Numerical investigation of reinforced laminated glass beams

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1. Introduction

Nowadays, a big challenge in architecture is to maximise transparency in buildings. To do so, structural elements usually built in reinforced concrete or steel can be made of glass. As glass is a brittle material, beams consisting of glass only do not exert a safe failure behaviour. To solve this problem, a lot of concepts were developed in which glass is used in combination with another material to create hybrid glass beams that possess post-breakage strength and ductility [1, 2, 3].

A promising concept in this regard is the one of reinforced glass beams [4]. The philosophy for this development is inspired by reinforced concrete. Despite obvious differences between glass and concrete, their structural behaviour has some significant similarities. Both materials are strong in compression, rather weak in tension and show brittle failure behaviour. To reach safe failure behaviour for concrete beams, ductile steel is added to the section. In this way, reinforced concrete beams are created that possess post-breakage strength and a ductile failure behaviour. Applying the same principles to glass beams, a stainless steel section is adhesively bonded at the tensile side of the beam. Assuming a typical bending test, once the glass starts to break, the reinforcement serves as a crack bridge, transferring tensile stresses from one unbroken section to the other. In this way, an internal lever arm exists between the compressive glass zone and the tensile reinforcement, providing further load-carrying capacity. Upon further loading, the cracks will develop further and eventually the steel will start to yield. This last phenomenon is responsible for the ductile failure behaviour of the beam. A promising concept within reinforced glass beams is the one in which the stainless steel section is incorporated in the glass section and is bonded to the glass using the interlayer. Louter has investigated these beams considering statically determinate support conditions [4]. He concluded that these beams, using SentryGlas® as the interlayer material and stainless steel as reinforcement, showed significant post-breakage strength and ductility. Post-breakage strengths up to 240% of the initial failure load could be attained. So, the feasibility of this kind of beams for statically determinate support conditions has been proven. Sadly, statically determinate systems do not possess any system safety.

A way to incorporate system safety is to make use of statically indeterminate support conditions in which an inherent transfer of moments can develop between support and field. Up to now, the behaviour of statically indeterminate glass beams has not been investigated. This paper presents numerical research into the feasibility of applying reinforced laminated glass beams in statically indeterminate support conditions. Firstly, a statically determinate model is created which is validated using available experimental research on four-point bending tests. From this validated model, the effect of adding reinforcement in the compressive zone is evaluated by simulating a doubly reinforced laminated glass beam with statically determinate support conditions. Next, a statically indeterminate model is created. With this model, an assessment of the overall bending behaviour will be performed in which the possibility of moment redistribution will be evaluated. Finally, a section is dedicated to the conclusions drawn from the research results.

2. Results & Conclusions

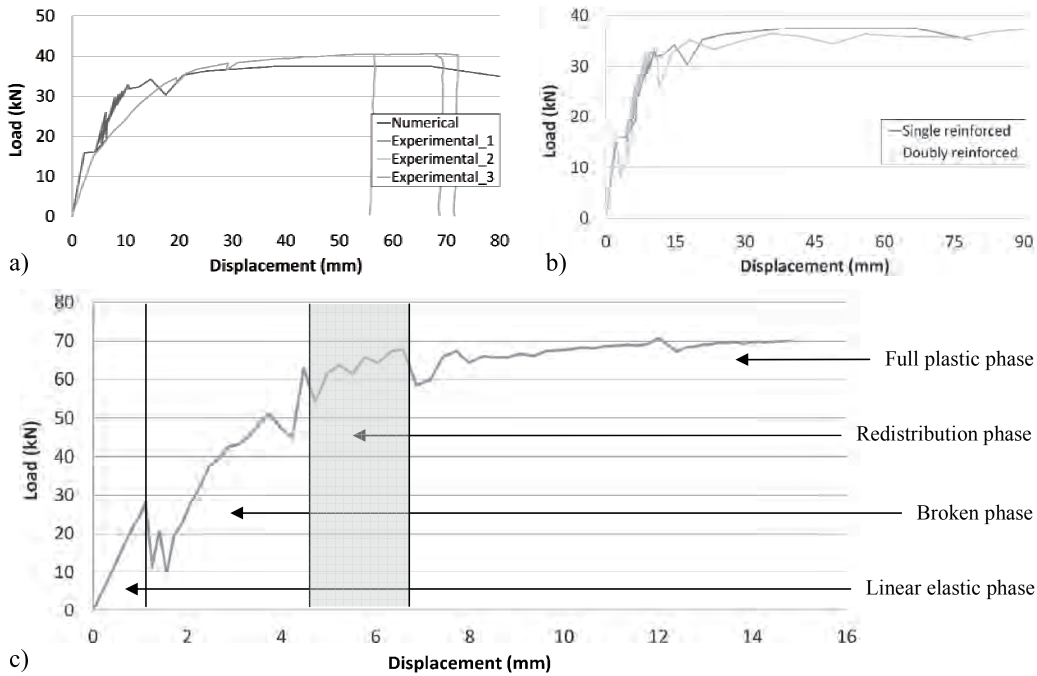

Fig. 1: Load-displacement diagrams

Fig. 1a) illustrates the experimental and numerical load-displacement diagrams for the statically determinate single reinforced glass beam. Despite the higher bending stiffness in the initial and broken phase, a good agreement exists between the curves. Fig. 1b) depicts the comparison between the doubly reinforced and single reinforced statically determinate models. It was concluded that adding reinforcement at the compressive edge of the beam did not significantly alter the bending behaviour of the beam. Only a slight increase in initial failure strength and bending stiffness was observed. Finally, Fig. 1c) illustrates the bending behaviour of the statically indeterminate model. It was concluded that the beam exerts a safe failure behaviour in which the ultimate load vastly exceeds the initial failure load. Moreover, compared to the statically determinate case, the beam possesses an extra load transfer mechanism in which moment redistribution occurs. This provides a form of system safety which is not present in statically determinate systems. The presented numerical results for the statically indeterminate case will be validated by an experimental testing program in the near future.

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