# An Innovative Concept for Pre-stressed Glass Beams

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## Summary

At Technische Universität Dresden structural glass researchers are developing an innovative concept for pre-stressing glass beams. These beams are post-tensioned by unbonded cables which are anchoraged at the beam ends. Four different cable layouts are chosen to investigate on an optimized global load bearing behavior and depend on the expected external bending loads and the chosen construction especially in terms of the supports and the connection to the glazing.

To increase the loadbearing capacity as well as the post fracture behavior reinforced glass beams in multiple applications may be post-tensioned. An embedded steel cable as it is known from the principles of reinforced concrete design is tensioned creating an internal constraint. This will result in a compressive stress constraint state in the glass. Additionally, the deformation of such a beam may be affected as needed before an external bending load appears.

Nevertheless, glass beams are subject to imperfections. Due to this initially unknown deviation from the theoretical perfect state the applied axial force from post-tensioning the beams will induce additional torsion as well as further bending moments. This may result in an unfavorable deformation of the glass beam during the post-tensioning process and increase the risk to suffer from early failure such as lateral torsional buckling.

The results of the experimental investigation in terms of load-cable force and load-deformation relations caused by four-point bending are shown and analyzed. Furthermore, the deformation behavior is compared between the different cable layouts leading to a conclusion what construction is most suitable to be post-tensioned from the perspective of this very load case. The project was funded through the German Federal Ministry of Economics and Energy (BMWi) and executed cooperatively with our partners Thiele Glas Werk GmbH (Wermsdorf, GERMANY) and KL-megla GmbH (Eitorf, GERMANY).

**Keywords:** glass beam; reinforced glass; pre-stressed glass; cable; glass bridge; glass edge.

## 1. Introduction

Reinforced glass beams are under examination to increase the load bearing capacity as well as the safe post-breakage behavior of the brittle glass [01-24]. A ductile reinforcement carries a part of the total load and cables are post-tensioned to provide an extra compressive stress at the glass edges.

The exploratory experimental study presented in this paper aimed for a variety of reinforcement and post-tensioned constructions to gain knowledge of how load may be transfered from the cables into the glass. Therefore, 23 Spannglassbeams (2.160 x 150 mm) were tested in four-point bending. A 28 mm gap between two glass packages contained a 6 mm stainless steel spiral cable reinforcing the beam. The specimen were tested with alternating the cable layout (A-D) and different levels of post-tensioning ($P_0$: 0; 3; 6 and 9 kN). Besides six reference specimen we designed steel connectors to redirect the cables and to transfere their load into the glass edge via either a plastic block or an adhesive joint with epoxy or acrylate adhesives. In a first step all beams were tested up to a moderate load level (HS: $F_{max}$ = 16 kN; FT: $F_{max}$ = 20 kN) without glass breakage and destructive test at a designated initial cable load to determine the ultimate load. All together one can describe the load bearing behaviour: $\sigma_I(P;F) = \varepsilon(P;F) \cdot E$, $w_z(P;F)$ and $v_y(P;F)$ and bridges the gap of knowledge regarding the design of post-tensioned glass beams.


*Fig. 1 Beam specimen with steel connectors*

## 2. Results

### 2.1 Ultimate Load

Fig. 2 shows the ultimate load of all specimen grouped by their type of redirectional construction.

| **reference** | **blocked** 34,6 ± 5,50 kN (0,16) | | **Epoxy** | **Acrylat** |
|---|---|---|---|---|
| 30,2 ± 3,54 kN (0,12) | **POM/EPDM** 33,1± 5,18 kN (0,16) | **POM** 36,4 ± 5,72 kN (0,16) | 21,2 ± 1,96 kN (0,09) | 38,0 ± 4,78 kN (0,13) |

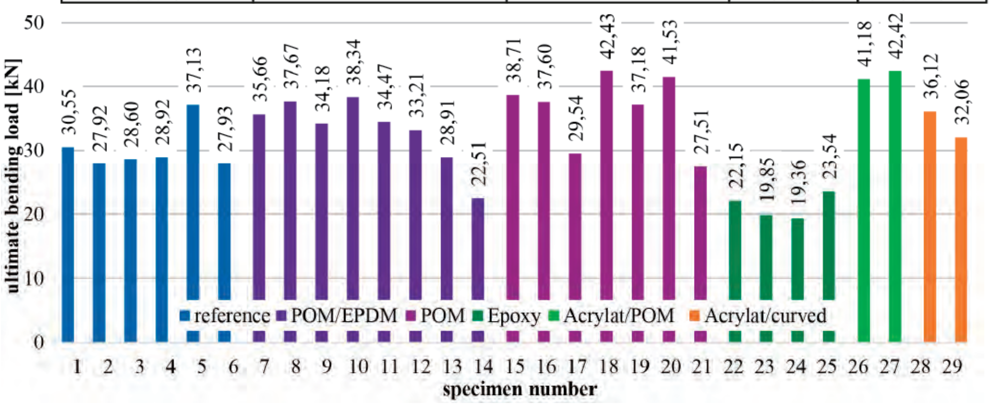


*Fig. 2 Ultimate loads by redirectional typ (mean ± standard deviation (variation coefficient)).*

## 3. Discussion and Conclusions

In summary the pre-stressing of the glass resulted in a compression of the tensile zone of the beam. We are able to describe the load bearing giving analytic and experimental results.

Unreinforced beams show on average a smaller ultimate load which leads to the conclusion that reinforced and pre-stressed glass beams may be loaded to a higher degree. On average the difference in average ultimate load of 33,7 kN (± 5,2 kN) for HS versus 36,8 kN (± 5,4 kN) for FT does not reflect the difference in their tensile strength. We recoreded a sudden lateral at high level of loading: lateral torsional buckling as the governing cause of failure.

Alltogether reinforced and pre-stressed glass beams for future structures may be designed with blocked or adhesively bonded options while the latter showed to be more transparent and introduced loads without major stress concentrations. Thus the preferd option uses the acrylate adhesive, will hold and redirect the cable and consists of heat strengthend glass.

We developed an innovative concept for pre-stressing glass beam in analogy to concrete structures and conducted an exploratory study on a variety of options. We showed that the concept of compressing the beam externally with a specific uplift is realizable. Furthermore, we designed a 9 m glass bridge with post-tensioned glass beams which was shown at glasstec 2014 in Düsseldorf, GERMANY.