Engineering and Scientific International Journal (ESIJ)
Volume 3, Issue 3, July– September 2016
ISSN 2394-7187(Online)
ISSN 2394 - 7179 (Print)

Finite Element Analysis of Reinforced Glass Beams using ABAQUS Software

S.Selva Sajitha[#1], D. Thanagar*[2]

[1]*Assistant Professor,* [2]*Associate Professor*
Department of Civil Engineering, Dr. Sivanthi Aditanar College of Engineering,
Tiruchendur, Tamil Nadu,
ssajitha2008@gmail.com, dthanagar69@gmail.com

Abstract— Glass is used in buildings as partition wall, window panels, etc in the past centuries as a non structural element which do not carry loads other than its self weight. But it is used as structural element for the past few decades. Glasses are used as beams in roofs of glass structures which bring light into the building and serves to eco - friendly world. Glass has very high compressive strength compared to other building materials but low tensile strength due to its surface flaws, also it is a brittle material. In order to increase the safety of structural glass in structures, glass has to be converted to ductile by providing reinforcement. In glass beams reinforcements are provided in the tensile zone in various forms to increase the flexural behavior. This work presents analytical study of glass beams with reinforcement provided by bonding stainless steel plate at the bottom by ABAQUS finite element software. Quarter beam is modeled by taking the advantage of the symmetry of the boundary condition, loading condition, and cross section. Four beams made up of polyvinyl butyl laminated annealed glass with three different thicknesses of stainless steel plates were analysed. The load carrying capacity from the ABAQUS software is compared with the numerical values calculated.

Keywords— Structural Glass; Glass Beams; Reinforcement; FE Analysis; ABAQUS

1. Introduction

Glass has been used as a non structural element in partition wall, windows, etc in the past centuries. Nowadays its use has been changed from non structural use to structural use which brings light into the building due to its transparency. Façade structures made of glass which makes the building transparent to light and gives aesthetic view. The glass beams are used as supporting elements of the glass panels in the structures of roof; it increases the aesthetic view of the structure.

Glass is a brittle material and it has a extremely high compressive strength compared to other building materials like steel, concrete, etc and has very short tensile strength similar to concrete. In order to increase the flexural strength of the glass beams, reinforcement is provided at the bottom (tensile zone) of the beam. Reinforcement may be provided in various forms like bonding of stainless steel plates at the bottom and inserting glass fibre rods in the interlayer of the glass, etc. Post tensioning is also done to increase the flexural strength of the glass beams. Reinforcing the single float glass does not give higher strength compared to heat strengthened glass or toughened glass. Hence laminated glass is preferred over single float glass.

In this study, the reinforcement is provided in the poly vinyl butyl (PVB) laminated glass beams in the form of channel by gluing with the bonding agent at the bottom. The stainless steel plates used for the reinforcement provide the ductility for reinforced glass beams. This study presents the analytical work of effect of the reinforcement percentage on glass beams. A series of four glass beams made up of annealed glass is modeled by using a finite element software ABAQUS. One beam is modeled unreinforced and other three were modeled with reinforcement with stainless steel plates of various thicknesses (0.36 mm, 1.2 mm, 1.5 mm). Quarter beam is modeled by taking the advantage of symmetry of boundary condition, loading condition and cross section.

2. Modeling and Analysis

The beam geometry of the test specimen is shown in Figure 1. The dimensions of glass beam are of 550 mm X 21.52 mm X 50 mm and reinforcement is provided in channel form of 22 mm x 4 mm and various thicknesses (0.36 mm, 1.2 mm, and 1.5 mm). C3D8R elements were used for glass and S4R elements were used for reinforcement.

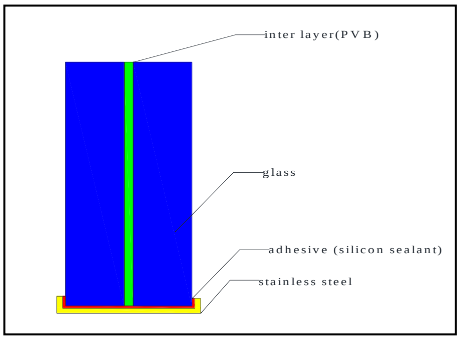

Fig. 1: Cross section of the reinforced glass beams

2.1 Glass

Glass is the linear elastic material and brittle nature which fails without warning when it is subjected to excessive stress. Glass is modeled as three dimensional solid deformable extrusion elements. The element type chosen for glass is continuum three dimensional eight node reduced integration (C3D8R). The geometry and the nodal location of the element is shown in Figure 2.

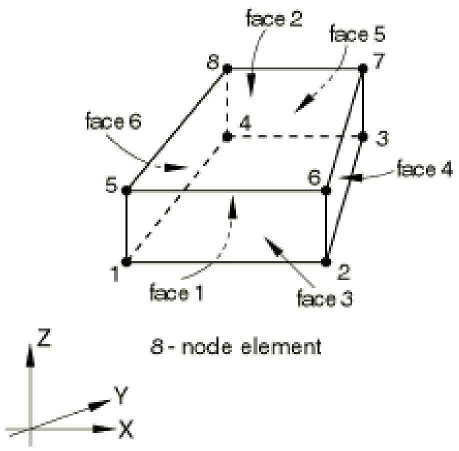

Fig. 2: C3D8R element

C3D8R element is of linear brick element which is of reduced integration to improve their bending behavior of the material. These element is expensive than the regular first order displacement elements but economical than the regular first order element. These elements have hourglass control as it uses reduced integration. This element is composed of single homogenous material and also can include several layers of different materials for the analysis of laminated composite solid and it is of more accurate, if it is not distorted. This element has eight nodes with three degrees of freedom at each node as translation in the nodal x, y and z directions.

2.2 Stainless steel

The stainless steel reinforcement is provided in the bottom of the glass beams in the form of channel for the reinforced glass beams. The analysis of the reinforced glass beams includes the linear elastic analysis. Stainless steel is modeled as three dimensional shell deformable extrusion element .The elements chosen for the reinforcement is S4R. It is of four noded general purpose shell, diminish integration with hourglass control, finite membrane strains. It has active six degrees of freedom at all nodes. The geometry and nodal location of the element is shown Figure 3. The material constants of the linear material model are shown in Table 1 Manufacturer provided the material properties.

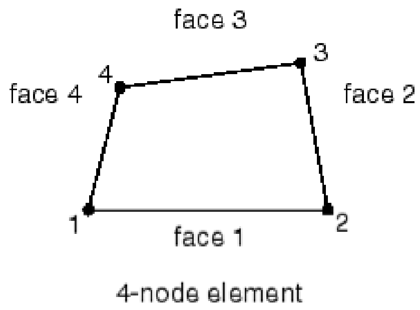

Fig. 3: S4R element

Table 1: Material constants of the linear material model

Material constant	Symbol	Unit	Annealed Glass	Stainless steel
Young's modulus	E	Mpa	70,000	200,000
Poisson's ratio	υ	-	0.22	0.3

In this model, beam is analyzed as simply supported beam with two point loading. The cross section of the beam is symmetry about its vertical plane so quarter of the full beam is modeled. Modeling of reinforced glass beam is shown in Figure 4.

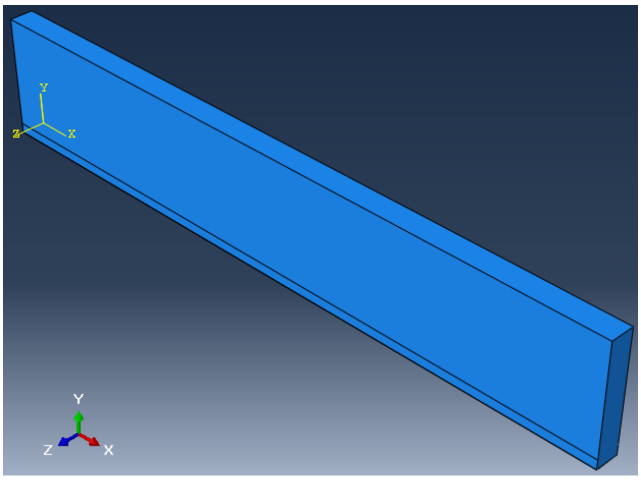

Fig. 4: Modeling of reinforced glass beam

Finite Element analysis requires the whole part of the model to be divided into number of small divisions called meshing to get more accurate results after that loading is done and load deflection response is studied in the required integration points. Finer the mesh the results are more accurate. The approximate size of the mesh is about 2.5 mm. The meshed model of reinforced glass beam is shown in Figure 5.

ISSN 2394-7187(Online)
ISSN 2394 - 7179 (Print)

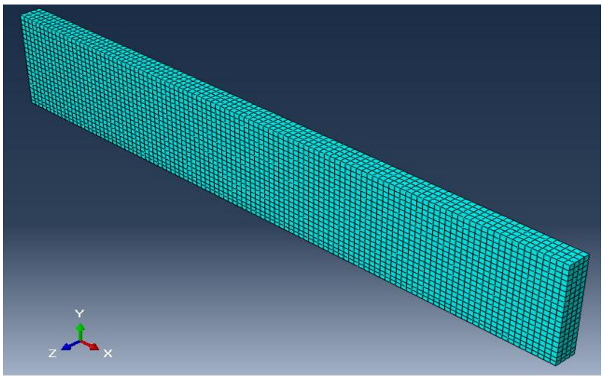

Fig. 5: Meshed model of reinforced glass beam

The model is symmetrical along the vertical plane of the cross section of the beam, so the beam is constrained in the perpendicular directions. So the nodes have restrained degrees of freedom in x direction. Similarly the nodes have restrained degrees of freedom in z direction which shows another plane of symmetry. Single line of the beam is restrained in x and y direction to specify the support. Loading and boundary conditions are shown in Figure 6. The analysis is of static analysis and the full newton solution technique is used.

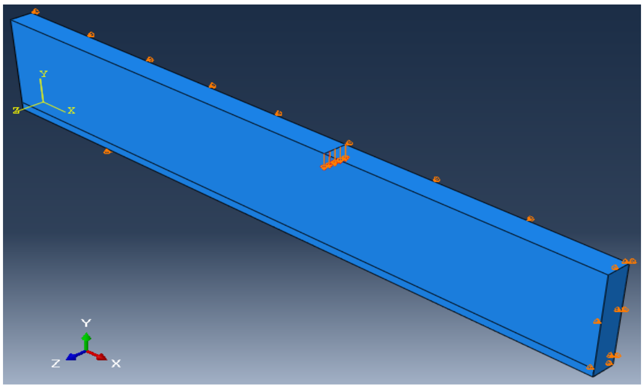

Fig. 6: Loading and Boundary conditions

3. Results and Discussion

3.1 Load Deflection Curve:

The static non linear analysis of the reinforced glass beam is done with ABAQUS software. The load deflection curve is studied in three stages as uncracked stage, cracked stage and plastic stage. The load deflection curve is of linear until the glass beam starts to crack as glass is the main load carrying member of the beam .The behavior of the glass is linearly elastic. Then in the cracked stage, load is taken by both glass and steel and so the load deflection curve start to be non linear. The stiffness of the glass beam is reduced and the deflection of the beam is large. In plastic stage, large number of cracks is formed in the tension edge and glass starts to collapse in the compression edge. Load deflection with the ABAQUS results is shown in Figure 7.

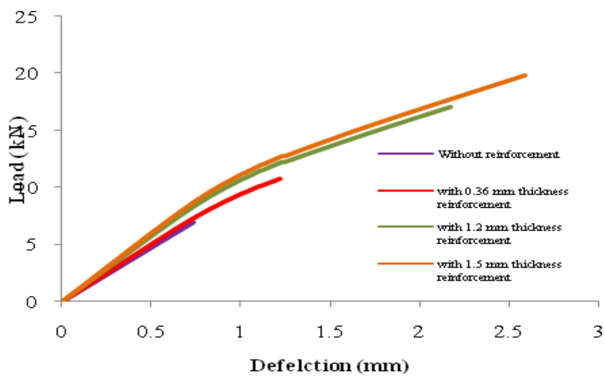

Fig. 7: Load deflection curve with ABAQUS results

4.2 Crack Patterns

The ABAQUS FEA software records the crack pattern in each step of loading by modeling xfem crack. Crack appears when the principal tensile stress exceeds the tensile stress of glass as the glass is a brittle material. The yielding of the stainless steel is also recorded by the ABAQUS software in each step of loading. Crack pattern of unreinforced glass beam and reinforced glass beam are shown in Figure 8 and Figure 9 respectively. The crack patterns are studied in three stages of failure of beam. The tensile cracks extend horizontally towards the support.

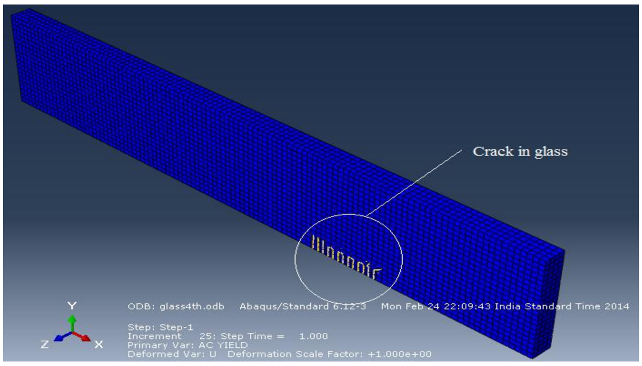

Fig. 8: Crack pattern of unreinforced glass beam

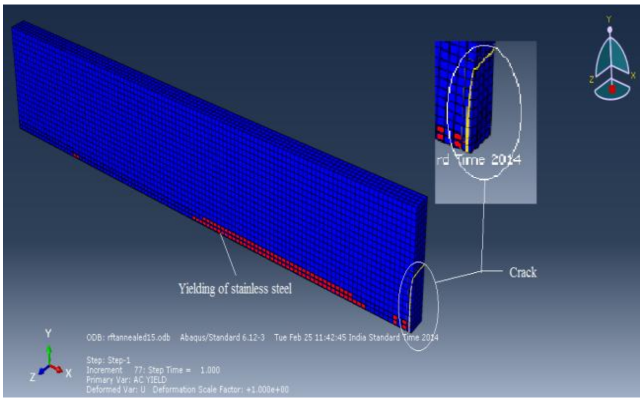

Fig. 9: Crack pattern of the reinforced glass beam

ISSN 2394-7187(Online)
ISSN 2394 - 7179 (Print)

4.3 Numerical Results

4.3.1 Unreinforced Glass Beam

The following relation is used to calculate the moment of unreinforced glass beam at first crack.

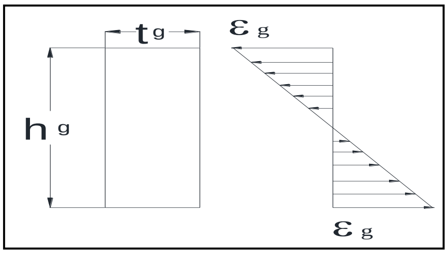

Fig. 10: cross-section for the uncracked unreinforced glass beam

$$M = \frac{E_g I_g \varepsilon_g}{y_0}$$

Where ε_g denotes ultimate tensile strain of glass, E_g denotes Young's modulus of glass, Moment of Inertia is denoted by I_g and it can be found from

$$I_g = \frac{t_g h_g^3}{12}$$

Where t_g denotes thickness of glass beam and h_g denotes height of the glass and depth of neutral axis is denoted by y_0 and can be found from

$$y_0 = \frac{h_g}{2}$$

4.3.2 Reinforced Glass Beam- uncracked stage

Moment for the reinforced glass beams is calculated from

$$M = \frac{\varepsilon_g E_g I_t}{(h_g - y_0)}$$

Where I_t denotes moment of inertia of the reinforced glass beams and can be calculated from

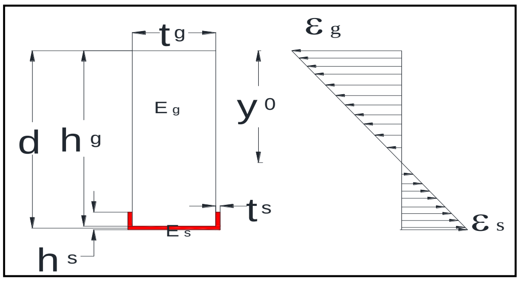

Fig. 11: cross-section for the uncracked reinforced glass beam

$$I_t = \frac{t_g h_g^3}{12} + t_g h_g \left(\frac{1}{2} h_g - y_0\right)^2 + n[\left(\frac{t_s h_s^3}{6} + \frac{t_g t_s^3}{12} + 2 h_s t_s \left(h_g + t_s - y_0 - \frac{h_g}{2}\right)^2 + t_g t_s \left(h_g + t_s - y_0 - \frac{t_s}{2}\right)^2 \right]$$

And y_0 can be found from

$$y_0 = \frac{h_g t_g + n\, t_s (t_g + h_s)}{2 t_g}$$

And n can be found from

$$n = \frac{E_s}{E_g}$$

Numerical results are compared with analytical results obtained from the ABAQUS software.

4.3.3 Cracked Stage

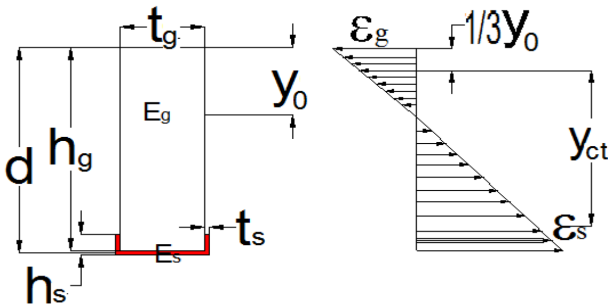

Fig. 12: Cross-Section for Cracked Reinforced Glass Beam

In the cracked Stage, the compression zone will be equal to tensile zone of the beam. So the glass starts to fail. The moment for the reinforced glass beams is calculated by the following relation.

$$M = (2 h_s t_s + t_g t_s) \varepsilon_s E_s \left(d - \frac{1}{3} y_0\right)$$

Where y0 denotes the neutral axis and it is derived by considering the basic concept in the cracked stage.

$$C = T$$

From the Above relation the depth of neutral axis is found as

$$y_0 = \frac{2\,(2 h_s t_s + t_g t_s) n \varepsilon_s}{t_g \varepsilon_g}$$

And it can be further derived from the similar triangle of strain and depth as

$$y_0 = \frac{n(2 h_s t_s + t_g t_s)}{t_g} \left(-1 \pm \sqrt{\left(1 + \frac{2 t_g d}{(2 h_s t_s + t_g t_s) n}\right)}\right)$$

Where, effective depth of the reinforced glass beam,d is given by

$$d = \frac{h_s^2 + t_g t_s}{2\,(h_s + t_g)}$$

4.3.4 *Yield Stage*

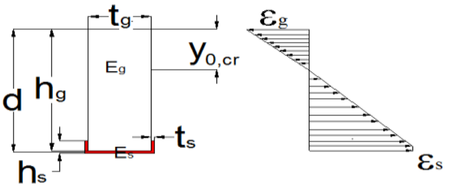

Fig. 13: Cross-Section for Yielded Reinforced Glass Beam

In yield stage, the same concept as that of cracked stage. The compression zone is equal to the tension zone of the reinforced glass beams. The moment for the reinforced glass beams is calculated by the following relation.

$$M = \left(2\,h_s t_s + \,t_g t_s \right) f_s \left(d - \frac{1}{3} y_0 \right)$$

Where y0 denotes the neutral axis and it is derived by considering the basic concept in the yield stage.

$C = T$ From the Above relation the depth of neutral axis is found as

$$y_0 = \frac{2\left(2h_s t_s + \,t_g t_s\right) n\varepsilon_s}{t_g\,\varepsilon_g}$$

Where $\varepsilon_g = \frac{k(-1 \pm \sqrt{(1+\frac{4\varepsilon_s}{k})}}{2}$

As the glass fractures, strain near cracked elements gets reduced and so the strain of the glass beam is calculated

And $k = \frac{2\left(2h_s t_s + t_g t_s\right) f_s}{t_g E_g\, d}$

Table 2: Comparison of theoretical and analytical results

Reinforcement Percentage	Load Carrying Capacity in kN	
	Theoretical	Analytical
0	5.75	6.912
1.13	6.41	10.8
3.77	14.68	17.1
4.71	18.83	19.8

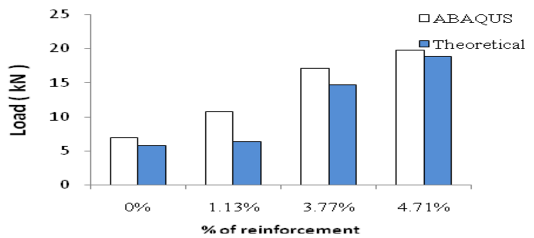

Fig. 14: Maximum Load Carrying Capacity

5. Conclusion

Based on the obtained numerical results and analytical results, the following conclusion has been made.

- Load carrying capacity of the reinforced glass beams is higher with respect to unreinforced glass beam.
- Initial height of the uncracked compression zone increases with increase of percentage of the reinforcement.
- Results from finite Element Analysis using ABAQUS shows good agreement with the numerical results.
- Ductility of the glass beams is improved by providing reinforcement in the tensile zone of the glass beams.
- The safety of the structural glass beams are improved by providing the reinforcement.

6. Acknowledgements

Sankar.B from Saint Gobin (Glass distributor - Tamil Nadu) and Sugumaran.S from TPRS enterprises are acknowledged for providing glass specimens for the project.

References

[1] AS 1288—2006 Glass in buildings—Selection and installation Sydney: Standard,2006

[2] Slivansky.M , "Experimental verification of the resistance of Glass Beams.", Solvak journal of civil Engineering, Vol. XX, 2012, No. 1, pp21 – 28, 2012

[3] Slivansky.M, "Theoretical verification of the resistance of Glass Beams.", Procedia Engineering 40 pp417 – 422, 2012

[4] Premalatha. E, "Structural Behavior of glass panels in facades." M.S thesis, Anna University, Chennai., 2012

[5] Nielse.J.H & Olesen. J.F, "Post-crack capacity of mechanically reinforced glass beams (MRGB)." Fracture Mechanics of Concrete and Concrete Structures Recent Advances in Fracture Mechanics of Concrete - B. H. Oh, etal. eds. pp180-188,2010

[6] Christian Louter , Jan Belis ,Frederic Veer, Jean-Paul Lebet, "Structural response of SG-laminated reinforced glass beams; experimental investigations on the effects of glass type, reinforcement percentage and beam size." Engineering Structures 36 pp 292–301 , 2012

[7] Christian Louter, Calvin Leung, Henk Kolstein, Jan Vamberský, "Structural Glass Beams with Embedded Glass Fibre Reinforcement." Challenging Glass 2 – Conference on Architectural and Structural Applications of Glass, Bos, Louter, Veer (Eds.), TU Delft, The Netherlands, 2010