Experimental and Analytical Study on Geopolymer Concrete Beam with Hollow Space below Neutral Axis

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Abstract - *In this paper, a detailed study was carried out on strength behaviour of flyash based geopolymer concrete with hollow space below neutral axis. Use of hollow space at and near the neutral axis will reduce the self-weight and saves concrete materials. This paper focuses on material minimization by introducing hollow space using pvc pipe in tension zone of beams. By this method, we can reduce the dead loads which contribute to seismic effect in high rise structures. Geopolymer concrete shall be produced without using any amount of ordinary Portland cement. Alkaline solution produced aluminosilicate gel that acts as the binding material for the concrete. Thus many efforts are being made to reduce the usage of opc which responsible for carbon dioxide emission. M30 grade concrete is used for ordinary and geopolymer concrete. Experimental validation was done by ANSYS software*

Key Words: Fly ash, alkaline solution, opc , pvc

1. INTRODUCTION

The global warming is an environmental problem caused due to the emission of greenhouse gases, such as carbon dioxide (CO2), to the atmosphere. As the demand for concrete increases in construction field, the demand for Portland cement also increases . Cement industry is held responsible for some of the CO2 emissions. Thus many efforts are being made to reduce the usage of cement. The concrete just above neutral axis is less stressed whereas the concrete below the neutral axis acts as a shear transmitting media. Sustainability can be achieved by replacing the partially useful concrete ,by saving concrete, which reduces the demand for material and cost. So new technology materials like geopolymers offer waste utilization and emissions reduction, in which fly ash is used as a base material instead of OPC in geopolymer concrete. Geopolymer concrete is an innovative construction material which is produced by the chemical action of inorganic molecules. Fly Ash, a by- product of coal obtained from the thermal power plant is available in plenty worldwide. Flyash is rich in silica and alumina reacted and an excellent alternative construction material to the existing plain cement concrete .In this work flyash based geopolmer is used. Flyash is a waste product generated from thermal power plant. Hence we can protect water bodies from contamination due to flyash disposal and by creating hollow space at tension zone by inserting the pvc pipe we can reduce the quantity of concrete and cost can be reduced. The electrical conduits, air conditioning small ducts etc .also been taken through these hollow beams.

2. OBJECTIVE

The main objectives of the present study is

- The main aim of this study is to find the structural behaviour of hollow GPC beam.
- To study the flexure behaviour of hollow pcc concrete beam at different diameter pvc pipe.
- To determine the flexural strength.
- To determine the load carrying capacity of hollow concrete beams.

3. METHODOLOGY

The work methodology consist of,

1) Selection of grade of concrete; M30 for opc and geopolymer concrete.

2) Mix design of M30 grade concrete.

3) Creating the hollow section inside the beam with two dia 25mm pipes and 32mm pipe.

6) Casting, Curing and Testing

7) Result and discussion

4. MATERIAL USED

4.1.Flyash

Fly ash is a by-product of coal-burning power plants. Therefore, huge quantities of fly ash will be available for many years in the future. Fly ash can be used in Portland cement concrete to enhance the performance of the concrete. Flyash has been successfully used to manufacture geopolymer concrete when the silicon and aluminum oxides constituted about 80% by mass.

4.2. Alkaline solution

A combination of sodium silicate solution and sodium hydroxide (NaOH) solution can be used as the alkaline liquid.

It is recommended that the alkaline liquid is prepared at least 24 hours before use. The addition of sodium silicate solution to the sodium hydroxide solution as the alkaline activator enhanced the reaction between the source material and the solution. The concentration of sodium hydroxide solution was 16 Molar.

4.3. Coarse aggregate

Coarse aggregate used was locally available crushed angular granite metal of 20mm size .These aggregates are bound together by the cement and fine aggregate in the presence of water to form concrete.

4.4. Fine aggregate

Fine aggregate consist of natural sand or crushed stone sand. It should be hard, durable and clean and be free from organic matter .sand conforming to zone II is used.

5. MATERIAL TEST

Test results on cement, fly ash, and fine aggregate and coarse aggregate are given in table 1.

Table 1: Material property

TEST	MATERIAL USED	VALUES OBTAINED
Specific gravity	Cement (53grade)	3.16
Specific gravity	Fine aggregate (m sand)	2.56
Specific gravity	Coarse aggregate	2.96
Specific gravity	Fly ash	2.3
Water absorption	Fine aggregate	2.01%
Water absorption	Coarse Aggregate	0.326%

6. MIX DESIGN

The compressive strength and the workability of geopolymer concrete are influenced by the proportions and properties of the constituent materials .Table 3 and 4 shows the mix proportion of geopolymer concrete and OPC concrete

Table 2: Mix Design of GPC

Flyash(kg/m3)	550
Sodium silicate(kg/m3)	239.64
Sodium hydroxide(kg/m3)	95.86
Fine aggragte(kg/m3)	576.51
Coarse aggregate(kg/m3)	854.68
Extra water(l/m3)	16.5

Table 3: Mix Design Of OPC

cement(kg/m3)	394.32
Fine aggregate(kg/m3)	643.15
Coarse aggregate(kg/m3)	1246.6
water(kg/m3)	197.16
Water cement ratio(kg/m3)	0.5

7. EXPERIMENTAL SETUP

7.1 Mixing of geopolymer

In the laboratory, the fly ash and the aggregates were first mixed together for about three minutes .The alkaline solutions, sodium hydroxide solution and sodium silicate solution were prepared separately before one day of casting to get the required strength and mixed together at the time of casting. Since lot of heat is generated when sodium hydroxide pellets react with water, the sodium hydroxide solution was prepared a day earlier to casting. The alkaline solutions were added to mixed materials. The mixing of total mass was continued until the mixture become homogeneous and uniform in colour.

7.2 Curing of geopolymer

After casting the specimens, they are kept in rest period in room temperature for one day. Heat-curing substantially assists the chemical reaction that occurs in the geopolymer paste the geopolymer concrete is de-moulded and then placed in an autoclave for steam curing for 24 hours at a temperature of 60degree Celsius. The compressive strength of geopolymer concrete cubes increase with the increase in age.

8. TEST PROCEDURE

Geopolymer concrete cubes, cylinder and beam according to standard dimension were cast. cube compressive strength, cylinder split tensile strength and beam flexural strength are determined by UTM .7,14,28 days results were taken. Typical PCC beams of size 100x100x500mm were used with hollow neutral axis are made by PVC pipes of 25 mm ϕ and 32 mm ϕ. For plain geopolymer beam the neutral axis will be at at the centre. The length of the pipe inside the beam neutral axis is 450mm and an anchorage length of 25mm on each side is provided for the transfer of load. The depth of neutral axis is taken as half of total length. All the beams were subjected to 2-point flexural test. Figure 1 shows the beam with pipe.

Fig 1:Beam with pipe

8. Result and Discussion

8.1. Comparison of geopolymer and conventional concrete

PARAMETRES	GPC	OPC
Compressive strength	31.01N/mm2	30.82 N/mm2
Tensile strength	4.46N/mm2	4.3 N/mm2
Flexural strength	4.85N/mm2	4.5 N/mm2
Poisson's ratio	0.224	0.2
Modulus of elasticity	22360Mpa	27386Mpa

From this it is observed that geopolymer concrete has same properties as that of ordinary Portland cement concrete

8.2 Comparison of solid geopolymer and geopolymer with two diameter pipe beam.

PARAMETRES	Solid GPC	25mm dia	32mm dia
Ultimate load	9.7KN	10.2KN	11.8KN
Flexural strength	4.85N/mm2	5.1N/mm2	5.9N/mm2
Bending moment	1.21KNm	1.29KNm	1.47KNm
Deflection	0.135mm	0.142mm	0.164mm

8.2.1 Ultimate load carrying capacity

Fig.2 show the Ultimate load comparison of solid and hollow beams

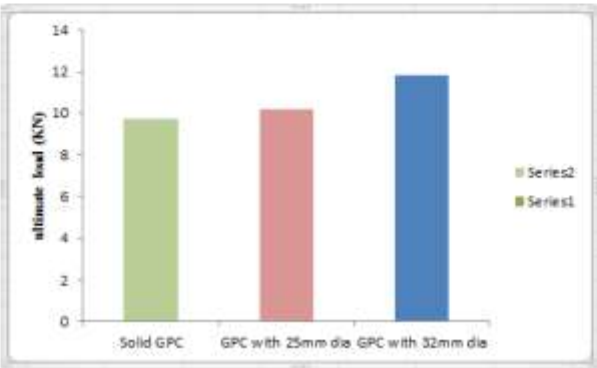

Fig2: Comparison of load

It is observed that ultimate load carrying capacity of GPC beam with hollow space is higher than the geopolymers solid beam

8.2.2 Flexural strength

In this test, plain geopolymer concrete beam was subjected to flexure using symmetrical two point loading until failure occurs. The comparative study of flexural strength of control beams with beams having hollow near neutral axis zone is as shown in Fig. 3

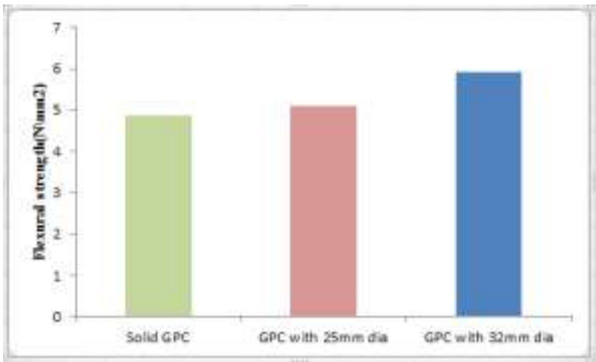

Fig 3: Comparison of flexural strength

8.2.3 Deflection

The corresponding deflection of solid control beam and beam with hollow neutral axis is given in fig:4 from manual calculation.it shows that it lies within the limit as per code IS456-2000.

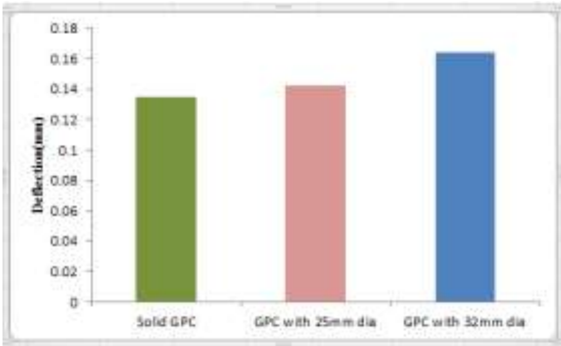

Fig 4: Comparison of deflection

8.3 Crack pattern

In initial stages of loading, all beams were un-cracked beam. When the applied load reached the rupture strength of the concrete on specimens, the concrete started to crack. The failure pattern in all the tested beams was observed as a flexure failure. All the beams showed the same pattern of failure.

Figure 6: Crack pattern

9. ANALYTICAL INVESTIGATION

ANSYS was employed to simulate the flexural and shear behaviour of the beam by finite element method. ANSYS is a general purpose finite element analysis (FEA) software package. FEA is a numerical method of deconstructing a complex system into very small pieces called element. The software implements equations that govern the behaviour of these elements and solves them all. These results can be presented in tabulated or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand.

9.1 Element Types and Real constants

Table 5: Element Types for Model

Material type	Element type
Concrete	Solid 65
Pvc pipe	4 noded quad shell element

9.2 .Material Properties

Table 6: Material Properties Of Elements

	Young's modulus	Poisons ratio	density
PVC	4.7Gpa	0.4	1.38g/cm3
GPC	22360Mpa	0.224	2400Kg/m3

9.3 Modelling Of Beam:

The analysis has been carried out for the comparison and the study of effect of GPC with and without pvc pipe experimental and ANSYS results. The beams modelled in ANSYS for the same Load from experiment.

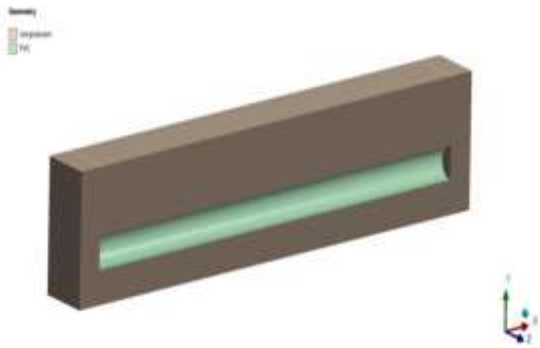

Fig 7 :Beam with 25mm dia pipe

Fig 8: Beam with 32mm dia pipe

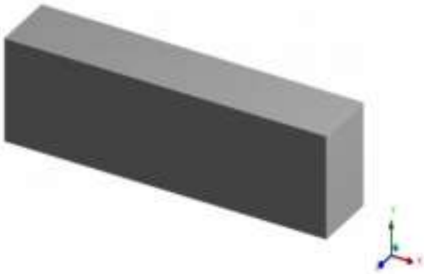

Fig 9: Beam without pipe

9 RESULTS FROM ANALYSIS

10.1. Total deflection

Deflection or deformation is the degree to which a structural element is displaced under aload. It may refer to an angle or a distance. The deflection distance of a member under aload is directly related to the slope of the deflected shape of the member under that load.The maximum deformation for static loading from experiment is given below.

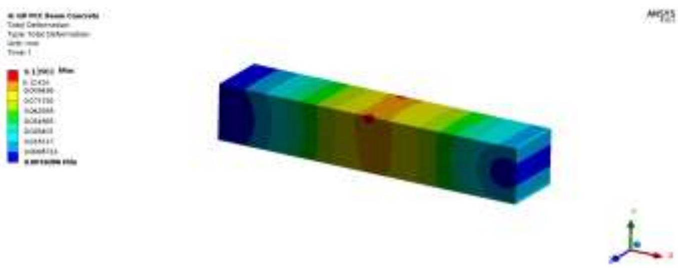

Fig 10 :Beam without pipe

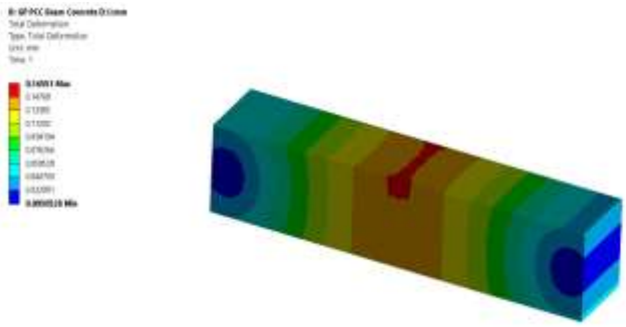

Fig12:Beam with 32mm dia pipe

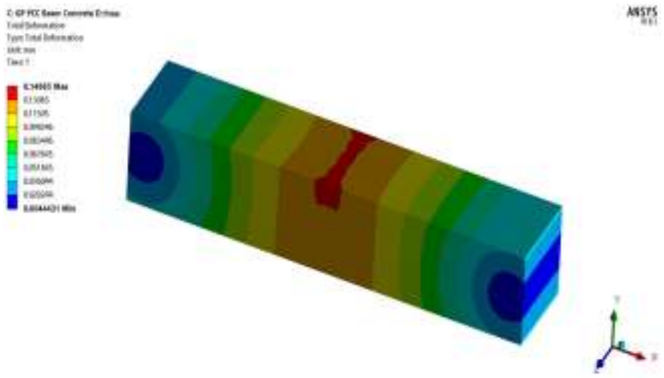

Fig11 :Beam with 25mm dia pipe

10.2 Equivalent Bending Stress

Equivalent stress (also called *von Mises stress*) is often used in design work because it allows any arbitrary three-dimensional stress state to be represented as a single positive stress value. Equivalent stress is part of the maximum equivalent stress failure theory used to predict yielding in a ductile material.

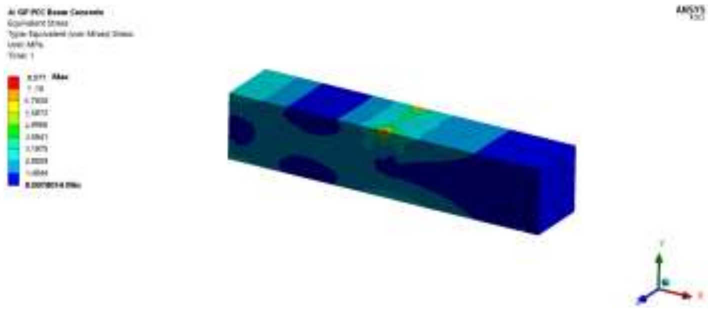

Fig 13 : Beam without pipe

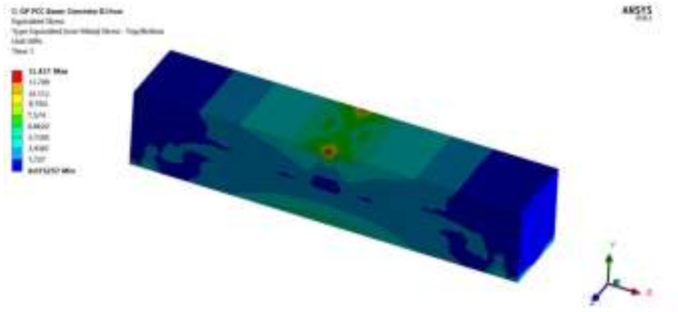

Fig14 :Beam with 25mm dia pipe

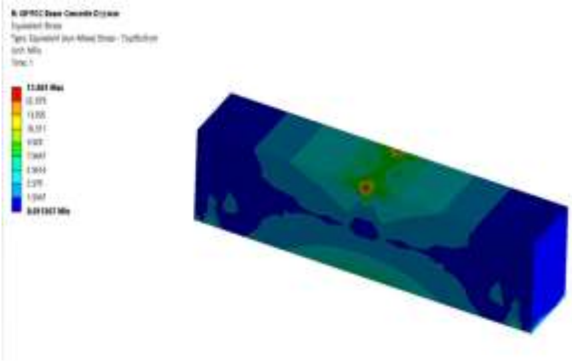

Fig 15: Beam with 32mm dia pipe

8.5.3 Equivalent Elastic Strain

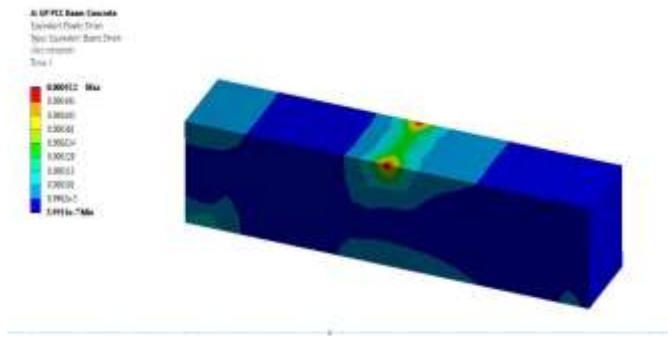

Fig 16 :Beam without pipe

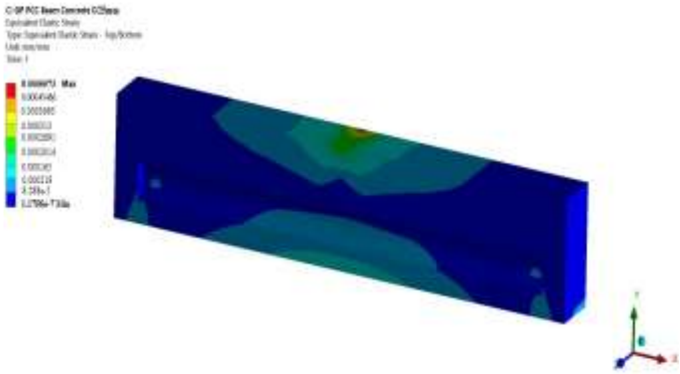

Fig 17:Beam with 25mm dia pipe

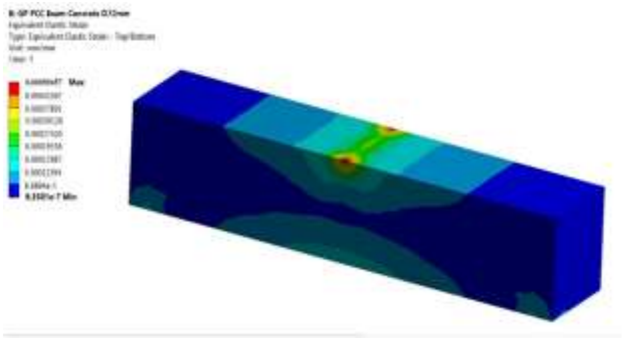

Fig 18: Beam with 32 mm dia pipe

11. Comparison of Results

Analytical and experimental results were compared and it is found that geopolymer with hollow space shows same properties as that of without hollow space.

11.1. Concrete

Total Volume beam V1=0.1x0.1x0.5 = 0.005m3

Volume of pipe V2= π x 0.0125x0.45x2 = 0.00221 m3

% of reduction in concrete = (V1 /V2)*100 = 14.20%

Since we have assumed a small

beam, the percentage reduction is also small. When we assume this for a larger section, the percentage reduction will be larger.

11.2. Labour Reduction:

Labours are one of the major factors in construction industries. Construction labour is most disorganised in India. Direct labour cost is also a part of the prime cost. It is clearly evident from the study that the total volume saving in concrete is directly proportional to the percentage reduction in labour. Concreting works in construction industry is labour intensive. When the volume of concreting works reduce, the need for labour also get decreased simultaneously, which in turn minimise the production cost.

11.3. Cost reduction:

In current days of competition, it is necessary that a business concern should have utmost efficiency and minimum possible wastages and losses to reduce the cost of production. If the cost of input increases, then naturally, the cost of the production will go up. The inputs in construction fields include material, machines, labour and other overhead expenses. From the above conducted study we have come to a conclusion that by using geopolymer beam with hollow neutral axis, we can save significant amount of concrete without compromising the strength up to a limit. This saving in material cost is more effectively utilised when considering large depth and length of beam or in similar other works, where abnormal reduction of concrete occurs. This can be compared to a chain reaction because as the volume of concrete decreases, the material cost reduces which decreases the labour cost, which in turn minimises the construction cost.

11.4 Decrease in self weight

Dead load shall include weight of all structural and Architectural components which are permanent in nature. It includes self-weight of the structure. The unit weight of concrete is 23kN/m3. If we can reduce the volume of concrete then the self-weight of the beam also get reduced.

Weight of 1 m3 concrete = 2300 kg

Weight of beam, W1 =12 kg

Weight of concrete replaced by pipe, W2 = 0.83 kg

	Properties	**Analytical**	**Experimental**
Without Pipe	Deflection	0.13902mm	0.135mm
	Bending stress	9.571N/mm^2	7.26N/mm^2
	Strain	0.000512	0.000327
	Shear force	4910N	4850N
25mm Dia Pipe	Deflection	0.14665mm	0.142mm
	Bending stress	12.42N/mm^2	7.54N/mm^2
	Strain	0.0005573	0.000339
	Shear force	5186.5N	5100N
32mm Dia Pipe	Deflection	0.16551mm	0.164mm
	Bending stress	13.861N/mm^2	8.641N/mm^2
	Strain	0.000594	0.000398
	Shear force	5981.3N	5900N

Weight of hollow beam = W1- W2 = 11.4 kg

Since we have assumed a small beam, the self-weight reduction is also small. When we assume this for a larger section, the weight reduction will be larger.

12. Conclusion

1. GPC has almost same properties as that of OPC.

2. From the above results, it is concluded that Hollow beam of 25mm and 32mm diameter provides higher strength and better performance and hence it is used for structure in effective way as electrical conduits, when compared to the solid conventional beam

3. Mode of failure is flexural in hollow beam of 25mm and flexure in solid and hollow (32mm)

4. It is seen that there is not much difference in the flexural strength of control beams and that of beams with low grade concrete near neutral axis zone and hollow neutral axis.

5. It can also be seen that with the increase in size of pipe replaced at neutral axis, there is no large difference in flexural strength

6. Thus in the overall study, it can be concluded that behaviour of PGC beams with hollow neutral axis behaves almost in the same manner as that of conventional concrete.

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