Design and Construction of The Feature Glass Stair for The New Mariinsky Theatre, St. Petersburg, Russia

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Keywords

1 = glass stair
2 = structural glass treads
3 = testing

Abstract

This paper will describe the design, detailing and construction of the 36 m long, 2 m wide glass stair for the new stage of newly built Mariinsky theatre in St Petersburg, Russia, designed by Canadian architectural firm Diamond Schmitt Architects and fabricated by Waagner Biro, Austria. Use of glass treads supported at short sides spanning 2m, is believed to be the first structural glass applications of that scale in public building in Russia, hence due to its unprece-dented nature, extensive testing program was carried out which will also discussed here.

INITIAL DESIGN

The concept

The inspiration for the glass feature stair at new Mariinsky was initially based on The Four Seasons Centre for the Performing Arts in Toronto, also designed by Diamond Schmitt Architects, completed in June 2006. However, in contrast to the Toronto stair, the approach to the design of the new glass stair was somewhat simplified to minimise use of glass to glass bolted connections to allow quick and relatively straight forward installation.

The staircase has a total length of approximately 34 metres between the +2.85m level and + 12.75m level. Laminated glass treads and landing panels span 2 metres between steel stringer plates. The stair is supported at each half landing level with brackets fixed to the RC columns and walls. The steel stringers span is approximately 7.4 metres. Laminated glass balustrade panels on each side of the stair are fixed into the steel stringer section.

Loading criteria for glass treads, landings and balustrades

In general, all loads are in accordance with Russian codes of practice (СП20.13330.2011) or higher. Higher load conditions were adopted from latest European norms (Eurocode 0&1), see table below.

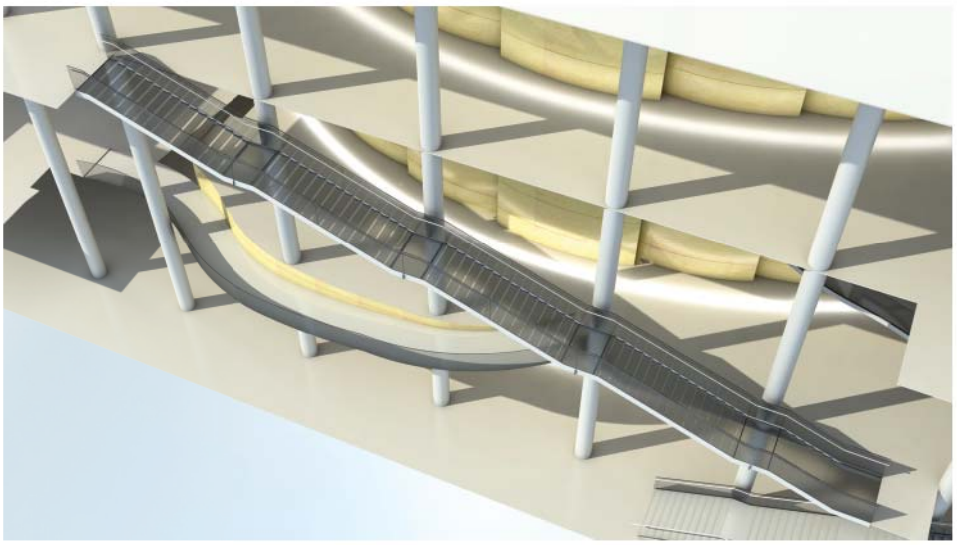

Figure 1 Computer visualization of the glass stair.

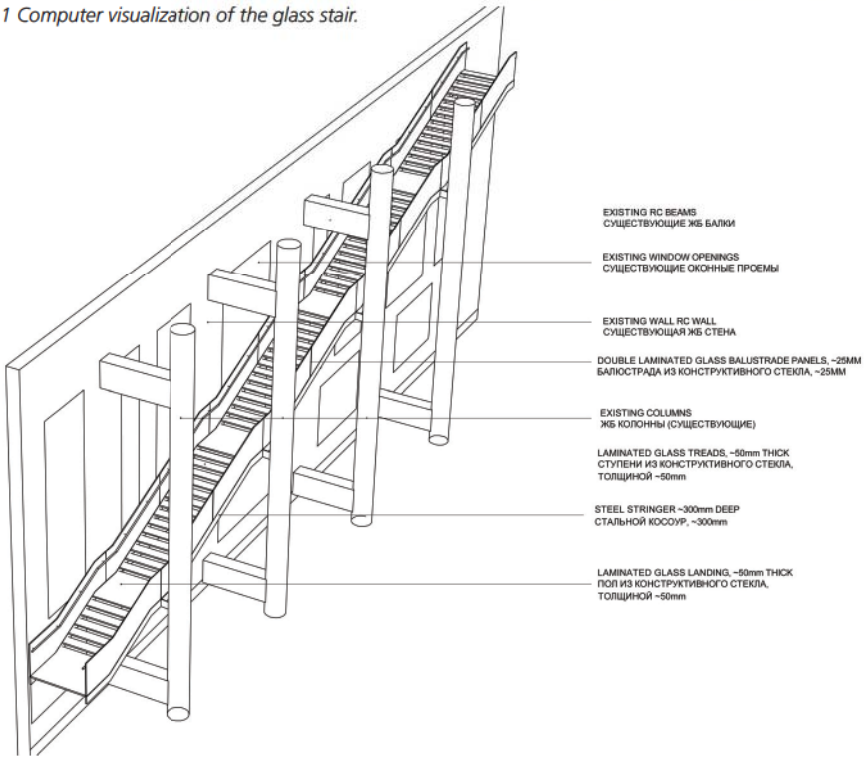

Figure 2 Initial concept drawing by Malishev Wilson engineers.

Load type	Load	Reference to the design code
Vertical floor load		
Imposed load, UDL	4кPa	NA.2 EN 1991 - Eurocode 1 category C35 (stairs of public buildings)
Ipomposed point load	4кN	NA.2 EN 1991 - Eurocode 1 category C35 (stairs of public buildings)
Balustrade loads		
Horizontal UDL	1.5кN/m	NA.2 EN 1991 - Eurocode 1, category C5 (ix)
Vertical UDL	1.5кN/m	П.8.3, СП20.13330.2011

Table 1 loads adopted for design of glass elements.

Load combinations taken in accordance with Eurocode 0&1.

Ultimate limit state
$1.35G_k + 1.5Q_k$

Serviceability
$G_k + Q_k$

Where
G_k = Permanent load
Q_k = Imposed load (live)

Performance criteria of glass elements

The differential deflections between inner and outer stringers are restricted in order to comply with the code requirements as follows;

Maximum deformations of the main structural elements of stairs due to imposed live load to be not more than: < L/360 (simply supported), L/180 (cantilevered)

Maximum deformations of the main structural elements of stairs under serviceability load com-bination (permanent + live) < L/240 (simply supported), L/120 (cantilevered)

Deformations of the glass balustrades: L/65

Glass treads deformations: L/500

Properties of structural glass adopted in the design

Mechanical properties adopted in the design were based on prEN-13474- Glass and glass structures, as follows:

Table 2 Mechanical properties of glass, based on prEN-13474

Glass type	Characteristic strength (MPa)
Annealed (float) glass	45
Thermally toughened	120
Thermally strengthened	70

Density (ρ) = 2,500 kg/m³
Young's modulus (E) = 70,000 MΠa
Coefficient of Poisson (μ) = 0.22

Glass tread composition

As part of Institution of Structural Engineers (IstructE, London, UK) task group which aims to revise existing guidance on "Structural use of glass in buildings", first published in 1999, we have used new design philosophy of limit state design principles which will form basis of the new guide. Based on effective thickness calculation method, glass tread composition was ad-opted as 8mm-12mm-12mm-8mm heat strengthened low iron glass laminated with 1.52mm SGP interlayer.

The riser

The riser was designed to take an impact of 50N at the speed of load application as T=0.05sec, with maximum allowable bending stress in glass around 52MPa. Based on this information, 2x10mm annealed laminated with SGP interlayer found to be sufficient to perform the task.

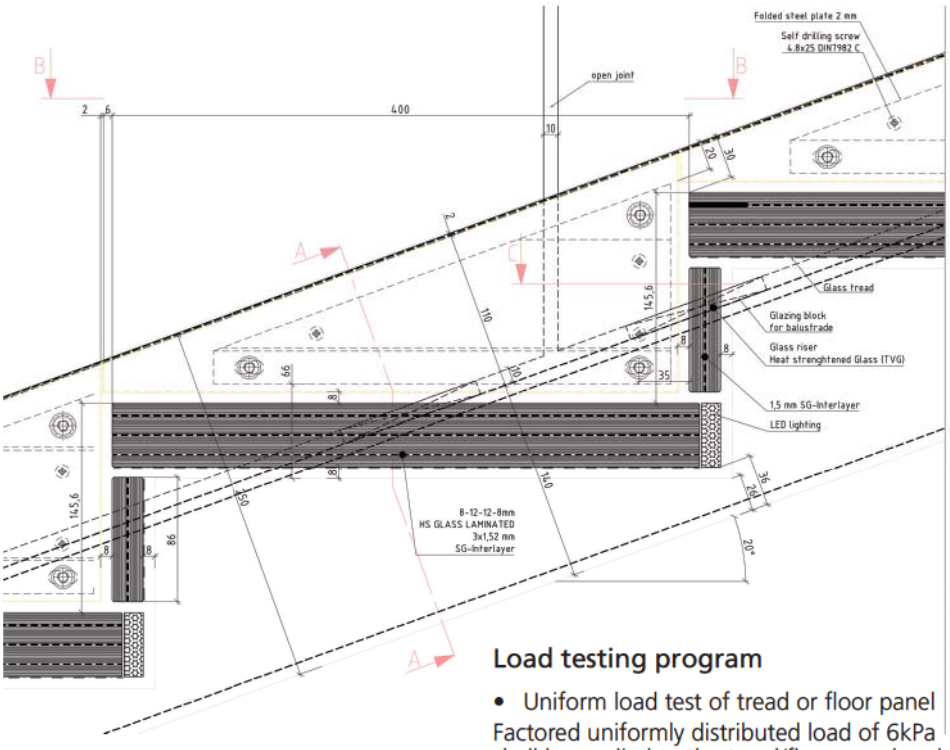

Figure 3 Typical section through the glass tread.

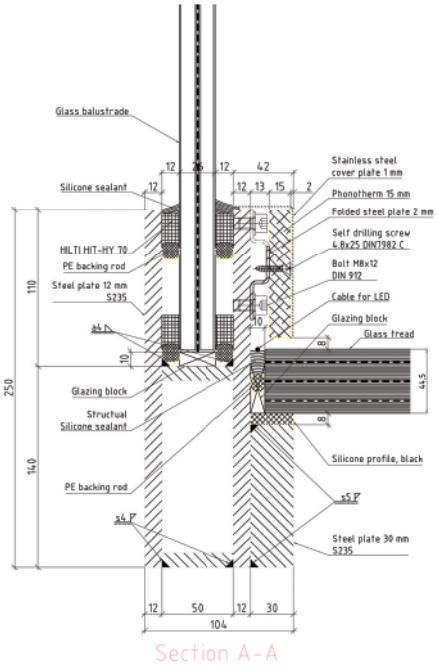

Figure 4 Typical glass tread to stringer connection detail.

Tread to stringer connection

The tread to stringer connection was chosen to be as simple as possible to facilitate quick in-stallation. The treads are supported in bearing by stepped shoulder plates. For extra lateral stiffness end of treads are bonded with silicone to the stringers.

TESTING

Mock up

From early stages of the project it has been clear that full size mock of the glass stair would have to be made to ensure that visual quality of the glass treads, its assembly as well as quality of lighting to meet aesthetic requirements set by the design team.

Load testing program

- Uniform load test of tread or floor panel

Factored uniformly distributed load of 6kPa shall be applied to the tread/floor panel and maintained for 1h. Minimum 3 specimens to be tested, deformations to be monitored during the test.

- Concentrated load test of tread or floor panel

Factored uniformly distributed load of 6kN shall be applied to the tread/floor panel via 100mm steel disc (separated from glass with nylon gasket) and maintained for 1h.

Minimum 3 specimens to be tested, deformations to be monitored during the test.

Figure 5 full size mock up for visual inspection of quality and testing.

Figure 6 Point load test with monitoring deformations

- Hard body impact test (EN356):

110mm steel ball impactor mass 4.11 kg dropped 3m to generate 120 Joules impact energy; 1st test all three or two panes intact apply 120 J once or three times at the centre of the panel;

Then, if one glass pane breaks or manually break top sheet, apply 120 J once or three times at the centre of the panel:

Apply characteristic live load of 4kPa maintained for half hour.

Apply characteristic live load of 4kN (at mid-span), maintained for half hour.

Figure 7 Hard body impact test.

Glass wall or balustrade panel - Heavy body impact load:

Standard 50 kg impactor dropped from 1200 mm to generate 600 Joules impact energy;

e) - 1st test all three or two panes intact apply 600 J three times at the centre of the panel

f) - Then, if one glass pane breaks or manually break outer glass pane, and apply characteristic horizontal load of 1.5kN/m

TESTING

All tests were carried out at Waagner Biro testing facilities ourside Vienna, by Hochschule fur Angewandte Wissenschaften FH from Munich supervised by Glass Institute from Moscow. All tests were successful and confirmed our initial design assumptions.

Following the testing, the stair went into fabrication and it is in a process of being installed on site in St Petersburg. The project will be officially open to public on 2nd May 2013.

Conclusions

We think that this project is an important step in use of structural glass in public buildings in Russia and we hope it sets a good example of design, detailing and installation of such struc-tures.

References

Vasilchenko-Malishev, G (2013), Design and construction of the feature glass stair for the new Mariinsky theatre, St Petersburg, Russia, COST Action TU0905, mid-term conference on Struc-tural Glass, Poreč Croatia, 2013.

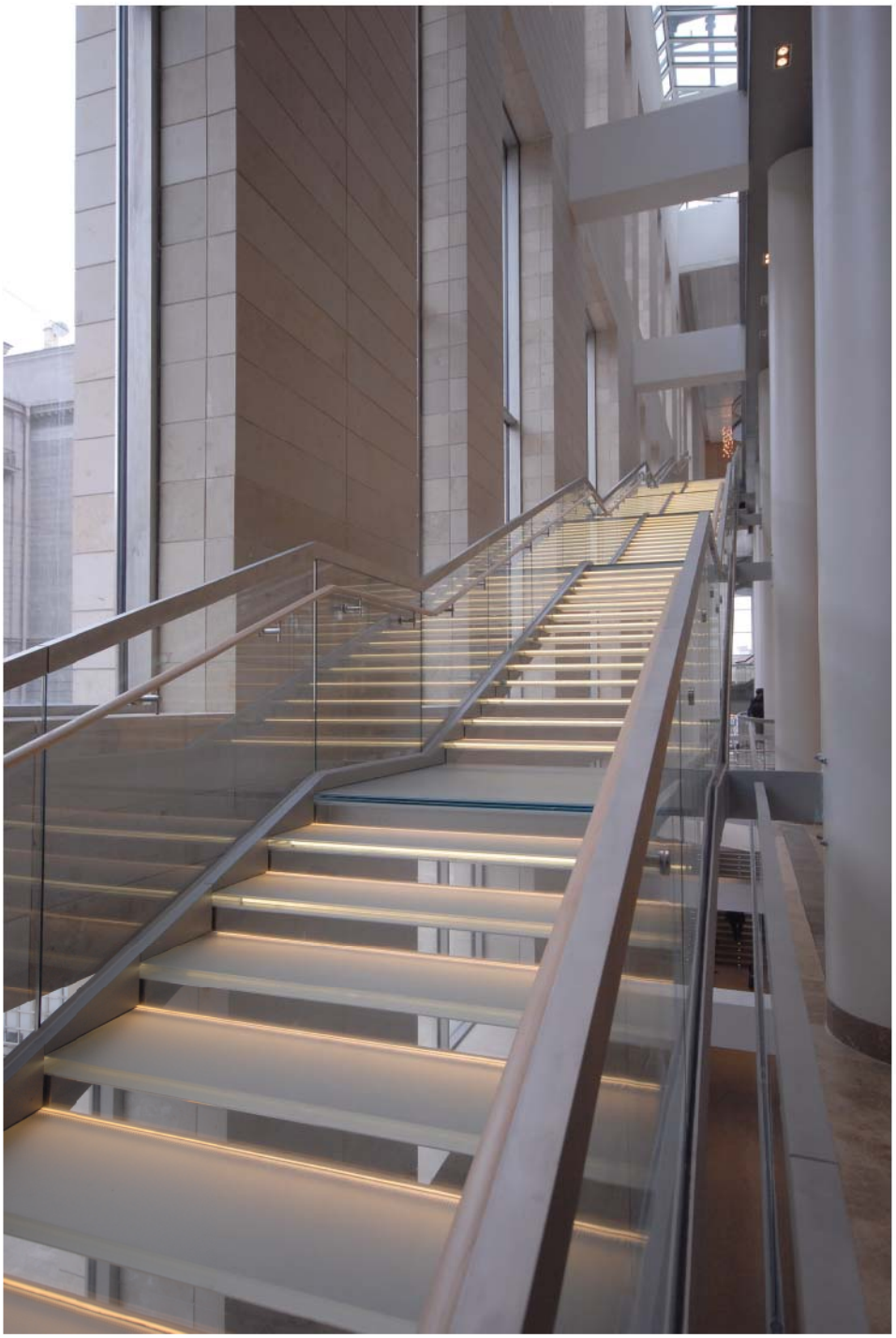

Figure 8 complete installation.