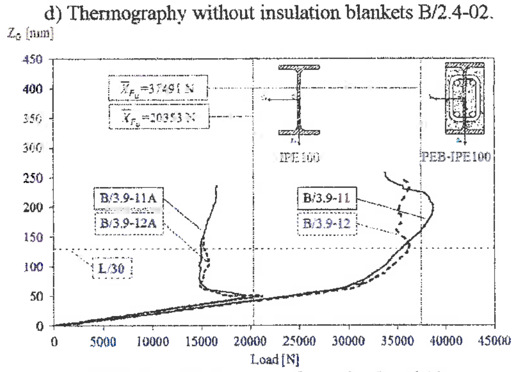
c) Temperature distribution and evolution for series 1.



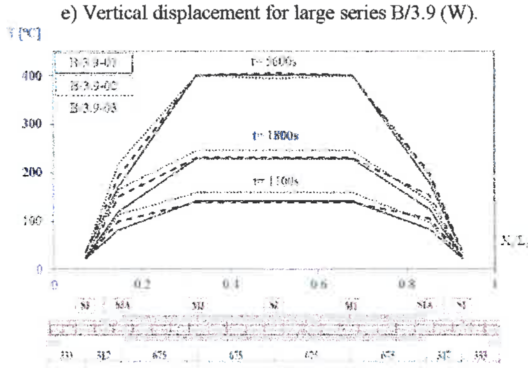
d) Thermography without insulation blankets B/2.4-02.



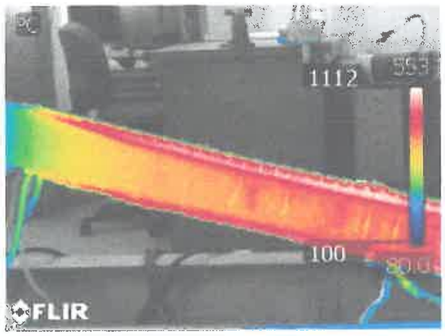
e) Vertical displacement for large series B/3.9 (W).



f) Vertical displacement for series 9 and 10.



g) Temperature distribution and evolution for series 6.



h) Thermography without insulation blankets B/3.9-05.

Figure 4: Bending performance and thermal behaviour for medium and large series.

4- CONCLUSION

Experimental tests confirmed that temperature is not constant over the length, presenting strong gradients at the extremities of the beams. Progressive damage of concrete occurred during experiments. Normal cracks due to tensile stress were the most visible ones, while crushing of concrete occurred due to developing of compressive stress and deformed mode shape. The bending resistance of PEB at room temperature is higher than bare steel beams. The reduction on bending resistance of PEB is not directly proportional to the increase of temperature. An increase of temperature from 200°C to 400 °C caused a reduction of 24 % on the load event $F_{L/30}$ for B/2.4 series, while an increase of temperature from room to 400 °C and to 600 °C caused a reduction of 37 % and 64% on the load event of $F_{L/30}$ for B/3.9 series, respectively. Although the strength of PEB is not proportional to the strength of material, the reduction coefficient of the yielding stress of steel is equal to 53 % at 600 °C. The deformed shape mode was identified as lateral torsional buckling for all tested PEB and bare steel beams, with exception to those tested at 600 °C, presenting plastic hinge formation. The bending stiffness of PEB at room temperature is 15% higher than the bending stiffness of bare steel beam, verified for both, medium and large series. The post buckling deformation of bare steel beams is quite different from PEB. Bare steel beams presented a decrease of load after reaching the ultimate load and a higher cross section rotation.

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