The Effect of Fire on the Behavior of Perforated Short Steel Compression Members and Evaluation after Retrofitting

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ABSTRACT

Steel is one of the most widely used materials in structures due to its high strength and speed of execution. One of the most important disadvantages of steel is corrosion damage and low fire resistance. When the temperature of the steel exceeds a certain value, its strength decreases to a great extent; therefore, in this paper, the performance of steel specimens with corrosion and at different temperatures has been investigated. Thus, the corrosion weakness is considered as a perforation and specimens with different positions of the perforation in 6 states and the application of heat in 5 different states 20, 100, 250, 500, and 700 are examined and the load-displacement diagrams of each column under axial loading are presented. Then, in order to improve the behavior of the damaged specimens by the two mentioned factors, the perforation location has been reinforced and reinforced using a steel sheet and axial loading has been done in two-temperature states of 20 and 700 ° C. The results show that: with increasing temperature, the bearing capacity of specimens has decreased and this reduction has reached up to about 15% for control specimens and up to about 35% for perforated specimens according to the type of perforation. Also, in steel members retrofitted with steel sheets, the bearing capacity has increased by about 5 to 15 percent (depending on the perforation).

KEYWORDS

Steel compression members, Perforation, Fire, Bearing Capacity, Retrofit.

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1. Introduction

Steel structures are one of the most popular structures designed and constructed these days. Steel structures are extensively used worldwide due to their advantages, such as more construction speed and interior spaces than concrete structures [1]. Due to the weakness of structures in natural or fabricated disasters such as wind, earthquake, and fire, the need for rehabilitation and repair of structural members to achieve their initial performance is inevitable. One of the most critical weaknesses of structures, especially steel structures, is weakness in high temperatures and fire events [2].

Various experimental studies have been carried out on the behavior of steel columns at high temperatures. In 2010, Correia et al. [3] investigated the behavior of steel columns in fire. In this parametric study, steel columns under different loads, sections, and slender ratios were investigated, and the effect of these parameters on column performance under fire conditions was presented. In 2014, Byström et al. [4] investigated the temperature rise of a hollow circular column under local heat and compared the results with Eurocode 1991-1-2. In 2016, Fan et al. [5] directed an experimental study on the fire resistance of steel columns with square hollow section (SHS). In 2018, Fan et al. [6], in a study similar to the one in 2016, tested the fire resistance of stainless steel columns with square hollow section (SHS), this time using constraints. The results showed that the bearing capacity of compressed steel columns with axial restraint and eccentricity under fire conditions went through two stages: pre-buckling and post-buckling.

According to the studies concerning the performance of steel compression members at high temperatures, some limitations exist, including the post-fire performance of steel compression members, their reloading capability after the fire, retrofitting methods, perforations influence on the performance, the cross-section shape, etc. Consequently, in this research, perforated short steel compression members are studied by considering various perforations in the column in post-fire conditions. For this purpose, control steel compression members, perforated steel compression members with six different perforations are designed and manufactured. Then, the specimens are exposed to five temperature levels between 20 to 700 °C. After the cooling phase, the compressive test is implemented on them. Finally, the effect of factors such as the type of perforations, temperature level, and the retrofitting method on the performance of steel compression member is evaluated and compared.

2. Experimental setup

In this research, steel compression members with dimensions of 32×10×10×0.3 cm (height of 32, cross-section dimensions of 10×10, and thickness of 3 mm) are evaluated. 47 specimens with six different types of perforations besides control specimens and retrofitted specimens are exposed to temperatures of 20, 100, 250, 500, and 700 ºC. In order to retrofit the perforated steel specimens, steel plates with the same specifications of the steel materials with a thickness of 3 mm and dimensions of 1 cm larger than the dimensions of perforation are used. The mentioned plates are welded on the perforations (Figure 1).

Figure 1. Retrofitting of column specimens by steel plate

Also, in this experiment, an electric furnace with manual power adjustment was utilized to heat the specimens. Two thermocouples of type k on the specimen and the furnace recorded the specimen and the furnace temperatures, respectively. Specimens were heated from ambient temperature to the target temperature at a rate of 10 ºC per minute. Five target temperatures of 20, 100, 250, 500, and 700 °C were selected. As soon as the specimen was heated to the target temperature, the temperature was kept constant for 60 minutes to create stable heat conditions in specimens and ensure a uniform temperature distribution. The furnace was then switched off, and the cooling phase of the specimens began. The specimen temperature was naturally reduced at the rate of 10 to 20 ºC per minute to reach room temperature. After completing this step, tensile strength tests were performed on the specimens at ambient temperature.

3. Discussion and results

In the compression test of the specimens, the maximum value of the load (critical load) and the corresponding axial displacement are determined. In order to analyze the axial bearing capacity and ductility of the specimens, the axial force-displacement diagram of the specimens is employed. Table 1 presents the results in the form of force-displacement diagrams for control specimens and specimens with different types of perforations.

Table 1. Summary of the results at different temperatures

Specimen description	Maximum vertical load P_{max} (kN)				
	20 °C	100 °C	250 °C	500 °C	700 °C
Control specimen	451.64	434.19	428.96	408.12	384.49
DHT	377.34	374.69	366.25	359.20	350.97
DHM	324.02	315.20	310.25	305.33	301.58
DHB	353.67	339.43	315.19	305.55	295.15
DVT	409.64	400.02	394.72	389.87	322.03
DVM	393.302	388.89	376.70	355.01	341.60
DVB	405.93	370.51	370.51	303.98	261.58

According to the results, the bearing capacity of all specimens is reduced by exposure to high temperatures. This reduction is 15% for control specimens at 700 °C and 35% for perforated specimens (specimen with vertical perforation at the bottom). In perforated specimens, weakness and perforation have reduced the bearing capacity and vertical loads bearing capability due to the reduction of cross-sectional area at the perforation location. In this regard, the lowest bearing capacity of specimens with a horizontal perforation is related to the perforation located at the middle of the column at 20 °C (28% decrease compared to the control specimen at 20 °C). Also, the lowest bearing capacity of column specimens with vertical perforations is related to the specimen with perforations at the bottom of the specimens and 700 °C temperature (32% decrease compared to the control specimen at 700 °C).

As described, perforated specimens are retrofitted with steel plates at the perforation location and then placed under loading. Table 2 explicates the complete results of retrofitted and non-retrofitted specimens at 20 and 700 °C for perforated specimens (to cover perforations, improve performance and increase load-bearing capacity).

Table 2. The results of non-retrofitted and retrofitted specimens with plates

Sample description	Maximum Vertical Load, P_{max}, for samples at 20 degrees (kN)		Sample description	Maximum Vertical Load, P_{max}, for samples at 700 degrees (kN)	
	Non-retrofitted	Retrofitted with steel plates		Non-retrofitted	Retrofitted with steel plates
DHT	377.34	405.64	DHT	350.97	360.30
DHM	324.02	343.42	DHM	301.58	317.86
DHB	353.67	389.53	DHB	295.15	313.06
DVT	409.64	415.85	DVT	322.03	340.75
DVM	393.302	409.20	DVM	341.60	353.23
DVB	405.93	419.87	DVB	261.58	295.65

4. Conclusions

In this paper, the effect of fire and perforations on the capacity of steel compression members was investigated. For this purpose, 35 specimens, including control specimens and specimens with perforations (six types), were made and exposed to five temperature levels of 20, 100, 250, 500, and 700 °C. Then, the compressive test was performed on the specimens, and load-displacement diagrams were determined. The results indicated that weakness and perforation reduced the strength of the steel compression members. The highest reduction in load capacity of specimen at ambient temperature (20 °C) was related to the specimen with a horizontal middle perforation (28% reduction), while in specimens at the temperature of 700 °C was related to the specimen with bottom vertical perforation (32% reduction). Also, high temperature reduced the strength of steel compression members. A 15% decrease in bearing capacity of the control or control specimen was observed with the temperature increase up to 700 °C, and the maximum reduction in strength of the specimen occurred in specimens with vertical perforations (35% reduction). Finally, by retrofitting the perforated specimens, the post-fire bearing capacity was improved. Depending on the type of perforation, this performance improvement increased the bearing capacity up to 10% at room temperature and up to 13% at 700 °C using steel plates.

5. References

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