INTENSIFICATION OF GEOCRETE BEAM WITH GFRP USING ABAQUS

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INTRODUCTION

1.1 General

Concrete is a versatile material having number of desirable properties, so widely preferred in construction industry. But having major disadvantage that under severe vibrations such as earthquakes it gets cracked and concrete has poor modification and repair quality. Therefore some repair or strengthening must be performed so that damaged element must stand for further useful life. Many civil structures are no longer considered safe due to increased load specifications in the design codes. Such structures must be strengthened in order to maintain their serviceability[4].

As the demand for concrete as construction material increases, the demand for Portland cement also increases. It is estimated that the production of cement will increase from about 1.5 billion tons in 1995 to 2.5 billion tons in 2015. On the other hand, the climate change due to global warming is caused by the emission of greenhouse gases, such as carbon dioxide (CO_2), into the atmosphere by human activities. Among the greenhouse gases, CO_2 contributes about 65% of global warming. The cement industry is held responsible for some of the CO_2 emissions, because the production of one ton Portland cement emits approximately one ton of CO_2 into the atmosphere. Several efforts are in progress to reduce the use of Portland cement in order to address the global warming issues. These include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag, rice-husk ash and metakaolin, and the development of alternative binders to Portland cement. In this respect, the geopolymer technology proposed by Davidovits shows considerable promise for application in concrete industry as an alternative binder to the Portland cement. In terms of global warming, the geopolymer technology could significantly reduce the CO_2 emission to the atmosphere caused by the cement industries [13].

In 1978, Professor Joseph Davidovits introduced the development of mineral binders with an amorphous structure, named geopolymers. Davidovits (1988; 1994) proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term 'Geopolymer' to represent these binders. This was a class of solid materials, producedby the reaction of an alumino silicate powder and an alkaline liquid. The initial goal for the research done on these geopolymers was to find a more fire resistant binder material due to the high amount of fires in Europe at that time. This research led to the material being used as coatings for the fire protection of cruise ships and thermal protect results in a low flexural strength. Brittleness of both concrete types is compensated by conventional steel reinforcement [18].

Geopolymer concrete is an innovative construction material which shall be produced by the chemical action of inorganic molecules. Otherwise geopolymer is an inorganic alumino- hydroxide polymer synthesized from predominantly silicon (Si) and aluminium (Al) materials of geological origin or byproduct materials such as fly ash. The term Geopolymer was introduced to represent the mineral polymers resulting from geochemistry. The process involves a chemical reaction under highly alkaline conditions on Si-Al minerals, yielding polymeric Si-O-Al-O bonds in amorphous form. Due to its high mechanical properties combined with substantial chemical resistance (magnesium or sulphate attack), low shrinkage and creep and environment friendly nature (very less amount of

CO_2 production in comparison with OPC), it is a better construction material for future.

1.2 Necessities of Geopolymer Concrete

One of the most important applications of geopolymer is in construction industry. However, the suitability of GPC to various structural components is yet to be established by large number of experimental studies. Various experimental works have been done to find out the suitability of geopolymer concrete to replace the Portland cement concrete (PCC) and based on these results the geopolymer concrete application can create an environmental friendly construction industry. Since the majority of existing buildings are deficient for resisting earthquakes, so nowadays retrofitting of the building has become a major issue. The recent earthquakes in India occurred during 2001 in Gujarat, damaged many buildings that were seismically deficient. This calls for techniques those are environmental friendly, technically sound and economically feasible to upgrade deficient structures. Various retrofitting techniques available are steel plate bonding, polymer injection followed by concrete jacketing, use of advanced composite materials like Glass Fibre Reinforced Polymer (GFRP), Carbon Fiber Reinforced Polymer (CFRP), and Ferrocement etc. But since these above mentioned methods are just strengthening the existing structure without removing the damaged portion many disadvantages exists, like their behavior changes as temperature varies, and also the materials tensile strength and stiffness not match with the concrete properties. So in order to overcome these drawbacks, a new attempt was made i.e. retrofitting of damaged portion using geopolymer concrete. In this study the retrofitting is done after the removal of damaged concrete and is rebuilt with geopolymer concrete [4].

1.3Geopolymer Concrete

Geopolymer concretes (GPCs), the commercial name of alkali-activated concretes (AACs), which usually result from the chemical reaction between aluminosilicate waste materials and alkaline activators, are currently regarded as greener alternatives to Portland cements concrete (PCC). The benefits of GPCs include reduction of CO_2emission, less energy consumption during production, and usage of wastes as raw materials. Despite some issues in practical application of GPC, such as effective evaluation of the waste source materials; poor workability due to a sticky and thick mortar that is generated and cost intensive when using alkali silicate as activator; and efflorescence in the final products due to the movement of unreacted alkalis in contact with water, many GPCs behave equally as PCCs. In some areas they perform even better under the same testing conditions, such as chemical resistance; high temperature strength; and resistance to chloride penetration and freeze-thaw cycles. These features can also be considered as important to future sustainability of building and construction industry.

Glass fiber reinforced polymer (GFRP) sheets/plates are widely used to strengthen deficient reinforced concrete (RC) structures. Over the past few decades, the adoption of adhesively-bonded composites to strengthen existing concrete structures has steadily increased. Bond behavior between GFRP reinforcement and concrete has been widely studied and some studies have been adopted by the design guidelines for concrete structures strengthened with externally applied GFRP. In recent years, a lot of research was focused on the strengthening of under-designed and deficient RC structures. GFRP significantly increases the flexural strength of masonry wall. Failure of a civil structure refers to the loss of structural integrity due to loss of the load-carrying capacity. In a well-designed system, a localized failure should not cause immediate or even progressive collapse of the entire structure for any kind of loading [22].

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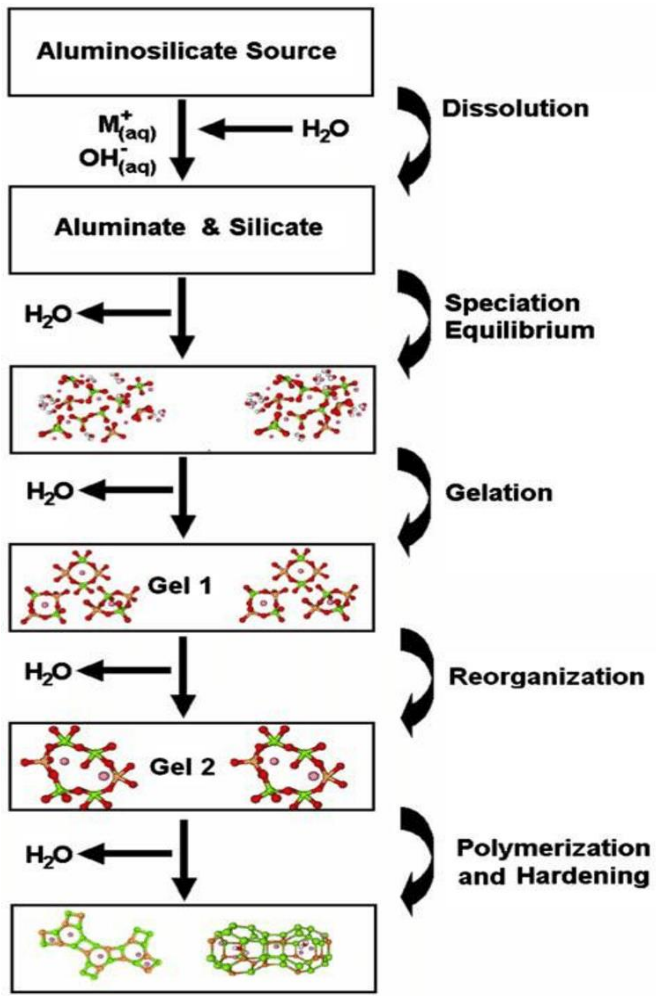

1.4. Constituents of Geopolymer Concrete

There are two main constituents of geopolymer, namely the source materials and the alkaline liquids. The source materials for geopolymer based on alumina-silicate should be rich in silicon (Si) and aluminium (Al). These could be natural minerals such as kaolinite, clays, etc. Alternatively, byproduct materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc could be used as source materials. The choice of the source materials for making geopolymers depends on factors such as availability, cost, type of application, and specific demand of the end users. In present investigation fly ash being used. The alkaline liquids are from soluble alkali metals that are usually Sodium or Potassium based. The most common alkaline liquid used in geopolymerization is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate.

Source materials-Materials which are rich in aluminum and silica can be used as source material. Examples: Fly ash, GGBS, Silica fumes, Rice husk ash etc.


1FLY ASH 2.GGBFC


3.SILICA FUME 4.RICE HUSK

Alkaline Liquids-The most commonly used alkaline liquids are combinations of sodium hydroxide with sodium silicate or potassium hydroxide with potassium silicate.

Fig.1.3:Alkaline Liquids

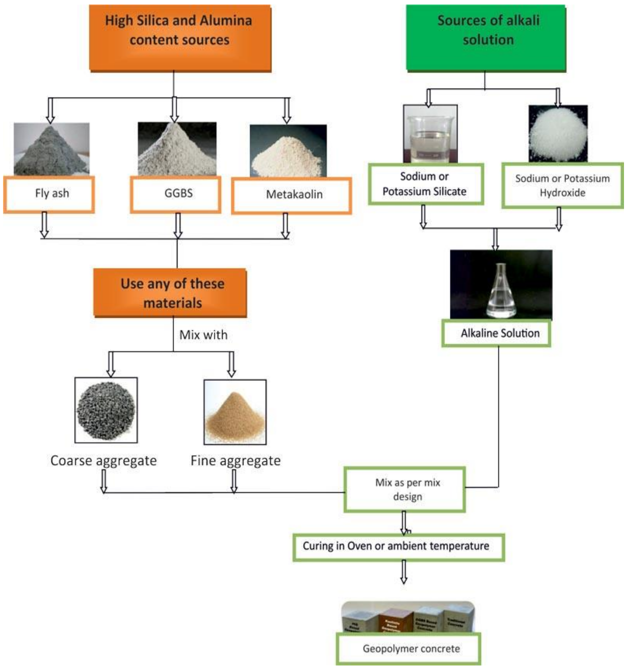

Fig.1.4: Constituents of Geopolymer

1.5. GEOPOLYMER CATEGORIES

There are currently four different geopolymer categories including:

- Slag based geopolymer
- Rock based geopolymer
- Fly ash based geopolymer
- Ferro-sialate based geopolymer

1.5.1 SLAG BASED GEOPOLYMER

The first geopolymer developed was a slag based geopolymer in the 1980s. The reason for using this type of cement is due to its the rapid strength gain as it can reach strengths of up to 20 MPa after just 4 hours. Slag is a partially transparent material and a by-product in the process of melting iron ore. It usually consists of a mixture of metal oxides and silicon dioxide. It is also used in the cement and concrete industry.

Examples of slag used are; Iron blast-furnace slag, Corex slag& Steel slag.

1.5.2 ROCK BASED GEOPOLYMER

To compose this type of geopolymer, a fraction of the MK-750("MK" is an abbreviation for metakaolin and the "750" represents the temperature at which it was produced) in the slag based geopolymer is replaced by natural rock forming materials such as feldspar and quarts. This mixture yields a geopolymer with better properties and less CO2 emissions than that of the ordinary slag based geopolymer. The components of rock based geopolymer cement is metakaolin MK-750, blast-furnace slag, natural rock forming materials (calcined or non-calcined) and a user friendly alkali silicate.

1.5.3 FLY ASH BASED GEOPOLYMER

Fly ash is the waste material produced in blast furnace. Components of fly ash are amorphous composition (60%), quartz (20%), mullite (17%), maghemite (1.7%).Fly ash can be divided in to two, type F fly ash and type C fly ash. The type F fly ash can be again classified into two Alkali-activated fly ash geopolymer and Fly ash/slag based geopolymer. most of the globally available fly ash material is a low calcium by product obtained from the burning of anthracite and bituminous coal.

1.5.4 FERRO SIALATE BASED GEOPOLYMER

This type of geopolymer has the same properties as rock based geopolymer but contains geological elements with high iron oxide content, giving the geopolymer a red colour. Some of the aluminium atoms in the matrix are substituted with iron ions to yield a poly (Ferro-sialate) type geopolymer with the following formation: (Ca,K)- (-Fe-O)-(-Si-O-Al-O-).and hematite (.9%).[19]

1.6. WHAT IS STRENGTHENING?

Strengthening can be defined as a method of modifying damaged or vulnerable structures with new components to improve the load-carrying capacities of the existing structures. Sometimes, a heavy load comes in a building that was not designed for it. It is not possible to vandalize the whole existing structure. Then CFRP, GFRP, Steel plates are used to increase strength. Strengthening aims to enhance the ultimate strength/deformation which means increasing the strength bearing capacity and decreasing the deformation of the structure by developing the structure's ability to go through inelastic deformation without total collapse during an earth tremor or other types of loads. Full structure renewal might have some disadvantages for instance a stronger environmental impact, high costs for labor and material, etc. Glass Fiber Reinforced Polymer (GFRP), Carbon Fiber Reinforced Polymer (CFRP) and Aramid Fiber Reinforced Polymer (AFRP), Jute Fiber Reinforced Polymer (JFRP) are typically used in fiber-reinforced polymer (FRP). Nowadays some of these materials are being used and becoming very popular as engineering materials side by side with the traditional materials e.g. concrete, steel in the structures of Bangladesh. These fibers are all linear elastic up to failure, with no significant yielding compared to steel. Steel has lower density and higher tensile strength compared to steel. So, FRP is more suitable compared to steel. The installation of FRP is simple and it gives temporary support until the adhesive gains its strength. FRP can be easily cut to length on site. They can also be formed on-site into complex shapes [18].

1.6.1What Is Need of Strengthening?

Concrete structures need to be strengthened for any of the following reasons:

- Load increases due to higher live loads, increased wheel loads, installations of heavy machinery, or vibrations.
- Damage to structural parts is due to aging of construction materials or fire damage, corrosion of steel reinforcement, and/or impact of vehicles.
- An improvement in suitability for use is due to limitation of deflections, reduction of stress in steel reinforcement and/or reduction of crack widths.
- Modification of structural system due to elimination of walls/columns and/or openings cut through slabs.

1.6.2 Effective Factors in Choosing Strengthening Techniques [15]

There are multiple factors in choosing strengthening techniques:

1. Cost versus importance of the structure.

2. Available workmanship.

3. Duration of work/disruption of use.

4. Fulfillment of the performance goals of owner.

5. Functionally and aesthetically compatible and complementary to the existing structures

6. Reversibility of intervention.

7. Performance level of quality control.

8. Structural compatibility with the existing structural system.

9. Irregularity of stiffness strength and ductility.

10. Control damage to non-structural components.

11. Sufficient capacity of foundation system.

12. Repair materials and technology available.

1.6.3Technique of Strengthening

1. Concentric or existence steel braces.

2. Post-tensioned cables.

3. Shear walls.

4. Masonry in filled.

5. Base isolator.

6. Steel jacketing.

7. FRP laminates or FRP wrapping.

8. Concrete armor.

9. frictional-hysteretic and viscoelastic dampers.

1.7 Objectives of Study

The objectives of the study are

1. To study the strengthening techniques for geocrete beams.

2. To model geocrete beam using ABAQUS.

3. To validate the results of geocrete beams using ABAQUS software.

LITERATURE REVIEW

2.1 General

On this chapter, the studies and practices followed by using many researchers are reviewed. Additionally, studies gap for this study summarized. There are numerous researchers have been done on geopolymer concrete for investigating its behavior with thinking about flexural strength and various properties.

Mariam Ghazy (2021)[16]studied Nonlinear finite element method based on advanced three direction models is an economical tool and powerful which can be effectively used to simulate the true behavior of concrete elements even under complex conditions. A 3 D nonlinear finite element analysis has been used to conduct an analytical study of the heat-cured alkali-activated fly ash-based geopolymer concrete specimens cast with polypropylene fibers. In the experimental part, ten notched beams were investigated in a three-point bending test. Three notch height 0, 50, and 75 mm have been investigated at reinforcement ratios of 0, 0.07%, 0.17%, and 0.3%. This study aims to present a model suitable for analyzing reinforced concrete notched beams using finite element methods. ABAQUS computer program version 6.16 is utilized in the analysis. The concrete was idealized by using the homogeneous solid elements, while the notch was modeled by using a planer shell and flexural steel reinforcement was modeled as a wire element by assuming a perfect bond between the concrete matrix and the flexural steel reinforcement rebar. The crack pattern is given by the finite element model similar to the experimental ones and the same trend of the load displacement relation.

B. Sudheer Kumar & K.Manoharini (2020) [3] studied Reinforced Concrete structures are suffering from various deteriorations like corrosion, cracks large deflection. These deteriorations are caused by various factors such as ageing, corrosion of steel reinforcement, environmental effects and accidental impacts on the structure. There is a huge need for repair and strengthening of deteriorated, damaged structures. There are various types of techniques for repairing the existing columns and beams. In recent years, retrofitting of concrete beams by wrapping and bonding of Fiber-reinforced polymer (FRP) sheets around the beams has become increasingly popular. Fiber – Wrapping using Fiber – Reinforced Polymer (FRP) shells is one of the effective methods, significantly enhances the strength and ductility of concrete beams. In the present work, the efficacy of GFRP for the flexural strengthening of the reinforced concrete beam is studied by laying various layers and it will compare with Glass Fiber Reinforced Polymers carrying out bending test on reinforced concrete beams. The work carries out the study of failure modes, flexural strengthening effect on ultimate load and load deflection behavior as well as the deflection ductility study of RC beams bonded externally with GFRP, wrapped in layers, along the entire length of the beam in full wrapping and strip wrapping technique.

PROBLEM STATEMENT

3.1 Modeling of Geocrete Beam

In this topic, geopolymer concrete beam using the ABAQUS program based on extended finite element method to analyze the externally bonded Glass Fiber Reinforced Polymer (GFRP) in the strengthening of the geopolymer reinforced concrete beams under bending tests are conducted until failure to enable full understanding of flexural behavior of the GFRP strengthened beams, and other characteristics such as the load-deflection behavior, load-stiffness behavior, ductility, and failure modes.

3.2 Description of Model

We consider the geopolymer concrete beam of size 1600 mm in length and 150 mm in depth and 100 mm wide. The point load is applied to the centre of the beam. The two roller supports are provided at 50 mm distance from the external edges of the beam. The Glass Fiber Reinforced Polymer sheet with one layer,twolayer,three layer of thickness 0.6 mm,0.7 mm,0.8 mm are applied at the bottom of the concrete beam specimen.

MODELLING OF GEOCRETE BEAM

4.1 Introduction

ABAQUS, Finite Element Analysis (FEA) software is being generally used by Engineer worldwide. ABAQUS can be employed in virtually all the field of engineering such as structural, thermal and fluid mechanics etc. In this present work, ABAQUS 2020 is used to model the geopolymer beam with GFRP layers to study the load deflection behavior.

In this sub sections, the details of the ABAQUS modeling are described. The terms related to ABAQUS and the steps to be followed are discussed below.

4.2 Terminology

The following general guidelines are used for ABAQUS 2020:

Pre-processing: It consists of defining material type, sectioning, material properties, assembling, step, interaction, loading, and meshing

1. Part

Create manager —create — Create part modeling space: 3D — Select type: Deformable— Select base features shape: shell— Type: extrusion — Continue

2. Assembly

Create instance-Parts-SelectGPCbeam, GFRP 1Layer, support-autoOffset-O.K

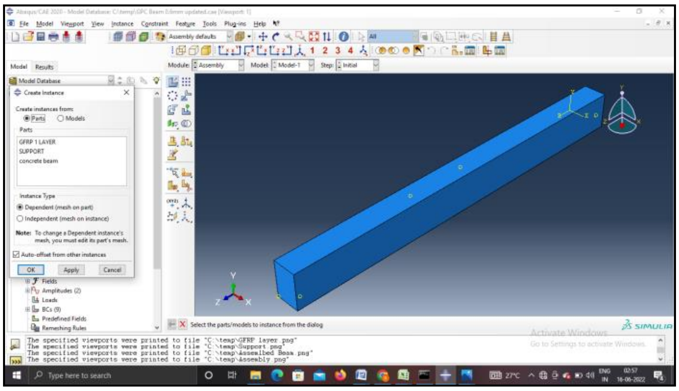

Fig.4.5:Assembly

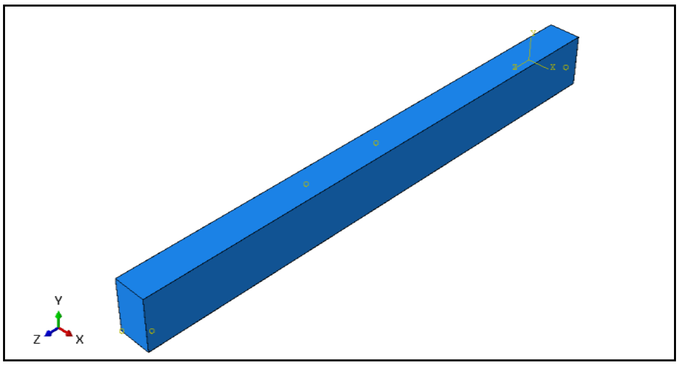

Fig.4.6: Assembly section

3. Meshing

Module-mesh-part-support-seed part-approximate global-1-apply-Part-GPC beam-seed part-approximate global size 25-apply-ok-mesh part-yes-Part-GFRP-1-seed part-approximate size 25-apply-ok-

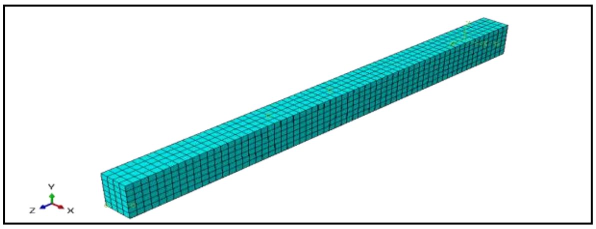

Fig.4.7: Meshing

4. Property

Create material-Geopolymer Concrete-mechanical-Elasticity-elastic-young's modulus Poisson's ratio-General-density-mass density-mechanical-plasticity-compressive behavior-yield stress& inelastic strain-tensile behavior –yield stress-cracking strain-plasticity-dilation angle-eccentricity-Fbo/Fco-K- viscosity parameter-O.K

Table No.4.1 Properties of Materials

Material Properties	Geopolymer Concrete	GFRP
Mass Density	2.5E-09	2560e-12
Poisson's ratio	0.2	0.3
Elastic Modulus	385000	55.7

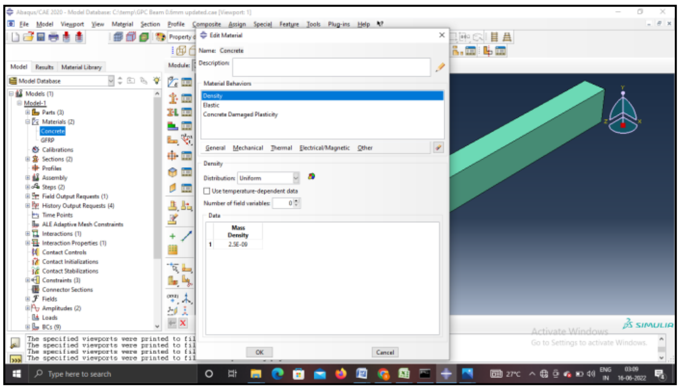

Fig.4.8 Property details - density

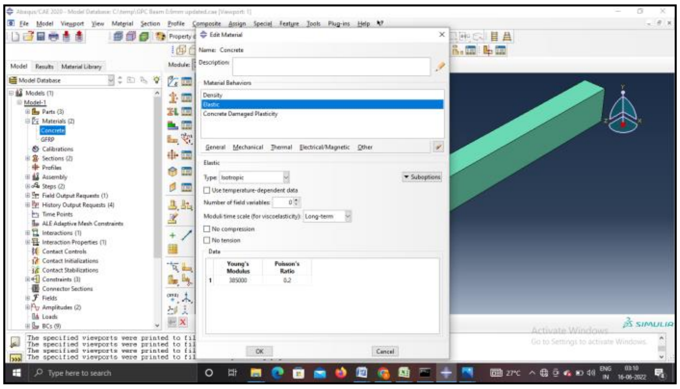

Fig.4.9: Property details - elastic

PARAMETRIC STUDY

5.1 General

To find the effect of thickness of GFRP layer on load capacity of geocrete beam it is required to carry out the parametric study of geocrete beams in different phases. Therefore in this chapter an attempt is made to perform parametric study of the geocrete beams for single layer, 2 layers and 3 layers of GFRP with varying thickness are modeled. The study has been performed by finite element analysis using commercially available software ABAQUS 2020.A The different parameter consist of shape and sizes of geocrete beams, thickness E-glass fiber, and material properties are considered in the analysis.

5.2 Validation

Before performing a comprehensive parametric study the validation of the FE model with the existing available experimental test result has been carried out. The validation is carried out on geocrete Group A beams tested by Prof. Kumutha Rathinam, et al. (2016).The geometric and material properties used in FE analysis are same that has been the adopted through reference papers used in the experimental investigation. The validation is performed using ABAQUS version 6.13 (2020) to simulate the beam experiments. The load-deflection response of the Group A beams is compared with that of the control beam.

Here we consider the control geopolymer concrete beam without GFRP laminate of size 1600 mm in length and 150 mm in depth and 100 mm wide. The point load is applied to the centre of the beam. The two roller supports are provided at 50 mm distance from the external edges of the beam.

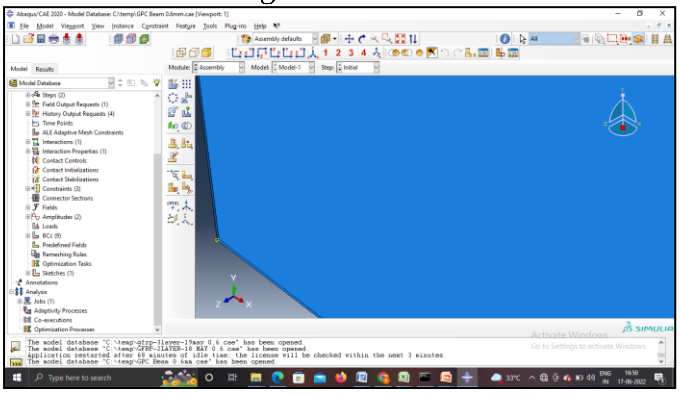

Fig.5.1: Single Layer of 0.6mm GFRP

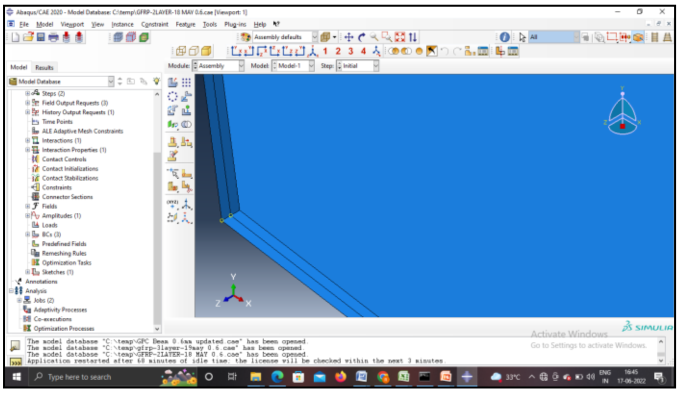

Fig.5.2: Double Layer of GFRP 0.6mm

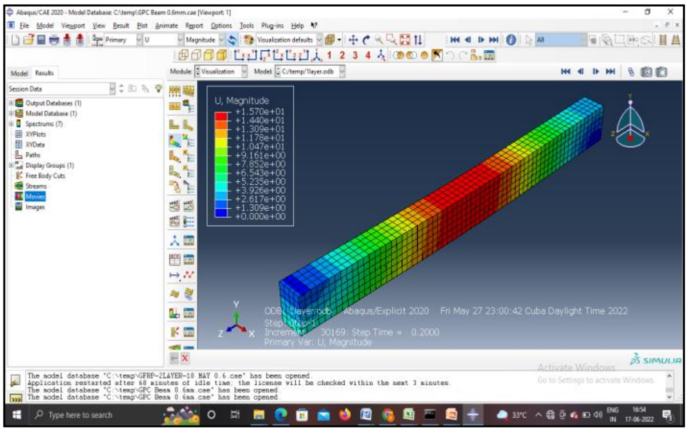

Fig.5.4: Deformed section

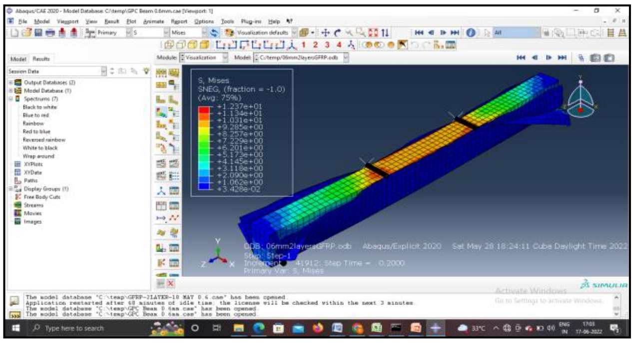

Fig.5.5: Deformed section double layer

RESULTS AND DISCUSSION

6.1 General

The results and discussion of this investigation work is given below. To study the analytical evaluation of effectiveness of the externally bonded Glass Fiber Reinforced Polymer (GFRP) in the strengthening of the geocrete beams ABAQUS software is used. To study the load-deflection behavior of geocrete beam.

6.2. Deformed section of specimen

The deformed sections of the geocrete beam with and without GFRP laminates are illustrated in images below. The variations in the deformations with and without GFRP sheets are seen from images. The GFRP sheets are provided with thickness 0.7mm and 0.8mm with single layer, double layer and triple layer to geocrete beam.

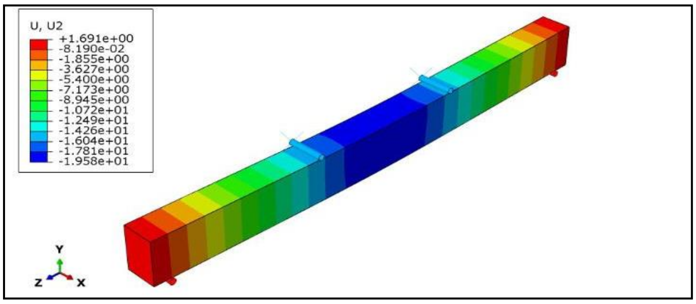

Fig.6.1: Model without GFRP

Table 6.1 Deflection and ultimate load Results of Model without Wrapped with GFRP

Properties	Results
Total Deflection in (mm)	62.6
Ultimate Load (kN)	10.21

6.3 Load-Deflection Behavior

The graphs below shows the load-deflection behavior of geocrete beam provided with 0.7mm and 0.8mm thickness of GFRP laminates in single layer, double layer and triple layer of GFRP laminates for 0.7mm and 0.8 mm thickness are also given the tables below.

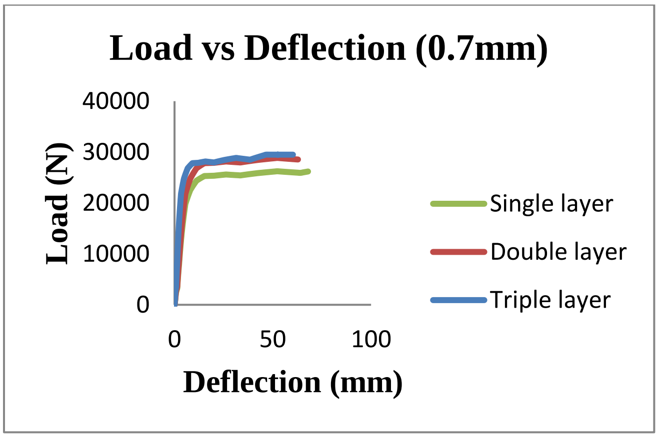

Fig.6.8: Load vs. Deflection for 0.7mm GFRP

Table No.6.3.1 Analysis results

Layers of GFRP	Deflection (mm)	Ultimate Load(kN)
Single Layer	66.93	26.18
Double Layer	62.80	28.54
Triple Layer	60.25	29.49

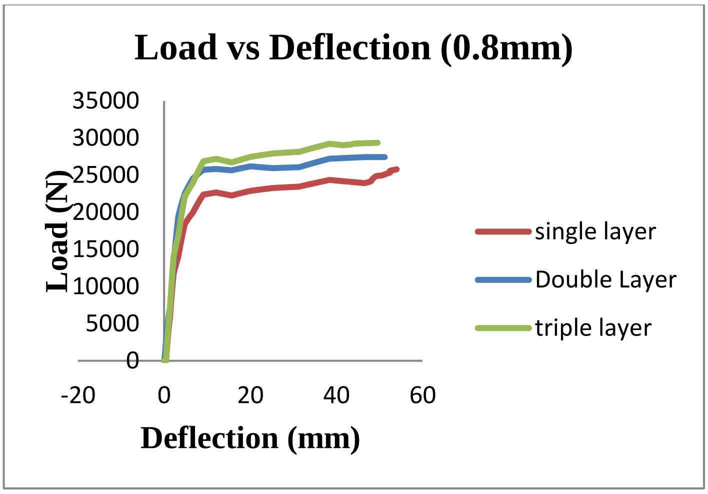

Fig.6.9: Load vs. Deflection for 0.8mm GFRP

Table No.6.2 Analysis results

Layers of GFRP	Deflection (mm)	Ultimate Load(kN)
Single Layer	61.99	25.78
Double Layer	58.23	27.43
Triple Layer	55.55	29.36

6.4 Comparison of deflections of geocrete beam with varying GFRP thickness

The percentage of maximum deflection of geocrete beam provided with 0.7mm and 0.8mm is compared with maximum deflection of geocrete beam without GFRP laminates. The percentage deflections are given below.

1. The difference of percentage maximum deflection between 0.7mm single layer GFRP laminated beam and control beam is 2.2%.
2. The difference of percentage maximum deflection between 0.7mm double layers GFRP laminated beam and control beam is 4.26%.
3. The difference of percentage maximum deflection between 0.7mm triple layers GFRP laminated beam and control beam is 8.15%.
4. The difference of percentage maximum deflection between 0.8mm single layer GFRP laminated beam and control beam is 5.5%.

5. The difference of percentage maximum deflection between 0.8mm double layers GFRP laminated beam and control beam is 11.1%.
6. The difference of percentage maximum deflection between 0.7mm triple layers GFRP laminated beam and control beam is 15.30%.

CONCLUSION

7.1 Concluding Remarks

In this analytical investigation, the geocrete beam strengthened GFRP laminates are studied. The GFRP laminates of thickness 0.7mm & 0.8mm are used for the study. The laminates are applied in single, double & triple layers in this study. From the study, following conclusions are drawn:

- The variations in the deformed section of control beam & GFRP laminated beam.
- As the GFRP layers increases in geocrete beam, ultimate load is also increases.
- As the GFRP layers increases in geocrete beam the maximum deflection is decreases accordingly.
- By increasing GFRP layers, deformation in the beam is reducing.
- Deflection of GFRP beam under ultimate load is less compared to control beam while it is retrofitted with glass fiber.

7.2 Future Scope

In the partial scope of the current work, the wide assumptions drawn since this work must remained reported. However, further study can be undertaken in the following areas: Strengthening of geocrete beam with different type of fiber reinforced polymer sheet like woven roving, unidirectional mat and Carbon fiber reinforced polymer. Variation of beam dimension. Variation of thickness and for different grades of concrete. Strengthening of beam weak in shear and torsion strength.