Finite Element Analysis of Glass Panels with Bolted Connections Designed for a Running Car

Eren Kalay[1], C. Erdem Imrak[1], Adem Candas[1]

[1] ITU Elevator Technologies Laboratory, 34437, Istanbul, Turkey
kalaye@itu.edu.tr
[2] ITU Elevator Technologies Laboratory, 34437, Istanbul, Turkey
imrak@itu.edu.tr
[3] ITU Elevator Technologies Laboratory, 34437, Istanbul, Turkey
candas@itu.edu.tr

Keywords: Lift, Elevator Cab, Finite Element Analysis, Point Fixed Laminated Glass

ABSTRACT

Nowadays, there is a growing trend to increase the transparency of buildings. With the developing technology now, it is possible to see this trend in the lift sector also. Increasing glass industry has revealed the term structural glass that consists of two tempered glasses with the layer of PVB. Designers have created four point fixed glass facade system for lifts with using the structural glasses to increase aesthetic view. However, fixed holes create stress concentration that could lead to catastrophic failures. The aim of this paper is to investigate stress distribution around the drilled holes of lift's glass facade during car running.

1 INTRODUCTION

The technological and innovative developments in glass industry have provided to construct transparent curtain wall system. In order to improve aesthetical view of lift cab, glass facade system came into use. Glass façade systems can be divided into two categories frame supported and point supported façade systems. In comparison to typical framed glass, point supported one is a novel system with additional benefits such as effective use of natural illumination and significance of aesthetic value. The four main components of point supported glass systems are as follows (Sivanerupan et al., 2014): glass panel, bush, bolt and spiders. Annealed glass has largely replaced with tempered glass in recent years which was also used in this study because glass that has been tempered is generally four times stronger than glass that has been annealed owing to residual stress (Zhang et al., 2014).

In (Wang et al., 2012), the bearing capacity of metallic spiders was investigated experimentally and numerically in glass façade systems. Based on the study reported in this article, aluminum alloy spiders are suggested due to the lightness and strength. To explore the mechanical behavior of glass panels joined by clamping joints in cable net facades (Feng et al., 2012) theoretical analysis and model test were also carried out. The core of the glass panel's edge showed the highest level of stress which does not meet the specifications for the maximum tensile stress in four fixed point systems. While researches have investigated on the mechanical behavior of glass panel and spider little is documented about the stresses around the holes (Wang et al., 2016).

Glass panel is fixed from the holes that drilled before by bolts that also called routels. As is known, drilled holes on a plate can cause stress concentrations because of that special attention is required on these holes to prevent failure. Come precautions are taken for safety like using plastic bush for uniform loading from bolts to drilled holes, assembling bolts into glass with gap etc. But calculation is still necessary by reason of the fact that glass is a brittle material that can engender catastrophic failure and this failure can lead to undesirable injuries.

Four point fixed glass panels on lift are under the influence of the forces that are acting from guide rails (Demizsöz et al, 2005; Imrak et al, 2008a) while running. The forces acting from outside transfer to the glass via bolts and these forces are called in-plane loads. First, these forces were calculated according to the given data from Buga OTIS and then finite element analysis of the glasses were performed under the obtained loads.

2 GLASS PANEL SYSTEMS

A four point fixed glass façade systems consist of glass panel, bolts, sealing materials and spider metallic supporter. Laminated glass (LG), which was used in this study as a glass panel, is made up of two or more glass panes that are permanently linked together with polymer interlayer (Hidallana-Gamage et al., 2014). LG panels typically employ annealed, tempered or heat strengthened glass with polyvinyl butyral (PVB) functioning as interlayer material. The interlayer keeps glass pieces once they break, preventing flying dangers and absorbs energy once the glass fractures. Along with choosing the glass, a support system can also be chosen. The frame and the point support system are two main categories (Tsalkatidis and Moastuen, 2019). Despite the need for drilling holes in the glass, bolted fastened structural spiders in other words point support systems are often used.

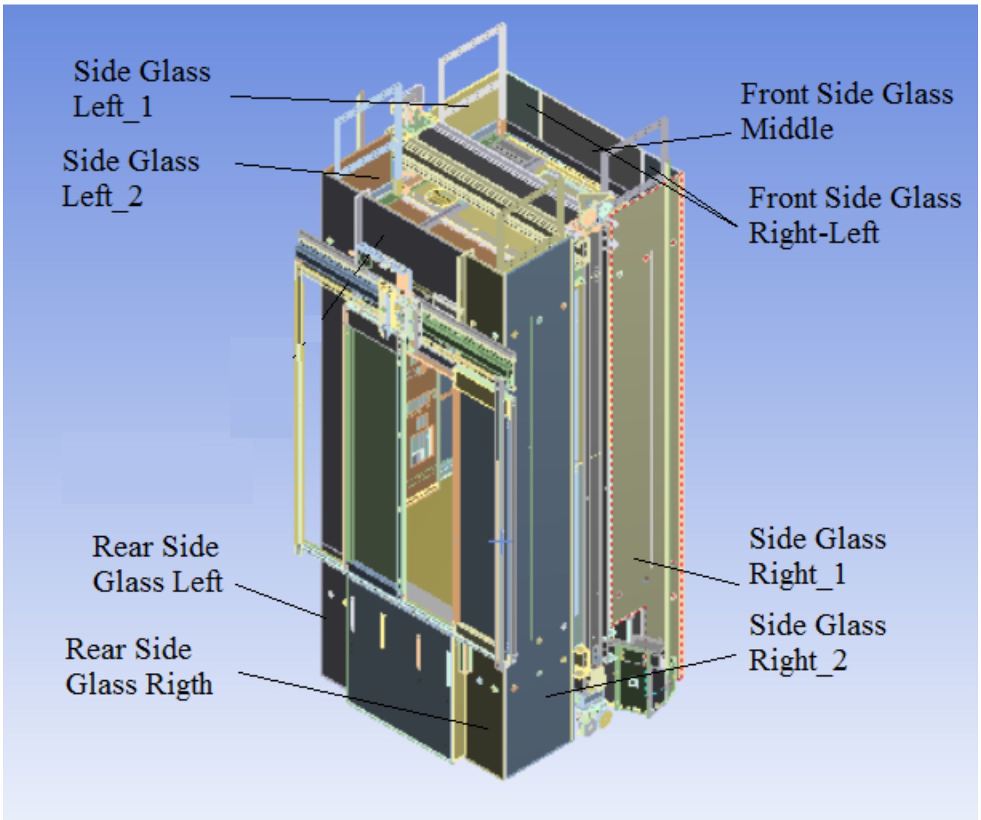

Figure 1. Glass panels of lift cab

In this study, laminated glass with point fixed supported system were used as a glass façade system for a lift cab. As it seen shape of the panels are different from each other and all parts of the glass panels that are labelled in Fig 2. analyzed separately by applying the in-plane forces derived from guide rails.

3 FINITE ELEMENT ANALYSIS OF GLASS PANEL

An engineering problem can be solved by using experimental methods, graphical methods and computational methods (Bi, 2018). Graphical techniques were crucial in the days before computers. Nevertheless, they can only deal with a few basic issues. Experiments are still widely used and still efficient way for resolving engineering challenges. However, cost and wasting time to perform experiments are the disadvantages that should be considered at the design stage. A computational method which can be analytical or numerical solves an engineering problem by using computers. Analytical methods can be applied only to simple problems or basic geometries. The most popular way engineers use computer is through numerical methods. It can be applied to complex engineering problems and usually finds an answer effectively.

The model developed for finite element modeling is generated and solved with ANSYS version 17.2. The finite element modeling includes following procedure; defining material properties, meshing, boundary conditions, defining the loads and solution at the end. First, the material properties (Hidallana-Gamage et al., 2014) of the parts were included. Some of the material properties of the assembly parts which are included in FEM analysis are shown in Table 1.

Table 1. Material Properties

Material	Material Behavior	Young Modulus [MPa]	Poisson Ratio
Glass Panel	Linear	72000	0,22
PVB	Nonlinear	1,5	0,49
Steel Bolt	Bilinear	210000	0,3

To perform the analysis, it is necessary to input the material properties such as modulus of elasticity E and Poisson's ratio v for a perfectly elastic material model like the glass used in lift cab facade. For this study, the material properties of soda-lime silicate float glass (tempered) obtained from literature (Hidallana-Gamage et al., 2014).

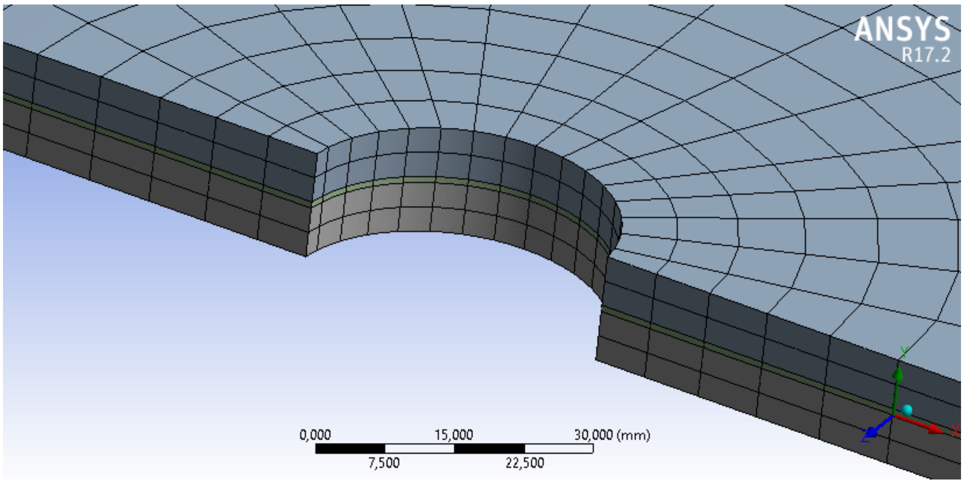

Figure 2. Meshing the glass panels

As it seen in Fig 1. glass panel model is split into a finite number of elements. In order to obtain correct results mesh quality is highly important. Solid186 element type is used for glass and uniformly distributed around the holes. Solid 186 is a higher order 3-D node solid element that displays quadratic displacement behavior. Twenty nodes, each with three degrees of freedom in the x, y and x directions define the element. The other process after meshing is embedding boundary conditions. Fixed support applied to the bolts and cylindrical support between glass holes and bolts thus connection within bolt and glass panel was unconstrained.

Glass panels are shown in Fig. 2. All these glass panels are modelled in similar way from meshing to boundary conditions. All parts were excluded except glass panels, bolts and bushes from the simulation in order to simplify the analysis.

Table 2. Weights and maintenance loads

Glass panel	**Load**
Front Side Glass-Left	60,26 kg
Front Side Glass-Right	60,26 kg
Rear Side Glass-Left	111,63 kg
Rear Side Glass-Right	111,63 kg
Side Glass-Left_1 Load for maintenance	108,13 kg 80 kg
Side Glass-Left_2 Load for maintenance	93,6 kg 80 kg
Side Glass- Right _1 Loads for maintenance	99,46 kg 80 kg
Side Glass-Right_2 Load for maintenance	103,1 kg 80 kg

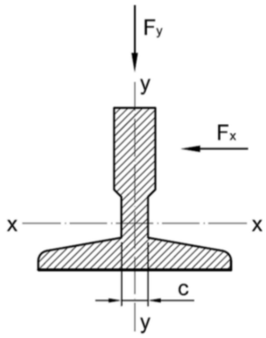

Figure 3. Forces acting on the guide rail

The loads acting on the glass panel via guide rails has calculated according to the EN 81-1-A3 standard and results are listed in Table 2. Two components of loads were considered, which are Fx and Fy, according to the standard. Beside this, different operation conditions were also considered as it seen in in Table 3 to be able to get most critical stress value on the panel.

Table 3. The loads transferred from guide rails

Car mass	P	= 4150 kg
Rated load	Q	= 2000 kg
Case 1		
Safety device operation	Fx	= 2921,55 N
	Fy	= 0 N
Normal Use - running	Fx	= 1752,93 N
	Fy	= 0 N
Normal Use - Loading & Unloading	Fx	= 2155,46 N
	Fy	= 4139,13 N
Case 2		
Safety device operation	Fx	= 0 N
	Fy	= 5472,15 N
Normal Use - running	Fx	= 0 N
	Fy	= 3283,29 N
Lift speed	v	= 1.2 m/s

The maximum value of F_x and F_y was chosen to apply to the lift cab in the analysis. Beside these loads, glass panel’s own weight and maintenance loads (see Table 2) are also considered in the FEM analysis. It is shown in Fig. 3 and Fig. 4 that maximum stress value is obtained around the drilled holes on Side Glass Right_1 part as expected because of stress concentration. The bolts and glasses are assembled with bushes to prevent crack risks and also bush also provides uniform load transferring which explains nearly similar stress distribution situation around all the holes in Fig 3. The maximum stresses for all glass panels are listed in Table 4. All these stress values are under the critical stress (Fors, C., 2014) which means that designed glass façade for lift cab is suitable for usage when considering car mass, rated load, its own weight and lift speed.

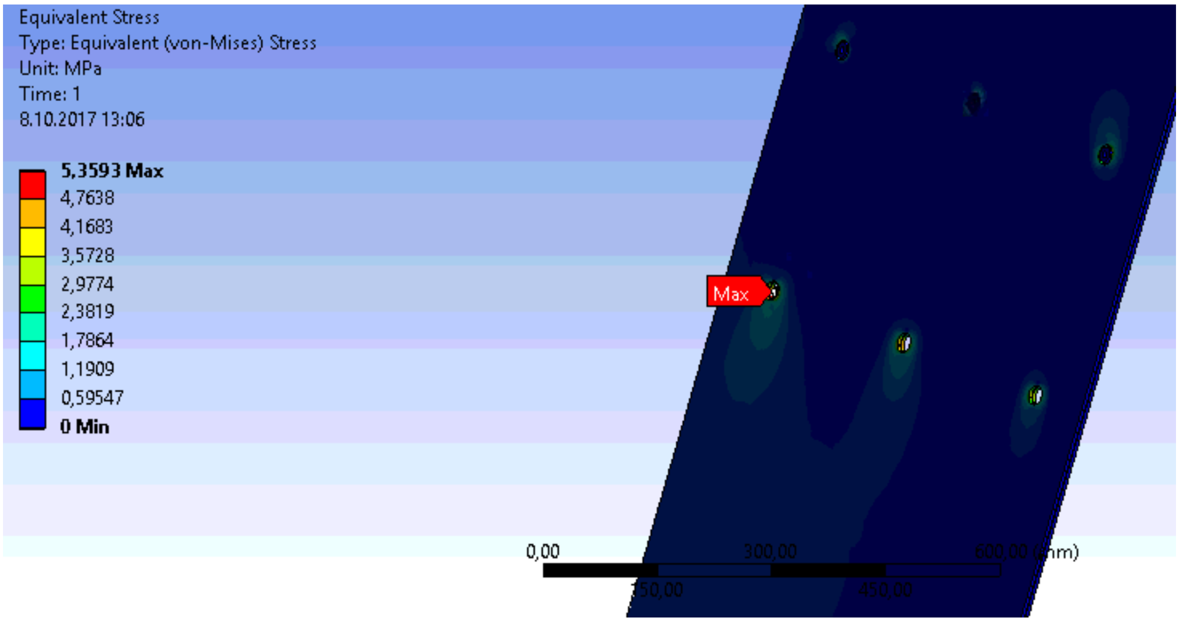

Figure 4. Von Misses Stress Value of Side Glass Right_1 part

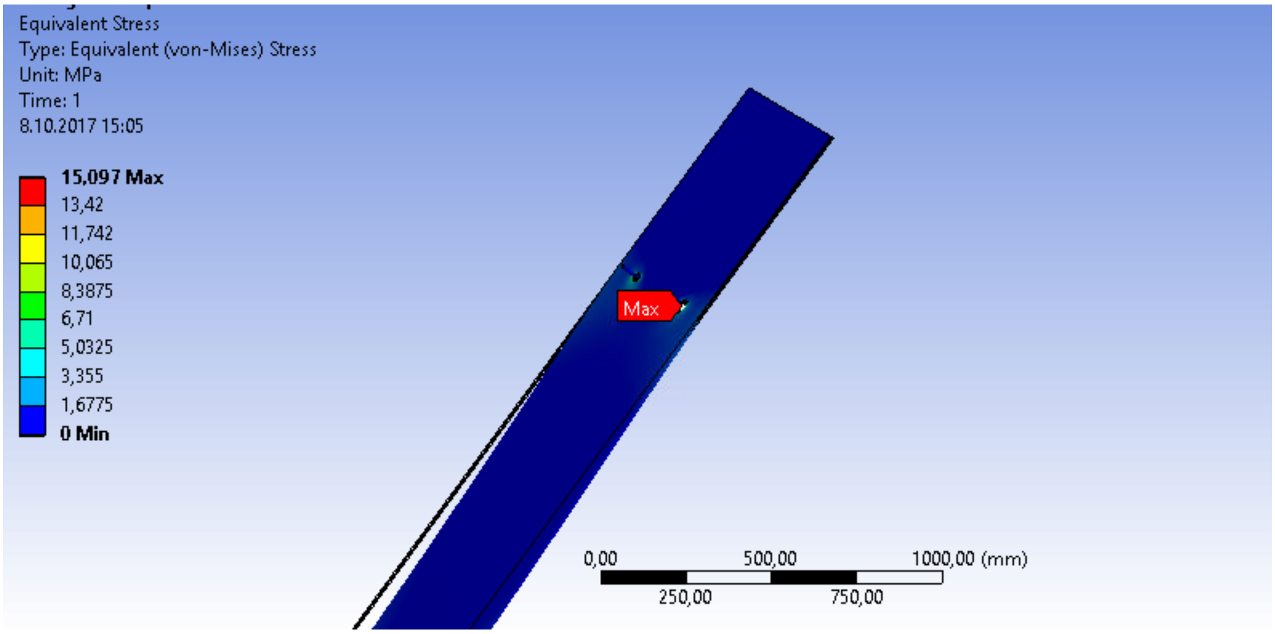

Figure 5. Von Misses Stress Value of Front Side Glass – Right

In addition to the stress around the holes, the closeness between the holes are another significant parameter to be considered. If the holes were closer the stresses may be multiplied despite applying the same load. From Fig 4 and Fig 5 it can be said that the distance between the holes are sufficient to design glass panel safely.

Table 4. The maximum stresses on each panel

Glass Panels	Von Misses Stress (MPa)
Front Side Glass-Middle	6,31
Front Side Glass-Left	14,94
Rear Side Glass-Left	9,7
Front Side Glass-Right	15,09
Rear Side Glass-Right	9,69
Side Glass- Left_1	6,83
Side Glass- Left_2	9,08
Side Glass- Right_1	5,36
Side Glass- Right_2	6,15

4 CONCLUSION

A finite element analysis of glass panel with bolted connections to lift cab is presented in this paper. The maximum stress was obtained near the holes because of the stress concentration surrounding the drilled gap. As it seen in Fig. 4 for right side glass, the holes that are colored according to stress value have nearly the same color on the panel and the stress value is around 5 MPa and rest of the surface is negligibly small. Beside mentioned glass panel, rest of the panels with their maximum stress value are listed in Table 3. It can be seen that all stress values are below the failure stress value.

If we look from the viewpoint of designing the glass panel, failure stress around the holes should be regarded as the regulating parameter. Because of the stress concentration, stresses around holes are larger than the rest of the area. The closeness between the hole is another crucial parameter that must be taken into account. As it is seen in Fig 3, distances between the holes are adequate to design the glass panel safely.

REFERENCES

Bi Z., Overview of Finite Element Analysis, Finite Element Analysis Applications, (2018) 1–29. DOI: 10.1016/b978-0-12-809952-0.00001-7

Demirsöz, R, Imrak, C. E., Targıt, S. (2005). Finite Element Analysis of Elevator Guide Rails during Safety Gear Operation, *Elevator Technology 15, Proc. Of Elevcon'2005,* pp.41-50.

Feng R.Q., Ye J.H., Wu Y., Shen S.Z., Mechanical behavior of glass panels supported by clamping joints in cable net facades, International Journal of Steel Structures, 12 (2012) 15–24. DOI: 10.1007/s13296-012-1002-5

Fors, C (2014). Mechanical Properties of Interlayers in Laminated Glass, MsC Thesis, Lund University, Sweeden

Hidallana-Gamage H.D., Thambiratnam D.P., Perera N.J., Failure analysis of laminated glass panels subjected to blast loads, Engineering Failure Analysis, 36 (2014) 14–29. DOI: 10.1016/j.engfailanal.2013.09.018

Imrak, C. E., Bedir, S., Targıt, S. (2008a) Investigation of Stresses on Guide Rails and Safety Gears, *Elevator Technology 17, Proc. Of ELEVCON'2008,* pp. 111-119

Sivanerupan S., Wilson J., Gad E., Lam N., Drift performance of point fixed glass façade systems, Advances in Structural Engineering, 17 (2014) 1481–1495. DOI: 10.1260/1369-4332.17.10.1481

Tsalkatidis T., Moastuen M., Numerical Investigation of Façade and Floor Glazing Systems, International Journal of Engineering and Technologies, 17 (2019) 1–10. DOI: 10.18052/www.scipress.com/ijet.17.1

Wang Y., Wang Z., Liang Y., Du X., Shi Y., Study on the stress and failure strength around the hole in point supported glass panels, Materials and Structures/Materiaux et Constructions, 49 (2016) 4375–4387. DOI: 10.1617/s11527-016-0794-8

Wang Y., Yuan H., Shi Y., Zou Y., Bearing capacity of non-linear metallic spiders used in point supported glass facades, International Journal of Steel Structures, 12 (2012) 191–204. DOI: 10.1007/s13296-012-2004-z

Zhang X., Hao H., Wang Z., Experimental investigation of monolithic tempered glass fragment characteristics subjected to blast loads, Engineering Structures, 75 (2014) 259–275. DOI: 10.1016/j.engstruct.2014.06.014

BIOGRAPHICAL DETAILS

Eren Kalay has been employed as a research assistant in Istanbul Technical University (ITU) since 2015. Mr. Kalay received the B.Sc. and M.Sc. degree in Mechanical Engineering from Istanbul Technical University. He is also a Ph.D. student at Yildiz Technical University.

C. Erdem Imrak has been employed as a fulltime professor in Istanbul Technical University (ITU). Dr Imrak received the B.Sc., M.Sc. and Ph.D. degrees in Mechanical Engineering from ITU in 1990, 1992 and 1996 respectively. He has carried out research in to materials handling and especially lift systems. Currently his activities include: a Member of the IAEE; a Member of the OIPEEC, a Member of chamber of Mechanical Engineers in Turkey; a Member of Steering Consulting Committee of Asansor Dunyası Magazine and a Member of International Committee of Elevatori and Rapporteur from Turkey

Sefa Targit graduated from the Division of Industrial Engineering, Faculty of Mechanical Engineering at Istanbul Technical University. After graduation in 1982, he worked as the mechanical engineer in various construction companies and in 1992 he joined ASRAY and thus, the manufacturers side of the Lift Industry. He is currently a partner and the General Manager of ASRAY; Vice President of AYSAD (Turkish Elevator and Escalator Association); Board member of SEDEFED (Federation of Industrial Associations of Turkey). He is a member of the Board of Adviser in Istanbul Technical University, Faculty of Mechanical Engineering, Lift committee of Ministry of Industry; ELA Component Committee; MMO Turkey (Chamber of Mechanical Engineers), IAEE. He is publishing advisor of the “Asansör Dünyası” Magazine published in Turkey.