FIRESTEEL: A COMPUTATIONAL TOOL FOR THE STUDY OF STEEL ELEMENTS IN FIRE SITUATION

Milton M. G. dos Santos[1], Luciano B. dos Santos[2]

Laboratório de Computação Científica e Visualização, Universidade Federal de Alagoas
Av. Lourival Melo Mota s/n, Cidade Universitária, CEP: 57072-970, Maceió/AL, Brasil
[1]*milton.santos@ctec.ufal.br, milton.guimaraes.ce@gmail.com*
[2]*lbsantos@ctec.ufal.br, lbsantos@lccv.ufal.br*

Abstract. Fire is the occurrence of uncontrolled fire, an extremely dangerous phenomenon that can affect the safety of buildings, sheltered heritage and living beings. By causing the temperature increase, the action of fire triggers physicochemical transformations that degrade the properties of materials and interfere with the integrity and behavior of structural elements, which can compromise the resistance capacity of the structure as a whole. This phenomenon is particularly important in the case of steel structures, as the elements usually used are generally light, slender and with an open cross-section, characteristics that tend to favor the quick heating of the parts. In this context, it is essential to study the evolution of the temperature in steel as a function of the temperature variation of the gases, as well as the consequent degradation of the resistance capacity of the structural elements. Once the problem is established, this work presents the *FireSteel* application, a computational tool developed in Python language that allows the evaluation of the thermal evolution, the verification of the resistant force and the determination of the critical temperature in structural steel elements in fire situation. For this, *FireSteel* has a customizable data entry that gives the user the freedom to select the data they want to obtain. The calculations were made in accordance with the Brazilian technical standards currently in force and the results were validated based on information available in the technical literature.

Keywords: Steel structures, Fire, Structural analysis, Thermal analysis, Numerical methods.

1 Introduction

Historical records demonstrate that great fires are problems present in the societies since antiquity, threatening the integrity of the heritage, constructions safety and living beings in the region of occurrence. In Brazil, it can be mentioned the tragedies of fire in the Gran-Circus North American in Niterói in the year 1961, Andraus building, placed in São Paulo, in the year 1972, Joelma building in São Paulo in the year 1974 and in the Kiss nightclub in the year 2013. Besides these, there is a characteristic case that occurred in Brazil: the Wilson Paes de Almeida Building fire, occurred in 2018, which caused the collapse of the own structure. These fires resulted in the loss of the heritage, integrity of buildings, beyond the loss of many lives.

In that regard, fire safety systems regulations are designed to protect the life and prevent fires from spreading if started (Sousa e Silva [1]), which are subdivided in active and passive systems in according to NBR 14432 [2]. The joint action of these systems seeks to allow the structure to resist the action of fire enough time to the action of firefighting and rescue forces, giving more chances for saving lives and recovering heritage.

Whereas that fires can compromise the stability of buildings, this work proposes the *FireSteel* application: a computational tool developed in the Python programming language for the analysis of steel structural elements in fire situation. The proposed tool performs the thermal analysis of the part through the Simplified Analytical Method proposed by NBR 14323 [3], which considers the standard fire curve. Thus, the resistant forces of the part are verified and the critical temperature for the structural part is determined.

2 Methodology

2.1 Implementation

The implementation is performed using the Python language [3], due to the possibility of object-oriented programming and the vast set of auxiliary libraries available. For the user to run the application, the input file must initially be created and, after that, run the application. With the insertion of data, it is performed the thermal evolution analysis of structural element is performed and, posteriorly, the resistance checks. Finally, the tool executed in console provides an interactive menu allowing the analysis of the conditions of the structural element in specific situations of exposure time and temperature, as well as resistance and temperature histories of structural element analyzed.

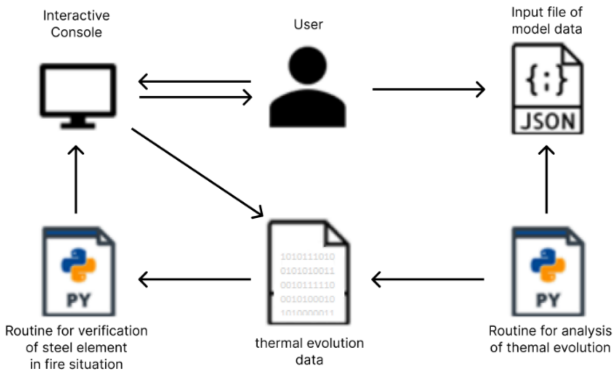

Figure 1: Flowchart of *FireSteel* application.

2.2 Thermal evolution

The rise in temperature provoked by fires in structural elements results in the degradation of materials that compose them, causing the reduction in the resistance capacity of a structural element and in the modulus of elasticity of the materials that compose it, may or may not be reversible depending on the temperature gradient. During a fire, this gradient acts through three physical mechanisms that allow heat transfer: radiation and convection., transferring heat from the gases to the structural elements, and the thermal conduction, which occurs between the structural elements. These phenomena allow the ambient temperature to be described as a function of time, which defines the real fire curve (Figure 2).

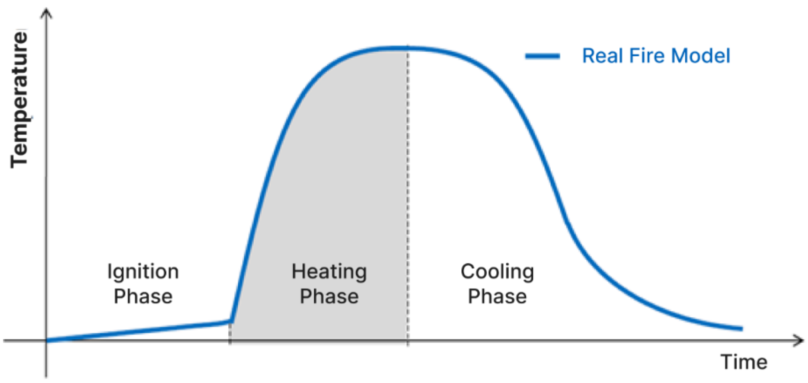

Figure 2: Real fire model.

The real fire curve has three phases: ignition, heating and cooling. The ignition phase consists in the start of inflammation, in which the temperature growth occurs gradually and is finished in the *flashover*. The *flashover* occurs when the entire fuel charge ignites, marking the beginning of the heating phase which consists in the branch which a rapid rise in temperature occurs until the maximum temperature of the real fire (Figure 3). Finally, the cooling phase occurs after the maximum temperature of the fire when there is no more combustible material to feed the fire.

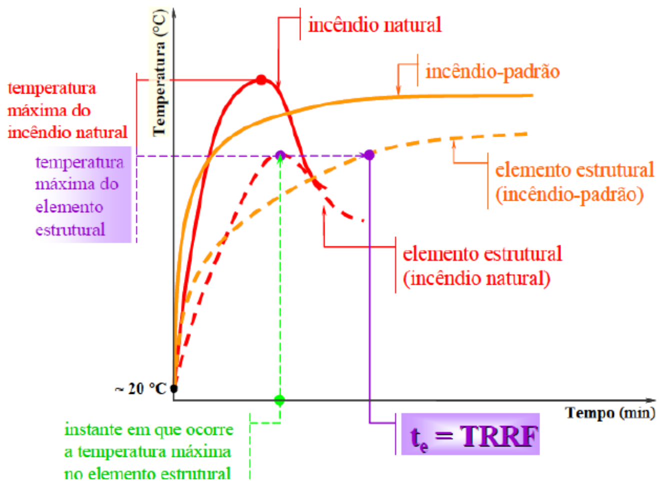

Figure 3: Real fire curve and standard fire curve (Source: Costa [4]).

According to Sousa and Silva [1], the real fire curve will have its characteristics determined in function of the location and the combustible material present in the analysis environment. Thus, the technical standards present simplified curves to analysis of environment temperature in fire, called standard-fire models, which allows the verification of maximum temperature for structural elements in function of the normative parameter TRRF (Required Fire Resistance Time), which checks the time to maximum temperature occurrence of the element in fire situation in function of the place and combustible material present in the occurrence environment.

For the thermal evolution of the environment in fire situation, the standard-fire curve is adopted by NBR 14432 [2], which describes the gases temperature θ_g through the equation

$$\theta_g(t) = \theta_0 + 345\,log(8t + 1) \tag{1}$$

which θ_0 is the initial temperature of the environment in ºC and t is the time in minutes.

The determination of the temperature of a steel element θ_a is accomplished through the iterative process described in the equation

$$\theta_a(t) = \theta_a(t - \Delta t) + \Delta\theta_a(t) \tag{2}$$

so that the variation of steel temperature per time step $\Delta\theta_a$ is calculated according to the existence or not of steel coating material following the premises of NBR 14323 [3].

In this regard, the Figure 4 shows the flowchart of the thermal evolution implementation.

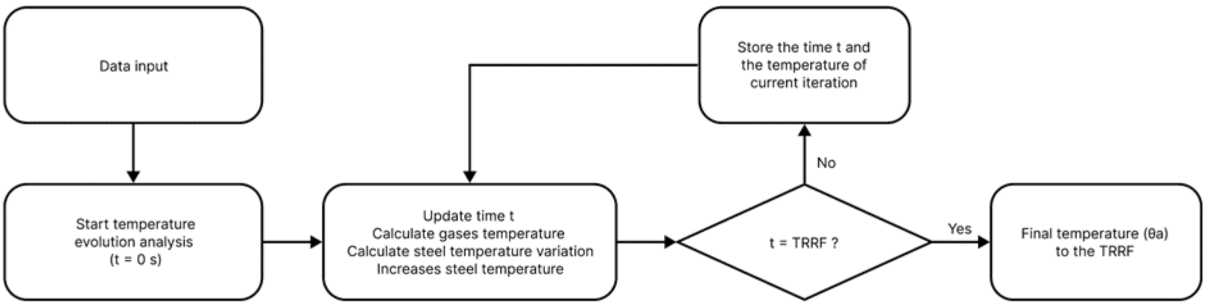

Figure 4: Flowchart of the temperature evolution process.

2.3 Resistant forces in fire situation

To determine the resistance capacity of steel structural elements in fire, the formulations present in NBR 14323 [3] e NBR 8800 [5] are used for elements subjected to traction, compression, shear and bending stresses. Through experimental procedures, the NBR 14323 [3] parameterizes factors for reducing of yield resistance in elements subject or not to buckling, $k_{y,\theta}$ and $k_{\sigma,\theta}$ respectively, as well as the elastic modulus reduction factor $k_{E,\theta}$, used to calculate the resistance capacity of steel elements according to their mechanical requests.

Thus, the proposed tool analyzes the resistant forces of interest in function of the exposure instant or temperature of interest. In this analysis, the resistant capacity to traction, compression or flexion, isolated or combined, and shear are calculated after the interpolation of reduction factors according to NBR 14323 [3]. Such procedure is implemented as specified in the following flowchart.

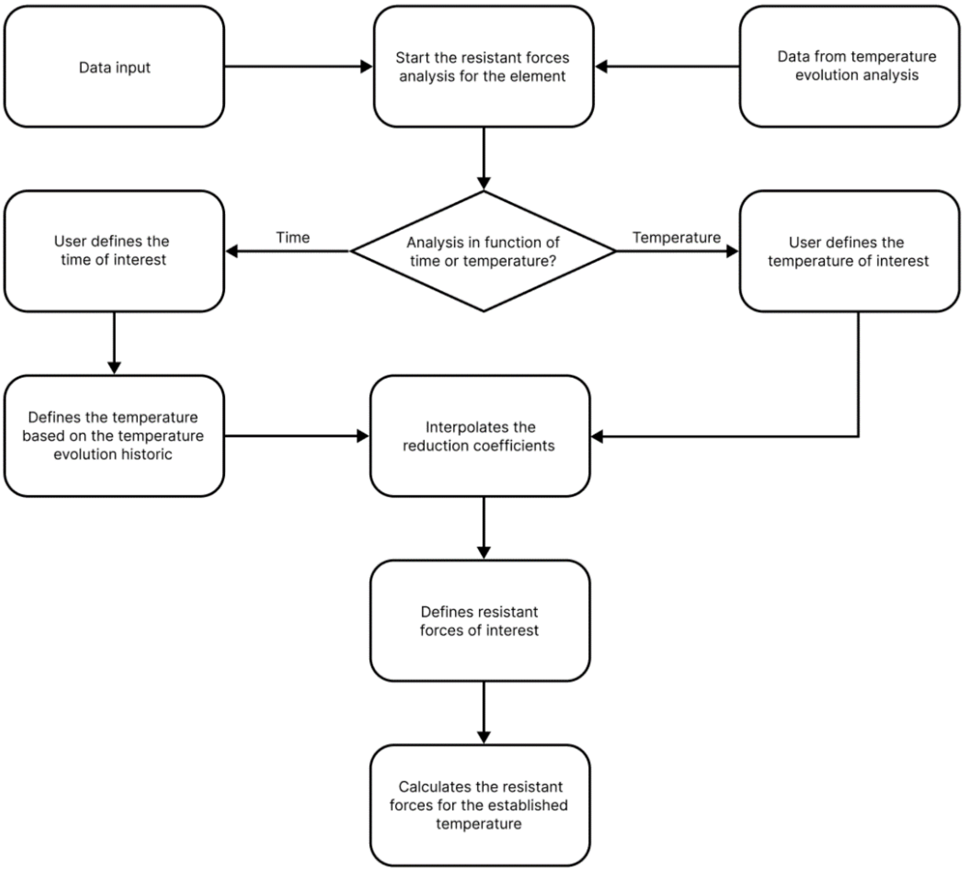

Figure 5: Flowchart for analysis of resistant forces in fire situation.

3 Application verification

To validate the application, a comparative analysis was performed comparing the values obtained for the case studied by Pastorello [6]. The case analyzed consists in the thermal evolution analysis of a steel beam element of shape W 250 x 115 (H) with and without plasterboard coating, which the results (temperature to TRRF equal to 30 minutes) obtained by Pastorello [6] and the tool *FireSteel* are compared in Table 1.

Table 1. Thermal evolution temperature data for TRRF equal to 30 minutes.

Temperature	Pastorello [6]	*FireSteel*
Initial	20 °C	20 °C
Final without coating	804.98 °C	804.9769 °C
Final with coating	154.82 °C	154.8269 °C

Regarding the design and verification of structural elements in fire situation, a comparative analysis was performed based on the example a tractioned element presented by Vieira *et al.* [7]. This case study refers to a steel element in shape W 150 x 31.7, in which the traction resistance of the element in question is determined at a temperature of 799.18 ºC. Thus, the values obtained by Vieira *et al.* [7] and by the application *FireSteel* are compared in Table 2.

Table 2. Resistant force of the column of shape W 310 x 38.7, length of 2.80 meters, at 500 °C.

Parâmetro	Vieira *et al.* [7]	*FireSteel*
Esforço resistente à tração	161,325 kN	161,3059 kN

Therefore, the representativeness of the application regarding the thermal evolution analysis, as well as the design of structural elements in fire situation, is attested, such that the results obtained have variations smaller than 0,02%, which are due to the high numerical precision of *FireSteel* results.

4 Conclusions

This works presented an application developed for the analysis of steel structural elements in fire situation, submitting them to axial, tangent and bending stresses, whether applied isolated or in combination. The formulations used are based on brazilian regulations and the results are faithful to the comparative examples, which are also based on ABNT formulations. Thus, the application proves to be extremely viable for the study and verification of steel structures in fire situation, may have applicability in educational and commercial environment of steel structures. Finally, we steel seek to improve the application, focusing on analysis witch dynamic thermal coefficients and on the development of a graphical user interface.

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