Construction and Building Materials 73 (2014) 235–246

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effects of fixing point positions on thermal response of four point-supported glass façades

Yu Wang [a,b], Qingsong Wang [a,*], Jinhua Sun [a], Linghui He [a], K.M. Liew [b]

[a] State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei 230026, China
[b] Department of Architecture and Civil Engineering, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong

HIGHLIGHTS

- Breaking mechanism of point fixed glass façade is revealed by finite element method.
- The stress caused by fixing constraint is dominant compared with thermal gradient.
- Fixing point position has a significant effect on the breakage of glass façades.
- The fire resistance of glass may differ markedly under various thermal loading.

ARTICLE INFO

Article history:
Received 4 June 2014
Received in revised form 28 August 2014
Accepted 24 September 2014

Keywords:
Point-supported glass façades
Fixing point positions
Breaking behavior
Finite element method

ABSTRACT

Different fixing forms of four point-supported glass façades are extensively used to satisfy the aesthetic requirement of modern buildings. While it may easily break and fall out when subjected to a fire, which could significantly affect compartment fire dynamics by creating a new opening for air to enter. In this work, sixteen cases with different fixing positions are designed to investigate the thermal response of four point-supported glass façades under both uniform and non-uniform thermal loadings. The Coulomb–Mohr criterion and stress intensity factors based mixed-mode criterion are employed to predict the crack initiation and growth, respectively. The glass stress distributions, breaking time and initiation and propagation of crack are presented, using three-dimensional finite element method. It is observed that all the cracks initiate at fixing points, which is attributed to the combination effect of constraining at supporting points and non-uniform temperature distribution. Fixing points changing in horizontal, vertical and diagonal directions has significant effects on glass breaking behavior. Moreover, thermal loading form also markedly affects the time of first crack initiations. The variation tendency of breaking time agrees well with our previous experimental study. It is intended that these results will provide some practical guidelines for fire safety engineers.

1. Introduction

Glass façades, because of their transparency, energy saving potential and architectural aesthetics, are extensively used as building envelope material alternative to cement and steel, especially in newly constructed buildings [1]. However, in comparison with steel and concrete structures, glass façades are more prone to breaking and falling out in fire scenarios. The loss of façade integrity may provide a corridor for fresh air to enter the compartment, and an outlet for fire spread, accelerating fire development in compartment. Emmons firstly highlighted this important issue [2]. Subsequently, many theoretical [1,3–6] and experimental [7–13] studies were conducted to analyze glass breaking behavior and mechanisms. For example, Joshi and Pagni [12] and Wang et al. [6] using Weibull distribution analyzed the glass breakage probability. Shields et al. [9,13] conducted some full scale experiments to investigate the single and double glazing behavior exposed to fire. Skelly et al. [11] conducted a comparative study of edge-protected and edge-unprotected glass panes, and found that the maximum temperature difference a glass pane could withstand between the central and the edge was 90 °C. Meanwhile, Keski-Rahkonen [3] theoretically obtained the value of 80 °C. These studies show that the thermal gradient between shaded and

* Corresponding author. Tel.: +86 551 6360 6455; fax: +86 551 6360 1669.
E-mail address: pinew@ustc.edu.cn (Q. Wang).

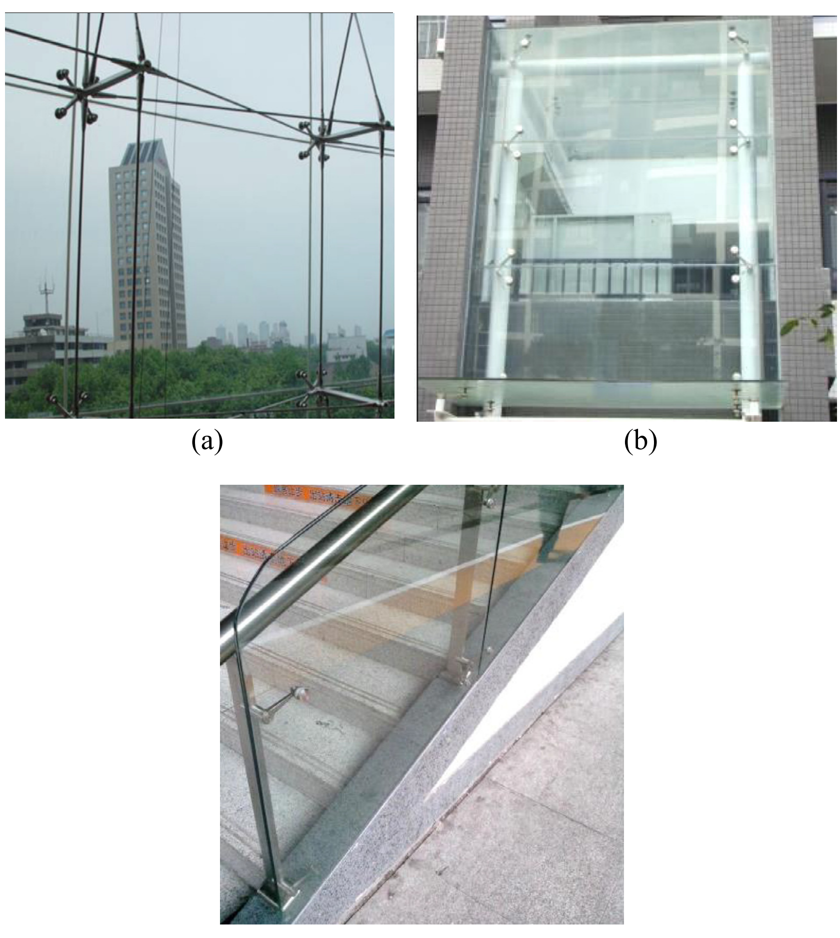
http://dx.doi.org/10.1016/j.conbuildmat.2014.09.085
0950-0618/

exposed regions of glass pane is the primary cause for glass breaking. However, almost all of the prior studies have focused on small-sized window glass with surrounding edges covered by a metal frame. Little is known about the breaking behavior of four point-supported façades. It is anticipated that, in a fire, the point fixing glass panes may show different performances from edge covered panes. Because of no glazing areas covered by frame in point fixed glass system, its breakage mechanism may also be different from edge-covered window glass, so the effect of thermal gradient on point fixed glass façades needs to be explored.

The authors conducted an onsite survey in different major cities in the Yangtze River Delta region of China [14]. It was found that point-supported glass façades are increasingly popular and often used as the outside walls of high buildings or separation walls inside buildings. Among them, the façades, which are generally supported by four points, are most common, as shown in Fig. 1. With this relatively new installation form, the façade has a better flexibility, lightness and structural beauty than traditional framing glass façades. Nevertheless, in case of a fire, glass pane is easily subjected to non-uniform thermal loading due to its large size, and its fixing points would inevitably constrain the glass expansion, which makes the kind of façade meet a new challenge to fire safety. What is more, from Fig. 1, it can be seen that, for aesthetic purpose, the fixing point is normally located in different positions: at the corner of pane (Fig. 1(a)), near the edge of pane (Fig. 1(b)) and close to the center of pane (Fig. 1(c)), which will increase the risk and render this issue much more complicated. With the fixing point position changing the breaking behavior may differ to some extent. Thus the fire resistance in different fixing forms of glass façades should also be determined.

Despite these problems demonstrated above, only limited work has investigated fire response of this structure [7,14,15]. Ni et al. [7] employed this kind of façade as external skins in a double-skin glass system, but he was focusing on smoke impact on the glass system. The breaking behavior was not analyzed in detail. Therefore, in our previous work, glass pane installed in eight different fixing forms were studied experimentally, and the time of crack initiation, behavior of crack propagation, heat release rates, central gas temperatures, glass surface temperatures and loss of integrity of the glazing assembly were investigated [15]. What is more, the safety distance between fire and glass panes was then determined, and it was established that toughened glass may has a better fire resistance than float glass panes when fixed at several points [14]. However, the cause and mechanism for some interesting phenomena is still unknown.

As highlighted in [15], numerical method, which may simulate the thermal stress distribution across glass panes, is appropriate for quantitatively revealing the mechanism of four-point supported glass breakage, as in experiments the combined stress caused by point fixing and thermal gradient in glazing is difficult to be measured accurately. In addition, the simulation model can be designed according to experiments and the results may be well compared. More different fixing positions can be investigated using numerical method, rather than conducting full scale



(a) (b) (c)

Fig. 1. Four point-supported glass façades with different fixing point positions, photographed in Suzhou.