

# THE INFLUENCE OF LATERAL BENDING RESTRAIN IN NUMERICAL AND EXPERIMENTAL EVALUATION OF LATERAL BUCKLING RESISTANCE DESIGN MOMENT OF STEEL I BEAMS AT ELEVATED TEMPERATURES

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<sup>3</sup>Mechanical and Civil Institute, University of Liège, 1, Chemin des Chevreuils, 4000 Liège, Belgium, e.-mail: jm.franssen@ulg.ac.be

## Abstract

The numerical and experimental determination of the buckling design moment of steel I beams is influenced by the type of support and load restraint during the mechanical and thermal load. As a result of beam temperature rise the axial movement will be allowed and the type of load and support restraint will be compared from fully to unrestrained state.

For this study a simple supported beam is bent about its axis of greatest flexural rigidity. Taking into account the geometric and material imperfections, the beam may twist before it reaches its strength limit state. This flexural stability limit state is most commonly referred to as *lateral torsional buckling* of a beam. The twisting of the beam occurs when the compression flange becomes unstable as a result of being subjected to flexural induced axial stresses.

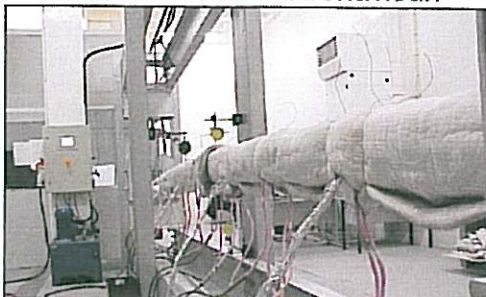
The design rules in Eurocode 3 related to design of steel structures in fire conditions presents their expressions as a function of the type of support and load. A particular attention will be paid to the type of experimental support and to the numerical finite element model used. The aim of this work is to investigate the value of the effective buckling length of steel I beam under the mentioned conditions. A relation between the beam buckling resistance and the lateral bending stiffness will be presented.

## 1- Introduction

In this work a special attention will be paid to the type of support and load system in the numerical and experimental validation of a new proposal for the design buckling moment resistance in case of fire [5,8]. The effective buckling length depends on the type and model of boundary conditions as it will be shown. The results of experimental and numerical tests will be presented.

## 2- Experimental tests

The experimental setup used in the beam design moment resistance is presented in figure 1a). Two end forks supports were used to prevent rotation and lateral movement as it can be seen in figure 1b). A reaction frame with two hydraulic jacks and a special heating system has been used to simulate the thermo-mechanical behaviour.



Due to lateral bending constraint during load application, the effective buckling beam length will be shorter than the real length between supports, given by the expression 1, where  $l$  represents the effective buckling length and  $L$  the distance between the two supports.

$$k = \frac{l}{L} \quad (1)$$

The effective length factor  $k$  will vary from 0.5 representing total restraint to lateral rotation and the value 1.0 representing the capability of free rotation along the vertical axis at support, shown in figure 1.

The results of the experimental investigation carried out using hot rolled IPE 100 at elevated temperatures helps to understand the influence of the supports restraint in buckling resistance [2].

The new proposal for the beam design buckling has been supported by 120 experimental tests at room temperature and at elevated temperature for several length specimens from 0.5 to 6.5 meter length. The residual stresses and the material characterization have been determined for a sample of the original profiles. The geometrical imperfections have been measured for each tested element.

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A set of numerical tests was performed with a non-linear geometrical and material program SAFIR, developed at the University of Liège specially to analyse structures in fire conditions. This programme uses a three dimensional uniaxial finite element with 3 nodes and 15 degrees of freedom [1]. The beams were tested to failure with two different degrees of vertical rotational restraint stiffness. The fibre model (plane 2D elements) is used to describe the geometric cross section, the residual stress state and the material characterization. The non-linear material behaviour is based on the Eurocode 3 material properties. The large displacement theory is also used.

### 4- Lateral torsional buckling

The theoretical background in lateral torsional buckling [3] for determining the critical elastic moment resistance  $M_{cr}$  will be assumed for the case of a simply supported beam at its ends, with both lateral deflection and rotation completely restrained but with no restraint to warping. Also will be considered the case where the beam is free from any initial imperfections and from residual stresses leading to the expression 2.

$$M_{cr} = \alpha_M \frac{\pi^2 EI_x}{(kL)^2} \times \sqrt{\frac{I_w}{I_x} \left( \frac{k}{k_w} \right)^2 + (kL)^2 \times \frac{GI_t}{\pi^2 EI_x}} \quad (2)$$

Where  $E$  represents the elastic modulus,  $L$  the buckling length,  $I_x$  the second moment of area from cross section about the major axis,  $I_w$  represents the warping constant,  $I_t$  the torsion constant of the cross section,  $G$  the elastic shear modulus,  $\alpha_M$  represents the coefficient for constant moment distribution and  $k_w$  refers to end warping. Unless special provision for warping fixity is made, this parameter should be taken as 1.0 [4]. The expression 2 should be arranged in the case where the moment distribution is not constant over the entire beam length [3].

The design buckling resistance moment of a laterally unrestrained beam with a class1 or 2 cross section type, in case of fire is given by [4]:

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where  $\chi_{LT,fi}$  represents the reduction coefficient,  $w_{pl,y}$  the plastic modulus,  $k_{y,\theta,com}$  the reduction factor for the yield strength  $f_y$ ,  $\gamma_{M,fi}$  represents the safety partial factor and the value 1.2 is empirical and accounts for several factors.

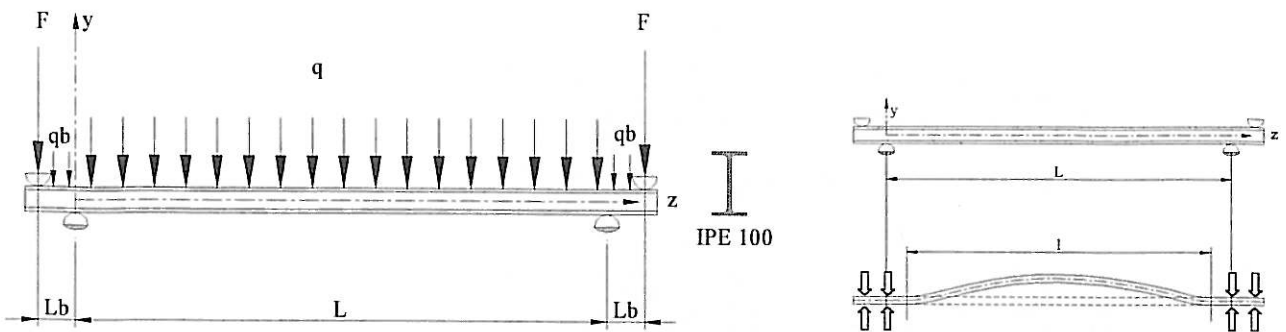
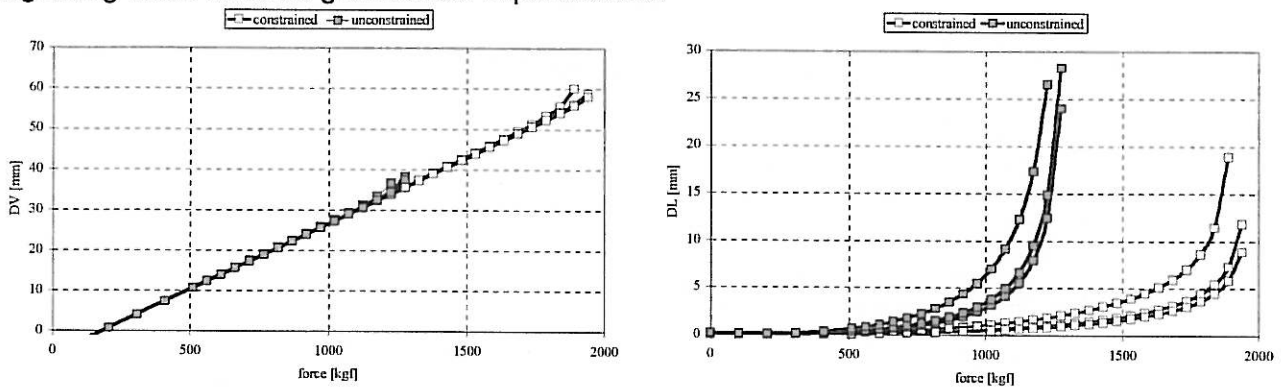


Fig. 2 – Case study. Simply supported beam with two forks separated by the beam length  $L$  and the effective buckling beam length.

The two point loads increases from zero to the beam collapse load as it can be seen in figure 3, regarding three different geometrical imperfections.



a) Vertical mid span displacement.

b) Lateral mid span displacement.

Fig.3 – Numerical results from a 5.5 [m] beam length at 400 [°C].

Vertical and lateral displacement has been evaluated at mid span beam length and plotted against the incremental two point load. If there is some kind of restraint due to the process of the load application, the buckling load of the beam is higher than the buckling load corresponding to a lateral unrestrained beam.

The relation between the critical load and the boundary conditions lateral restraint stiffness will be presented by figure 4.

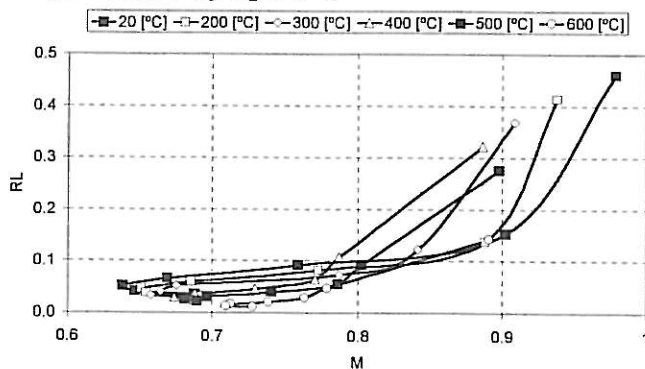


Fig.4 a) - Relation between  $R_L$  and  $M$ .

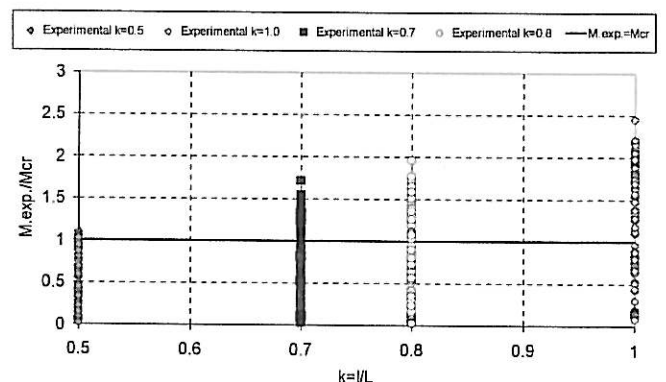


Fig. 4 b) – Different effective buckling lengths.

Where “ $M$ ” represents the ratio between the buckling design load for beams with unrestrained lateral supports and the buckling design load for the case of full restrained lateral supports. “ $R_L$ ”, represents the ratio between the beam stiffness and the support stiffness itself.

As it can be seen in figure 4 a), as “ $R_L$ ” increases (the beam length becomes shorter) the difference between the buckling design load will also increase.

The result of the numerical simulation is in accordance to the experimental test procedure, considering the effective length factor equal to 0.5. As it can be seen in figure 4b) the majority of the experimental collapse load is below the critical elastic moment (Euler) only for  $k = 0.5$ .

For each experimental and numerical test, the collapse load corresponding to the buckling design load has been registered and compared to the plastic moment calculated at the same beam tested temperature. The figure 5 represents the results of the experimental and numerical tests, considering full lateral restraint at supports, i.e.  $k = 0.5$ .

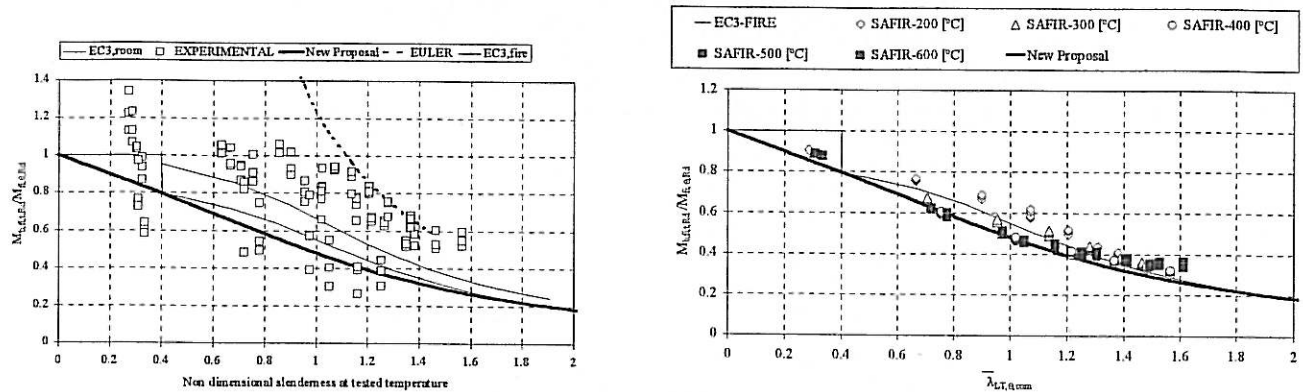


Fig.5 – Design buckling moment. Experimental and numerical results.

The results presented in figure 5 shows that for a certain range of the non dimensional slenderness the Eurocode 3 design buckling curve is unsafe and the horizontal plateaux should vanish for the threshold value of 0.4, in accordance to the new design buckling proposal [5,8].

## 6- Conclusions

Taking in to account the type of load and support, the results prove that the design buckling resistance according the Eurocode 3 may lead to unsafe results, being the new proposal from Vila Real et al. safer than the actual reference [4]. The experimental procedure to validate the new simple formula was based on a system with full-constrained lateral rotation. It was also shown that the buckling length depends on the boundary conditions type.

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# COMPUTACION APLICADA A LA INDUSTRIA DE PROCESOS

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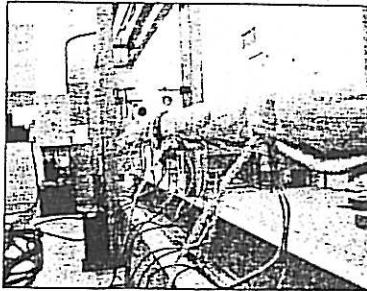


Fig. 1a)– Experimental setup.

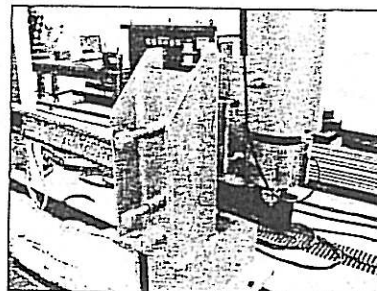


Fig. 1b) Type of support and point load.

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Due to lateral bending constraint during load application, the effective buckling beam length will be shorter than the real length between supports, given by the expression 1, where  $l$  represents the effective buckling length and  $L$  the distance between the two supports.

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### 5- Case study

A set of numerical results is presented, representative from the experimental set-up used in full scale tests, relating the buckling load with the beam cross section mid span movement. The load case is presented in figure 2. Two point incremental load and a constant uniform distributed load, due to the weight of the ceramic mat and the insulation material was also considered.

buckling beam length  $l$ , where  $l$  represents

(1)

to lateral rotation and at support, shown in

of IPE 100 at elevated temperature resistance [2].

20 experimental tests from 0.5 to 6.5 m were determined for a sample of each tested element.

and material program in fire conditions. This 5 degrees of freedom nodal restraint stiffness. In this section, the results of the analysis are based on

ing the critical elastic load of the beam at its ends, with lateral warping. Also will be considered the effect of residual stresses

moment of area from the torsion constant of the cross-section or constant moment of inertia. If a restraint is made, this is the case where the beam is supported with a class 1 or 2

$\gamma_{y,\theta,com}$  the reduction factor. The value 1.2 is empirical

experimental set-up used in the test. The load is a distributed load,

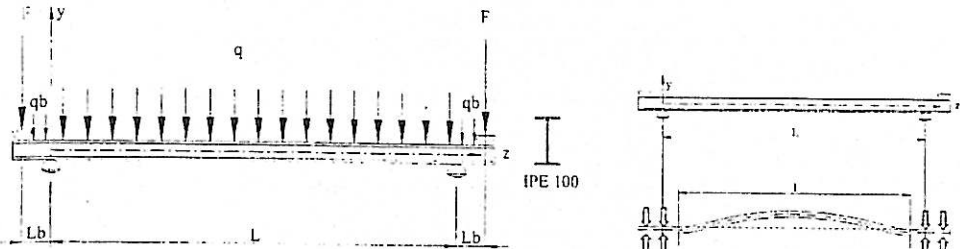


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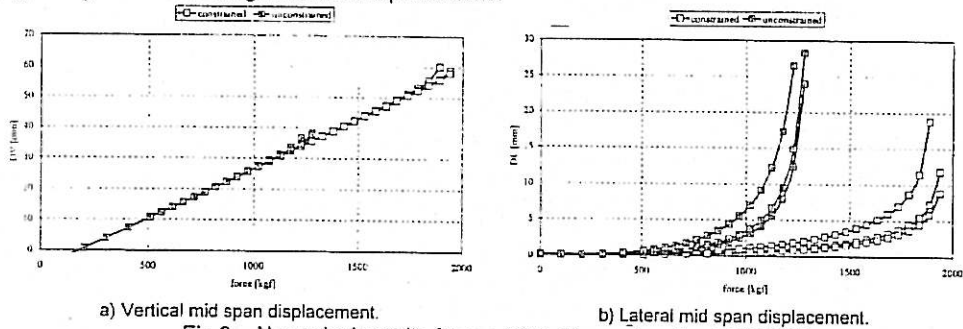


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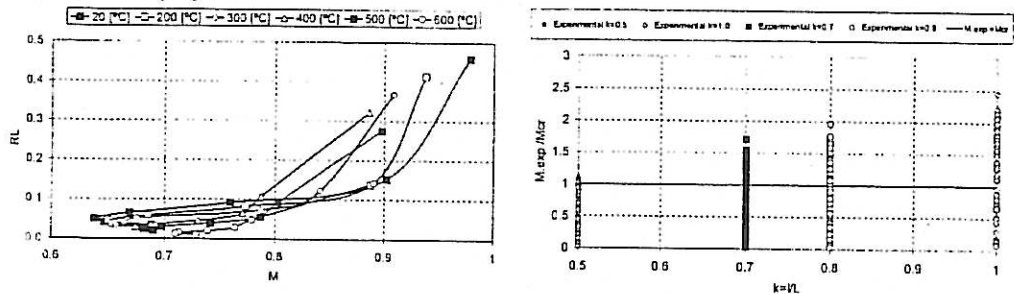


Fig. 4 a) - Relation between  $R_L$  and  $M$ .

Fig. 4 b) - Different effective buckling lengths.

Where "M" represents the ratio between the buckling design load for beams with unrestrained lateral supports and the buckling design load for the case of full restrained lateral supports. " $R_L$ ", represents the ratio between the beam stiffness and the support stiffness itself.

$$R_L = \frac{k_{E,\theta} EI_y / L}{EI_y / L_b} \quad (4)$$

In expression 4,  $k_{E,\theta}$  represents the reduction factor for the elastic modulus  $E$  due to thermal heating and  $I_y$  represents the second moment of area from the cross section about the minor axis.

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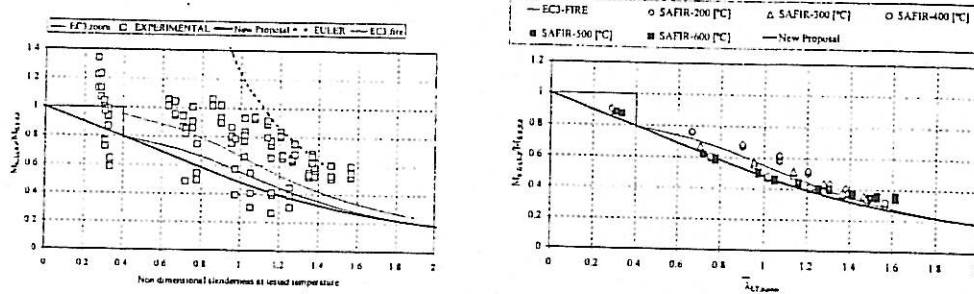


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## Abstract

During recent years, the use of numerical tools has become a key factor in improving casting quality. The application of these tools in the production process will demonstrate the advantages of casting quality conditions to c

## Introduction

This paper describes the capabilities of the tools produced by the process using the refining method. The amount of sale will be evaluated to evaluate the amount produced. To c

## Methodology

Figure 1 shows the design of the casting process. It requires the generation of the computational model. The represented the

## Numerical Simulation

### Original Casting

The geometry was shown in Figure 1. The existence of symmetrical modes was created. The respective mode shapes are shown in Figure 1.

After the pre-processing, the simulated filling process was analyzed. The analyses of macro and micro scales showed the good real case