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Shear glass panels with point-fixed mechanical connections: Finite-Element numerical investigation and buckling design recommendations

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ABSTRACT

In the paper, an extensive Finite-Element (FE) numerical study is carried out on glass shear walls with point mechanical connectors. Based on calibration of FE models to experimental and numerical data of literature, both linear bifurcation analyses (*lba*) and incremental nonlinear static simulations (*inls*) are performed, in order to assess the shear buckling response of the examined structural panels. Analytical fitting curves are proposed for the shear buckling reduction factor, so that the Euler's critical load associated to a given number of point connectors could be correctly calculated. Based on extensive *inls* analyses, the buckling failure mechanism is emphasised for a wide set of geometrical configurations of practical interest. Finally, simple buckling design considerations derived from earlier research projects are extended to glass shear walls with point mechanical connectors.

1. Introduction

Point mechanical connections, bolted joints, metal fasteners are largely used in current practice, to provide an appropriate structural restraint to glass beams and plates (e.g. Fig. 1 [1–3]).

The point mechanical connection design concept is strictly related to steel structural methods, where specific geometrical requirements (e.g. distance of the holes from the edges, etc.) should be properly taken into account in order to avoid possible local failure phenomena.

Several authors assessed the structural performance of glazing systems supported by means of bolted point connections, under several loading conditions of practical interest for designers and researchers. Analytical solutions, design methods and simplified calculation approaches for glass panels with point fixings have been proposed in [4–7], so that their actual resistance under various loading conditions could be properly assessed. Experimental and numerical studies on glass panels with bolted joints under uniaxial loads have been discussed in [8]. In [9,10], the structural performance of point fixed glass curtain walls under ordinary wind loads or fire conditions has been studied, while in [11] the in-plane deformation capacities of point supported façade panels subjected to seismic loads have been assessed. Some further studies have been dedicated to adhesive point fixings, being characterised by a specific behaviour and stress distribution in glass [12–14], compared to traditional metal bolted joints.

Glass shear walls with linear adhesive connections or point bolted connections have been investigated in [15] by means of experimental, analytical Finite-Element (FE) methods. Careful consideration has been dedicated to the shear buckling behaviour and ultimate resistance of glass panels under the assigned boundary conditions, providing some preliminary design formulations of practical interest. In [16–19], the effect of linear adhesive joints on the buckling response and ultimate failure mechanism of shear glass panels or glass beams has also been assessed. It was shown, specifically, the importance of mechanical interactions between several structural components, as well as the difference between actual restraints and idealised boundary conditions.

In this paper, the response of structural glass panels with point mechanical connectors, used as shear walls and stiffeners in buildings and envelopes is investigated. First, Finite-Element numerical models able to properly reproduce the mechanical behaviour of point bolted connectors are developed in ABAQUS/Standard [20] and validated towards experimental data and further FE studies derived from past research projects [15]. The so validated FE modelling approach is then extended to a wide set of geometrical configurations of practical interest, e.g. by varying the geometrical properties of the glass panels, the glass type, as well as the geometrical features of the point supported connectors (e.g., the

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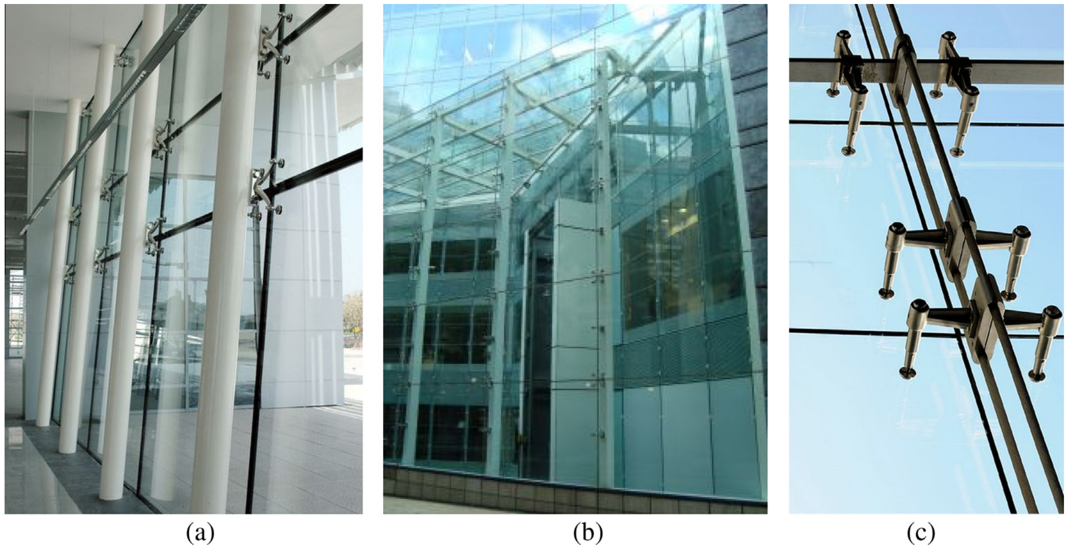

Fig. 1. Examples of point supported structural glass panels. (a) [1]; (b) [2]; and (c) [3].

position of the holes and the number of point connectors). Both linear bifurcation analyses (*lba*) and incremental nonlinear static simulations (*inls*) are carried out through the parametric study. In the first case, the buckling coefficient k_t required for the calculation of the Euler's critical load of mechanically point-fixed shear glass walls is properly estimated. Analytical fitting curves of practical use are also provided. Subsequently, *inls* analyses are carried out on glass panels subjected to initial geometrical imperfections, so that the typical buckling failure mechanism and the main influencing parameters could be properly detected. In conclusion, some standardized design buckling considerations derived from past research projects [21,22] are recalled and extended to the examined boundary conditions. Based on the close agreement between them, the same standardized buckling design method is proposed for the verification of point supported glass panels under in-plane shear loads. In order to provide safe design recommendations, based on the collected FE normalised data, modified imperfection factors are also proposed. In view of further mock-up experiments and full-scale tests, it is expected that the current outcomes could represent a strong theoretical background for the implementation of buckling design recommendations and rules of practical use.

2. Theoretical background

Often, buckling design methods proposed in literature for structural elements composed of various construction materials are strictly derived from classical analytical formulations for plates, beams, columns, under the hypotheses of ideal mechanical material behaviour as well as boundary and loading conditions. In doing so, the estimation of the corresponding Euler's critical load represent a first – although not fully exhaustive – information related to the expected buckling performance for the structural element object of study.

When assessing the shear buckling response of a monolithic, fully isotropic panel subjected to in-plane shear loads, for example, with reference to Fig. 2a, analytical calculations are in fact usually performed by taking into account classical formulations derived from literature [23], that is by assuming that:

(a) the material has an elastic, homogeneous, isotropic behaviour
(b) the panel is initially perfectly flat and its thickness is small, compared to the global dimensions
(c) the strains due to deflection in the middle surface are negligible, compared to strains due to bending
(d) deformations are such that straight lines initially normal to the middle surface remain straight and normal

where $b \times H$ are the global dimensions of the panel; t the nominal thickness; E, ν the Young's modulus and Poisson' ratio respectively.

The corresponding Euler's critical shear load $V_{cr}^{(E)}$ is given by:

$$V_{cr}^{(E)} = \frac{\pi^2 D}{b} k_\tau. \tag{1}$$

where $D = Et^3/12(1-\nu^2)$ denotes the bending stiffness per-unit-of-length of the panel, while k_τ is the buckling coefficient depending on the assigned boundary conditions and the aspect ratio $\alpha = H/b$. For panels with fully simply supported edges ('*ss-ss*'), k_τ can be calculated as [23]

$$k_\tau = \begin{cases} 4.00 + \frac{5.34}{\alpha^2} & \alpha \leqslant 1 \\ 5.34 + \frac{4.00}{\alpha^2} & \alpha > 1 \end{cases} \tag{2}$$

As far as the actual restraints can be rationally assumed to behave as ideal continuous simply supports or fully clamps, the Euler's critical load given by Eq. (1) can represent a useful and rational estimation of the expected buckling resistance of a given panel under in-plane shear loads V.

When specific restraints are used, in contrary, appropriate studies should be carried out, e.g. in the form of appropriate but often time consuming Finite-Element analyses, so that the effect of these restraints on the global structural response could be properly taken into account. It was shown in [16], for example, how to perform the buckling analyses of glass shear walls when supported by metal frames of variable out-of-plane stiffness and continuous adhesive joints, while in [18,19] the effects of continuous sealant joints on the lateral–torsional buckling response of glass beams working as fins and stiffeners for facades or roof plates have been properly analysed. Another relevant example, in this context, is represented by structural glass panels working as stiffeners and shear walls in buildings, where point mechanical supports or adhesive joints are often preferred for aesthetic and architectural motivations (e.g. Fig. 2b).

Point mechanical connectors are in fact frequently used in practice, due to their capacity to minimize the presence of bracing systems as well as to provide appropriate restraint conditions.

Several researchers focused on the performance of glass panels with point mechanical supports, e.g. assessing by means of