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Glass Bridges and Glass Walls

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In the last years Gartner Steel and Glass has designed, engineered and erected several complex structures with load carrying glass elements. This presentation concentrates on current projects that will be finished in 2010. Glass bridges are under construction for the projects "Eaton Centre" in Calgary and "Ritz-Carlton Hotel" in Toronto. Projects with glass walls are in design and testing phases for the projects "Willy Brandt Platz" in Frankfurt and "Kravis Center, Living Room" in Los Angeles. Besides an overview of the structural systems this presentation concentrates on challenges in testing, production, transportation, and erection of these structures.

Keywords: Glass Bridge, Glass Wall, Testing, Production, Transport, Erection

1. Glass Bridge in the "Eaton Center", Calgary

1.1. Design

The glass bridge is in total 14,25 m long and 3,66 m wide. The load bearing structure is composed of 12 glass floor elements (8 mm tempered, 1,52 mm PVB, 10 mm heat strengthened, 1,52 mm PVB, 10 mm heat strengthened) , 11 glass floor beams (3x10 mm heat strengthened, 1,52 mm PVB), and 6 glass balustrade elements (12 mm tempered, 1,52 mm PVB, 12 mm heat strengthened, 1,52 mm PVB, 12 mm tempered). The middle balustrade elements are supported by a tree column (mild steel).

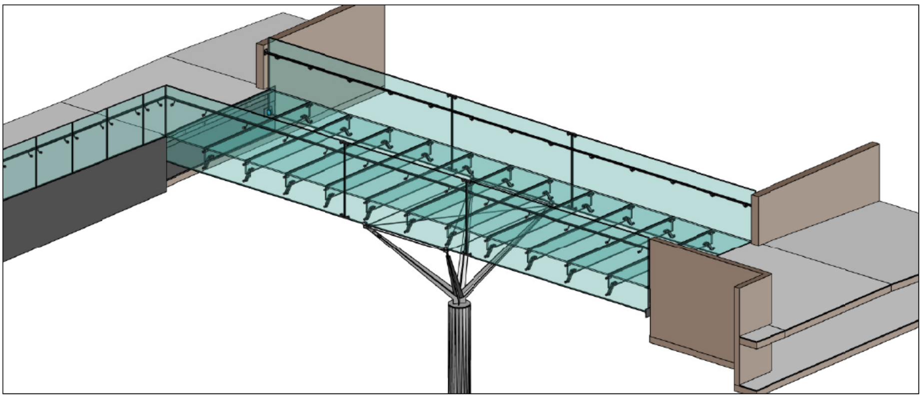

Figure 1: Glass Bridge – "Eaton Center", Calgary

During the design phase the global buckling behavior and the local stresses in the bolted connections have been in the focus of the FE-analysis (see fig. 2). Besides the design with allowable stresses in the borehole, the bolted connections were also checked with allowable connection forces determined in a series of detail tests.

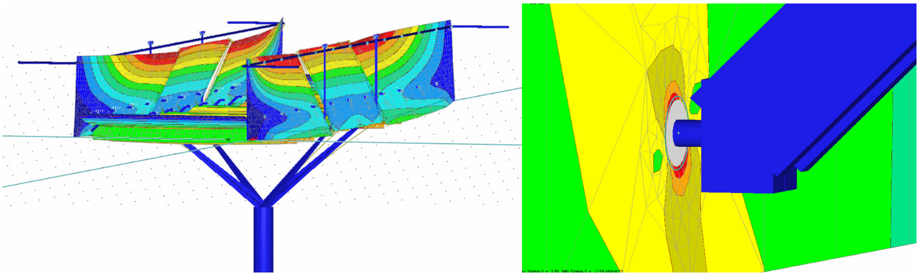

Figure 2: Buckling analysis (left) and local stress analysis (right)

1.2. Production and Transportation

All glass and steel elements where produced in Germany and transported by container to the site in Calgary. All stainless steel elements have the grade 1.4301 with a grinded surface finishing.

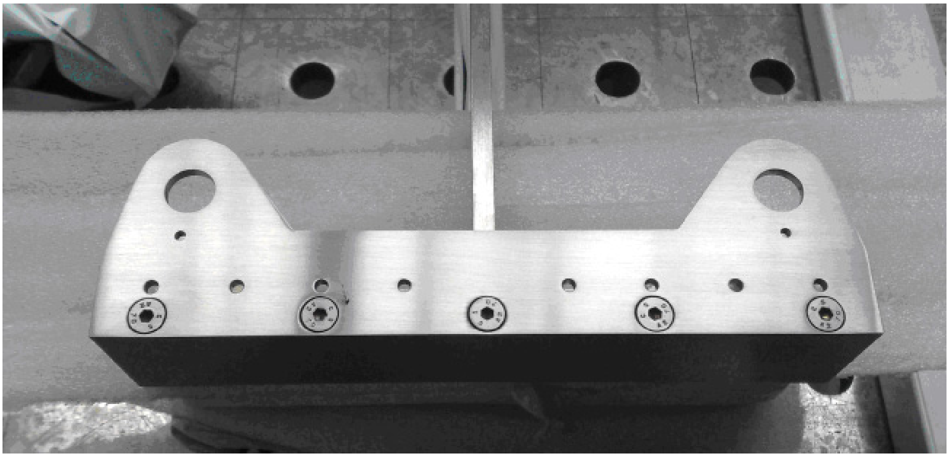

Figure 3: Production of the stainless steel connectors of the glass balustrade elements

1.3. Installation

To minimize the erection time and the risk of damage the installation was planed very detailed. The installation sequence is:

1) Installation of the mild steel column
2) Installation of the connection plates on both sides of the bridge
3) Check of the distance between the connection plates and correction of the column position
4) Installation of the scaffolding with open space for the tree-props
5) Installation of the tree-props including rods
6) Finishing of the scaffolding in the area of the tree-props and preparation for the working platform
7) Installation of six hydraulic jacks in correct position

8) Installation of assembly support
9) Installation and welding of support brackets at connection plates
10) Installation and adjustment of the glass floor beams (Figure 4)
11) Installation and adjustment of 8/10 glass floor elements (Figure 5)
12) Installation and adjustment of all glass balustrade elements (Figure 6)
13) Installation of the balustrade connection steel bars and the two remaining glass floor elements (Figure 7)

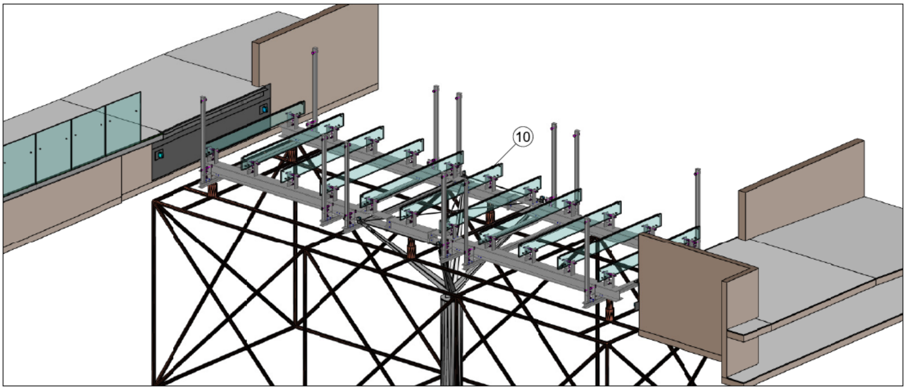

Figure 4: Installation Sequence 10) Installation and adjustment of all glass floor beams

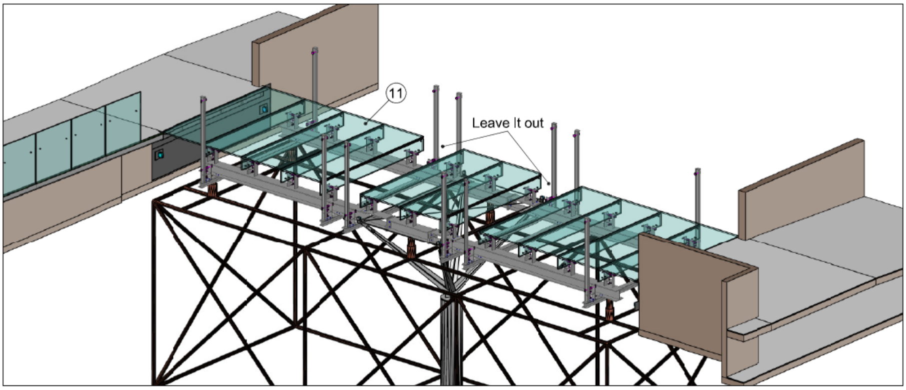

Figure 5: Installation Sequence 11) Installation and adjustment of 8/10 glass floor elements

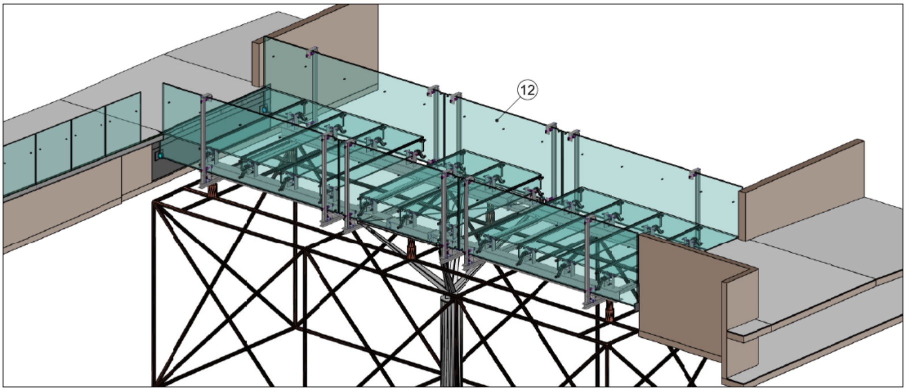

Figure 6: Installation Sequence 12) Installation and adjustment of all glass balustrade elements

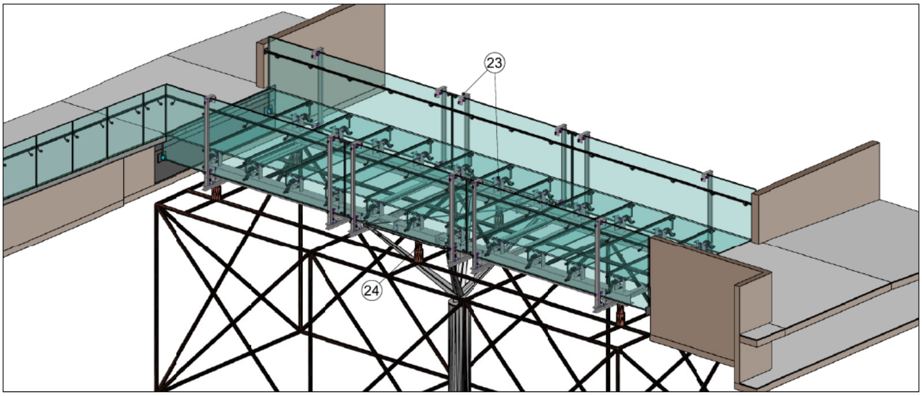

Figure 7: Installation Sequence 13) Installation of the balustrade connection steel bars

2. Glass Bridge in the "Ritz Carlton Hotel", Toronto

2.1. Design

The glass bridge is in total 9,00 m long and 2,10 m wide. The load bearing structure is composed of 9 glass floor elements (8 mm tempered, 1,52 mm PVB, 10 mm heat strengthened, 1,52 mm PVB, 10 mm heat strengthened) , 8 glass floor beams (3x10 mm heat strengthened, 1,52 mm PVB), and 2 glass balustrade elements that span over the total length of the bridge (12 mm tempered, 1,52 mm PVB, 12 mm heat strengthened, 1,52 mm PVB, 12 mm tempered).

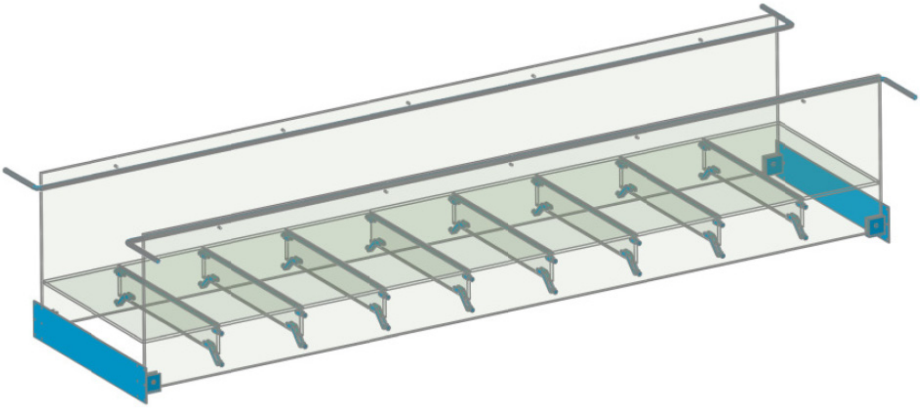

Figure 8: Glass bridge in the Ritz Carlton Hotel, Toronto

2.2. Production and Transportation

All glass and steel elements where produced in Europe and transported by container to the site in Toronto. All stainless steel elements have the grade 1.4301 with a grinded surface finishing.

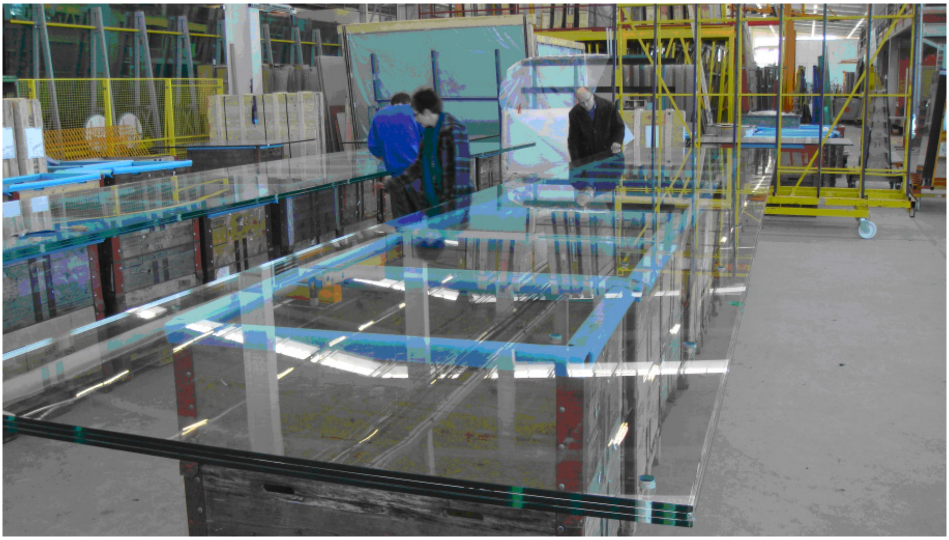

Figure 9: Production of the balustrade glass

Theoretically the bridge would fit with its overall dimensions into one standard container. The idea to transport the bridge as one piece was not followed, because undefined horizontal forces due to accelerations during the transport might cause damages. But also the transport of these extra large and heavy glass balustrade elements required special detail planning of the positioning and the fixation in the container.

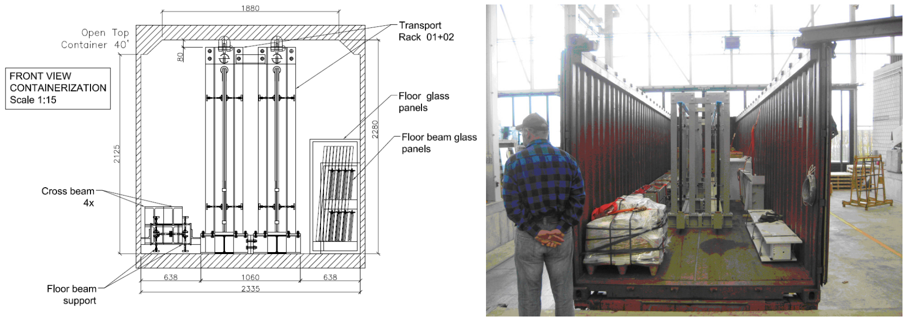

Figure 10: Transportation of the steel and glass elements

2.3. Installation

The installation sequence is similar to the installation sequence for the "Eaton Center" Bridge. The Bridge was properly cleaned before the hand-over.

Figure 11: Installation in the Ritz Carlton Hotel

3. Glass Walls in the "Willy Brandt Platz" Subway Entrance, Frankfurt

3.1. Design

The steel grid roof of the subway entrance is supported by two small steel columns and 15 glass wall elements. Horizontal forces were transferred from the roof to the ground by compression forces in the diagonal of the glass wall elements. As the self weight of the roof and the glass walls is not high enough, additional small steel tension bars were positioned in the gaps between the glass wall elements.

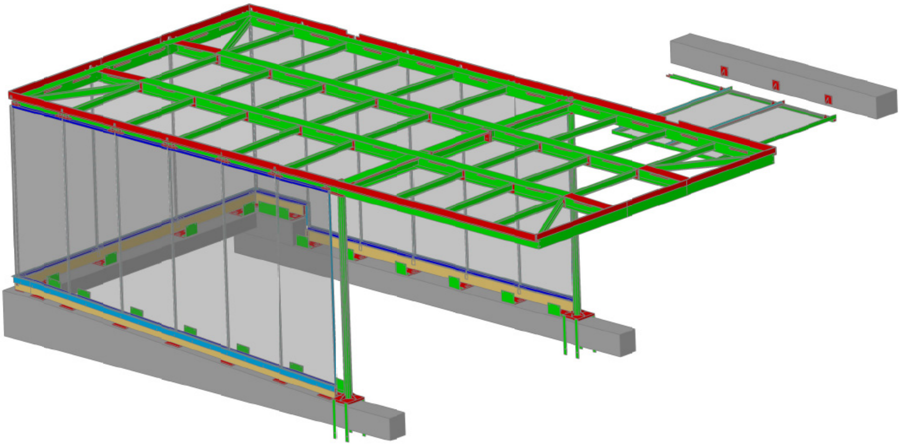

Figure 12: Design of the subway entrance

3.2. Testing

To achieve the approval by unique verification from the building authority a detailed test procedure was defined in an early stage of the project. The test procedure included the following load scenarios:

1) Evidence of the stability under serviceability limit state with additional horizontal impact load (pendulum test with double tire (50 kg) and 900 mm drop height)
2) Evidence of serviceability under serviceability limit state loads with an additional balustrade load (h = 1,0 kN/m)
3) Evidence of the local load introduction point under the controlling ultimate limit state load combination.

Note: The buckling stability of the glass walls was analyzed by detailed calculations. In these calculations the shear interaction in the laminated glass was conservatively neglected.

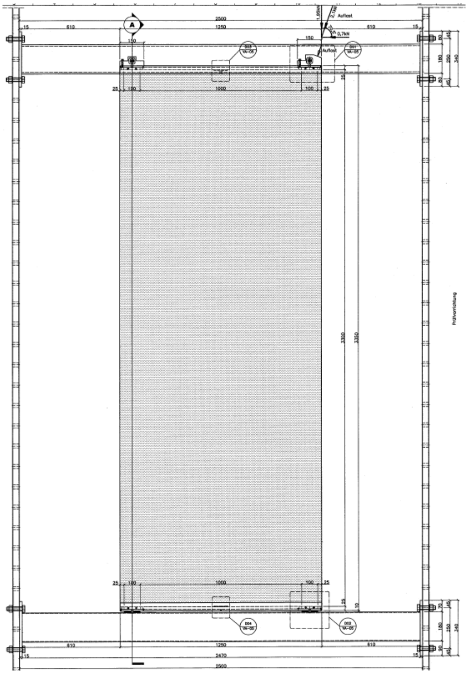


Figure 13: test set up

4. Glass Walls in the "Kravis Center, Living Room", Los Angeles

4.1. Design

The new Kravis Center at the Claremont MC Kenna College contains besides other buildings a "living room" in the middle of a courtyard. The 11 m x 11 m large steel grid roof is supported by 8 glass walls. Under dead weight and live load the normal force acting on each glass wall is 30 kN. But the real challenges are the high earthquake load assumptions according to the California Building Code. It defines for the area of the MC Kenna College an equivalent horizontal force of 150 % of the self weight for allowable stress design methods.

In the controlling load combinations for allowable stress design the horizontal force at the top of each glass wall is 80 kN combined with a normal force of 10 KN (or 18 kN).

Figure 14: Kravis Center, Living Room (Rafael Vinoly Architects)

4.2. Testing

The planed test procedure contains detail tests for the critical pull-out situation at the bolted bottom connection of the shear walls. The interaction of the vertical and the horizontal component of the connection force are considered by the angle φ.

As the load assumptions were related to allowable stress design methods the required test loads have to include a global safety factor.

In the actual design of the full scale tests the combination of normal forces and shear forces can be tested.

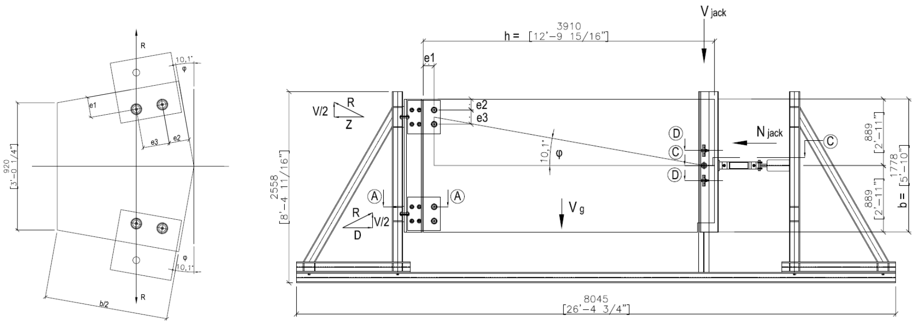

Figure 15: Test set up for the bottom connection tests (left) and the full scale tests (right)

5. Acknowledgements

At this point we like to name and to thank the architects and the structural engineers that played the leading role in the design of these projects.

Glass Bridge "Eaton Center Calgary"
- Architect: MMC International Architects, Toronto
- Structural Engineer: Halcrow Yolles, Toronto

Glass Bridge "Ritz Carlton Hotel"
- Structural Engineer: Halcrow Yolles, Toronto

Glass walls "Willy Brandt Platz"
- Architect: Scheffler+Partner, Frankfurt
- Structural Engineer: Bollinger + Grohmann, Frankfurt

Glass walls "Kravis Center, Living Room"
- Architect: Rafael Vinoly, NY
- Structural Engineer: Magnusson Klemencic, Seattle