Journal of Constructional Steel Research 130 (2017) 159–176

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

An innovative solution for hybrid steel-glass self-bearing modular systems

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ARTICLE INFO

Article history:
Received 20 January 2016
Received in revised form 6 December 2016
Accepted 11 December 2016
Available online 20 December 2016

Keywords:
Composite system
Steel frame
Laminated glass
Adhesive
Steel-to-glass interaction
Experimental tests

ABSTRACT

The performance of a quadrangular steel-glass self-bearing system for roofs and facades is analyzed through numerical simulations and experimental tests. The system is characterized by a double deformed configuration obtained using cold bending procedure, applying displacements in correspondence of two opposite corners and avoiding spring back phenomena through the steel frame. Nonlinear analyses were executed to simulate the assembly process of the system and to determine the load bearing capacity of the deformed system under vertical loads. Experimental tests were executed allowing to validate the model and to assess the behaviour of corners. A simplified resistance domain is finally proposed.

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1. Introduction

Contemporary architectural trends aim to realize suggestive lightweight transparent building skins joining aesthetical, structural and energy efficiency requirements. The development of glass technologies allows the production of elements for roofs and façades connecting architectural, structural and manufacturing aspects through the adoption of curvature-variable and free form surfaces (Fig. 1a) able to achieve very pleasant results. Since the realization of such complex surfaces is related to the traditional combination of flat panels, lot of attention shall be paid to the use of proper tessellation techniques, able to reduce the manufacturing costs and to simplify the assembly process. Triangular and quadrilateral topologies can be adopted for tessellation: triangular panels discretize a generic surface using flat elements, easy to be manufactured and assembled (Fig. 1b); quadrangular panels offer, otherwise, higher transparency and a lower amount of metallic profiles resulting in optimum aesthetical characteristics (Fig. 1c). Single Gaussian curvatures and simple sweep geometries can be tessellated with equal-size quadrangular panels; in the case of double Gaussian curvatures, on the other hand, simple equal size-quadrangular panels cannot be used (Fig. 2).

In such case, several approaches were proposed to approximate complex surfaces using quadrangular flat elements: to make few examples, Scale-Trans Meshes algorithm [1] adopted geometrical schematization to tessellate double curved surfaces by means of equal quadrangular panels, while Liu et al. [2] developed the Panel Quadrangular (PQ) perturbation algorithm to optimize a generic surface using planar quadrangular elements [3,4]. Despite the reliability of these methods, only approximation of the original surface is allowable, while to avoid any mismatch between the effective and the tessellated geometry the use of curved panels is needed. Several techniques exist for the manufacturing process of quadrilateral solutions [5,6]: among them, the Hot Bending Method (HBM) and the Cold Bending Method (CBM) are the most diffused.

HBM takes advantage of the glass's mechanical characteristics modification at high temperature: for values higher than 550 °C, glass undergoes the reduction of the elastic modulus and the increase of the viscosity, simplifying the bending technique; the cooled glass panel maintains the deformed configuration with a low coactive stress field. The high manufacturing costs of HBM can be, otherwise, avoided with CBM at room temperature, executed through either Cold Bending (CB) by lamination (i.e. two glass panels are deformed and joined in autoclave by means of the interposition of a stiff interlayer) or through CB by assembling (i.e. the panel is curved and fixed on metallic support avoiding the spring back). In such cases, the stress field induced on the glass plies during CB shall be properly taken into account.

The evolution of architectural and manufacturing techniques increased the interest in the use of glass as primary structural material [7–9]. Several methods were investigated to reduce the issues of the brittle failure of the glass under tensile stresses: Louter et al. [10,11] introduced steel bars or polymeric fibres on the traction side of a laminated glass increasing then the ductility of the composite system while reducing the crack propagation; Netusil et Eliasova [12] proposed a

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http://dx.doi.org/10.1016/j.jcsr.2016.12.014
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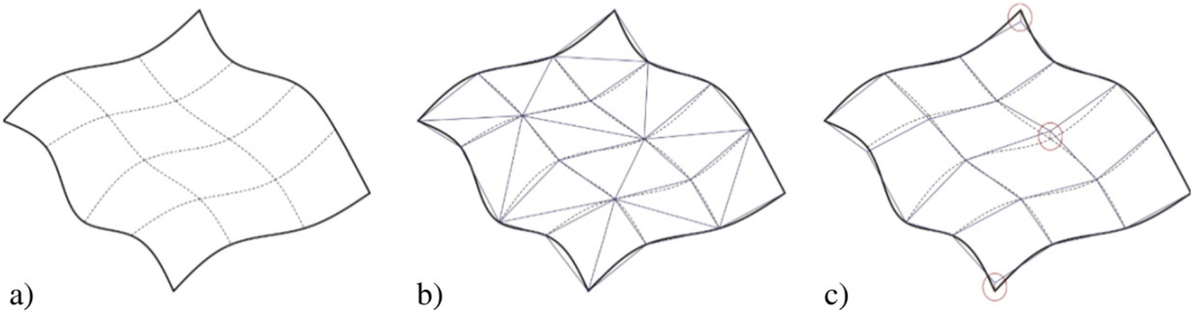

Fig. 1. Example of tessellation of: a) free-form structure by means of b) triangular or c) quadrangular panels.

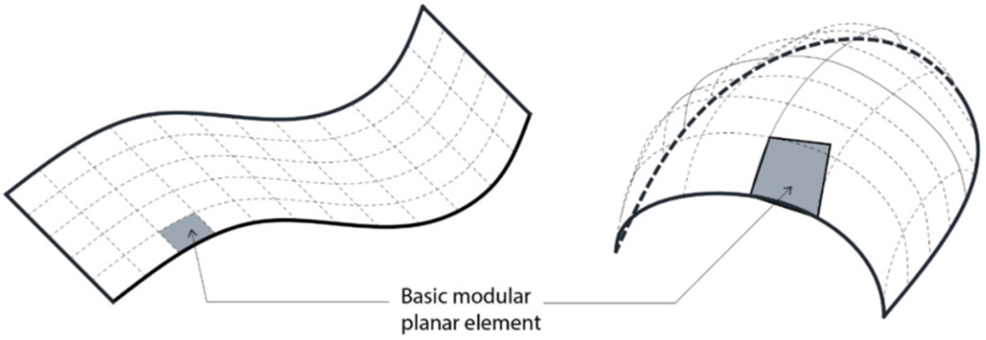

Fig. 2. Tessellation of a) single curvature and b) double curvature surfaces by means of quadrilateral elements: skewness mismatches can be encountered in the case of solution b) using equal size elements.

hybrid steel/glass beam bonded using structural adhesive: a linear and continuous connection avoided the concentration of stresses in correspondence of the glass with resulting oversizing of the plies. Mocibob [13] applied the linear bonding technology to analyze the feasibility of glass shear panels for building stabilization. The advances in shell-like structures were then mainly focused on reducing the presence of steel substructures fixing the panels in the correct position for the time required to apply the adhesive [14,15].

In the present paper an innovative self-bearing composite Steel/Glass (S + G) solution with double-curvature configuration is proposed for horizontal and vertical architectural solutions (i.e. façades and roofs). The composite cell was designed, realized and experimentally tested to optimize the aspects related to feasibility, assembly and fabrication. The cell was developed inside the frame of the European research project, funded by the Research Fund for Coal and Steel (RFCS), "S + G: *Innovative steel glass composite structures for high-performance building skins* (*2012-2016*)" aiming at the definition of modular steel/glass solutions for smart glazed building skins. The system is designed as a self-bearing structure, taking advantages from each of its three main components: glass, steel and adhesive; the double curvature configuration is obtained through CB by assembly [16] and guaranteed by the external metallic frame preventing spring-back.

2. Methodology

The design of the S + G cell considers the behaviour of the three main components (i.e. steel, glass, adhesive) and their mutual interrelationship during cold bending and under the effects of external actions; the bearing capacity in the deformed configuration is then determined. Possible applications of the S + G cell were analyzed to define the deformation δ imposed to the system when used in façades and roofs (Fig. 3).

The methodology adopted for the design of the cell is summarized in the following steps, combining numerical and experimental investigations.

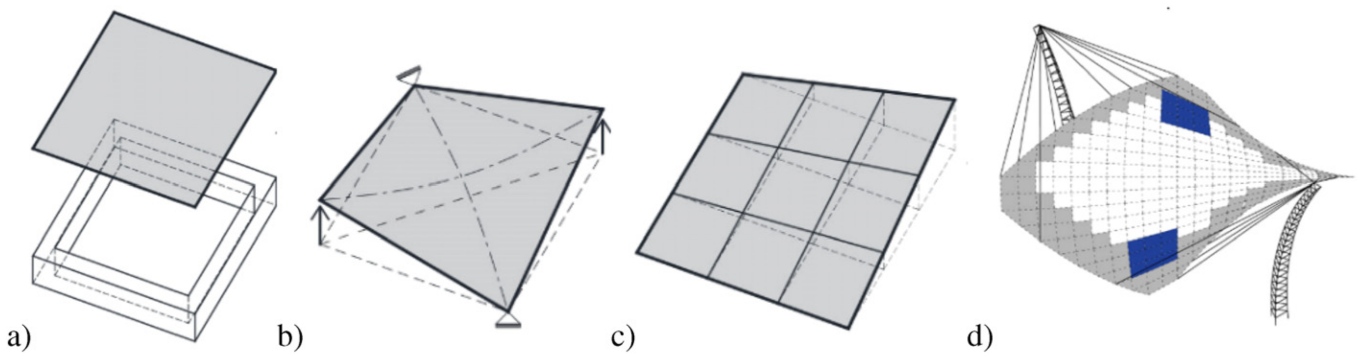

Fig. 3. Schematic workflow from the assembly an hypothetic suspended transparent roof: a) assembly of the single cell, b) application of cold bending procedure, c) assembly of deformed panels, d) hypothesis of application of the obtained curved solution.

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