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Influence of corner and edge distance of adhesive point-fixings for glass structures

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ABSTRACT

Nowadays, bolted point-fixings are widely used, which implies that the glass has to be drilled and tempered. Consequently, the glass is significantly weakened exactly at the position where peak stresses occur when forces are applied. In contrast, this disadvantage does not occur when adhesive technologies are used in which the glass is directly bonded at discrete points.

From bolted point-fixings, it is well-known that the distance between the connection and on the one hand the glass corner and on the other hand the glass edge are major parameters that influence the strength and behaviour of the connection. However, for adhesive point-fixings this influence has not been extensively investigated yet. Consequently, in this paper the results of a thorough experimental study of the influence of the corner and edge distance on a full-scale glass panel supported by adhesive point-fixings is published and analysed. A numerical model is constructed and validated with the experimental results. By means of a parametric study on this numerical model the effects of several parameters, such as geometrical dimensions and material properties, are studied.

The experimental and numerical results demonstrate that the corner and edge distance have a significant influence on the stress distribution and deflection of the glass panel: stresses and deformations are reduced with increasing corner and edge distance. However, from a certain distance the location of maximal stress and deflection will shift from the centre to the corner and edge causing the stresses and deformations to rise again. From the parametric study the influence of several material and geometrical parameters are investigated, and an optimal distance can be found. Increasing the glass thickness, the connection diameter, the adhesive stiffness and the adhesive thickness will have a positive effect on the occurring stresses.

1. Introduction

The demand for architectural transparency has drastically increased the use of glass as a structural material. However, connections between structural glass members still represent one of the most critical aspects of structural glass engineering. Traditional systems to connect glass to the supporting substructure consist of linear supports. By using such systems, the transparency of the facade is highly reduced [1,2]. In contrast, the overall transparency improves significantly by using so-called point-fixings [3,4]. Bolted point-fixings are widely used in facades and canopies, as depicted in Fig. 1. These fixings typically consist of locally installed metal pieces, of limited size, connecting the glass elements to the structure using bolts through the glass. This requires the glass panel to be drilled in corner or edge zones, tempered and bolted [5].

The distance between the centre of the bore hole and the corner, i.e. the corner distance, and the distance between the centre of the bore hole and the edge, i.e. the edge distance, have a great influence on the mechanical behaviour. A first approach to study the influence of the corner and edge distance is inspired by the steel research, where a relatively large amount of research has been performed on the influence of the corner and edge distance of a bolt bearing on a single steel plate. The experimental and numerical research of Rex and Easterling shows that the initial stiffness of a bolt bearing on a single steel plate increases with increasing distance [6]. Theoretical and experimental studies of pinned connections that have been published over the past 65 years are discussed by Duerr [7]. With increasing distance the limit state load will increase proportionately.

Due to the profound influence of the corner and edge distance known from steel research, research has been performed widely

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Fig. 1. Federal Public Service Finance in Brussels and bus terminal in Kaiserslautern.

on the influence of the corner and edge distance for glass panels supported by bolted point-fixings. The research of Klinkenberg et al. is one of the first research projects on this topic [8]. The optimal position of bolted point-fixings for a glass panel is determined from a Finite Element Analysis (FEA). The stresses decrease with increasing corner and edge distances. The analytical results and initial experimental investigations by Overend of the conventional point-fixings demonstrate that an optimum hole diameter d exists for a given corner distance $H/2$ and edge distance c [9]. The largest stress peaks can be found for the smallest edge distance with the largest glass panel width. In her doctoral dissertation, Maniatis also investigated the influence of the edge distance H of bolted point-fixings [10,11]. The principal tensile stresses increase with the reduction of the distance H. In the numerical investigation of Nielsen et al. the influence of the edge distance is investigated on the minimal value of the residual compressive in-plane stress at the surface of the hole resulting from the tempering process [12]. This stress will decrease when decreasing the edge distance, so the strength of the panel will be reduced when reducing the edge distance. Interpolation curves have been proposed to predict the average failure load based on the distance between the hole and the panel edge by Amadio et al. [13]. It can be observed that the specimen strength rises as the distance of the hole from the panel edge increases. The influence of the edge distance is investigated by FEA and validated by empirical methods for bolt bearings on a single steel plate by Overend et al. [14]. The maximal peak principal stress occurs with the smallest edge distance. The principal stress will decrease with an increase of edge distance. Smaller bore hole diameter will introduce higher stresses in the glass. This phenomenon is also noticed in other research [15].

A general conclusion from literature is that the maximal occurring stresses will reduce with increasing the corner and edge distance, which results in a higher strength of the glass panel. The occurring stresses will also diminish when the diameter of the connection is enlarged. Due to its significant influence, the corner and edge distance for bolted point-fixings is described in several guidelines and standards [16–18]. In the latter the influence is not described, only the minimal or maximal edge distance is specified depending on the diameter of the bore hole d and the glass thickness t. Table 1 gives a summary of three standards according to Fig. 2 for minimal values of the corner distances A, B and D and of the edge distance C.

Despite the widespread use of bolted point-fixings, a major disadvantage of this type of connections is the significant weakening by the drilling process at the holes edges, which is where high stress peaks occur due to the transfer of forces by contact between metal and glass [9,10,15,19,20]. The use of adhesive connections avoid this issue because the glass is directly bonded to the metal

Table 1
Summary of the minimum corner and edge distance according to guidelines and standards.

	CSTB, 2012	EN 12150-1	DIN 18008
A (mm)	$>2t + 0.5d$	$\geqslant 2.5d$	$\geqslant 80$ mm $+ 0.5d$ $\leqslant 300$ mm $+ 0.5d$
B (mm)	$>2t + 0.5d$	$\geqslant 2.5d$	$\geqslant 80$ mm $+ 0.5d$ $\leqslant 300$ mm $+ 0.5d$
C (mm)	$>2t + 0.5d$	$\geqslant 2.5d$	$\geqslant 80$ mm $+ 0.5d$ $\leqslant 300$ mm $+ 0.5d$
D (mm)	$\geqslant 6t + 0.5d$ for $t \leqslant 12$ mm $\geqslant 4t + 0.5d$ for $t \geqslant 15$ mm	$\geqslant 6.5d$	
E (mm)		$\geqslant 3d$	$\geqslant 80$ mm $+ d$

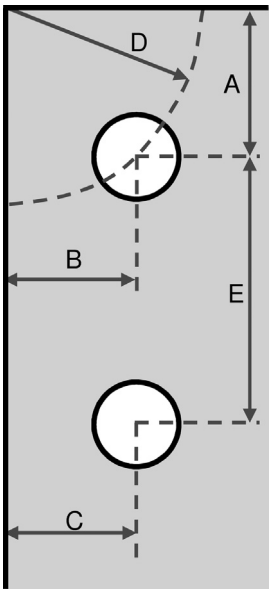

Fig. 2. Definitions of the symbols.