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Adjustable Point Supported Glass Floor in the Renewed Building of the National Museum in Prague

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The building of the National Museum in Prague is a part of the historical heritage of the Czech Republic. Very huge reconstruction and maintenance of whole building was ongoing during the last decade. Special emphasis was devoted to every detail of the interior as well as the facade elements to keep the historical value of the building adding modern architectural elements like transparent glass flooring and balustrades. This paper deals with the project of the glass flooring in total area about 200m2 placed directly in the main tower of the building as a representative place with nice view to a historical parts of the city. The tower is a part of the main Pantheon with historical coloured glass elements visible from the inside of the building, therefore, glass flooring was the only possible solution to open this area for people by keeping the daylight from the top of the Pantheon, see (Fig. 1a,b).

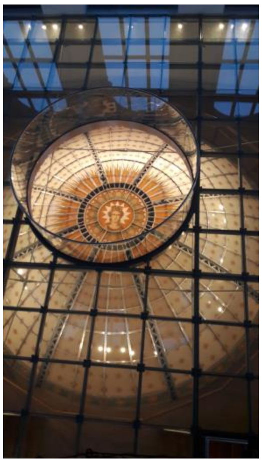


Fig. 1 a, b Coloured glass in the Pantheon visible thru glass flooring allowing exposure by daylight from the top.

Keywords: National Museum Prague, glass floor, point supported

1. Introduction

1.1. Motivation for point supported solution

Initial architectural plan was to place the glass panels continuously linearly supported around all edges on the supporting steel substructure, consisting of steel reversed beams. Linearly supported glass copied deflection of the substructure. Due to the very strict requirements of geometrical flatness of the final glass floor, there was a need to choose a different system to allow rectification of each pane in the floor. Special adjustable point supporting system was developed without the need of drilling to the glass pane, consisting of different types of heat treated glass.

1.2. Description of the supporting system

Each glass panes is placed on 4 non-drilled targets near the corners of the pane, see (Fig. 2). Steel plates with 4 targets were bolted to the main steel structure additionally. On the target, there is separating polymer bedding layer with special patented material parameters to provide advantageous stress distribution around supporting points as well as shear contraction between steel target and glass needed for the horizontal load. This bedding serves as the separator of the direct contact of the steel and glass. Each target allows vertical rectification by countersunk screw thread inside, therefore, each corner of every glass pane can be vertically adjusted separately, see (Fig. 2 and 3).

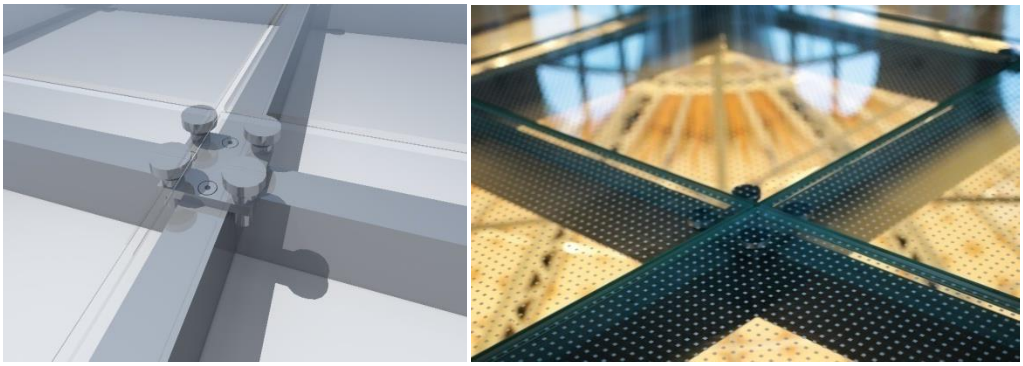


Fig. 2 a, b Additionally assembled targets for point supporting of the glass floor.

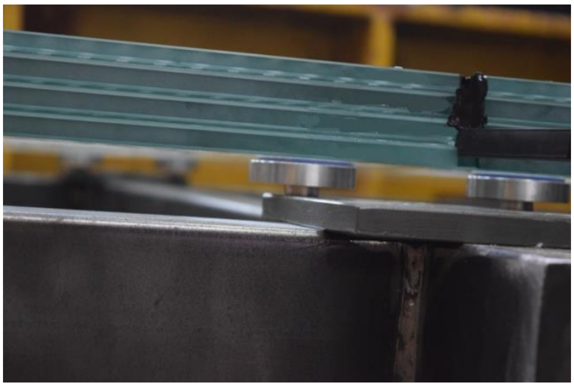


Fig. 3 Side view of the corner plate with local supports.

1.3. Glass panes

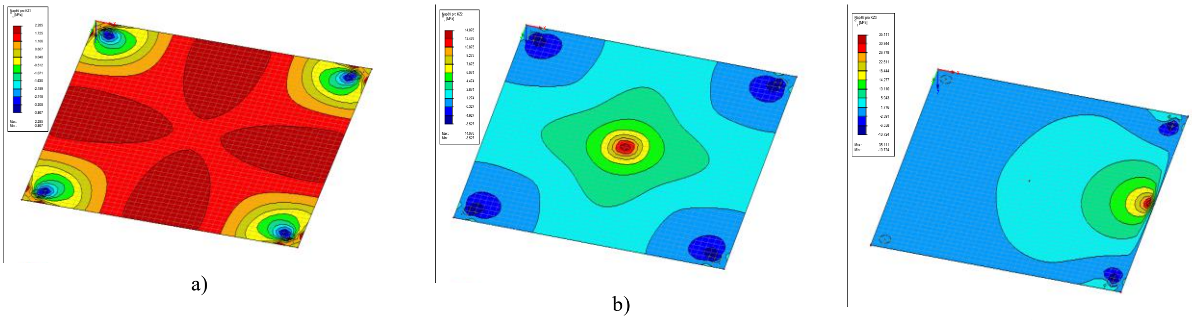
Glass panes are designed and statically evaluated as laminated safety glass with different thermally treated glass types using ionomer laminating foil. Total thickness of the pane is up to 45 mm and consists of 4 layers, where toughened 8 mm glass on the top with printed non-skid frames to avoid slippery floor were used. For the main load part of the pane, 3 x 10 mm glass was used as the combination of the thermally strengthened and toughened. The basic dimensions of each glass pane are approx. 1,0 x 1,0 m.

2. Static evaluation

Stress state within the glass pane was evaluated numerically by non-linear analysis by the software package Rfem and additional module RF-GLASS. To assume the shear interaction between the glass plies provided by ionomer interlayer, non-linear elastic model predefined in the numerical software was taken into account. Material parameters of the interlayer were chosen as long-term loaded to be on the safe side and achieve appropriate level of the rigidity and redundancy. Static analysis was performed in the Ultimate limit state, Serviceability limit state and also for accidental post breakage behaviour of the pane with cracked upper and bottom ply in the laminate to proof the safe behaviour in all possible load cases and post failure load cases. As there is no obligatory standard valid in Czech Republic for the design procedure of the load bearing glass structures, all calculation and evaluation procedures (safety factors, ultimate glass strength etc.) were performed according to the code (DIN 18008, Kasper 2016)

2.1. Results

Representative glass pane was statically evaluated for the effect of uniformly distributed area load of $5kN/m^2$ (public building) and concentrated load of 4kN according to the national annex of the (EN 1991-1-1). Concetrated force was considered on the area of 50 x 50mm and placed on different positions on the glass pane to obtain the worse effect on the stress distribution. Expected resulting position of the force was near the edge of the pane in the middle of the span between local supports. All plies of the laminated glass pane were evaluated compared to the design value of the strength of each type of glass with safe and satisfying results in Ultimate limit state as well as post failure criteria. Some significant stress distribution patterns for different type of applied load in different positions are described in the following (Fig. 4a,b,c). Level of stress is different under specific load conditions and will be described further.



a) b) c)

Fig. 4 Stress distribution patterns from the numerical analysis of the representative glass pane a) uniformly distributed areal load, b) concentrated load in the middle of the pane c) concentrated load near the edge of the pane.

3. Experimental part

To prove the behaviour of the designed laminated glass composition subjected by concentrated load, an experimental part was performed at the lab of CTU Prague on full-scale specimen of the floor element.

3.1. Experiment configuration

Representative full-scale floor element was subjected to vertical and also horizontal load. Vertical deflection was measured continuously as well as the stresses in both directions on the bottom toughened glass pane surface (Fig. 5). Gap filling by polymer adhesive was tested in the same time on the same specimen (Fig. 6).

Fig. 5 Photo of the test specimen (applied vertical and horizontal load).

Fig. 6 Gap filling test.

In the first step, glass pane was subjected to some service vertical load up to 1kN. Horizontal force was introduced after that to prove the friction on the polymer target. Horizontal force increased to 1kN without any horizontal movement. Normative requirement for horizontal load applied on the force is usually much smaller. After this provement, structure was subjected to increasing vertical load step by step by keeping a bit time to relax in each step. Tension stress value was measured by strain gauges on the bottom surface under the load introduction point until the bottom toughened glass failure.

3.2. Evaluation

In the graph bellow (Fig. 7) there is a record from the strain gauge on the bottom surface. Each step represents sustained force introduction of 30 kN, 35 kN, 40 kN, 45 kN a 50 kN. The failure of the bottom pane occurred by 50 kN, when the tension stress peak reached 140 MPa, see (Fig. 8). In fact, the normative requirement for concentrated load is approx. 10 x lower. Therefore, there is enough of the load bearing capacity also for the post failure limit state, which was further proved on the partially broken pane subjected to load again.

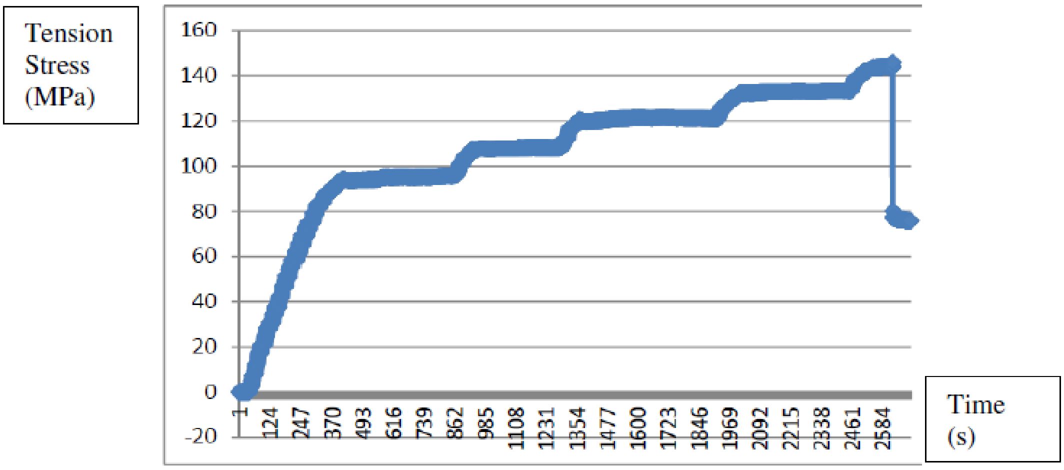


Fig. 7 Record from the strain gauge on the bottom surface under the load introduction point.

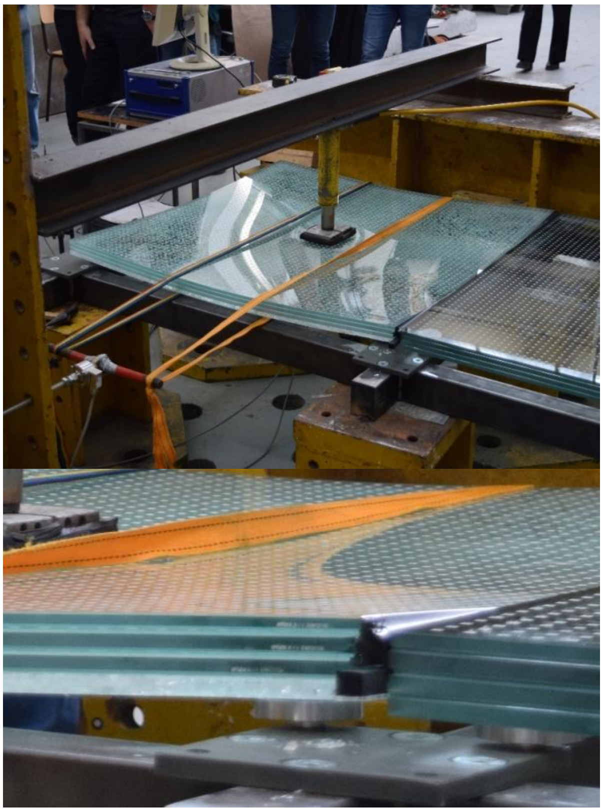


Fig. 8 Reached ultimate capacity of the pane by 50kN.

Deformation of the glass pane was measured during whole experiment under increasing load see (Fig. 9). Numerically obtained values of the vertical deflection from the model of the practical application with normative external load are much lower because of the level of safety and redundancy factor in case of partial breakage of the pane. In fact, the numerical results under the normative load can be compared only with the beginning of the test diagram in the Fig.

10 and in case of performed structure, deflection under the normative load reaches up to 1 mm corresponding with the level of the principal stress within the most subjected glass around 20 Mpa.

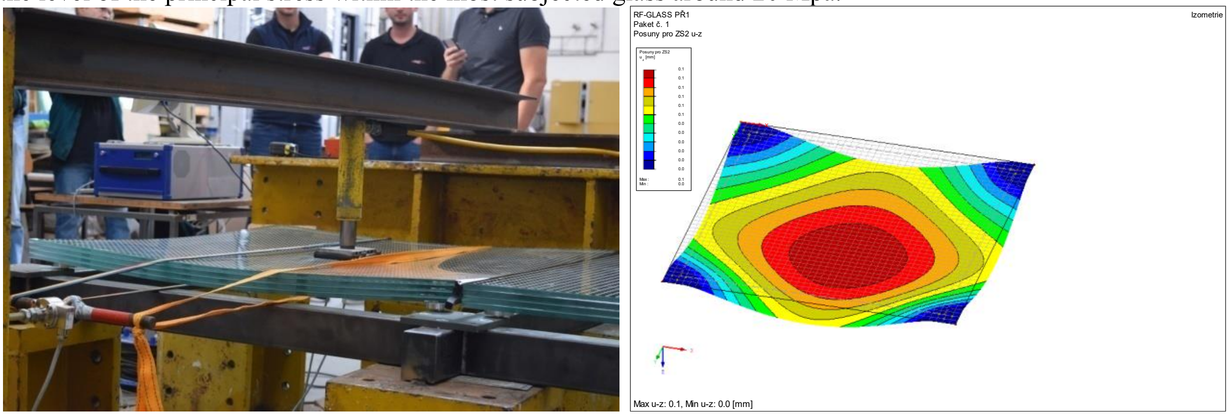


Fig. 9 a, b Measured visible vertical deformation of the glass pane.

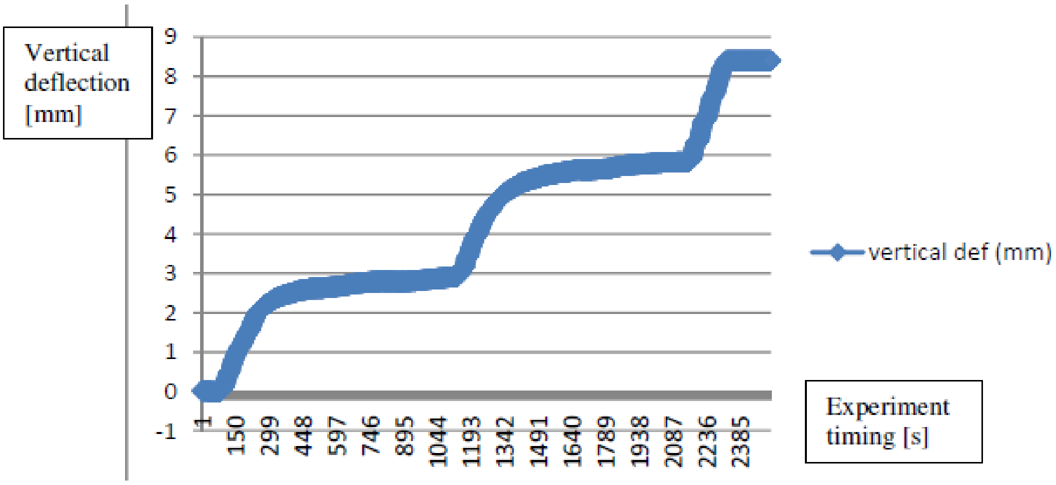


Fig. 10 Vertical deformation in time of testing.

4. Fabrication - mantling

Floor panels were placed step by step from the central part to the edges, see (Fig. 11). Calculated vertical deflection in the central part of the structure was adjusted in the targets by higher elevation compared to targets near the supports of the steel substructure. In final, due to the adjustable point supports, perfect flatness of the floor was achieved as was desired. After adjusting the whole floor to its final shape and position, gap between glass panes were filled up by elastic polymer adhesive, (Fig. 11b). After the final cleaning, the structure was given to operation (Fig.12).

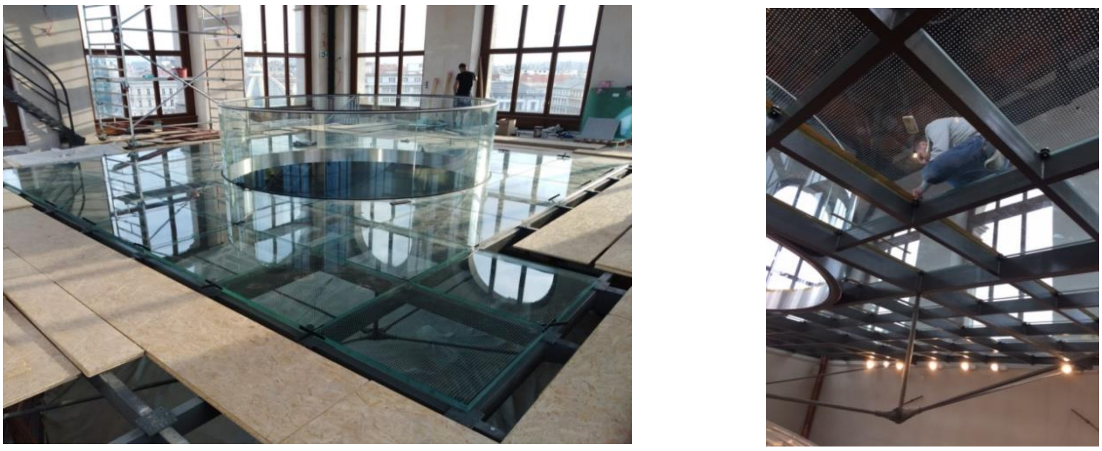


Fig. 11 a) Placing the panels from the central part, b) gap filling on site.

Fig. 12 Finally cleaned structure ready for service.

5. Conclusion

Explained adjustable point supported glass floor structure was evaluated numerically and experimentally to prove its safety behaviour in Ultimate limit state as well as in the post failure limit state. Specific solution of the point supported glass panels allows separate initial elevation of each glass panel to required vertical level (assuming the total deflection including the glass panel self weight) and achieve perfect flatness of the overall structure even if the substructure shows significant vertical deformation, see (Fig. 13). Final structure is reliable, but still keeping astonishing filigree design.

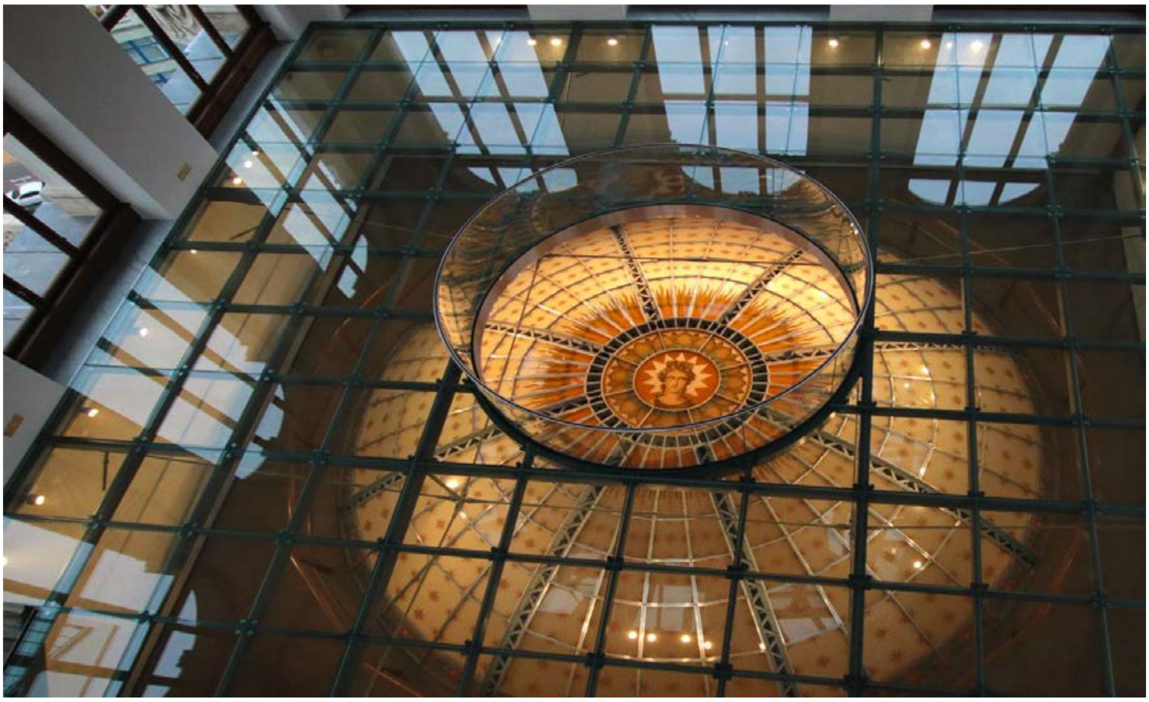


Fig. 13 Overall structure.

6. Acknowledgements

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