Fire-resistant Structure: The Concrete Filled Steel Tubular Column

Ping-Zhou LIN
Senior Engineer
CNBMI
Hangzhou, China

Born in 1936, graduated from Tsinghua University China

Zong-Cheng ZHU
Senior Engineer, E. Master
CNBMI
Hangzhou, China

Born in 1945, graduated from Nanjing University of Aeronautics & Astronautics, China

Zhi-Jun LI
Senior Engineer
CNBMI
Suzhou, China

Born in 1931 graduated from North Eastern University, China

Summary

The concrete filled steel tubular column for supporting a furnace at one glass factory has been firstly used in the world, with a total number of 70 columns in four rows.Hundreds of tons of high-temperature molten glass leaked out onto the ground at the bottom of the furnace columns and caused the fire. These columns had not miraculously been burnt away in the fire and had still effectively supported the furnace weight . This paper presents the fire situation, structure damaged status and mending work, and evaluates the fire-resistant characteristics of these columns.

1. General situation of engineering and fire

The concrete filled steel tubular column for supporting glass furnace was firstly used at one Chinese large glass factory in 1992, and it succeeded completely.The plane size of the furnace is 50 m × 10 m. At the furnace bottom,there are 70 columns altogether, four rows,eighteen teams (figure 1).The column grid is 3 m×4 m. Each column is 7300 mm high,Φ245 mm,C 30 concrete used .The cross-section of the column is only 1/14 of the traditional reinforced concrete square column for 3 ' ×3 '(914 mm × 914 mm) in size.

Unexpectedly, a crack occurred at the furnace bottom in the maximum temperature area during the process of production.Hundreds of tons of molten glass over 1300 ℃ leaked out for several hours. A sea of fire like magma occurred at the furnace bottom.

The fire was put out by the fire hose.After it was cold, we watched and found that the molten glass firstly leaked to the second concrete floor beside the furnace, then flowed to the ground along the plate edge of the platform. A great deal of the molten glass accumulated at the furnace side and flowed forward. The mass of leaked glass on the ground was about 1 meter thick. Another part of molten glass crossed the footpath and flowed to the other side of the furnace. The mass on the ground got thinner and thinner. The thinnest part was about 2 - 3 mm thick. The glass accumulation under the accident point reached 3m high. A concrete filled steel tubular column was casted in it (here-in-after referred to as column A). The mass around the root of another column (here-in-after referred to as column B) was almost 400 mm thick. The mass on the second concrete floor was more than 1.5 m thick. Fortunately, the whole furnace was still safe as before,even no great integral deformation occurred. This miracle sufficiently showed that the concrete filled steel tubular is one kind of fire-resistant structures.

2. Concrete filled steel tubular column yielded but not fell

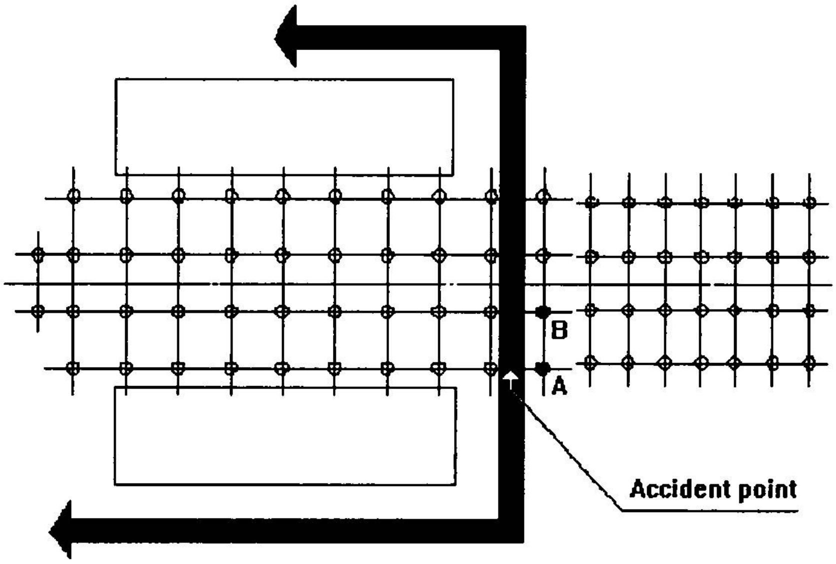

Figure 1

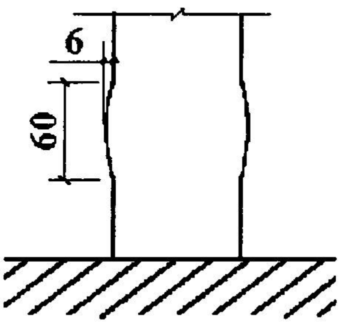

Figure 2

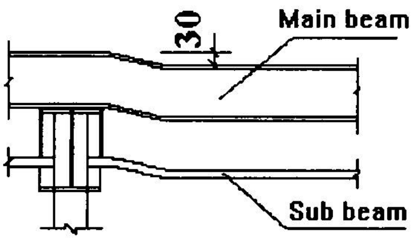

Figure 3

After cutting off the solidified glass rock which was still over 100 ℃ on it's surface, we found that there was a circle of convex vestige at each root of column A and B which had risen because of buckling(figure 2).The convex vestige rise cylinder about 6 mm. The leaning lateral deflection of the lower part of column A was about 3.0 cm. But the two column were still supporting about 80 % of the design load acting on their top. The steel II-beam was roasted by the poured down molten glass from the accident point, and had about 3.0cm shear deformation (figure 3).The rendering and protective coating of the boundary beam on the second floor were scoured and peeled off. By the flowing molten glass,several hoop reinforcements in the boundary beam had already been faintly visible. The concrete floor slab was already map cracking and loose.

3. Strengthening the concrete filled steel tubular column with the concrete filled steel tubular.

We sleeved the root of column A and B with two Φ500 mm×5 mm semicircle steel tubes 2.5 m high, then butted and welded them together, and poured the gap with C 30 concrete.The work finished in eight hours.In addition, we added the channel steel to both side of the damaged main steel II-beam and laid them directly onto the top of column to replace the action of the former main beam. The loose concrete of the platform was cut off and repaired after the production resumed.The resumption of the normal production showed that the reinforcement we did was successful.

4.Time of burning more than 3 hours

Normal plate glass softens at 700 ℃, melts and flows at 900 ℃. So the temperature of molten glass flowing along the floor must be over 1000 ℃. Calculating with formula $W = \frac{\sum Qi}{4500A}$ [1],the load density of the molten glass piling up about 1 m high on the ground in fire was about 156 kg/m^2. It was 3-6 times as it in as in common fire. The time of burning corresponds to 3.25 hours on standard temperature rise curve line (similarly hereinafter). The average height of the glass mass on the ground about ten square meter under the accident point was about 2m,it's load density in fire was over 312 kg/m^2, and it's burning time was 8.40 hours. The fire-resistant limit of multiply column in first rating fire -resistant building stipulated is in 3.0 hours in China.

5.Unique fire-resistant supporting ability

It is well known that the cohesive force between reinforcing bar and concrete has almost been lost when the reinforced concrete structure is at 300-400 ℃. $CaSiO_3$ decomposes to CaO and SiO_2 at 400 ℃ and concrete will fail permanently [1] [5]. Both elastic modules of concrete and yielding limit of steel tend towards zero at 600 ℃ [2] [6]. It shows that the temperature of 400-600 ℃ will seriously damage the reinforced concrete structure or steel structure. In this fire, column A and B were in the state of the temperature which was far above 600 ℃ for a long time. They supported more than 80% of the former design load effectively though their roots had yielded. It showed amazing fire-resistant supporting ability. The three conditions of the experiment to judge the fire-resistant limit of building structural members are supporting ability, integrity of structural members and fire division function. The concrete filled steel tubular column doesn't belong to fire division component. So it was the supporting ability that resolves the column's fire-resistant limit. Supporting ability behaves as the former intensity indication doesn't depress or depresses little, the structural deformation does not exceed preset limit and lose stability. The fact that column A and B didn't occur general meaning lose stability failure showed that the concrete filled steel tubular column had nice fire-resistant supporting ability.

6. Discussion about the high fire-resistant function

Currently, there is no sufficient and clear information on the experiment and evaluation about the fire-resistant function of the concrete filled steel tubular. The structural characteristics of the concrete filled steel tubular and the effect of its fire-resistant function are macroscopically discussed just from the fact in this fire:

(1) The buckling deformation of column A and B under high temperature was similar to that of short concrete filled steel tubular column pressed by axial pressure under normal temperature in laboratory. The common ground was that the column top did not unload or unloaded little when the cross-section at column root yielded. The whole column could still keep safe and work on, and the vicious sudden failure did not occur like reinforced concrete structure or steel construction did when the cross-section yielded or the stability lost. It kept the structure safe fundamentally.

(2) The load-bearing capacity of the concrete filled steel tubular column is much higher than that of reinforced concrete or steel column with same cross-section size. At the same time, the concrete filled tubular column can fit the adverse circumstances better. Comparing the three kinds of column : the concrete filled steel tubular column $\Phi 245 \times 8$($f_y = 235$ N/mm^2 C 30), the steel tubular column 245×8($f_y = 235$ N/mm^2), the reinforced concrete circular column $\Phi 245$($12\Phi 12$, $f_y = 345$ N/mm^2, $\mu = 4.19$ %, C 30), and calculating by 7300mm in height, the ultimate bearing capacities of the three kinds of column respectively are 1513.4 kN, 1030.2 kN, 543.3 kN. The ratio of bearing capacity of the three columns is 1 : 0.68 : 0.36. It means that the bearing capacity of the concrete filled steel tubular column is 1.47 and 2.79 times as that of the other two. The bearing capacity of the above-mentioned three columns respectively is 750.0 kN, 381.5 kN, 179.9 kN if the three columns were fixed at the bottom and 30mm horizontal displacement occurred on the top. The ratio of bearing capacity of the three columns is 1 : 0.51 : 0.24. It means that the bearing capacity of the concrete filled steel tubular column is 1.96 and 4.17 times as that of the other two. It shows that the bearing capacity of the concrete filled steel tubular column is higher than that of the other two when the horizontal displacement occurs on the column top.

(3) The surface of the concrete filled steel tubular column will not burst what matter if it met fire or water on fire. It can keep certain cross-section integrity. The harmful consequence such as the crack and exfoliation of the protective course or the twisting of steel structure cross-section will not engender.

(4) The concrete filled steel tubular column will not be damaged by the secondary disaster such as the crack on the margin of the concrete column or the concave on the steel tubular when it is collided unexpectedly on fire.

(5) The mechanical property of the yielded cross-section of the concrete filled steel tubular will be improved greatly along with the decrease of the external temperature. Its main reason is that a certain the strength of steel tubular recovers and the structure integrity increases greatly than it is on fire. It supplies fairy safe working environment to strengthen the structure. It also reduce the working capacity of strengthening. While the mechanical property of the cross-section and the structure integrity of the reinforced concrete structure which has modified and cracked in high temperature can not be recovered or improved along with the decrease of the external temperature. The lost stability or twisted member of steel structure can not bring any more safety to structure in normal temperature, too.

(6) The yielded cross-section of column B was at the column root, it perhaps relates to the characteristics of this fire. But about 3m high of lower part of column A has been covered with molted glass, and its yielded cross-section was at the root too. All other cross-sections of column A was in good condition. This phenomenon probably means that the most dangerous cross-section of the internal force for concrete filled steel tubular structure will be the firstly yielded cross-section in fire. It perhaps indicates that the position of the yield cross-section uncertainly relies on the specific location of fire distribution. It also can supply a chance for designers to foresee and take prevention, thus the designers can improve the fire-resistant function directly. The fact that the concrete on platform lost widely shows that the cross-section position where the concrete material had modified and cracked depends on the distribution of the fire, and not certainly at the most dangerous cross-section of internal force. So it is fairy undefined.

(7) The point that should be put forward is that the diameter of this concrete filled steel tubular column is only 245mm because of the particularity of the design load in this engineering. It is one kind of small diameter, large slenderness ratio columns which is very seldom used in engineering. The fire-resistant supporting time of short or middle length columns with larger diameter which are widely used will improve greatly.

7.Conclusion

The fire was a real test for the concrete filled steel tubular columns. Although this fire was very particular, its result was quite valuable. The fact shows that the concrete filled steel tubular column is one kind of fire-resistant construction, and has wide developing field. Its fire-resistant limit should be measured on the scientific experiment so as to direct design work . It has a great practice significance to research the load effectiveness of the concrete filled steel tubular structure on fire.

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