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Zaryadye Park, Glass Grid Shell Roof

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This paper will describe the design, detailing, testing and construction of the structural glass beams which make up the load bearing grid shell structure of the newly built Zaryadye Park in Moscow, Russia. The canopy structure is situated short distance from Red Square and the Kremlin. Structural glass beams, 72 in total, are connected into the main undulating steel grid shell structure which measures approximately 120m long and 60m wide. The beams themselves vary in length according to the geometry but are generally 3m long, 0.2m deep. The beams meet each other and the main steel structure at bespoke stainless steel nodes, and are topped by triangular glass roof panels. The glass beams were designed to accommodate Moscow's extreme weather conditions, with drifted snow loads of up to 350 kg/m^2. Differential movement of the main structure was another challenge for the design team, and required sophisticated linear analysis with over 150 load combinations. The resulting movements called for further development of the nodal connections and non-linear analysis of their performance. Due to a lack of legislation covering structural glass in Russia a so called 'Special Technical Standard' was required. This document was written with significant input from us and covers the technical aspects of glass and its performance. A full scale mock-up of one roof panel, complete with beams and node connections, was constructed and tested to gain approvals from the authorities. Zaryadye Park is Moscow's first new major landmark in 50 years and was opened on the 9th of September in time for the City Day celebrations.

Keywords: Glass, Structural, Beams, Russia

1. Concept

Malishev Engineers were approached to design 72 Glass Beams which form part of the main undulating steel grid shell structure which measures approximately 120m long and 60m wide. The beams themselves vary in length according to the geometry but are generally 3m long, 0.2m deep. The beams meet each other and the main steel structure at bespoke stainless-steel nodes, and the whole structure is topped with triangular glass roof panels.

Fig. 1: General view of the canopy with area in question highlighted in red

2. Global Analysis

2.1. Geometry

Geometry was a significant factor in the analysis, much of the stress is a result of nodal deformations and thus implicitly tied to the geometry.

The geometry was provided by the main engineer, scaled and imported straight into the structural analysis software.

2.2. Material

The glass beams are laminated from 5 pieces of 10mm toughened glass using a 1.5mm Trosifol PVB interlayer.

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As discussed in section 3.1 Dow Corning 895 Silicone was used to form the connections, this two-part silicone was required due to the size of the bite being used.

2.3. Loading

19 separate loads were considered, ranging from 0.25kPa for the lightest wind load to 3.36kPa for a rather more onerous Snow load.

Wind loads and resulting snow load drifts were provided based on wind tunnel test carried out specifically for this project. Snow and Wind and Temperature loads formed 19 separate load cases, which can be found in Table 1.

Table 1: All load cases.

Load case Number	Description	Value	Units
1	Self-Weight	1	kPa
2	Cladding Panels	0.5	kPa
3	Imposed Dead Load	0.5	kPa
4	Snow Load 1	1.4	kPa
5	Snow Load 2	1.1	kPa
6	Snow Load 3	1.7	kPa
7	Snow Load 4	1.6	kPa
8	Snow Load 5	3.4	kPa
9	Wind Load 1	0.2	kPa
10	Wind Load 2	0.3	kPa
11	Wind Load 3	0.5	kPa
12	Wind Load 4	0.4	kPa
13	Wind Load 5	0.3	kPa
14	Wind Load 6	0.1	kPa
15	Wind Load 7	0.3	kPa
16	Wind Load 8	0.4	kPa
17	Wind Load 9	0.3	kPa
18	Summer Temperature	46	ºC
19	Winter Temperature	48	ºC

2.4. Displacements

Each of the 19 load cases were accompanied the nodal displacements of the steel structure where it interfaced with the proposed glass beams an example of which is shown in Fig. 2.

node tables

node number	deformations						loadcase number	notes
	X (mm)	Y (mm)	Z (mm)	UX (rad*1000)	UY (rad*1000)	UZ (rad*1000)		
112	- 0.369	- 0.055	0.354	1.719	- 0.693	- 3.043	17	-
1839	- 0.216	- 0.109	0.098	- 0.058	- 0.009	- 0.028	17	-
1843	0.021	- 0.197	- 0.253	- 0.337	0.151	- 0.241	17	-
2698	- 0.098	- 0.134	- 0.050	- 0.001	- 0.016	- 0.002	17	-
2699	- 0.217	- 0.111	0.082	- 0.007	0.055	- 0.023	17	-

Fig. 2: Example of Data received from main engineers

2.5. Combinations

Armed with the geometry, loading, and known displacements of the steel structure we were able to form our own analysis.

Loading on our structure was twofold; primarily there was the direct loading on the structural elements (e.g. Snow) and secondly the imposed translations from the steelwork deforming transferred load to the structural elements. Within our analysis both methods of load application needed to be factored, with imposed translations and loads considered in one model.

This was a challenge for the design team because; although it is easy to ascertain the critical load case combination when dealing exclusively with traditional loads its not so easy when dealing with imposed translations as accumulations of errors and built in stresses may occur. A comprehensive study into the translations was carried out which involved generating over 150 load combinations using Microsoft Excel and VBA. The combinations were imported directly into the analysis software in tabular format.

2.6. Connection Stiffness

Due to the complex geometry and particularly the axial loads which were presented as a result. It was necessary to pay particular attention to the connection stiffness's. The connection themselves are discussed in more detail in section XX. But in order to analysis the structure successfully the following stiffness's were used.

T1	4000 N/mm	R1	30000000 Nmm/rad
T2	400000 N/mm	R2	3000000 Nmm/rad
T3	1000 N/mm	R3	30000000 Nmm/rad

2.7. Stress in Glass beams

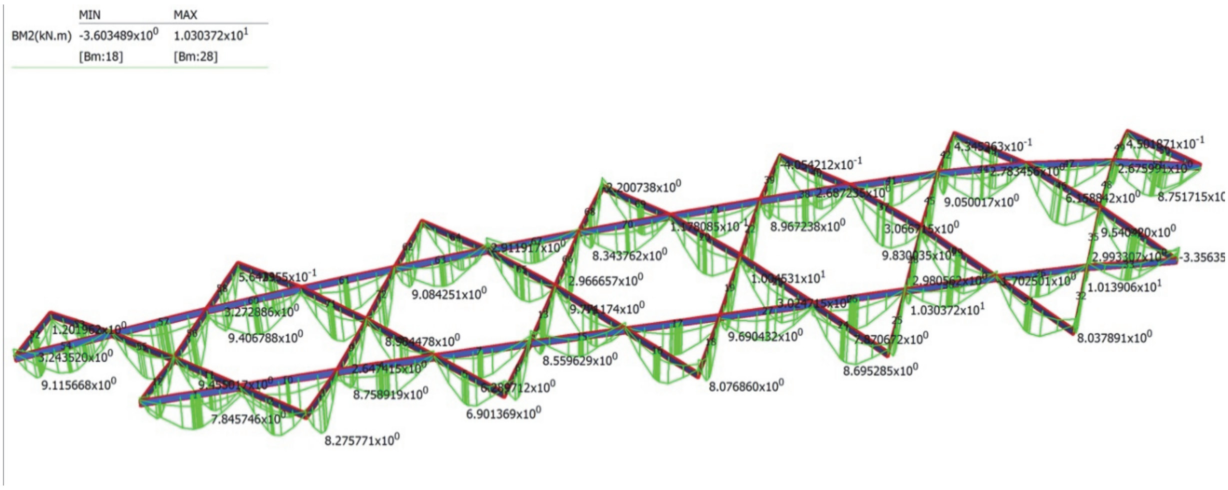

Fig. 3 a) Bending Moment diagram

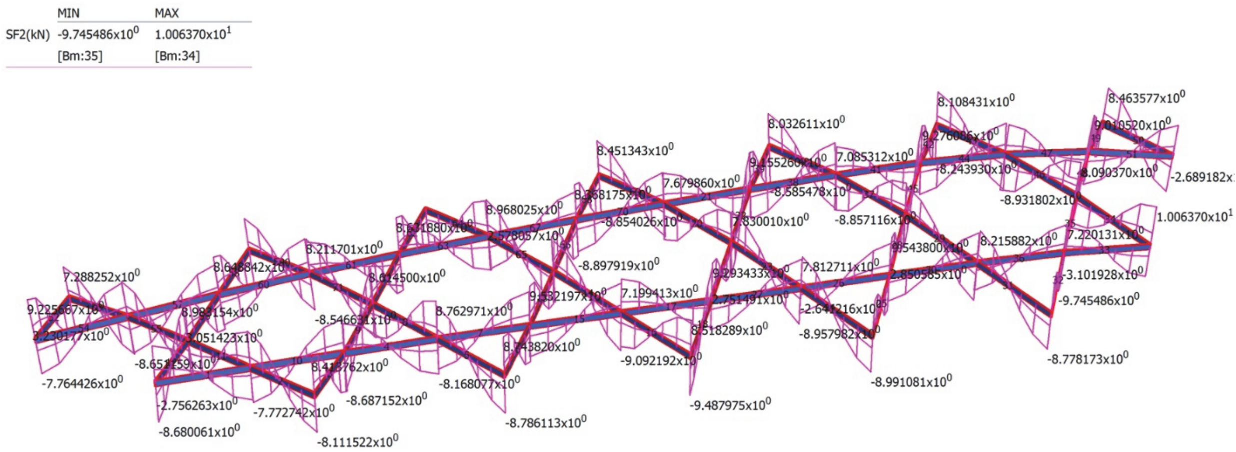

Fig. 4 b) Shear Forces

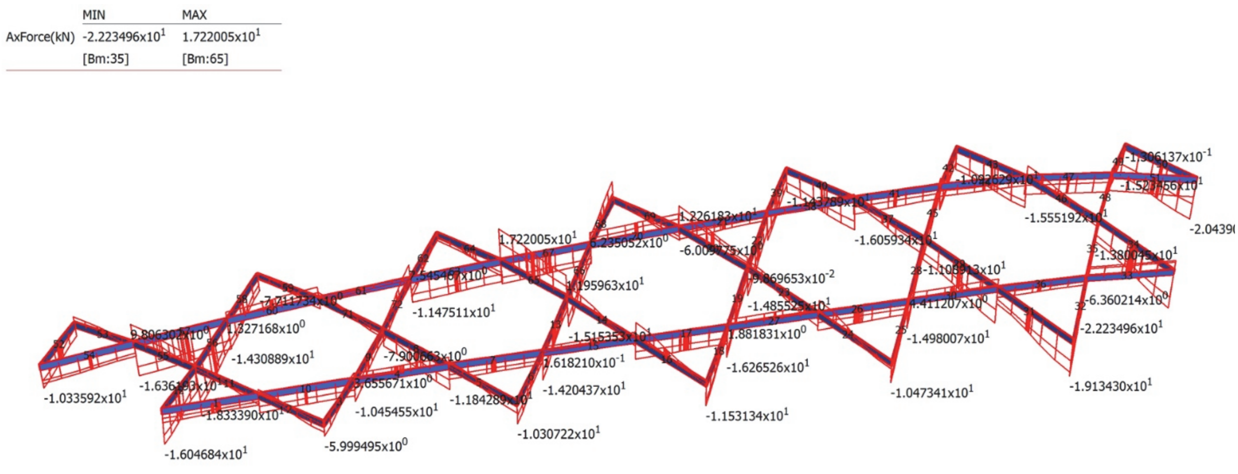

Fig. 5 c) Axial Forces

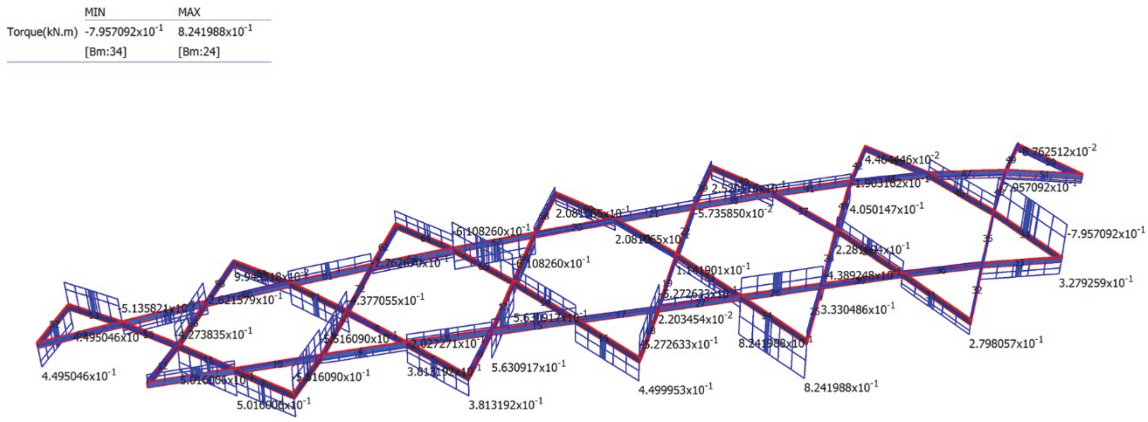

Fig. 6 d) Torsional forces

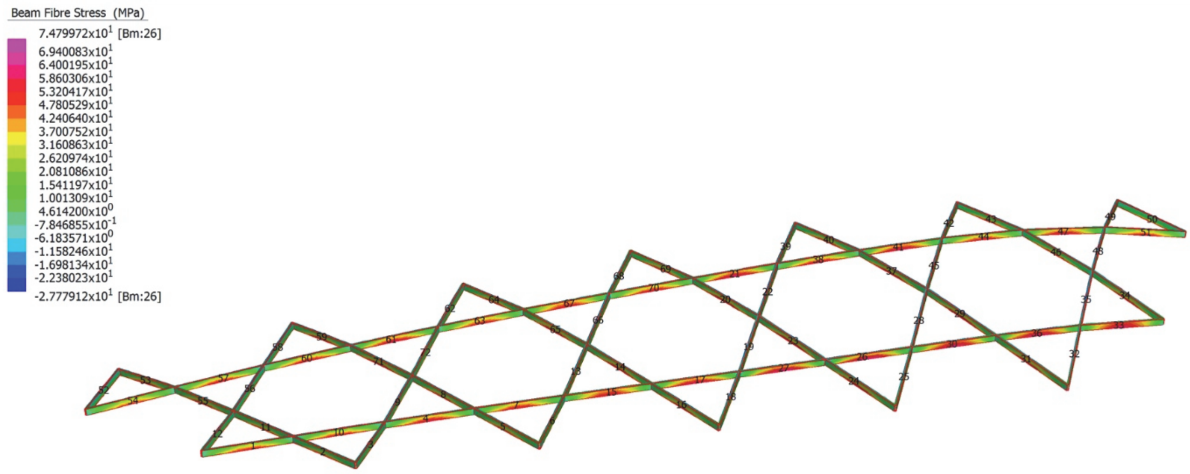

Fig. 7 e) Combined stresses in the beams

The stress in the glass beams could then be read directly from the analysis model. The maximum stress observed was 74 MPa, which was in accordance with maximum stress stipulated in the ‘Special Technical Standard’.

3. Local Analysis

3.1. Detailing

Originally the concept had allowed for bolted connections to the Stainless-Steel Nodes, but during the analysis it became clear that there was a requirement for more flexibility within the connection, particularly in the local T3 direction.

A combination of setting blocks and structural silicone were used to deliver the required flexibility. Due to the width of the silicone bite a two part Silicone Dow Corning 895 was used.

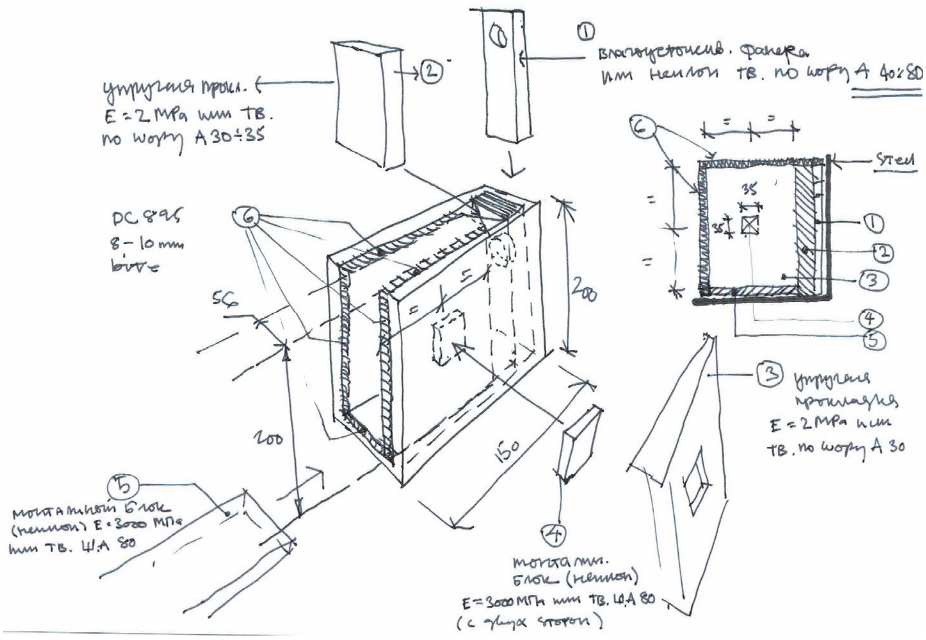

Fig. 8: Detailing of the Silicone Connections

3.2. Silicone brick model

Due to the complexity of the silicone connections and their obvious importance, a FEM anaysis model was constructed of the connection. This included the Stainles-Steel Shoe, the Silicone, the setting blocks and the end of the glass beam.

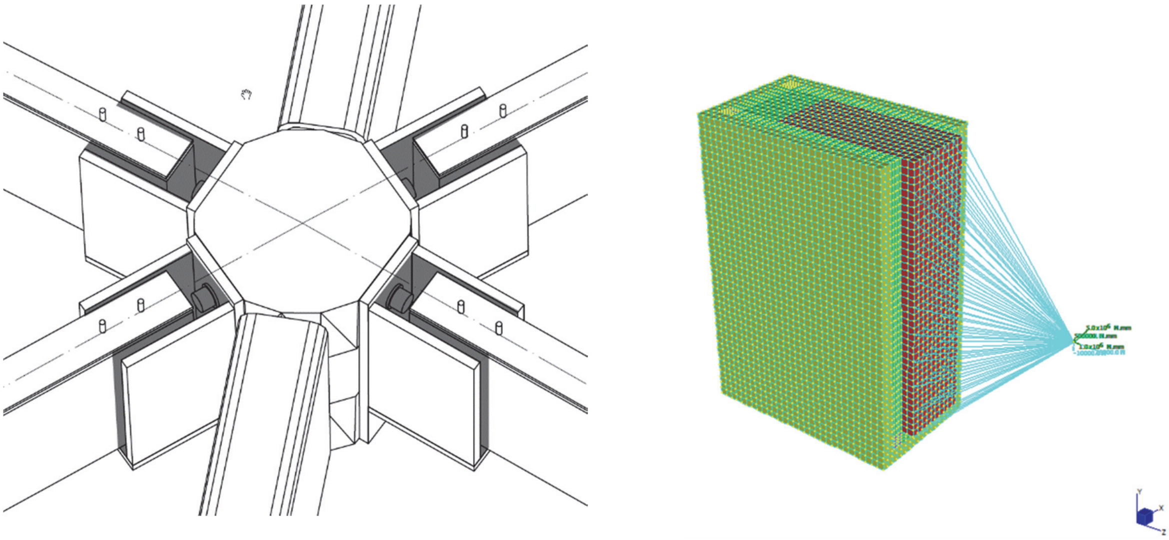

Fig. 9: Typical joint detail (left), Brick Model of the Silicone Connections (Right)

The silicone was modelled as a Non-linear material, using a stress-strain curve derived from (reference). The analysis software allowed direct input of this graph, and used the method of hook-rivilin.

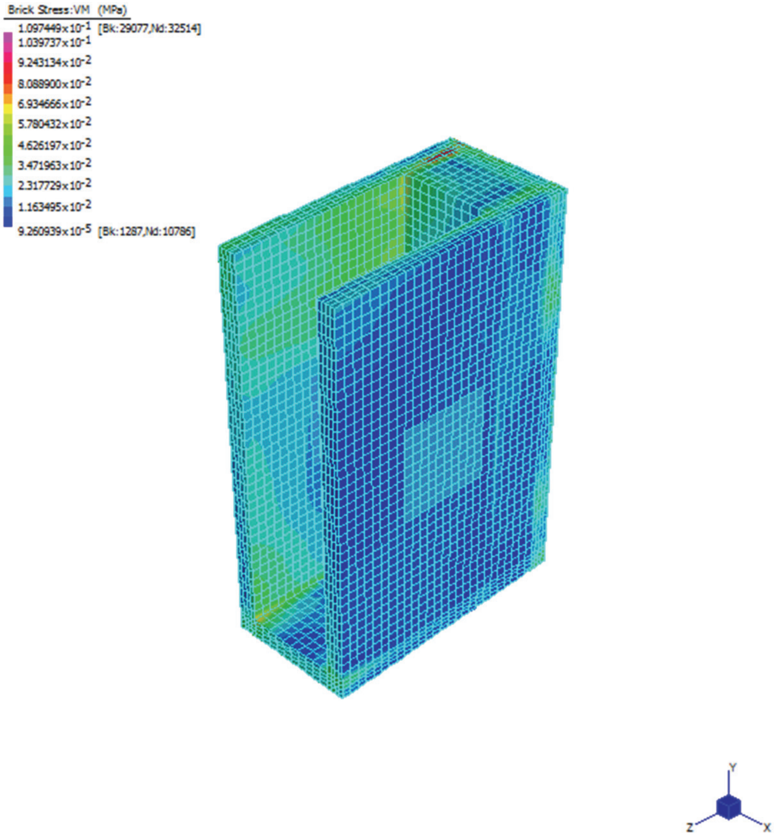

Fig. 10: Stress in the silicone from the Connection Forces

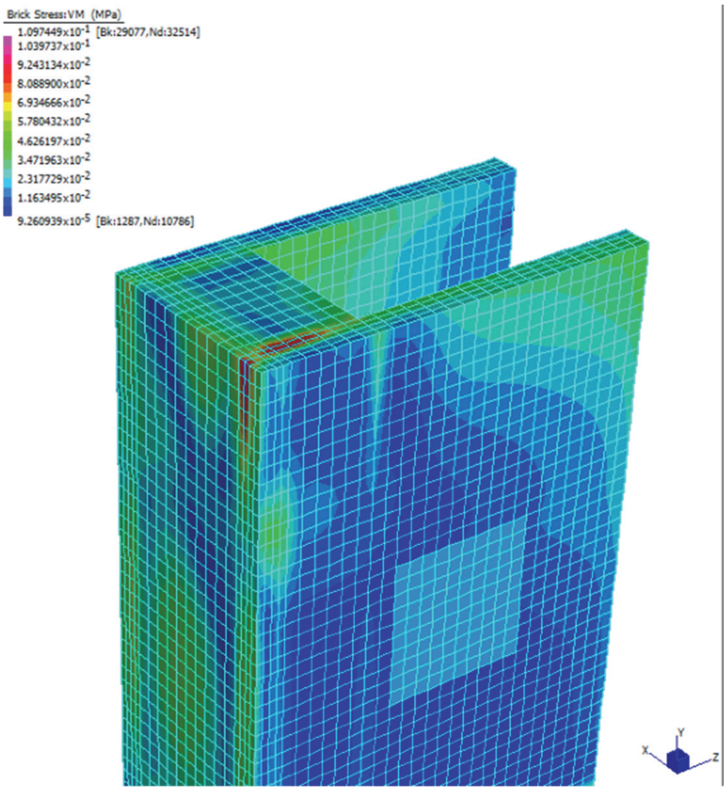

Fig. 11: Peak Stresses in the Silicone

4. Construction

4.1. Mock up

To demonstrate to the client that the glass is indeed capable of carrying required loading a full-scale mockup was tested on site before going into production.

Three nodes were fixed, with the stainless-steel shoes added. The glass beams were then installed with the silicon, before being topped with a glass panel.

The mock up was then loaded with sandbags to an equivalent of 6KPa

Fig. 12: Full Scale Testing of Glass Beam, Nodes and Panels

4.2. Installation

The installation of the glass beams took place in August 2017, after the

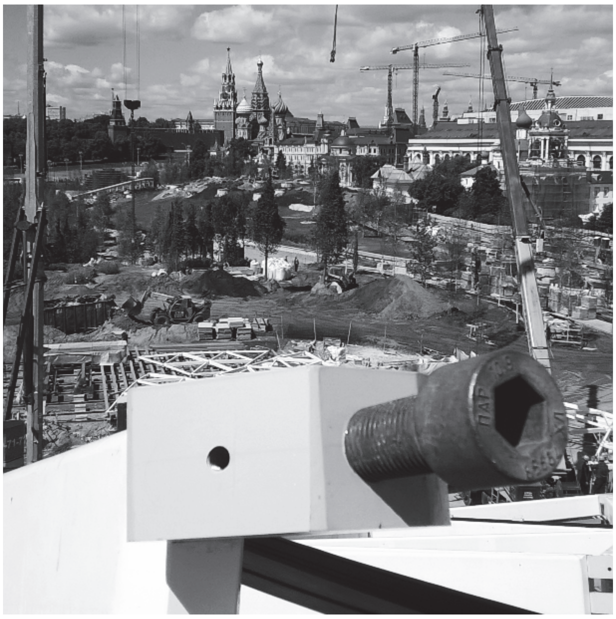

Fig. 13: Nodes being installed in view of the Kremlin

4.3. Completion

Zaryadye Park is Moscow's first new major landmark in 50 years and was opened on the 9th of September in time for the City Day celebrations.

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Acknowledgements

We would like to acknowledge our testing authorities in Moscow, Glass Institute for organizing full scale fragment testing.

References

Institution of Structural Engineers: Structural use of glass in buildings (2nd ed), London, IStructE, (2014)
prEN13474, Glass in building - Determination of the load resistance of glass panes, replaced by prEN16612 (2013)
Vasilchenko-Malishev, G.: Zaryadye Park, Glass Grid Shell, Glass Performance Days, Tampere, (2017)