Engineering Structures 102 (2015) 214–229

Contents lists available at ScienceDirect

Engineering Structures

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

Structural assessment and lateral–torsional buckling design of glass beams restrained by continuous sealant joints

Chiara Bedon [a,*], Jan Belis [b], Claudio Amadio [a]

[a] University of Trieste, Department of Engineering and Architecture, Piazzale Europa 1, 34127 Trieste, Italy

[b] Ghent University, Laboratory for Research on Structural Models – LMO, Technologiepark-Zwijnaarde 904, B-9052 Ghent, Belgium

ARTICLE INFO

Article history:
Received 25 January 2015
Revised 31 May 2015
Accepted 12 August 2015

Keywords:
Lateral torsional buckling (LTB)
Glass beams
Analytical models
Finite-element modeling
Structural silicone joints
Composite sections
Incremental buckling analysis
Imperfections
Buckling design methods
Buckling curve

ABSTRACT

Glass is largely used in practice as a structural material, e.g. as beam and plate elements able to carry loads. Their structural interaction is often provided by mechanical connections, although recent trends are moving toward the minimization of metal components and the primary involvement of adhesives or silicone structural joints working as partially rigid continuous restraints.

In this work, the lateral–torsional buckling (LTB) behavior of glass beams laterally restrained by continuous silicone joints is assessed. Based on earlier contributions of literature and extended parametric Finite-Element (FE) numerical investigations, closed-form solutions are suggested for the estimation of their Euler's critical buckling moment under various loading conditions. Finally, by means of more detailed incremental nonlinear analyses, their global LTB response is also investigated, to assess their sensitivity to initial geometrical imperfections as well as their prevalent LTB failure mechanism. In conclusion, a generalized buckling design curve able to account for the structural contribution provided by structural silicone joints is proposed for a rational and conservative LTB verification.

1. Introduction

Glass is largely used in practice as a structural material, e.g. as beam or plate elements able to carry the loads deriving from other structural components or external forces. Especially in the field of façades and building envelopes, the use of glass panels combined with steel frames, aluminum supporting bracings or cable-nets resulted in an extremely wide variety of case studies. Typical applications of glass assemblies are often derived – and properly modified, to account for the tensile brittle behavior of glass – from practice of traditional construction materials (e.g. steel structures, sandwich structures, etc.), and take the form of properly designed and well-calibrated mechanical or chemical connections (e.g. steel fasteners, silicone sealant joints, adhesives, etc.) able to offer a certain structural interaction among multiple glass components. Recent design trends, however, are often oriented toward the minimization of metal joints and mechanical connectors. Typical examples consist in fact in frameless glazing systems, in which glass to glass interaction is provided by sealant joints or adhesives only (Fig. 1). This is the case of beam-like glass elements used in practice as stiffeners for façade or roof plates, where the coupling between them is often provided by continuous silicone joints. From a structural point of view, the effect of silicone joints can be compared to a partially rigid shear connection, of which the effectiveness should be properly taken into account.

In [5], for example, results of a recent research study carried out on laterally restrained (LR) glass beams in LTB have been presented. Assessment of existing analytical models available in literature for the prediction of the Euler's critical buckling moment of LR beams under constant bending moment, accounting for the shear stiffness provided by continuous, partially rigid lateral restraints, has been presented. Based on extended Finite-Element (FE) linear bifurcation analyses (*lba*), the effects of various loading conditions of practical interest (e.g. mid-span concentrated F or uniformly distributed loads q, applied both at the top or bottom edge of the laterally restrained beams) have then been also emphasized. The final result consisted in correction factors of practical use for a suitable prediction of the Euler's critical moment for LR glass beams in LTB, thus in correction factors numerically calibrated to properly take into account the effects of silicone joints, beam-to-joint stiffness ratios, loading condition.

In this work, based on earlier contributions [5–7], the LTB response of glass beams laterally restrained by means of structural silicone joints is further assessed by means of incremental buckling, Finite-Element (FE) numerical simulations. While several

* Corresponding author. Tel.: +39 040 558 3837.
E-mail address: bedon@dicar.units.it (C. Bedon).

http://dx.doi.org/10.1016/j.engstruct.2015.08.021
0141-0296/

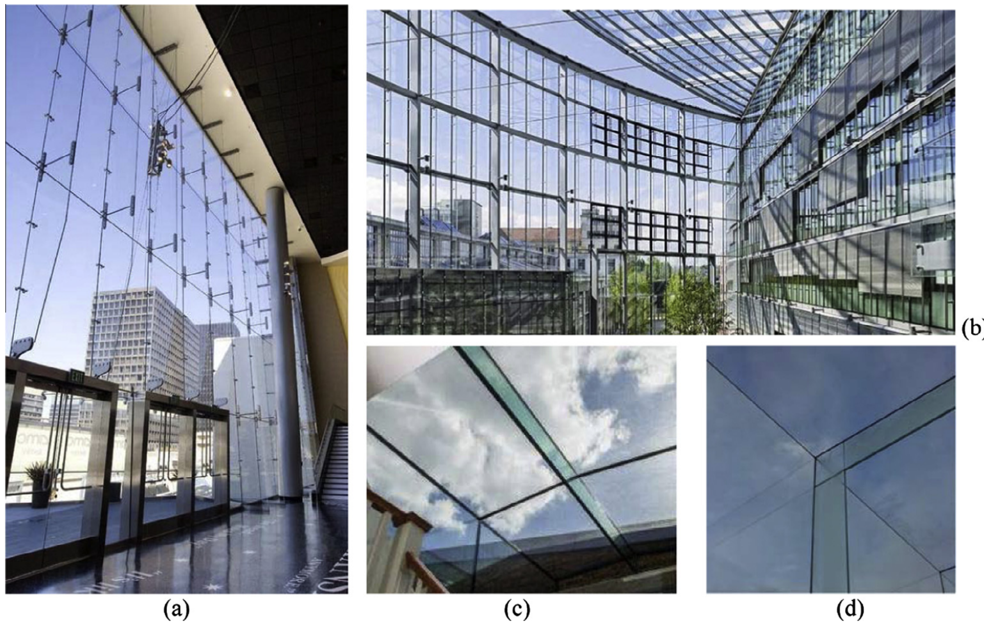

Fig. 1. Example of application of glass fins as support for façade panels and roofs. (a) [1]; (b) [2]; (c) [3] and (d) [4].

studies have been dedicated to the assessment of the LTB structural behavior of laterally unrestrained (LU) glass beams, and buckling design methods have also been proposed (e.g. [8–11]), the extension of the same simplified analytical methods must be checked. At the same time, although practical formulations are provided in [5] for the estimation of the Euler's critical moment of LR glass beams under various loading conditions, it is well known that a proper assessment of the buckling resistance of a given structural system should be carried out by means of more refined analyses able to account for several mechanical and geometrical aspects.

For this purpose, small specimens of silicone joints are subjected to shear experiments, to properly estimate their elastic stiffness, but also the ultimate resistance and deformation capacities, with respect to common applications of practice. Incremental nonlinear analyses are then performed on a wide set of geometrical configurations. The main advantage of these FE-investigations is given by the appropriate description of effects deriving from initial curvatures (with specific shape and amplitude), as well as the detection of the ultimate condition as the first attainment of tensile cracking in glass or failure of the silicone joint, respectively. Based on extended parametric studies, a practical design method based on a suitable design buckling curve is also proposed for the LTB verification of LR glass beams. In this work, as a preliminary exploratory study of the main expected effects of sealant joints in LR beams, glass elements composed of a monolithic section only are analyzed. It is thus expected that the current theoretical approach could represent a strong reference background for further full-scale experimental investigations and detailed analysis of structural glass assemblies (e.g. laminated glass beams laterally restrained to glass roofs by means of sealant joints).

2. Euler's critical moment of laterally restrained glass beams in LTB

2.1. Literature background for LR members in LTB

LTB of structural beams with lateral restraints has been widely investigated and assessed in the last years. In [12,13], research studies have been dedicated to the typical LTB response of doubly-symmetric steel I-beams, with careful attention for possible distortional buckling phenomena in the steel webs. Khelil & Larue proposed in [14,15] a simple analytical model for the assessment of the critical buckling moment in steel-I sections with LR tensioned flanges, highlighting that the presence of rigid continuous lateral restraints in steel I-beams under LTB can have a weak influence, compared to their unrestrained Euler's critical buckling moment. The same authors presented in [16] a further alternative, analytical approach for the LTB assessment of I-beams continuously restrained along a flange by accounting for the buckling resistance of an equivalent, isolated "T" profile. The latter approach, due to its basic assumptions, typically consisted in a conservative analytical prediction for the LTB resistance of rigidly LR steel I-beams. Conversely, the main advantage of this method consisted in the implementation of Appendix values of practical use for designers.

The LTB behavior of thin-walled cold-formed steel channel members partially restrained by steel sheeting has been assessed, under various boundary conditions, by Chu et al. [17], by means of an energy-based analytical model. Bruins [18] numerically investigated the LTB response of steel I-section profiles under various loading conditions (e.g. distributed load q, mid-span concentrated force F, constant bending moment M_y) and laterally restrained by single, elastic, discrete connectors, highlighting through parametric FE-numerical studies and earlier experiments that partial elastic restraints can have significant influence on the overall LTB response. The effects deriving from initial geometrical curvatures with different shape were also emphasized by means of FE simulations, while simple equations were proposed as strength design method for 'rigid' discrete lateral restraints. Chu et al. [19] assessed by means of an energy-based method the influence of lateral restraints on the LTB response of cold-formed steel zed-purlin beams under various loading/boundary conditions, demonstrating that lateral restraints generally provide an increase of the unrestrained critical load, but this improvement is largely affected by boundaries or the point of load application. Further assessment of structural effects deriving from discrete rigid supports on the buckling behavior of steel beams and braced columns are discussed in [20–24].