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FLEXURAL BEHAVIOUR ON GEOPOLYMER CONCRETE PRE STESSED AND POST-TENSIONED BEAMS

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Abstract- *In view of the serious impact of carbon dioxide on the environment and the continued anticipated growth of industrialization and urbanization, there is a need to redirect the building industry from its overwhelming reliance on Portland cement to alternative binder systems like geopolymer binders. Experiments have been conducted and the behavior of flash based geopolymer concrete beams, post-tensioned beams and presterssed concrete sleepers were developed. Five normal beams and four post-tensioned beams of 125 x 250 x 3200 mm size were cast and tested. Out of this five normal beams, one is control beam with normal cement concrete and the remaining four are geopolymer concrete beams and also four post-tensioned beams (two normal concrete and two geopolymer concrete beams) with Alkali –Activator Solution / Fly ash ratio 0.40, 0.45, 0.50, 0.55 and comparable compressive strength. The load-deflection and moment curvature behaviors obtained from the experimental results are compared with analytical solutions*

Key words: *environment, geopolymer binders, post-tensioned beams, presterssed Concrete sleepers, load-deflection and moment curvature.*

1. INTRODUCTION

Fly ash based geopolymer concrete possesses the improved qualities to be used widely for any construction purpose. Geopolymer mixed concrete develops a glossy surface that can give a good appearance if used in constructing floors and walls. Activation by alkali gives rise to material with varied properties from that of OPC and make fly ash based geopolymer concrete more fire resistant and resistance against abrasion and cracking. Since fly ash is only a byproduct material found from industrial wastes cost of such geopolymer concrete is less than or almost equal to OPC concrete which uses expensive cement as binder material.

1.1 Preparation of Specimens

The concrete batch was mixed using the following procedure:

i) The fly ash and fine aggregate were mixed dry until the mixture is thoroughly blended and is uniform in colour.

ii) The coarse aggregate was added and mixed with the fly ash and fine aggregate until the coarse aggregate was uniformly distributed throughout the batch. The aggregates were kept in saturated surface dry condition.

iii) The Alkali-Activator solution was added and the entire batch was mixed until the concrete appeared to be homogenous and get the desired consistency.

The solid constituents of the fly ash based geopolymer concrete; the aggregates and the fly ash were dry mixed using a Pan mixer for about three minutes. The wet mixing of Alkali-Activator solution was prepared earlier and dry mixture of aggregates usually continued for another four minutes. The wet mixing is usually in cohesive condition.

1.2. Mix Proportions

A mix ratio of 1:1.3:2.7 (1 fly ash: 1.3 fine aggregate: 2.7 coarse aggregate) with water cement ratio of 0.38 has been obtained for normal concrete for a cube compressive strength of 40 N/mm^2 (approximate) by adopting the mix design procedure given in IS 10262 – 2009. The same mix ratio has been retained as a trial mix for geopolymer concrete with the replacement of cement with fly ash and water cement ratio with Alkali –Activator Solution / Fly ash ratio. The constituent materials used in the mix for 8 molar solutions is shown in Table 1. In this study, various concentrations of NaOH solutions 8M, 10M, 12M and 14M were used along with different Alkali –Activator Solution /fly ash (AAS/FA) ratios 0.40, 0.45, 0.50 and 0.55.

Table.1. Constituents of Geopolymer concrete (Per 1m³)

Sl. No	Beam Designation	Details	Compressive strength of concrete N/mm2
1.	NCB	Country concrete beam	43.3
2.	GCB1	Geopolymer concrete beam with Alkali –Activator Solution /fly ash ratio 0.4 (NaOH-8M)	46.4
3.	GCB2	Geopolymer concrete beam with Alkali –Activator Solution /fly ash ratio 0.45(NaOH-8M)	46.0
4.	GCB3	Geopolymer concrete beam with Alkali –Activator Solution /fly ash ratio 0.5(NaOH-8M)	45.8
5.	GCB4	Geopolymer concrete beam with Alkali –Activator Solution /fly ash ratio 0.55(NaOH-8M)	44.2

2. Test on Geopolymer Concrete Beams

Totally five beams of 125 x 250 x 3200 mm size were cast and tested in the laboratory over an effective span of 3000 mm. Out of this, one is normal beam made of normal concrete using country Portland Cement and the remaining four beams are made of geopolymer concrete as detailed in Table 2.

Table 2 Strength and deformation properties of beams

Beam code	First crack stage		Service stage		Yield stage		Ultimate stage		Average crack width at service load (mm)
	Load (kN)	Central deflection (mm)	Load (kN)	Central deflection (mm)	Load (kN)	Central deflection (mm)	Load (kN)	Central deflection (mm)	
NCB	15.00	5.32	30.00	25.50	34.15	21.00	42.75	46.19	0.20
GCB1	32.50	7.28	46.45	41.50	51.50	30.83	62.50	55.37	0.09
GCB2	34.00	7.35	46.75	41.33	52.00	29.85	61.75	58.25	0.11
GCB3	35.00	7.70	47.25	42.15	53.00	31.76	61.00	60.18	0.12
GCB4	37.25	8.64	47.75	42.40	52.50	32.03	61.50	62.28	0.12

The beams were designed as under reinforced section, reinforced with 2-Y12 at bottom, 2-Y10 at top using 6 mm diameter stirrups at 150 mm c/c (Figure 1) and the yield strength of steel used is 451 N/mm2. Beams were tested in four point bending, the maximum stress is present over the center, 1/3 portion of the beam under static monotonic loading. Deflections were measured at the 1/3 points and midpoint and strains were measured at the extreme compression fiber and at the level of steel in the middle third zone. The casting of beams is shown in Figure 2 and the test set up arrangement of the beam is shown in Figure 3.

Fig.1. Arrangement of Reinforcement grill

Fig.2. Casting of Concrete Beam

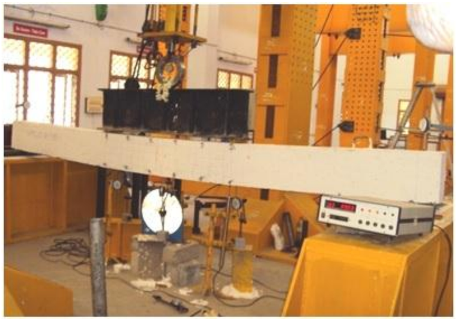

Fig.3. Loading set up

The moment - curvature and load - deflection relationships were obtained using deflection measurements from LVDTs and strain data collected from demec gauges for the normal beam and geopolymer concrete beams under static monotonic loading. From the load - deflection, it is noted that the geopolymer concrete beams exhibit decreased deflection and appreciable flexural strength when compared to normal concrete beam. The first crack loads were obtained by visual examination only. The crack width with respect to load under monotonic condition is shown in Figure 4.

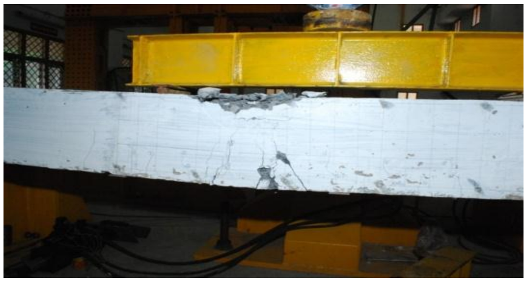

Fig.4. Beam failure

Strength and deformation properties of the normal beam and geopolymer concrete beams are reported in Table 2. The details of Moment-Curvature relationship for geopolymer concrete beams and normal concrete beams are presented in Figure 5.

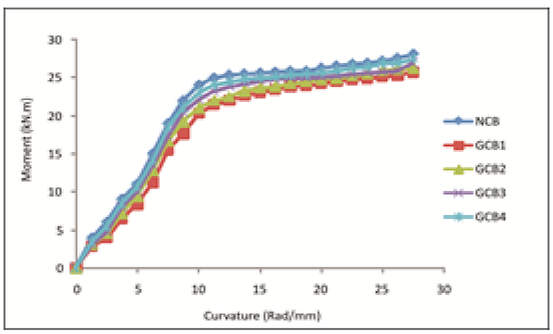

Fig. 5. Moment - curvature relationship

The load and deflections for normal concrete beams and geopolymer concrete beams are presented in Figure6. The geopolymer concrete beams behave in a similar way as that of normal concrete beams.

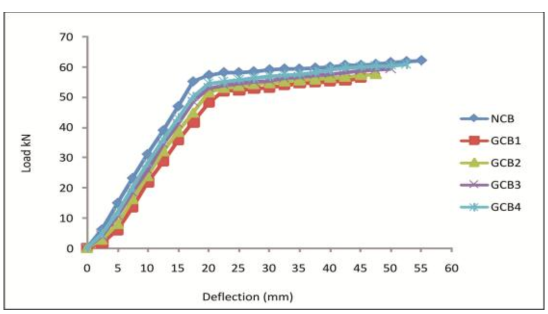

Fig.6. Load – deflection behavior

The comparison of load-strain behavior of normal and geopolymer concrete beams is shown in Figure 7.

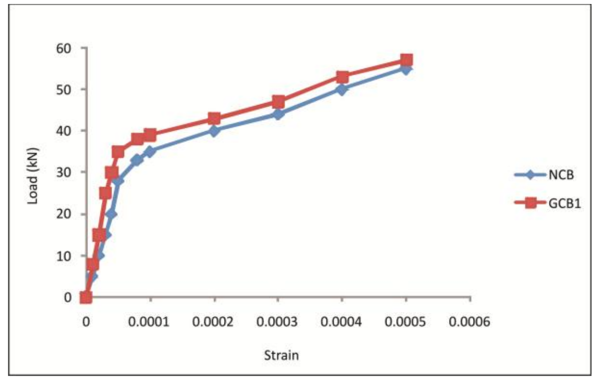

Fig.7. Load-strain curve

2. 1 Crack Pattern

The crack pattern for normal concrete beam and geopolymer concrete beam are shown in Figure 8. Flexural behavior is observed in all the beams and geopolymer concrete beams behave in a similar manner as that of normal concrete beam.

Fig.8. Crack pattern

2.2Theoretical Load-Deflection Behavior (Section Analysis)

The theoretical multi-linear moment - curvature (M-∅) relationships were derived for the normal beam following the procedure given in Park and Paulay (1975). The three important stages or points identified in the M-∅ curve are the cracking stage, yielding stage, and ultimate stage. In this study, one more stage which corresponds to the start of non-linearity in stress strain curve of steel is proposed and thus making it a multi-linear curve. From the multi-linear M-∅ relationship multi-linear load-deflection curve was derived by adopting a curvature distribution similar to that of a bending moment variation and conjugate beam method of analysis. The same procedure was adopted for geopolymer concrete beams.

The experimental and theoretical moment - curvature curves are compared for both normal concrete beam and geopolymer concrete beam and are shown in Figure 9. It can be seen that the predicted behavior is in close agreement with the experimental behavior.

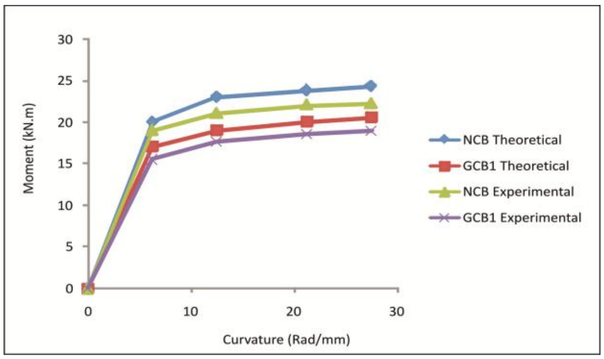

Fig.9. Theoretical moment - curvature curve

The experimental and theoretical load-deflection curves are compared for both normal concrete beam (NCB) and geopolymer concrete beam GCB1 and are shown in Figure 10. It can be observed that the predicted deflections are fairly in close agreement with the experimental results.

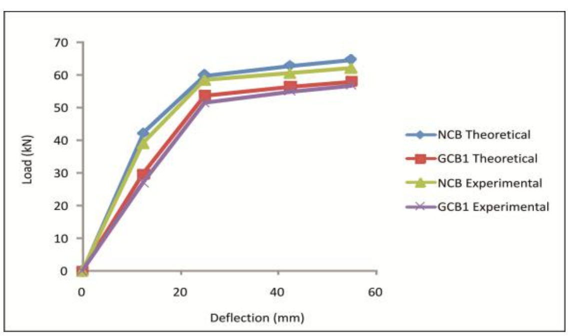

Fig.10. Load - deflection curve

2.3 Numerical Analysis by Ansys

The non linear finite element analysis was carried out to investigate the performance of beam. The finite element modeling of the sub assemblage was performed using software ANSYS 8.0. The experimental results were used to compare the finite element model. The finite element model, element types, material properties used in this analysis are given below.

3. Finite Element Modeling

Software ANSYS is capable of handling dedicated numerical models for the non-linear response of reinforced concrete under static and dynamic loading. The general purpose finite element code, ANSYS utilized in this study to analyse the behavior of the geopolymer concrete beam has a variety of routines, which allows the implementation of specific material models (concrete and steel), boundary conditions, and bond behavior. The interaction between the reinforcing steel and concrete can also be considered. Eight node solid brick elements (SOLID 65) were used to model the concrete. These elements include a smeared crack analogy for cracking in tension zones and a plasticity algorithm to account for the possibility of concrete crushing in compression regions. Internal reinforcement was created using 3-D spar elements (Link 8) and these elements allow the elastic-plastic response of the reinforcing bars.

The analysis is done by applying an incremental load, with interaction in each increment. The modified time to time algorithm with assumed proportional loading history is used. The approach determines the static equilibrium solutions for unstable response in concrete, due to cracking in tension, yielding of reinforcement, and concrete softening in compression. It neglects any permanent strains associated with cracking.

3.1 Reinforced concrete

The solid element (SOLID 65) has eight nodes with three degrees of freedom at each node and translations in the nodal x, y, and z directions. The element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. The geometry and node locations for this element type are shown in Figure 11.

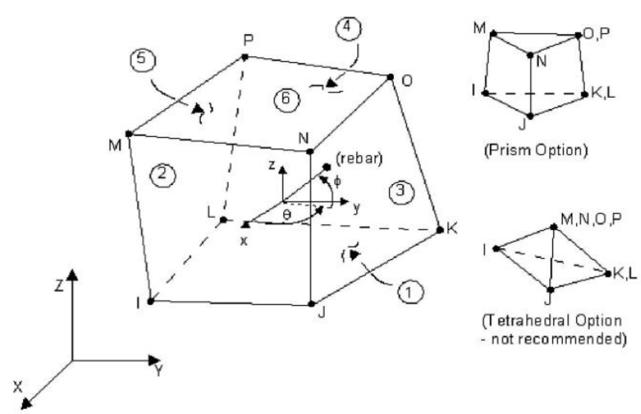

Fig.11.SOLID 65 elements (concrete)

The geometry and node locations for Link 8 element used to model the steel reinforcement are shown in Figure 12. Two nodes are required for this element. Each node has three degrees of freedom, translations in the nodal x, y, and z directions. The element is also capable of plastic deformation.

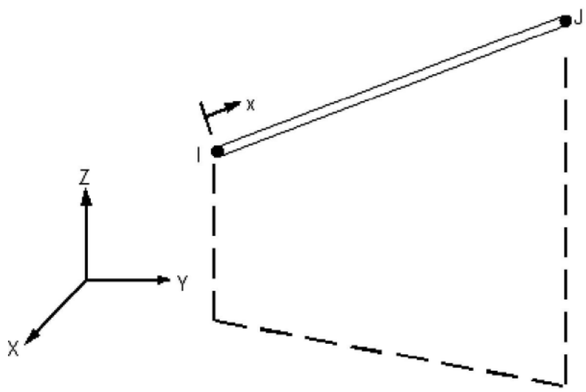

Fig.12. Link 8 element (Reinforcement)

3.2 Boundary conditions and loading

The boundary conditions were exactly simulated as in the test set up. Horizontal and vertical restraints, representing a pin connection were applied at the top and bottom of the beam. At the middle of beams, only vertical displacement was provided to simulate the static load conditions used in the test.

3.3 Material properties

The material properties used for modeling, concrete and reinforcement are given in Table 3.

Table 3.Material properties

Normal Concrete

Parameters	Values
Elastic modulus (Ec)	37018.90 MPa
Compressive strength (f ck)	43.3 MPa
Poisson's ratio (μ)	0.2

Geopolymer Concrete

Parameters	AAS/FA Ratio	Values
Elastic modulus (Ec)	0.4	41141.80 MPa
Elastic modulus (Ec)	0.45	41092.21 MPa
Elastic modulus (Ec)	0.5	41085.54 MPa
Elastic modulus (Ec)	0.55	39951.29 MPa
Compressive strength (f ck)	0.4	46.4 MPa
Compressive strength (f ck)	0.45	46.6 MPa
Compressive strength (f ck)	0.5	45.8 MPa
Compressive strength (f ck)	0.55	44.2 MPa
Poisson's ratio (μ)		0.2

Reinforcement

Parameters	Values
Elastic modulus (Ec)	**2x105MPa**
Yield stress (fy)	**451MPa**
Poisson's ratio (μ)	**0.3**

The element discretization, loading pattern and boundary condition in finite element analysis model for beam specimens are shown in Figure13.

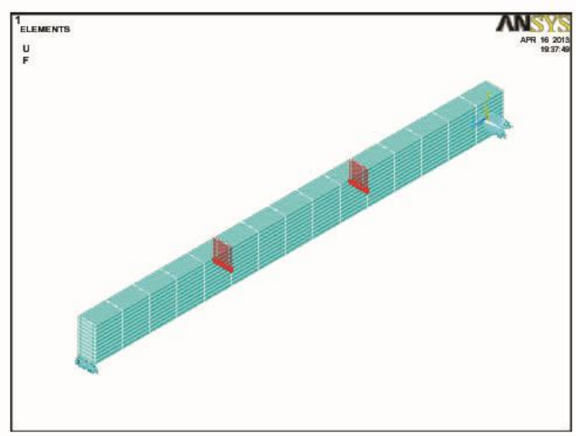

Fig.13. ANSYS model of Beam

3.4 LOAD DEFLECTION – EXPERIMENTAL Vs ANSYS

The theoretical load deflection relationships were derived for the normal beam using ANSYS software. The experimental and ANSYS load and deflection details for normal and geopolymer concrete beam details are given in Table. 4. The experimental and numerical load deflection behavior for normal concrete and geopolymer concrete beams are shown in Fig. 14.

Table 4 Strength and deformation properties of beams (Experimental Vs ANSYS)

Beam Designation	Load (kN)		Deflection (mm)	
	Experiment	ANSYS	Experiment	ANSYS
NCB	56.5	54.2	52.5	51.6
GCB1	62.5	61.3	46.5	44.5
GCB2	58.0	56.8	49.5	48.3
GCB3	57.5	56.2	50.5	49.2

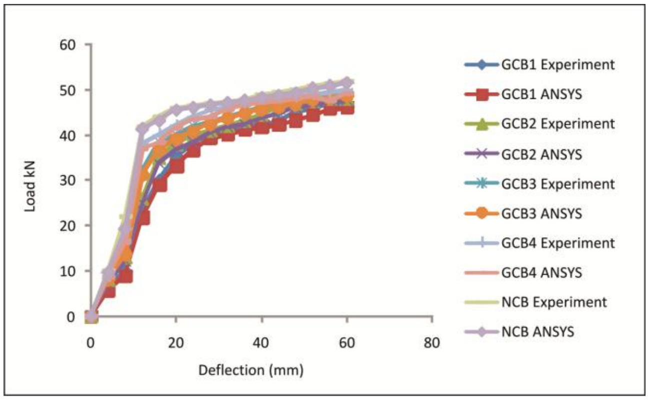

Fig.14. Load deflection – Experimental Vs ANSYS

The typical deflected shape of beam specimen is shown in Fig. 15.

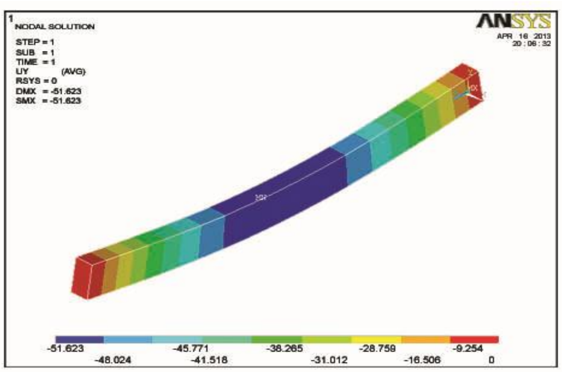

Fig.15.ANSYS model and deflected shape of Beam

4. TEST ON PRESTRESSED CONCRETE BEAMS

As concrete of strength more than 50 MPa was obtained, it was decided to use geopolymer concrete for presterssed concrete beams using post tensioning technique.

4.1 Specimen Details

In this study, four beams of 3200 x 250 x 125 mm size were cast (Two normal concrete and two geopolymer concrete beams). At the time of casting, hollow ducts of 60 mm size with grouting provisions were installed for post tensioning operations. The ducts were placed at a constant eccentricity of 40 mm at both ends of the beam, spiral rings of 6 mm diameter at a length of 600 mm was placed. It gave the shear capacity to take care of end anchorage. Four numbers of 3 mm 3 ply strands were used to pre-stress one beam. The pre-stressing strands were stressed to 350.3 N/mm^2. The compressive stress of geopolymer concrete beam is 58.25 N/mm2. The above arrangements are shown in Fig. 16.

Fig.16. Mould with spiral end anchorage

4.1.1 Casting of Geopolymer Concrete Post-tensioned Beam

The fly ash and the aggregates were first mixed in the pan mixer for about 3 minutes. The alkaline liquid mixed with super plasticizer (CONPLAST SP 420 was used at 3 ml/Kg of cement) then added with the dry mixers in the pan mixer itself.

The workability of the fresh concrete was measured by conducting slump test and it is about 30mm.All the specimens were cast using geopolymer concrete and normal concrete of grade M50 (Mix 1 : 1.66 : 2.58, W/C 0.36). Each specimen was cast in three layers by compacting manually as well as by using vibrator. The casting process is shown in Fig. 17.

Fig.17. Casting of Post-tensioned Beam

4.1.2 Steam Curing of Geopolymer Concrete Post-tensioned Beam

The beam specimen was placed inside the steam curing chamber as shown in Fig.18. The geopolymer concrete specimens undergo a steam curing (60°C) for 24 hours.

Fig.18. Specimens inside Steam Curing Chamber

4.1.3 Post Tensioning of Beams

Pre compressive forces were induced in a concrete beam by tensioning steel tendons of strands placed in ducts embedded in the concrete. The tendons were installed after the concrete was cured. The strands were properly anchored by end blocks. The end blocks are rigid steel plates of size 125 × 250 mm and thickness of 20 mm as shown in Fig. 19. All the beams were grouted manually with cement paste through the holes placed inside the beams.

Fig.19. End Block and Barrel and Wedges of Post Tensioned Beam

4.1.4 Experimental Setup

The beams were tested under two point loading which was monotonically increased. The experimental setup is shown in Fig.20.

Fig.20. Experimental Setup of Beam

The load and deflection details (Fig.21) reveal that the behavior of GPC and OPC post tensioned beam are almost same.

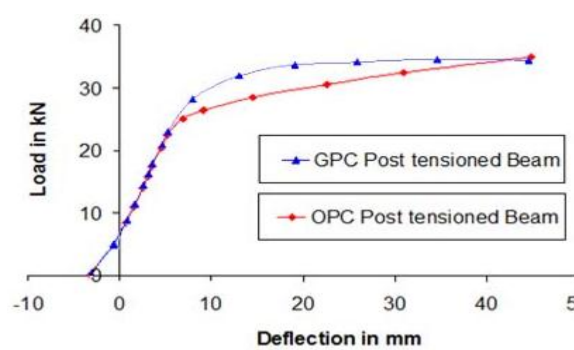

Fig. 21 Load - Deflection of GPC and OPC Post tensioned Beam

The ultimate load carrying capacity of GPC beam is slightly higher than the OPC post tensioned beam. The crack pattern of post tensioned beam is shown in Fig.22.

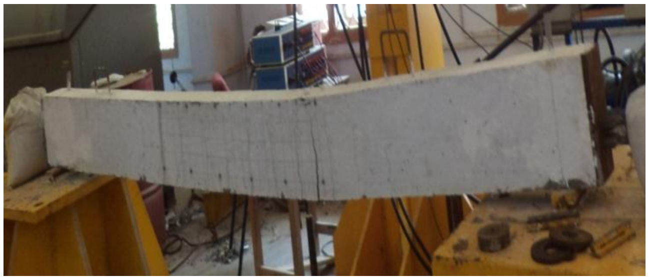

Fig.22. Crack Pattern of GPC Post Tensioned Beam

From the experimental results (Table 5), it is found that the flexural behavior of OPC and GPC post tensioned beams are same.

Table 5 Experimental Results

Beam code	First crack stage		Yield stage		Ultimate stage		Average crack width at service load(mm)
	Load (kN)	Central deflection (mm)	Load (kN)	Central deflection (mm)	Load (kN)	Central deflection (mm)	
OPC	**30.0**	**56.85**	**73**	**210**	**230**	**730**	**0.80**
GPC	**35.0**	**105.50**	**120**	**308**	**250**	**1100**	**0.15**

6. RESULT AND DISCUSSIONS

The geopolymer concrete beams were cast and tested, based on the results the moment -curvature and load-deflection relationships were obtained using deflection measurements from LVDTs and strain data collected for the normal concrete beam and geopolymer concrete beams under static monotonic loading. From the load-deflection, it is noted that the geopolymer concrete beams exhibit decreased deflection and appreciable flexural strength when compared to normal beam.

The post-tensioned beams were tested under two point loading which was monotonically increased. From the load and deflection details, it is found that the behavior of GPC and OPC post tensioned beam are almost same. The ultimate load carrying capacity of GPC beam is slightly higher than the OPC pre-tensioned beam.

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