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Behavior of Steel Structures under Elevated Temperature

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Abstract

The purpose of this paper is to investigate the damages of an industrial steel building affected by a fire event. The author's main objectives are to identify different types of damages produced by fire to the building structure and nearby built environment, highlighting the idea that nowadays the fire safety must be seen as a sustainable practice. The presented research is based on a case study regarding the damages of an industrial steel building subjected to fire. Structural design of buildings exposed to fire requires the achievement of two main objectives; the first one is to reduce the loss of life and the second one regards the load bearing resistance of the building for a specified period of time. The behavior of steel structures under elevated temperature can be assessed using both numerical simulations and experimental studies. There are a lot of studies regarding the behavior of multi-storey steel buildings under fire conditions and progressive collapse mechanisms. Unfortunately, little information regarding the industrial steel buildings subjected to fire can be found. Analyzing the behavior of single storey steel buildings at elevated temperatures, it can be conclude that not always the collapse of an element leads to the collapse of the entire structure. A correct expertise of the damage level of steel structures exposed to fire, in order to identify the elements which can be kept and which have to be replaced, in most of the cases lead to a lower consumption of materials and financial resources.

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Keywords: fire safety; sustainability; industrial steel buildings; non- destructive tests; computational analysis.

1. Introduction

Structural design of buildings exposed to fire requires the achievement of two main objectives; the first one is to reduce the loss of life and the second one regards the load bearing resistance of the building for a specified period of

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time [1, 2]. The main drawback of steel structures remains the sensitivity to elevated temperatures due to the rapid loss of strength and stiffness [5]. The thermal expansion of the materials at elevated temperatures has a great contribution to the failure of the elements. Elevated temperatures excite the electrons at the atomic level of any material and force the atoms to move to a lower energy state and change orientation of atomic planes, leading to dimensional changes of the elements.

In Romania, data regarding the safety design of steel structures exposed to elevated temperatures is given by the national standard SR EN 1993-1-2. The information presented in this code can be used to find out if and how long a steel structure is able to resist, loaded and in safety conditions, to fire action. The Eurocode 1 Part 2 [1] describes the approaches used for the calculation of the thermal action produced by fire on structures. The effects of fire are given using three different representations, such as the temperature–time equations, the zone models and the localized models [12, 13 and 14]. For a fully developed fire, the temperature–time curves are usually used to represent the action of the fire. The temperature-time equations presented in Eurocodes describe the evolution with time of a unique temperature produced by fire in the environment, in which the structure is located [4].

The increasing number of fires that affected single storey industrial steel buildings highlights the lack of information regarding the behaviour of this type of structures exposed to fire. The assessment of the behaviour of steel structures during a natural fire is almost impossible and for this reason, the post-fire investigation is very important. While fire tests involve high costs and often are limited to an item analysis, numerical simulations proved their utility for thermal and structural analysis of steel structures affected by fire [5, 6]. There are a lot of studies regarding the behaviour of steel structures at elevated temperatures. First of all, it should be pointed out that the behaviour of a single steel member exposed to a standard fire is significantly different in comparison with the behaviour of the whole structure [7]. The behaviour of steel members under elevated temperatures is complex and it is directly affected by the restraint of the ends of the members [8].

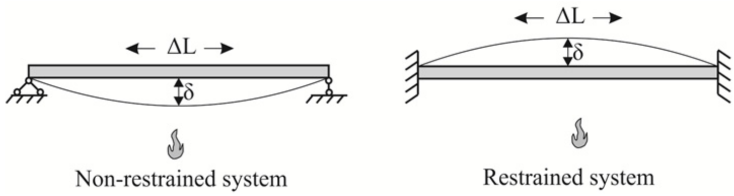

Fig. 1. Thermal effect and restraint [7]

Usmani et al. [9] identified three different types of failure of a restrained beam subjected to fire. The first failure mode is the yielding failure, for members with a low slenderness ratio and the second one is the buckling failure, characteristic for members with high slenderness radio, which also develop outward deflection. The third failure type is a combination of the first two and depends as well on the slenderness of the steel member. M. El-Heweity [3] analyzed the behaviour of steel portal frame under different fire conditions. The goal of its study was to assess the failure mechanism of horizontal portal frames. He concluded that the failure occurs when a sufficient number of plastic hinge are attained to produce a mechanism.

There are two aspects which should be considered in a post-fire evaluation. Firstly, it should be checked if the grain structure of steel is damaged by fire action and secondly, the behaviour of loaded steel members should be analysed. Under elevated temperatures, the steel members can be bent or damaged but the whole stability may not be affected.

2. The post-fire assessment of structural steel

The integrity of structural steel exposed to elevated temperature can be assessed by visual observations, destructive and non-destructive testing [10]. Visual observations can provide information regarding the temperature reached during the fire exposure in the fire compartment and also the extend damage of structural steel and other construction materials. It is known that the wood burn at 230ºC and the concrete surface starts to spall at approximately 600ºC. According to Drill [11] if the temperature exceeds 650ºC the surface of structural steel will become rough and with an eroded appearance. Also, different types of paints used for structural steel can give