29th International Conference
ENGINEERING MECHANICS 2023
Milovy, Czech Republic, May 9 – 11, 2023

ANALYSIS OF CABLE-NET SYSTEMS FOR GLASS FACADES

Komlev V.[*], Machacek J.[**]

Abstract: *The paper deals with numerical analysis of cable-net systems supporting large facades of prominent buildings/halls. Following the former proposal and validation of the numerical model by the Authors the current paper provides some details on the modelling in ANSYS software. Based on the previous results the embodiment of glass panes and their rigidity for the apt description of the behavior is essential. The use of geometrically nonlinear analysis for the planar cable-nets with glass laminated panes attached to the net with point-fixed bolted connections comprising glazing bolt and spider fittings is described. The preliminary parametric study concerning the net arrangement is presented.*

Keywords: Cable-net, Prestressing, Glass facade, Nonlinear analysis.

1. Introduction

Recent frequent use of large glass facades in exceptional buildings and halls (see Fig. 1) started the intensive investigations into the respective load carrying elements. Both experimental (Yussof, 2015, Yang et al., 2015 Marzuki et al., 2020,) and theoretical (e.g. Shang, 2014, Piyasena et al., 2019) studies are available.

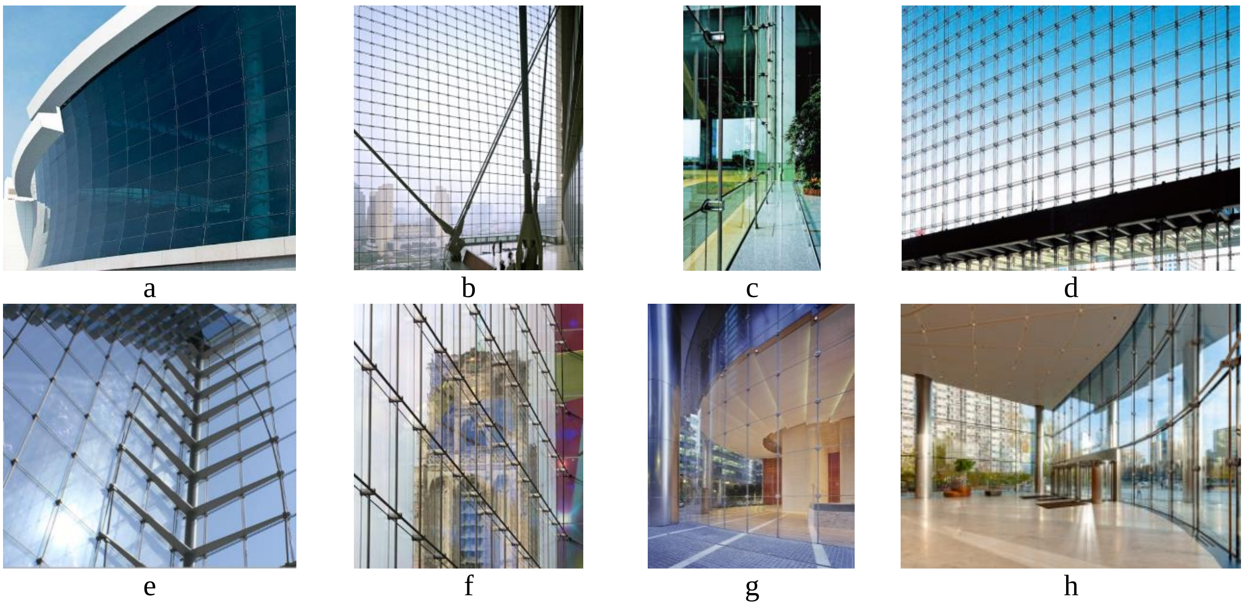


Fig. 1: Sea-Tac Int. Airport Seattle (2005), Beijing New Poly Plaza (2007), Kunming Changshui Int. Airport (2011), Beijing Petroleum Building (2007), Abu Dhabi's stock exchange (2012), Market Hall Rotterdam (2014), South Wacker Drive Chicago (2015), Mennica Tower Warsaw (2019).

[*] Mgr. Vitalii Komlev: Czech Technical University in Prague, Faculty of Civil Engineering, Thakurova 7; 166 29, Prague; CZ, vitalii.komlev@fsv.cvut.cz

[**] Prof. Ing. Josef Macháček, DrSc.: Czech Technical University in Prague, Faculty of Civil Engineering, Thakurova 7; 166 29, Prague; CZ, machacek@fsv.cvut.cz

ISSN: 1805-8256, doi: 10.21495/em2023-123

Basically, these facades are using laminated glass panes (typically from 2x6 mm to 2x12 mm, depending on pane sizes, with one or more 0.38 mm interlayer PVB sheets), point-fixed bolted (spider) or clamped system and prestressed net from stainless steel cables ranging of 19-36 [mm]. The cable-net may be formed as a single layer one-way cable system (Fig. 1c, 1h), double layer planar (Fig. 1b, 1d, 1e, 1f) or double layer curved systems (Fig. 1a, 1g). Some appraisal of the systems was described in the previous paper of the Authors. Typical square meshes of the nets range from l300-1500 [mm] or similar rectangular ones up to 1200x2400 [mm].

The paper describes some details of the numerical analysis in ANSYS 2021/R2 software using Python code for a facilitation of the work with data. Finally, the starting progress of a parametrical study within the above mentioned practical limits is demonstrated.

2. Numerical analysis

Three finite element models of prestressed facade cable-nets were created for the numerical analyses. Each model has 5 vertical and 4 horizontal cables and 4 main elements: glass panes, point-fixed bolted fittings (“spiders”), the actual bolts and cables (see Fig. 2). Model 1 with glass panes 1.2x1.2 [m] and due to a gap between the adjacent glass pane of 5 mm with the total size 7.22x6.015 [m], model 2 with glass panes 1.5x1.5 [m] and the total size 9.02x7.515 [m], model 3 with glass panes 1.8x1.8 [m] and the total size 10.82x9.015 [m].

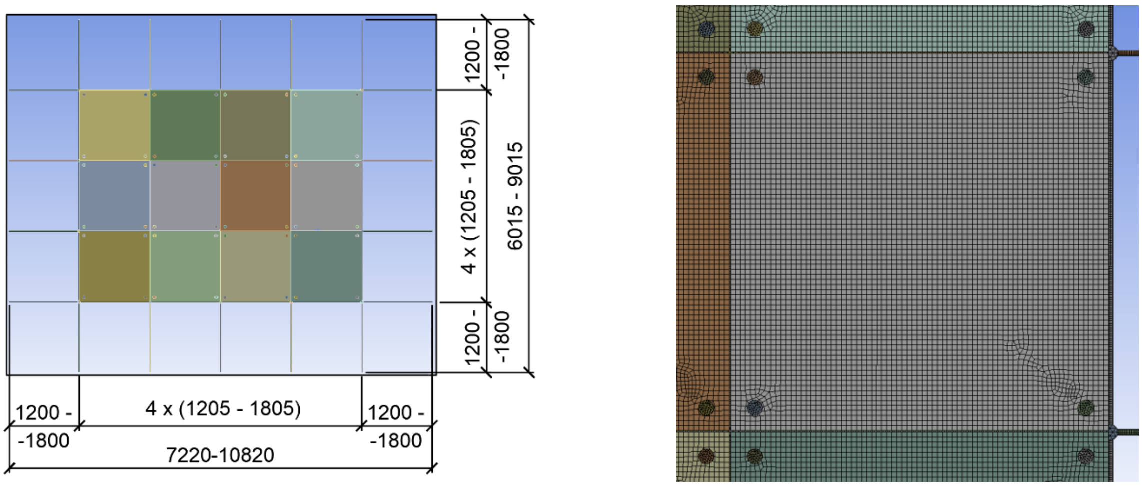
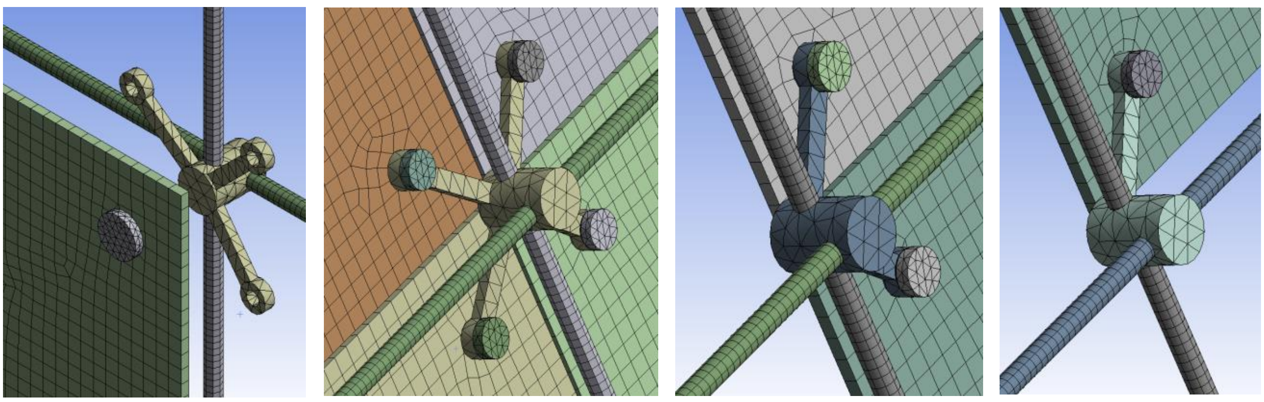


Fig. 2: Finite element model: General view and the example of one glass pane FE meshing.

The glass panes are attached to the net by the spider fittings with bolts. The spiders have two holes for joining with the horizontal and vertical cables. All the cables’ ends have movement restrictions in all axes.

There are three types of spiders with different number of arms depending on the number of the glass panes to connect with (see Fig. 3). There are six 4-arms joints around the model center, ten 2-arms joints at the cable-net’s edges and four joints with one arm in the corners of the cable-net.



a b c d

Fig. 3: Attachment of the glass panes to the net (front and back views), edge joint and corner joint.

Contact pairs of glass pane/bolt, spider/bolt and spider/cable have a frictional connection between their contact surfaces with the appropriate friction coefficients. All the elements were created as solid bodies ("bricks").

The material of the glass panes (thermally strengthened to EN 12150-1 and heat soaked thermally toughened safety glass to EN 141179-1) was considered as 2x6 mm glass with PVB (polyvinylbutyral) 0.76 mm interlayer. In the FE model the glass was applied as "laminated glass" of 12 mm thickness in accordance with the ANSYS default settings, with modulus of elasticity 70 GPa, density 2500 kg/m^3, tensile strength 120 MPa (f_{gd} = 120/1.8 = 66.7 MPa), compression strength of 1000 MPa and Poisson's ratio 0.2. Cables were considered as Macalloy stainless steel strands 1x19 with diameter of 19 mm, modulus of elasticity 107 GPa, minimum break load 212 kN (F_{Rd} = 212/1.5 = 141.3 kN) and Poisson's ratio 0.27.

The mesh sensitivity test was conducted with a simple finite elements model, which consisted of 2x2 cables with one glass pane. The mesh sizes were reduced step by step until the response of the model didn't demonstrated significant changes. Resulting model 1 consists of 114027 finite elements, model 2 of 159563 finite elements and model 3 of 202645 finite elements.

The prestressing of the cables was defined by applying an initial stress in the cables. The ANSYS software provides its APDL command "INISTATE", which allows to change the initial state of the structure by using appropriate parameters. The value of the initial force was applied as 30% of minimum break load, i.e. 63.6 kN per cable. This value corresponds to the initial stress of 224.43 MPa, which was applied in the first loading step.

The façade wind loading was taken in accordance of EN 1991-1-4 (region III, terrain IV, force coefficients for suction as -1.4) as a pressure of F_{wd} =1 kPa and applied on the glass panes surfaces in the next, final loading step.

3. Parametrical study

The study demonstrates a detailed deflections and stresses of the cable-net finite element model under the prestressing and given load.

The maximum deflections are naturally in the geometrical center of the models (see Fig. 4). The largest model 3 has the maximum displacements w_{max} =156.5 mm. The limits for façade deflections in accordance with CEN/TS 19100-2:2021 (E) (Design of glass structures - Part 2: Design of out-of-plane loaded glass components) may be considered as $w_{lim} = L/50$, where L is the shortest length between the supports. The maximum deflection for the model 3 is w_{lim} = 9015/50 = 180.3 mm and, therefore, acceptable.

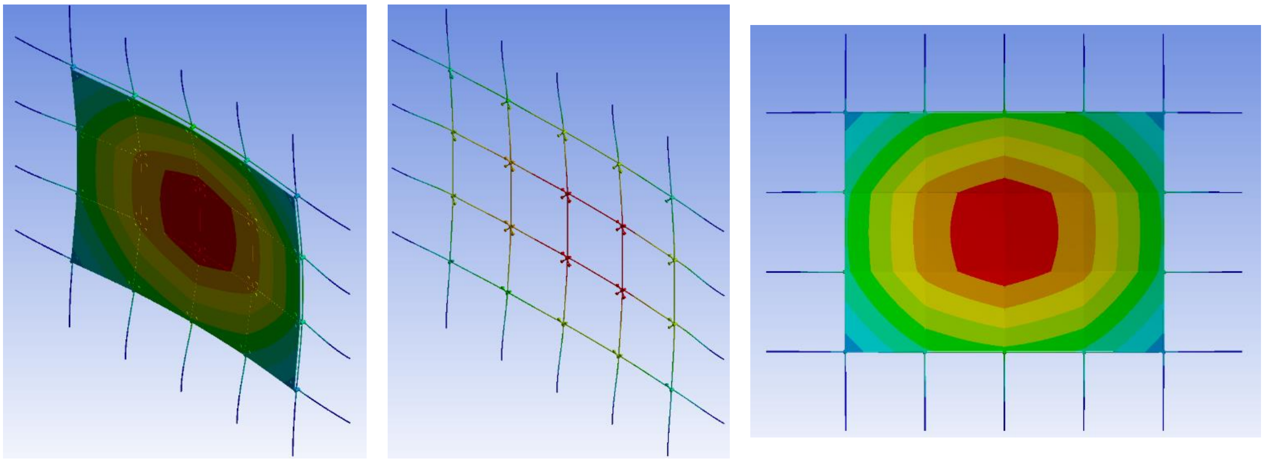


Fig. 4: The displacements distribution of the model 3.

The maximum stress in the glass panes was indicated around the holes for the bolts and exceeds the tensile strength given in Chapter 2. This indicates the need for greater thickness of the laminated glass (instead of 2x6 [mm]) as indicates also realized facades. Relatively large stresses were found also in the spiders (see Fig. 5). This indicate a necessity of a careful choice of the spider material (usually stainless steel 1.4404).

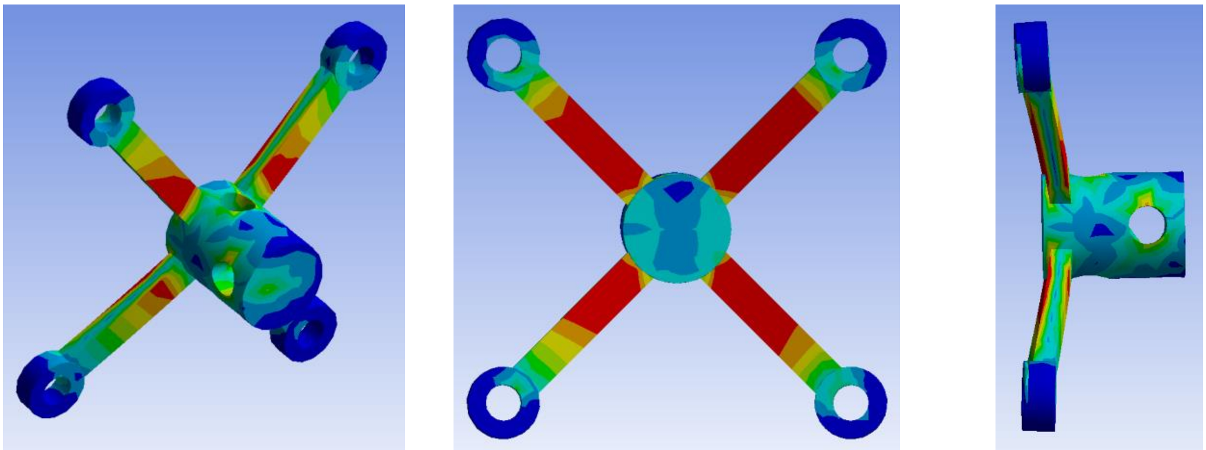


Fig. 5: The stress distribution in the spider fitting of the model 2.

4. Conclusions

The study presents results of numerical analyses concerning the façade prestressed cable-nets. Following the published contribution of Authors, 2022, dealing with validation of a numerical analysis on test provided by Yussof (2015), this paper deals with façades of the regular dimensions. The FE model using ANSYS software describes input data of the relevant materials (laminated glass, cables and fittings), appropriate FE elements and meshing procedure including study of the mesh sensitivity. The resulting models are using up to 200 000 finite elements. The façade models were subjected to initial prestressings and external loading modeling of a realistic wind suction/pressure of 1 kPa. The maximum deflections found in the centers of the models indicate reasonable and acceptable values. The results also indicated that the maximum stresses were located in the spiders, followed by cables and glass panes, which are unacceptable and require use of greater glass pane thickness. The study provides an insights into the cable-net façade systems and specifies the orientation of the continuing parametrical study.

Acknowledgement

Support of the Czech Technical University grant SGS22/141/OHK1/3T/11 is gratefully acknowledged.

References

Aeworldmap.com (2015) https://aedesign.files.wordpress.com/2015/09/111swackentry1.jpg

Fentress Architects (2005) Sea-Tac Int. Airport https://novumstructures.com/project/sea-tac-international-airport/

Glass curtain wall for China Petroleum Building (2007) https://www.broadwayglass.us/case-view/217.html

Komlev V., Machaček, J. (2022) Cable-net systems supporting glass facades, Int. Conf. Eng. Mechanics 2022, Eds. C. Fišer and J. Náprstek (ITAM of the Czech Academy of Sciences, Prague), Milovy, pp. 205-208.

Kunming Changshui International Airport, https://www.airport-technology.com/projects/kunming-changshui-international-airport/

LED News (2019) https://laufsed.com/mennica-cable-wall-is-largest-in-poland/

Marzuki, N. A., Yussof, M. M., Keong, C. K. (2020) Experimental performance of the cable-net structure supported glass systems with cable damages. AIP Conf. Proc. 2239, 020030.

Octacube (2014) https://www.octatube.nl/en_GB/project-item/projectitem/6-market-hall.html

Piyasena, R. R. C., Thambiratnam, D. P., Chan T. H. T., Perera, N. (2019) Comparative analysis of blast response of cable truss and cable net façades. Eng. Failure Analysis, 104, pp. 740–757.

Seele (2012) https://seele.com/references/sowwah-square

Shang, C. D. (2014) Numerical simulation and analysis of the mechanical behaviour of cable supported glass façades. PhD Thesis, UPC University of Barcelona, 171 p.

Skidmore, Owings & Merrill: Sarkisian, M., Mathias, and Mazeika, A. (2013) Suspending the limits, ASCE, https://archello.com/project/the-new-beijing-poly-plaza-2

Yang, L., Shi, G., Yin, H., Shi, X. and Guo, Z. (2015) Full-scale experimental study on the influence of damages on the static behavior of the single-layer cable net structure. Structures, Vol. 3, pp. 153-162.

Yussof, M. M. (2015) Cable-net supported glass façade systems. PhD Thesis, University of Surrey, 279 p.