Advances in Computational Design, *Vol. 7, No. 3 (2022) 173-188*
https://doi.org/10.12989/acd.2022.7.3.173

An approach to a novel modelling of structural reinforced glass beams in modern material components

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(Received May 7, 2021, Revised November 25, 2021, Accepted December 8, 2021)

Abstract. In modern buildings, glass is considered a structurally unsafe material due to its brittleness and unpredictable failure behavior. The possible use of structural glass elements (i.e., floors, beams and columns) is generally prevented by its poor tensile strength and a frequent occurrence of brittle failures. In this study an innovative modelling based on an equivalent thickness concept of laminated glass beam reinforced with FRP (Fiber Reinforced Polymer) composite material and of glass plates punched is presented. In particular, the novel numerical modelling applied to an embedding Carbon FRP-rod in the interlayer of a laminated structural glass beam is considered in order to increase both its failure strength, together with its post-failure strength and ductility. The proposed equivalent modelling of different specimens enables us to carefully evaluate the effects of this reinforcement. Both the responses of the reinforced beam and un-reinforced one are evaluated, and the corresponding results are compared and discussed. A novel equivalent modelling for reinforced glass beams using FRP composites is presented for FEM analyses in modern material components and proved estimations of the expected performance are provided. Moreover, the new suggested numerical analysis is also applied to laminated glass plates with wide holes at both ends for the technological reasons necessary to connect a glass beam to a structure. Obtained results are compared with an integer specimen. Experimental considerations are reported.

Keywords: carbon FRP-rod; laminated glass plate; reinforced glass beam; structural glass modelling

1. Introduction

In the last decade the need of realizing buildings utilizing transparent load-bearing elements is considerably increased, with an excellent aesthetic value of transparent and translucent structural components (Richards 2006). These aspects are all present in the so-called structural glass, which is characterized by a brittle behavior and a time-decreasing strength due to surface damages. The break of a glass specimen usually occurs due to the growth of a superficial defect rather than inside. Furthermore, depending on environmental conditions, glass can present failures after the

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http://www.techno-press.org/?journal=acd&subpage=7 ISSN: 2383-8477 (Print), 2466-0523 (Online)

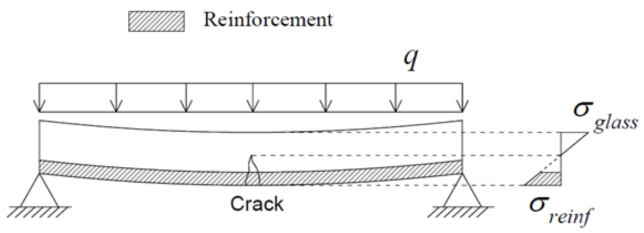

Fig. 3 Schematic overview of distribution of stress after glass failure

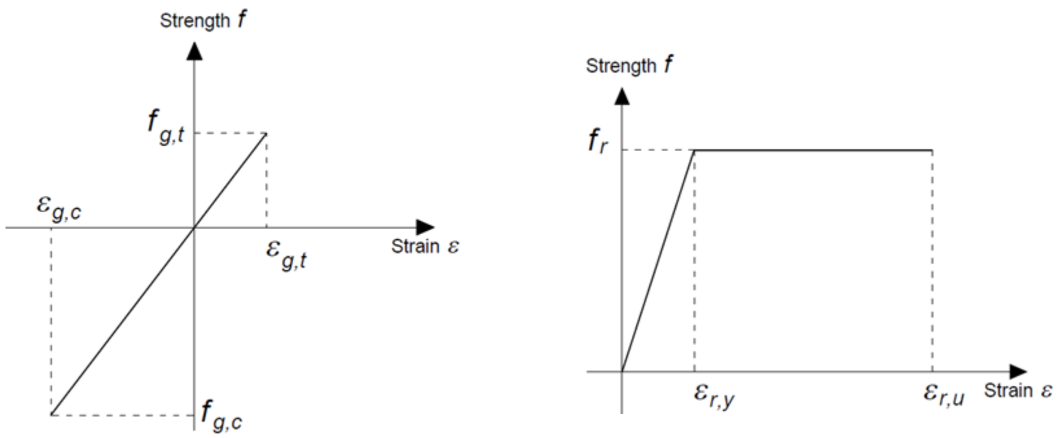

Fig. 4 Schematic representation of the stress-strain diagrams adopted for the analytical prediction method; (a) Glass; (b) Reinforcement.

modelling approach based on the response of laminate considered as a monolithic glass element with a proper equivalent thickness h_E is presented, where this equivalent thickness h_E of laminated glass can be computed by accurately processing the values of three glass plies of the same thickness h_G together with the values of two PVB layers of thickness s, properly combined via Young's moduli E_{PVB} and E_G as expressed in Eq. (1):

$$h_E = \sqrt[3]{h_G^3 + 3h_G(h_G + s)^2 + \frac{E_{PVB}}{3E_G}s^3} \tag{1}$$

In this relation, it has been assumed that a full bonding occurs between the glass and the PVB interlayer due to loading.

The innovative numerical modelling conducted in this paper focuses on the prediction of the structural response of both reinforced glass beams and punched ones. Since the structural concept of the FRP-rod reinforced glass beam can be considered comparable to the reinforced concrete beam, in this paper the reinforced concrete theory is consequently supposed to be valid also for reinforced glass models as shown in Fig. 3.

For the sake of a better comprehension, fundamental concepts of the reinforced concrete theory are briefly reported. On the basis of the reinforced concrete theory, the relations used to describe the F-δ (force-displacement) are implemented to reinforced glass beams. It is assumed that the glass responses are completely linear and elastic and that the reinforcement response is elastic perfectly-plastic, as shown in Fig. 4.