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Experimental and Analytical Study of External Reinforced Glass Beams

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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. Nowadays 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 experimental and analytical study of glass beams with reinforcement provided by bonding stainless steel plate at the bottom reinforcements are provided in the tensile zone in various forms to increase the flexural behavior. This work presents experimental and analytical study of glass beams with reinforcement provided by bonding stainless steel plate at the bottom. Analytical study is done in ABAQUS finite element software where Quarter beam is modeled by taking the advantage of the symmetry of the boundary condition, loading condition, and cross section. Eight beams made up of polyvinyl butyl laminated glass of annealed and toughened type with three different thicknesses of stainless steel plates were analyzed. Results from Analytical simulation show good agreement with the experimental results. The analytical work performed in the ABAQUS software was verified by analyzing similar reinforced glass beams with the input values from the published literature.

Keywords — crystalline, flexural, simulation, Discretization, Elastomeric, Convergence.

I. INTRODUCTION

1.1 GENERAL

Glass is no longer considered as a non-structural element. It is increasingly called upon to constitute innovative structural components of a building, such as flooring, fins, beams or complete bolted glass assemblies in facades. Now it has been turned to use as the structural element which serves as a good building material to carry load. Glass has two opposite characteristics that transparent and impermeable for liquids and air. This combination of the behavior made the building to visually contact with the environment and day light access so it plays a vital role in architecture. Glass is the growing up structural field. Glass beams are used as the supporting member of glass panels in the roof of facade structures. Glass is a brittle material that is weak in tension because of its non-crystalline molecular structure. When glass is stressed beyond its strength limit, breakage occurs immediately without warning, unlike steel and aluminum where plastic mechanism can be formed. As glass is a brittle material that stress cannot be re-distributed and failure is assumed once crack occurs, the failure stress can only be referred as a probability of failure. Glass has very high compressive strength compared to other building materials like concrete, steel etc. and has very low tensile strength similar to concrete. To enhance its flexural strength, different types of reinforcement can be provided in the tensile zone of glass beams. Different types of reinforcement is provided in the glass beams as stainless steel solid or hollow section, stainless steel plates in bottom in both sides, glass fibers in the interlayer of the laminated glass. Post tensioning process is also used in increasing the tensile strength of glass beams in bottom of the beams.

1.2 TYPES OF GLASS

For conventional glass panels under heat-treatment for strength improvement, structurally they can be classified into 3 groups as annealed, heat-strengthened and tempered glass. The amount of heat used in the glass manufacturing process has a direct effect on the type of glass produced. Basically, the more heat used during the glass production process the stronger the final glass product will be. The following provides a breakdown of different types of glass available starting with the lowest amount of heat used (Annealed) and working up to the hottest method (Tempered).

1.3 Methodology

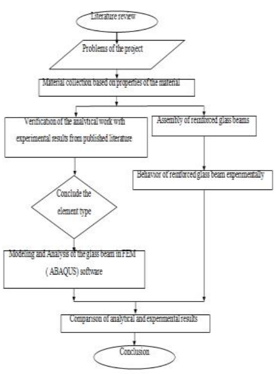

Fig 1 Methodology

1.4 Introduction to ABAQUS

The Abaqus unified FEA product suite offers powerful and complete solutions for both routine and sophisticated engineering problems covering a vast spectrum of industrial applications.Abaqus are used in the automative, aerospace and industrial products industries. The product is popular with academic and research institutions due to the wide material modeling capability, and the program's ability to be customized.

1.5 General Steps for ABAQUS

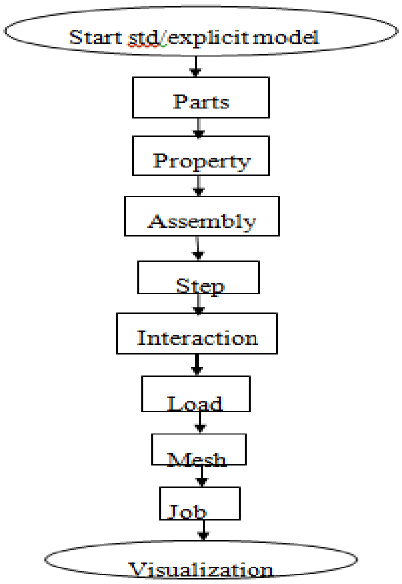

Fig 2 General Steps of ABAQUS

1.6 Comparison of ABAQUS Results

1.6.1 Stage I – Un-cracked Stage

In this stage, the glass is uncracked and the beam behaves in the linear elastic manner as the beam is loaded within the linear elastic state. The main load carrying capacity of the reinforced glass beam is the glass until the glass gets cracked.

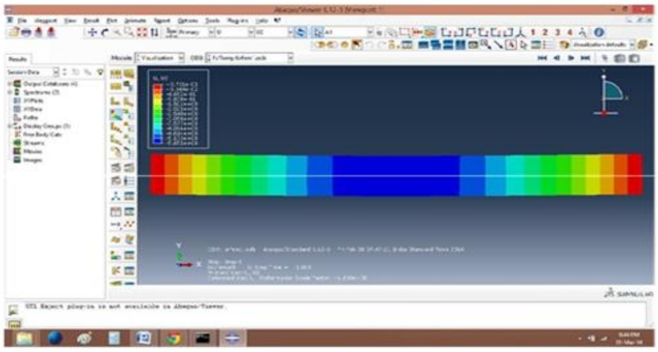

Fig 3: Deflected Model Un-cracked Stage from ABAQUS Software

1.6.2 Stage 2 - Cracked Stage

In this stage, crack is developed in the glass and the reinforcement in the tensile zone becomes active and takes the load. The compression edge remains un-cracked and large number of cracks starts to appear on the glass and load is carried by the reinforcement. The load starts to drop and the deflection gets increased.

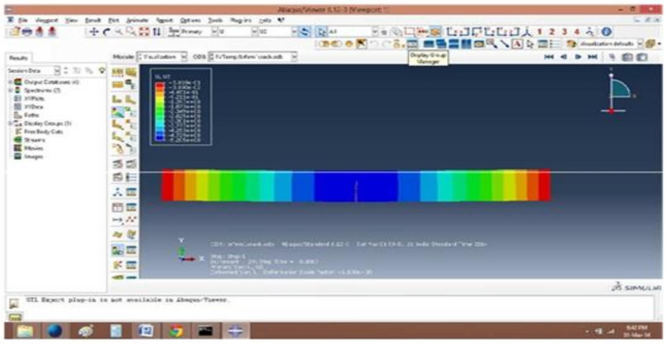

Fig 4: Deflected Model Cracked Stage from ABAQUS Software

1.6.3 Stage 3 – Yield Stage

In this stage glass is extensively cracked and the crack extends to the compressive zone. The reinforcement plastically deforms and the finally the collapsed caused in the compressive zone of the beam.

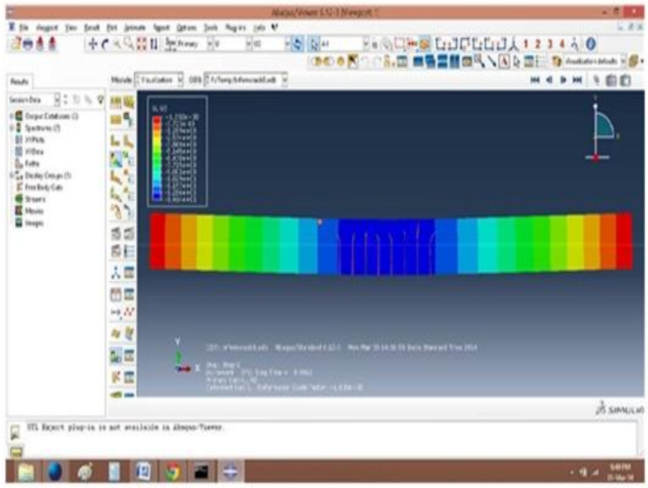

Fig 5 : Deflected Model Yield Stage from ABAQUS Software

1.6.4 Comparison

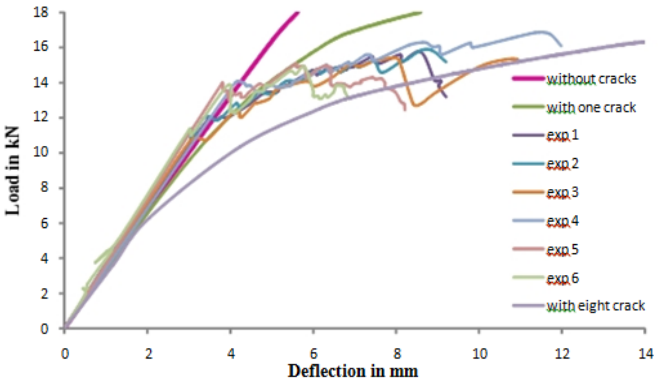

Fig 6 : Comparison of Load Vs. Deflection in the Middle of the Span

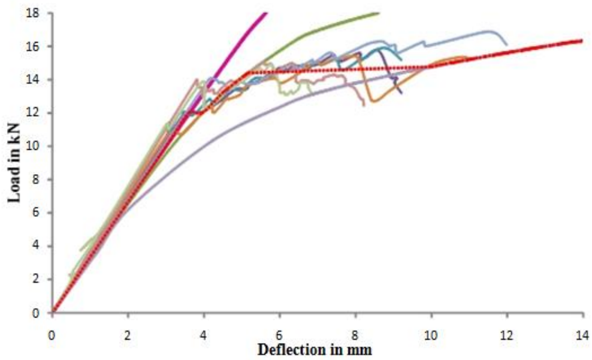

Fig 7: Interconnected Load vs. Deflection in All Three Stages of Failure in the Middle of the Span

2. Experimental Study

2.1 Testing Method of glass beam

According to the site provisions, load would be transfer to the glass beam where the glass panels to be supported. The support is made by the spider arm fitting for the glass panels which forms the load transferring object. The distance between the supports of glass panels varies with strength of glass placed above glass beam. In order to study the behavior of the glass beam uni-axial bending test is carried out.

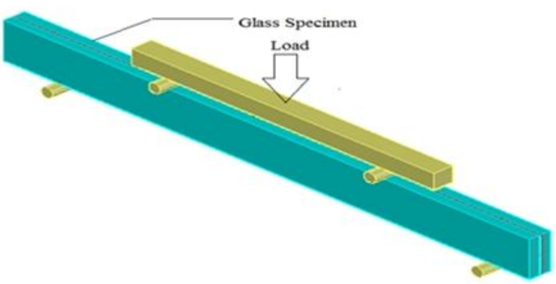

Fig 8 : Four-Point Bending Test

2.2 Details of Glass Beam Specimen

Two points loading is applied in the glass beam in one fourth of the effective span. The glass beam used for the entire test have same geometry (1500 mm X 22 mm X 50 mm) and glass type (annealed and heat strengthened).To minimize the variation in glass strength, all the specimens were purchased from the same supplier and were transported and stored before testing with methods and in conditions as similar as possible. The glass beams are reinforced by the stainless steel. The stainless steel plates are folded in the form of channel of 22mm X 4mm and varying thickness.

2.3 Observation

The experimental testing is carried out in the loading frame with the jack capacity 250 KN. The Load applied in the interval of 0.1 KN at 10 seconds time interval. The observations during the testing of the glass beams are listed below.

2.3.1 Annealed Glass

The annealed glass without reinforcement fails suddenly without any warnings and its load suddenly drops to zero at failure. The glass starts to fail at the failure load in the tensile zone and glass particles spreads in surrounding area. The glass beam after failure too remains in the support. The glass fails suddenly when the loading steel comes in contact with glass. Reinforced glass beams with reinforcement of 0.36 mm thickness plate, the stainless steel plate starts to buckle and detached from the glass at the failure point of glass. In the reinforced glass beams with reinforcement of 1.2 mm thickness, slip occurs between glass and steel face, it has occurred near the ends of beam.

Fig 9: Failure Pattern of Annealed Glass

2.3.2 Toughened Glass

The toughened glass without reinforcement fails suddenly without any warnings and its load suddenly drops to zero. The glass starts to fail at the failure load in the tensile zone and glass particles do not spread in surrounding area and slips from the support. The glass fails suddenly when steel in the loading point comes in contact with the glass. Reinforced glass beams do not slip from the support. Reinforced glass beams with reinforcement of 0.36 mm thickness plate, the stainless steel plate starts to buckle and detached from the glass at the failure point of the glass. In the reinforced glass beams with reinforcement of 1.2 mm thickness, slip occurs between glass and steel face, it has occurred near the ends of beam.

Fig 10: Failure Pattern of Toughened Glass

3. Results and Discussion

3.1 Comparison of Experimental and ABAQUS Results

Load deflection curve of experimental and abaqus results are compared. From the results it has been observed that 9.2% of difference in the results, in which the experimental results shows higher load carrying capacity and large deflection has occurred in Abaqus results than experimental results.

For Annealed Glass

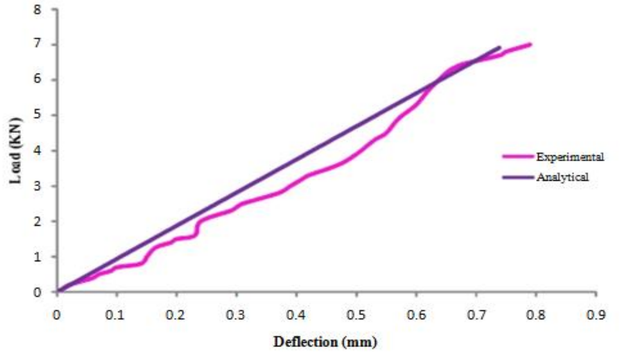

Fig 11: Comparison of Experimental and ABAQUS Load Vs. Deflection Curve of Annealed Type Glass without Reinforcement

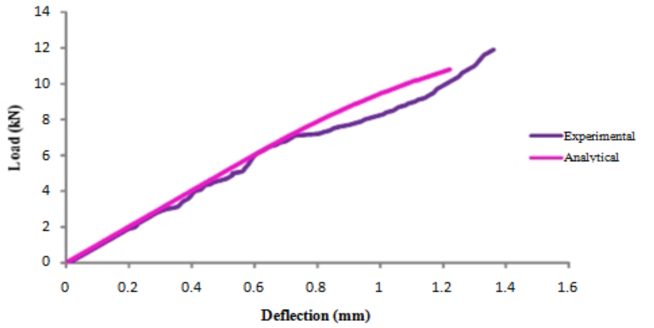

Fig 12: Comparison of Experimental and ABAQUS Load Vs. Deflection Curve of Annealed Type Glass with 0.36mm Thickness S.S Plate Reinforcement

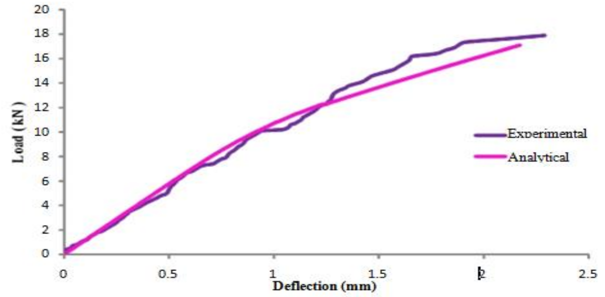

Fig 13: Comparison of Experimental and ABAQUS Load Vs. Deflection Curve of Annealed Type Glass with 1.2mm Thickness S.S Plate Reinforcement

For Toughened Glass

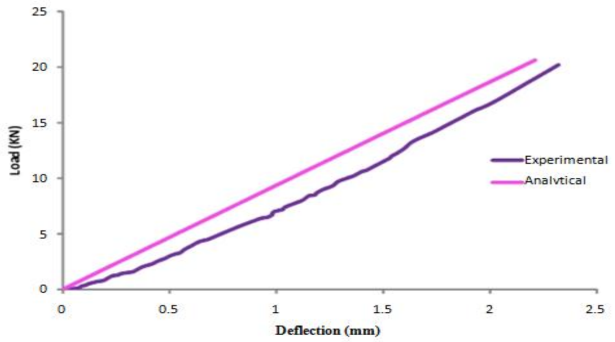

Fig 14: Comparison of Experimental and ABAQUS Load Vs. Deflection Curve of Toughened Type Glass without Reinforcement

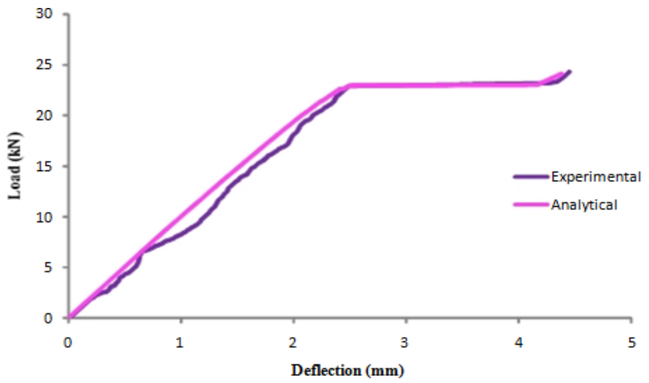

Fig 15: Comparison of Experimental and ABAQUS Load Vs. Deflection Curve of Toughened Type Glass with 0.36mm Thickness S.S Plate Reinforcement

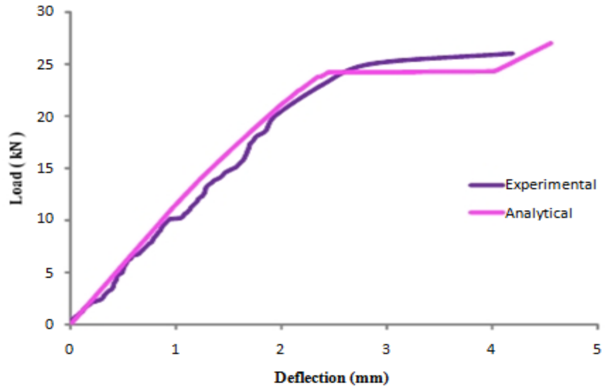

Fig 16: Comparison of Experimental and ABAQUS Load Vs. Deflection Curve of Toughened Type Glass with 1.2mm Thickness S.S Plate Reinforcement

3.2 Result for load carrying capacity for glasses

GLASS TYPE	THICKNESS OF SS PLATE (mm)	EXPERIMENTAL (KN)	ABAQUS (KN)
	0	7.8	7.4
Annealed glass	0.36	12.4	11.2
	1.2	18	17.5
	0	21	19.8
Toughened glass	0.36	26	23.5
	1.2	30.2	28.2

4. Conclusion

- Load carrying capacity of the reinforced glass beams are higher compared to unreinforced glass beam.
- 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
- Load carrying capacity of the reinforced glass beams increases with increase in percentage of reinforcement.
- Load carrying capacity calculated analytically and theoretically is less than the experimental results whereas the analytical and theoretical results do not over estimate.
- Results from finite element analysis using ABAQUS Shows good agreement with the experimental results.

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