BEHAVIOUR OF GEOPOLYMER CONCRETE FILLED PVC TUBES

REPORT
Submitted by

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IN

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Under the guidance of
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DECLARATION

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text."

Place: IIT ROORKEE

Date: 20th MAY, 2019

Signature:

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CERTIFICATE

This is to certify that the project work entitled ***"Behaviour of Geopolymer concrete filled PVC tubes"*** *is a bona fide record of the work carried out by*

DIPU SINGH 17523008

during 2018-19 towards the partial fulfilment of the credit requirements in ***Masters in Technology in Structural Engineering*** *of the Department of Civil Engineering.*

Dr. P K Gupta

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ABSTRACT

Concrete is till now the one of the most popular material for construction on earth. Ordinary Portland cement (OPC) is most widely used with other materials like water and aggregates to act as binder. Due to the increased demand for concrete as construction material, the demand for Portland cement also increases. Geopolymer concrete (GPC), which is recognised as an environmentally friendly alternative to ordinary Portland cement (OPC) concrete, has been reported to possess high fire resistance. There has been quite a number of researchers who have worked on geopolymer concrete and good amount of literature is available on it. At the same time, deterioration of concrete and its restoration has been a subject of recent concern and people are coming up with methods to improve the strength and durability of a structure. Two evident deficiencies are lack of lateral confinement and low energy absorption capacity. Taking these points in account PVC pipes have been used as lateral confinement since also because there is very little work done in this direction. Very limited research has been conducted to investigate the behaviour of geopolymer concrete-filled PVC tubular (GCFT) columns at either ambient or elevated temperatures. The present work is an attempt to fill the knowledge gap present in the field.

The review of literature shows that in most of the earlier studies on GPC source material was only fly ash which requires an elevated temperature for curing. But when coupled with ground granulated blast furnace (GGBS) slag, this could also be used without requiring the temperature to be raised. i.e. normal temperature curing. Concrete filled PVC tubes have some literature but there has not been much work done in the with geopolymer concrete filled PVC tubes.

In view of this, present experiment is designed to find out the strength of geopolymer concrete filled PVC tubes with variation in the GGBS content and the molarity of the alkaline solution used to activate the binder. The main purpose of this project was to study the load- displacement and ductility behaviour of fly ash based geopolymer concrete blended with GGBS (Ground Granulated Blast Furnace Slag). There are a total of 2 different mix designs for both 8M and 14M solution having 80% and 100% replacement with Ground Granulated blast furnace slag (GGBS). Two different sizes of tubes were used for the experiment.

Chapter 1 INTRODUCTION

1.1 Background and context

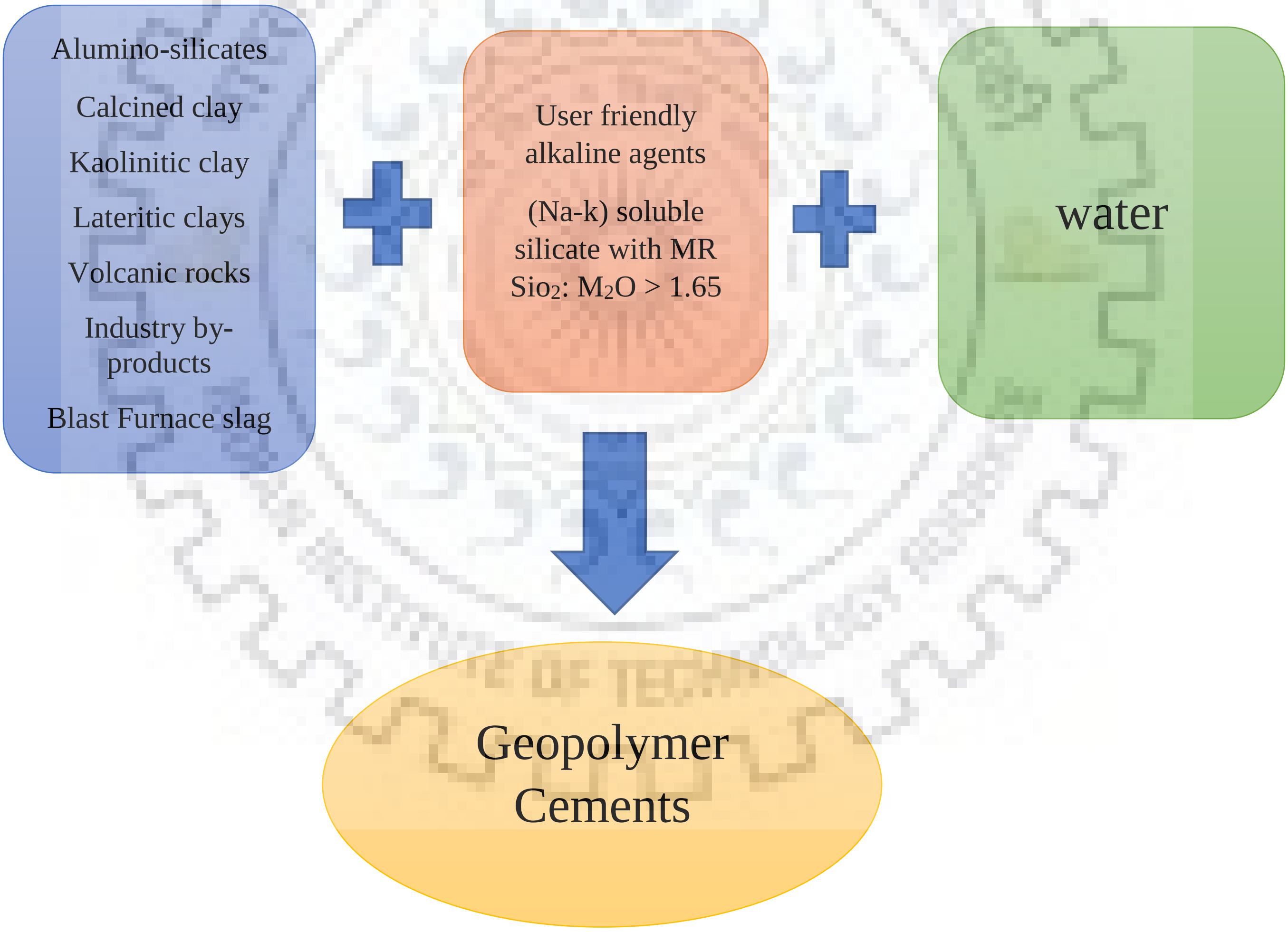
It is a known that in building construction, the merits of a structure are based on factors such as availability, structural strength, durability, and workability. The properties of the structure materials may differ from each other and there is no single material which can fulfil all structural requirements and which led to the application of composite structures. Composite columns, particularly composite concrete filled steel tube (CFST) columns, are increasingly used for high-rise building structures, owing to the advantage of combined characteristics of the steel and concrete materials. It is well known a fact that concrete when restrained from dilation exhibits better strength. In the recent past it has been established that use of composite concrete filled steel tube columns is proving beneficial owing to the symbiotic characteristic of both steel and concrete. Many researches have also been done on fibre reinforced polymer confined concrete columns and the results investigate the performance of these columns. However, in applications to metal composites like Poly-vinyl chloride (PVC), Un plasticized poly-vinyl chloride (UPVC), High-density polyethylene (HDPF) can be considered given their ease of procurement, price and their non-corrosive nature. They are also light weight and easy to handle and install and is not affected by corrosion and other forms of degradation. Hence, it is looked upon as an alternative to metal in many applications where corrosion is an issue. These can be used as an integral part of the column.

Concrete-filled steel tubular (CFST) columns have been used widely as main structural elements to carry loads in multi-storey and high-rise buildings. Accidental fire remains a high risk for building structures, which may lead to civilian casualties and high cost for repairing structural damage. Therefore, external insulating coating and/or internal reinforcing steel are often required to improve the fire resistance of CFST columns. But these two methods tremendously increase the cost of CFST columns and raise the difficulty of construction. PVC pipes not only provide confinement to the core concrete but also is the cheapest materials and is available in abundance locally. Also, climate change in the recent times have caught attention of the environmentalists and activists and it has become all the more important to take important steps to counter climate change. More recently, geopolymer concrete (GPC) has been developed as an environmentally friendly alternative to OPC concrete. Geopolymer is an aluminosilicate binder which is synthesised through a reaction of a solid material of geological origin (e.g. metakaolin) or industry by-products (e.g. fly ash) with alkaline solutions. Previous studies have demonstrated that Geopolymer can be successfully used as a binder to make GPC, which generally has better fire performance than OPC concrete.

The Ordinary Portland Cement (OPC), whose production has a severe environmental impact, is the principal ingredient of concrete. Cement production contributes with about 7 % to the overall global greenhouse gas emission. The greenhouse gas emission from the production of Portland cement about 1.35 billion tons annually. The production of one tonne of the OPC requires 4GJ of energy, and also emits about one tonne of carbon dioxide into the atmosphere. Also, raw materials required for cement production are non-renewable, and are depleting at a rapid rate. Construction activity is a major user of the world's non-renewable resources. The use in the construction industry of non-renewable fossil fuels is the most serious concern, both because of the dependency of virtually all human activities on them at the present time and also because of the current rate of depletion of these fossil fuels. Yet since burning of fossil fuels also contributes to the global production of greenhouse gases, there is a double urgency about the environmental costs of fossil-fuel consumption in and through construction. At the same time, a lot of industrial and agro wastes with inherent cementitious properties are produced abundantly, but are mostly dumped into landfills. Employing such by-products as alternates for cement has manifold benefits including conservation of environment, sustainability of resources, and solution to the by-product's disposal problem. Extensive research is being carried out to assess the feasibility of utilizing industrial wastes as competent replacement for OPC, and for generating superior binders. One such successful attempt is geopolymer concrete, which entirely eliminates the use of OPC in concrete production.

Geopolymer Concrete

Joseph Davidovits coined the term "geo-polymer" in 1978 to describe a family of mineral binders that possess a chemical composition similar to zeolites while exhibiting an amorphous microstructure. In contrast to OPC, principal binders in geopolymer concrete are not calcium-silicate-hydrates (CSHs). Instead, the role of binder is assumed by an aluminosilicate polymeric gel, formed by the tetrahedrally-bonded silicon and aluminium with oxygen atoms shared in between. Two important constituents of geopolymer concrete are source materials and alkaline liquids. The source materials must be rich in silicon (Si) and aluminium (Al). These could be either natural minerals like kaolinite, clays, etc. or by-products like fly ash, blast furnace slag, silica fume, rice-husk ash, etc. The alkaline liquids are based on soluble alkali metals, most frequently sodium or potassium. The most common alkaline liquid used is a combination of sodium or potassium hydroxide along with the sodium or potassium silicate, correspondingly. In the present study we have used a combination of sodium hydroxide and sodium silicate to activate the binder.



Portland cement chemistry vs Geopolymer cement chemistry

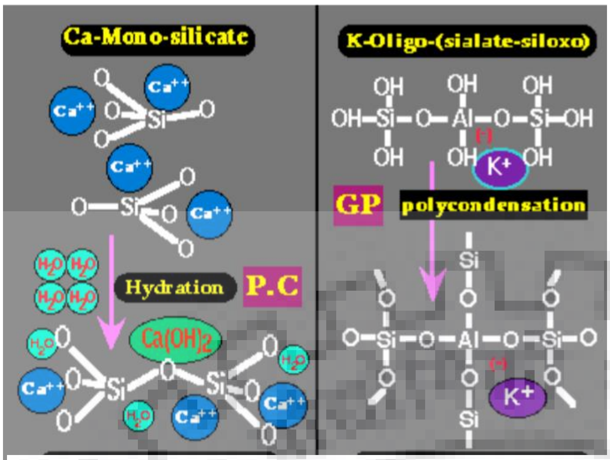


Figure 1 Portland cement chemistry vs Geopolymer cement chemistry

Left: hardening of Portland cement (P.C.) through simple hydration of Calcium Silicate into Calcium Di-Silicate hydrate (CSH) and lime $Ca(OH)_2$.

Right: hardening (setting) of Geopolymer cement (GP) through polycondensation of Potassium Oligo- (sialate-siloxo) into Potassium Poly(sialate-siloxo) cross linked network

There is often confusion between the meanings of the two terms 'geopolymer cement' and 'geopolymer concrete'. A cement is a binder whereas concrete is the composite material resulting from the addition of cement to stone aggregates. In other words, to produce concrete one purchases cement (generally Portland cement or Geopolymer cement) and adds it to the concrete batch. Geopolymer chemistry was from the start aimed at manufacturing binders and cements for various types of applications. Figure 1 represent hardening of Portland cement (P.C.) through simple hydration of Calcium Silicate into Calcium Di-Silicate hydrate (CSH) and lime $Ca(OH)_2$ and hardening (setting) of Geopolymer cement (GP) through polycondensation of Potassium Oligo- (sialate-siloxo) into Potassium Poly(sialate-siloxo) cross linked network. Geopolymer cement is an innovative material and a real alternative to conventional Portland cement for use in transportation infrastructure, construction and offshore applications. It relies on minimally processed natural materials or industrial by-products to significantly reduce its carbon footprint, while also being very resistant to many of the durability issues that can plague conventional concretes. Geopolymer cements cures more rapidly than Portland-based cements. They gain most of their strength within 24 hours. However, they set slowly enough that they can be mixed at a batch plant and delivered in a concrete mixer. Geopolymer cement also has the ability to form a strong chemical bond with all kind of rock-based aggregates

CO_2 emission during manufacture of Portland cement clinker

Ordinary cement, often called by its formal name of Portland cement, is a serious atmospheric pollutant. The manufacture of Portland cement clinker involves the calcination of calcium carbonate according to the reaction:

$$5CaCO_3 + 2SiO2 \rightarrow (3CaO,SiO_2)(2CaO,SiO_2) + 5CO_2$$

The production of 1 tonne of Portland clinker directly generates 0.55 tonnes of chemical-CO_2 and requires the combustion of carbon-fuel to yield an additional 0.40 tonnes of carbon dioxide.

To simplify: 1 T of Portland cement = 0.95 T of carbon dioxide

The only exceptions are so-called 'blended cements', using such ingredients as coal fly ash, where the CO_2 emissions are slightly suppressed, by a maximum of 10%- 15%. There is no known technology to reduce carbon dioxide emissions of Portland cement any further.

On the opposite, Geopolymer cements do not rely on calcium carbonate and generate much less CO_2 during manufacture, i.e. a reduction in the range of 40% to 80-90%. Joseph Davidovits delivered the first paper on this subject in March 1993 at a symposium organized by the American Portland Cement Association, Chicago, Illinois.

1.2 Objectives of the study

In the context of increasing awareness regarding the ill-effects of the over exploitation and over use of natural resources, eco-friendly technologies are to be developed for effective management of these resources. Construction industry is one of the major users of the natural resources like cement, sand, rocks, clays and other soils. The ever-increasing unit cost of the usual ingredients of concrete have forced the construction engineer to think of ways and means of reducing the unit cost of its production. At the same time, increased industrial activity in the core sectors like energy, steel and transportation has been responsible for the production of large amounts like fly ash, blast furnace slag, silica fume and quarry dust with consequent disposal problem. Adoption of the geo-polymer technology could reduce the CO_2 emission caused due to cement industries. So, geopolymer concrete has come up with dual benefit of complete replacement of cement by waste materials like fly-ash and GGBS which puts it in a position of promising future. So, one of the main objectives is to find an alternative to ordinary Portland cement. Also, different strength properties of Geopolymer Concrete with percentage replacements with

GGBS will be found out. The optimum mix proportion with fly-ash replacement with various percentages of GGBS will be looked upon. Methods to reduce deterioration of concrete is also one of the areas of research. Confinement is one of the important methods to do that. Here in this study, energy ratios and ductility ratios would be found out to understand the increase or decrease in these properties when confinement is used with PVC pipes. Also, the increase in load carrying capacity will be seen with variations in the length of the pipe, size of the pipe and the type of mix.

1.3 Scope of study

Geopolymer stores a great potential as a replacement to ordinary cement concrete which would considerably reduce CO_2 emission in the atmosphere that poses one of the biggest problems of the time. This would make Geopolymer concrete a green replacement to OPC with additional benefit of contributing positively to the disposal problem of fly-ash and GGBS. Factories acquire large units of lands for disposing these waste products, making use of these would also lighten the burden on these factories to acquire lands and these lands could then be used to contribute to enhance the income of others.

India hasn't taken upon the usage of Geopolymer cement on a large scale yet but among western countries Geopolymer has been taking pace in the mainstream construction. Companies like British company banah UK (www.banahuk.co.uk) sells its banah-Cem™ as geopolymer cement, whereas the Australian company Zeobond (www.zeobond.com) markets its E-crete™ as geopolymer concrete. There are few companies in India like Green Global Green cement (www.geocement.in/) which produce Geopolymer aiming towards a greener concrete.

Geopolymers possess high early strength, low shrinkage, freeze-thaw resistance, sulphate resistance, corrosion resistance, acid resistance, fire resistance, and no dangerous alkali-aggregate reaction. Based on laboratory tests, geopolymer concrete can harden rapidly at room temperature and gain the compressive strength in the range of 20 MPa after only 4 hours at 20^oC and about 70-100 MPa after 28 days. Geopolymer mortars gain most of the 28- day strength during the first 2 days of curing. Geopolymer concrete when infilled within tubular columns enhances its bearing capacity owing to it the composite behaviour of steel and concrete. Furthermore, it increases its fire bearing capacity and eliminates the need of formwork.

2.1 General

Geopolymer concrete is being studied extensively and shows promise as a greener substitute for ordinary Portland cement concrete in some applications. It is manufactured from predominantly silica and alumina containing source material. Geopolymer concrete filled tubular columns (GCFST) finds its usefulness especially in tall structures wherein fire safety plays an important role. GCFST's enhances the fire resistances significantly which eliminates the use of a coating material or reinforcement in the infill concrete. Usage of reinforcements or coating material shoots the cost of construction considerably. Hence GCFST's can prove out to be an economic and viable option.

2.2 Experimental Studies

Lloyd and Rangan (2010) carried out various experiments and found out the influence of various parameters on Geopolymer concrete. He also proposed the design procedure for heat cured low calcium based Geopolymer concrete and its economic feasibility. Various conclusions made are as follows

1. Higher concentration of sodium hydroxide solution resulted in higher compressive strength of Geopolymer concrete.
2. Higher ratio of sodium silicate to sodium hydroxide solution ratio by mass, resulted in higher compressive strength of Geopolymer concrete.
3. The slump value of the fresh Geopolymer concrete increases when the water content of the mixture increases. Admixtures may assist in improving workability.
4. As the H_2O to Na_2O molar ratio increases the compressive strength of the Geopolymer concrete increases.

Tao et. Al (2018) used calcium aluminate cement (CAC) as partial replacement to fly-ash since fly-ash based geopolymer concrete needed elevated temperature curing. CAC is an important type of non-Portland cement, and has rapid hardening characteristics and wide applications in refractory materials. Rapid hardening characteristic of CAC eliminated the need of heat curing and also improved the mechanical properties of Geopolymer concrete (GPC). He concluded that the mechanical properties (i.e., the initial stiffness, ultimate strength and concrete confinement effect) of geopolymer concrete-filled steel tubular (GCFST) columns at ambient temperature are similar to those of conventional CFST columns. He matched his results with the FE models given by previous researchers with reasonable accuracy. GCFST were seen to possess better fire resistance than the conventional CFST columns.

Shi et. Al (2015), carried out an experimental study on 12 concrete filled steel tubular columns under axial loading, in order to fill a knowledge gap on the engineering and structural properties of Geopolymeric recycled concrete filled steel tube (GRCFST). Two section sizes of square hollow sections filled with GRC and recycled aggregate concrete (RAC) respectively, with different recycled aggregate (RA) replacement ratios of 0%, 50% and 100%, were used in the experiments. The test results indicated that the ultimate strength was reduced when adding more RAs in the columns, while the peak strain increased. The ductility of the columns was improved by increasing the RA replacement ratio. Overall, the influence of RA on the strength and ductility of GRCFST columns is greater than that of RAC filled steel tubular (RACFST) columns. The assumed theoretical model for predicting load versus deformation relation of GRCFST columns under axial loading was examined, and a revised theoretical model proposed. The results of the new model showed good correlation with the experimental results.

Han et. Al (2002) carried out a research on experimental study and calculation on the fire resistance of concrete-filled square hollow steel (SHS) and rectangular hollow steel (RHS) columns. The differences in this test program compared with similar studies carried out by other researchers mentioned above are:

1. Both concrete-filled steel columns with square sections and with rectangular sections were tested, seldom concrete-filled steel RHS columns under fire were reported before.
2. Both concentrically and eccentrically loaded columns were performed, seldom eccentrically loaded concrete-filled steel SHS or RHS columns were performed in the past.
3. Both columns with fire protection and without fire protection were performed, seldom fire tests on such columns with fire protection were performed.
4. Load ratio is greater than 0.7 (in the past, the load ratio was less than 0.5)

The main objectives of this paper were threefold: first, to report a series of fire tests on composite columns. Secondly, to analyse influence of several parameters, such as sectional dimension, slenderness ratio and protection thickness on the fire resistance of the composite columns. Finally, to develop formulas for the calculation of the fire resistance and the fire protection thickness of the concrete-filled HSS columns, such formulas to be suitable for incorporation into building codes.

Gupta P (2013) carried out **an investigation to** find out the effectiveness of un-plasticized Poly-vinyl-chloride (UPVC) tube for confinement of concrete columns. UPVC tubes having 140mm,160mm and 2000mm were used to confine the concrete having compressive strength of 20 Mpa,25 Mpa and 40 Mpa. The concrete was designed using the relevant IS code. The testing was carried out on displacement controlled Instron with a capacity of 2500 KN. During the experiment, mode of deformation and corresponding load-compression curves were drawn and obtained results were compared with the existing models.

Following were some conclusions that were drawn:

1. Compressive strength and ductility were improved by confining the concrete with UPVC pipes. The improvement in strength was dependent upon the geometrical properties of the tube.
2. Failure pattern of all the specimens were shear failure type
3. Confinement effect of UPVC were compared with already existing models and were found to be within a limit of 6%.
4. The diameter/thickness ratio affected the post peak behaviour of the load compression curve.

Jamaluddin et. Al (2017) carried out research on concrete column filled with PVC tubes confined by plain sockets with 5,8- & 6.8-mm thickness, 102 mm diameter and 100mm depth. Total of five concrete filled columns using PVC tubes were tested to investigate columns behaviour. The column was 700 mm height, 100mm external diameter and 3.5 mm tube thickness with different thickness of plain socket. The results presented include maximum axial load plain socket confinement effect, the mode of failure and lateral PVC strain. Some conclusions are as follows:

1. PVC tube Confinement led to increment of ultimate load.
2. The enhancement in axial load due to confinement was substantial depending upon the level of confinement, in which the ultimate load increased from 21.2% and 55.2% of the column without column socket.

Ozbakkaloglu et.Al (2015) carried out an experimental study on the axial compressive behaviour of concrete filled fiber-reinforced polymer (FRP) tubes (CFFTs), prepared using either ordinary Portland cement (OPC) concrete (OPCC) or fly ash-based geopolymer concrete (GPC). Thirty-six CFFTs were tested under axial compression. The effects of the type of the concrete and FRP tube material, number of FRP layers used in the FRP tube, and specimen cross-sectional shape were studied. The results suggested that the axial stress-strain behaviour of CFFTs is affected by the type of concrete, with GPCFFTs developing a similar strength enhancement ratio to but a lower axial strain enhancement ratio than the corresponding OPCCFFTs. Owing to the higher shrinkage of the OPCC, OPCCFFTs exhibit a plateau at the transition region of their stress-strain curves, which is not seen in GPCFFTs. At a similar confinement ratio, OPCCFFTs confined with different fibers exhibited comparable strength and strain enhancement ratios, whereas slight differences are seen among GPCFFTs manufactured with different fibers. The strength and strain enhancement coefficients of both OPCC- and GPC-FFTs decrease with an increase in the thickness of FRP tube. An accurate model that was originally proposed to predict the ultimate conditions of FRP-confined conventional concrete was modified to enable the application of the model to circular and square GPCFFTs.

1. Due to the significantly higher shrinkage of OPCCs compared to GPCs, in the transition region of their stress-strain curves OPCCFFTs experienced a brief plateau where the stresses remained nearly constant for the range axial strains approximately between 0.25% and 0.4%, which was not seen in the curves of GPCFFTs.
2. The relations between the strains obtained from mid-height and full-height LVDTs remain unchanged for companion OPCC- and GPC-FFTs.
3. At a given confinement ratio GPCFFTs exhibit a similar strength enhancement ratio, but a lower ultimate axial strain and axial strain enhancement ratio than the companion OPCCFFTs.
4. The FRP tube thickness affects the compressive behaviour of OPCC- and GPC-FFTs in much the same manner, with the strength and strain enhancement coefficients (k1 and k2) of both types of CFFTs decrease with an increase in FRP tube thickness.

2.3 Summary of Literature review

Various researches have been carried out in the field of concrete filled steel tubes (CFST) columns with respect to bearing capacity, fire resistance, failure pattern and much more, while Geopolymer concrete is new in the field and not much work has been done in the direction of Geopolymer filled concrete filled tubes (GPCFT). There is a knowledge gap in this field. Tao.et Al used geopolymer concrete with partial replacement with calcium aluminate cement (CAC) because of their rapid hardening characteristics which will assist in their room temperature curing. Since, GPC's always required elevated temperature curing like oven or heat curing, it questioned it viability as a potent material to replace ordinary Portland cement concrete. GPC's were always suggested to be used as precast members. This normal temperature curing has strengthened its case to be used in-situ. Since fly-ash has a very slow dissolution rate it needs to be mixed with CAC or Ground Granulated Blast Furnace Slag (GGBS) to elevate its curing time. B.V Rangan has carried out a considerable amount of work on Geopolymers and published many research papers for the same. He has provided the roadmap for designing GPC's and took into consideration various factors which contributes to its strength.

The literature review gave some insight into the amount of work being done on CFT columns. There has been some work done with fly-ash and GGBS combination on beams and columns but there hasn't been much work being done on the combination in PVC tubular columns. So, we will be concentrating on Fly-ash-GGBS combination in the present work mainly. The higher percentage of 100% and 80% of GGBS were taken so as to eliminate the need for elevated temperature curing. The confinement was achieved with PVC tubes as the material since not much work has been done using it. PVC tubes have been used earlier with ordinary Portland cement concrete but there hasn't been much work done with geopolymer and PVC combination. So, the present work serves as an attempt to provide a knowledge base for any further study that may come out of it.

3.1 General

In the present experimental work, one of the methods to prevent concrete from deterioration has been presented in the form of confinement of concrete by an external agency which in the present case is PVC tube. To study the parametric effect the sizes of the specimens were varied with three variations in the diameter and two variations in the length. While, to see the effect of the type of concrete there were two variations of geopolymer concrete that were used i.e. P100% and P80% wherein cement has been completely replaced. P100% and 80% are the mix in which the amount of GGBS and fly-ash is 100% and 80% respectively. The design procedure for designing geopolymer concrete is given in the following section.

3.2 Design Procedure

Assume normal density and the unit weight of concrete to be 24 kN/m^3. Take the weight of combined aggregate to be 75% of the mass of concrete, i.e. 0.75x24=18 kN/m^3 i.e. 1835 kg/$m^{3.}$ The mass of low calcium fly-ash and the alkaline liquid = .25 x 24= 612 kg/m^3. Take the alkaline liquid to fly-ash ratio as 0.35; the mass of fly-ash = 612/ (1+0.35) = 453 kg/m^3 and the mass of alkaline liquid = .35 x 453 = 159 kg/m^3. Take the ratio of sodium silicate to sodium hydroxide as 2; the mass of sodium hydroxide solution= 159/ (1+2.5) = 53 kg/m^3; and the mass of sodium silicate as 159-53 = 106 kg/m^3

Therefore, the trial mixture proportion is as follows:

Table 1 Proportion of various constituents.

Combined aggregates	1193 kg/m^3
Fine aggregates	642 kg/m^3
Low-calcium fly-ash	453 kg/m^3
Sodium- silicate solution	106 kg/m^3
Sodium hydroxide solution	53 kg/m^3

To manufacture the geopolymer concrete mixture, commercially available sodium silicate solution A53 with SiO_2-to-Na_2O ratio by mass of approximately 2, i.e. Na_2O = 14.7%, SiO_2 = 29.4% and water = 55.9% by mass is selected. The sodium hydroxide solids (NaOH) with

97-98% purity is purchased from commercial sources and mixed with water to make a solution with a concentration of 8 Molar. The solution comprises 26% of NaOH solids and 74% water by mass.

<u>Preparation of Alkaline Solution</u>

The sodium hydroxide (NaOH) solids were dissolved in water to make the solution. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. For instance, NaOH solution with a concentration of 8M consisted of 8x40 = 320 grams of NaOH solids (in flake or pellet form) per litre of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids was measured as 262 grams per kg of NaOH solution of 8M concentration. Similarly, the mass of NaOH solids per kg of the solution for 14M concentration was measured as 404 grams. Note that the mass of NaOH solids was only a fraction of the mass of the NaOH solution, and water was the major component.

The sodium silicate solution and the sodium hydroxide solution were mixed together at least one day prior to use to prepare the alkaline liquid. On the day of casting of the specimens, the alkaline liquid was mixed together with the super plasticizer and the extra water (if any) to prepare the liquid component of the mixture.

3.2 Procurement of materials

3.2.1 Fly-ash

Fly-ash is procured from heavy testing laboratory, IIT Roorkee. It is low calcium ASTM class F fly-ash.

Plate 1 Fly-ash from the lab

3.2.2 Ground Granulated Blast furnace slag (GGBS)

It is available in heavy testing lab, IIT Roorkee. Ground granulated blast furnace slag (GGBS) is a by-product from the blast-furnaces used to make iron. The iron ore is reduced to iron and the remaining materials form a slag that floats on top of the iron. This slag is periodically tapped off as a molten liquid and if it is to be used for the manufacture of GGBS it has to be rapidly quenched in large volumes of water. The quenching optimizes the cementitious properties and produces granules similar to coarse sand. This 'granulated' slag is then dried and ground to a fine powder

Plate 2 GGBS from lab

3.2.3 NaOH pellets

NaOH pellets of 97-98% purity was obtained from vishwani traders in Roorkee. They were mixed with water in appropriate amounts to make up a 8 Molar and a 14 Molar solution which was then mixed with Sodium silicate to make up the activator alkaline solution.

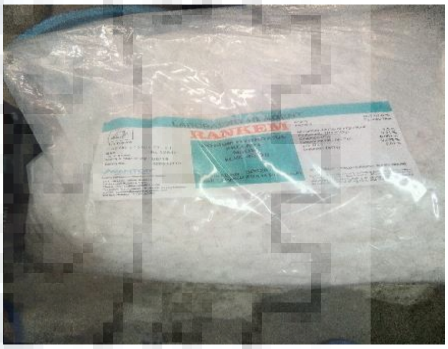


Plate 3 NaOH pellets

3.2.4 Sodium Silicate solution

Sodium silicate solution was obtained from vishwani traders in Roorkee

Plate 4 Sodium silicate solution

3.2.4 Aggregates

Plate 5 Fine Aggregates

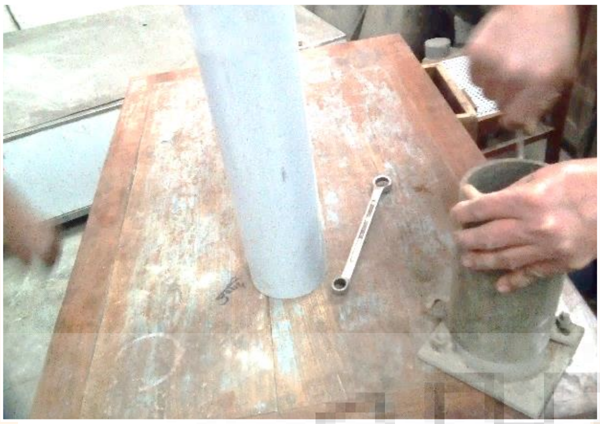
Plate 6 Coarse aggregates

3.2.5 PVC tubes

Poly-vinyl-chloride tubes of different sizes are available in the first floor of heavy testing lab, IIT Roorkee. The tubes of required sizes were taken and cut out to the length required for the experimental work. Three different diameters of 110, 140, and 160 mm were cut out up to a length of 300 and 900mm.

PVC pipe being cut to the length

The PVC pipes which were required for the experiental work was cut use to cut to the lenght. In the present picture the pipe is being cut to a length of 300mm.



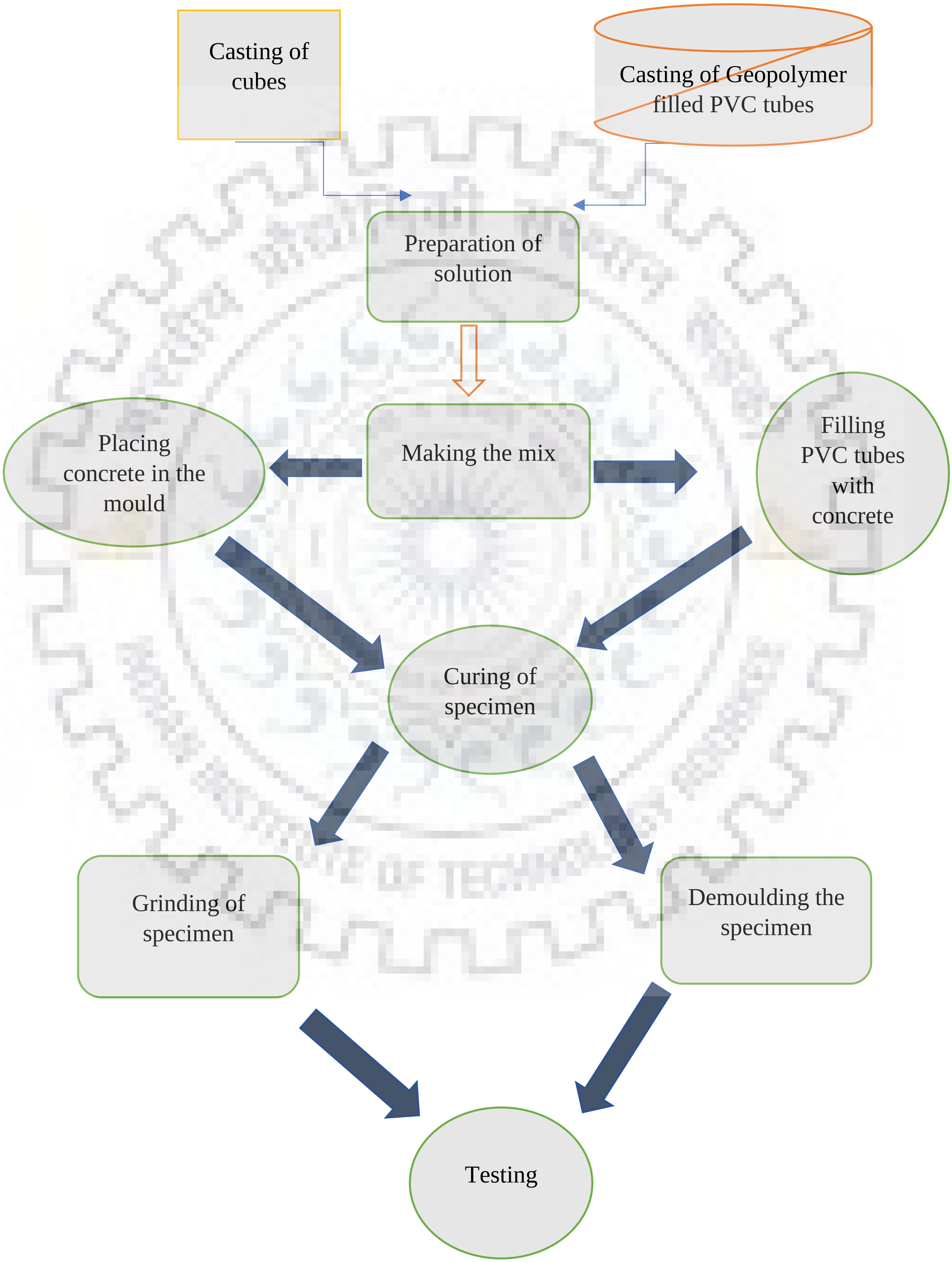
Preparation of the mould

The mould is being prepared to serve as the base for the PVC pipe so that the concrete does not pour out.

Pipe fixed upon the mould

After the peparation of the mould the it was placed at the bottom and fixed so that the process of placing of concrete can take place

4.1 Flow chart



4.2 Overview of work done

Literature review revealed that not much has been done on GGBS-fly-ash combination on CFST columns. So, the objective of the present work is to carry out experiments to fill the knowledge gap in this direction. Since, fly-ash based geopolymer concrete has a slow rate of dissolution which requires elevated temperature curing. Hence, we have used GGBS as partial replacement to fly-ash which can eliminate the need of elevated temperature curing. Hence, one of the major drawbacks of fly-ash based geopolymer can be overcome by using GGBS along with fly-ash. In the present work, we have used a replacement of GGBS as 80% and 100% of the fly-ash and the impact of molarity change has also been taken into account by considering two different molarities of NaOH as 8 Molar and 14 Molar. A 14 molar solution was cast for 100% GGBS replacement which is named as P100 mix and a 8 molar solution for 80% GGBS replacement named P80. A total of 12 PVC filled Geopolymer concrete were cast along with 12 cubes with 6 of each mix. Three PVC filled geopolymer concrete were cast for P100 mix and 9 specimens of the same were cast for P80 mix.

Cube casting to find out the cube compressive strength was carried out in structural engineering lab.

Preparation of solution

Plate 7 NaOH Solution and sodium silicate mixed to form alkaline solution

Mixing of aggregates with alkaline solutions

GGBS and fly-ash were mixed with fine and coarse aggregates in the mixer for about 3 minutes and then alkaline solution was poured and mixed for another 4 minutes.

Plate 8 Mixing of Geopolymer concrete constituents.

Measurement of slump

Slump was measured by slump cone test to estimate the workability of the mix. The mix was filled in the cone in 3 layers and each layer was tamped with 25 strokes each. Mould was raised slowly in vertical direction. Slump was measured as the difference between the height of the mould and that of height point of the specimen being tested.

Plate 9 Slump measurement

Placing the concrete in the mould

Plate 10 Placing the concrete in the mould

Concrete were placed in moulds of sizes 150x150 mm. Before placing them in the moulds were cleaned with oil and were compacted with table vibrator**.**

Demoulding of specimens

Specimens were demoulded after 48 hours of casting and were tested with compression testing machine

Plate 11 Demoulding of cubes

Geopolymer concrete does not require water for curing. Though Geopolymer concrete with fly-ash requires elevated temperature of around 60^o Celsius for curing. But in the present experimental work, we have used GGBS as a major replacement to fly-ash just so that we do not require an increased temperature. The benefit of GGBS is that it produces internal heat which enhances the rate of strength gain.

Testing of specimens

Specimens were tested after 7 days from the day of casting; specimens were cured at room temperature and water curing was not employed in this case.

Plate 12 Testing of Cube specimens

4.1.2 Casting of geopolymer concrete filled PVC tubes.

Poly vinyl chloride (PVC) tube

In the experimental programme, poly-vinyl-chloride was chosen to confine concrete after taking into consideration the following points

1. Polymer is one of the most stable substances as far as corrosion is concerned. Its anti-corrosive properties have proven to be significant. Since, the last century polyethylene copolymer coatings have been used for the protection of onshore and offshore pipelines.
2. PVC tube can also be used as a mechanical damage protector against damage caused by severe environment.
3. It can withstand those mechanical damages which occur in the environments of high energy environments like marine and saline.

Twelve PVC tubes with outer diameter (D) of 140mm, 160mm and 200mm were cut out in 300 and 900mm length. Typical nomenclatures are used to designate them. For example, T110P100-300 stands for a specimen of 110mm diameter, a mix of 100% replacement and a length of 300mm. While, T110P80-900-1 stands for a specimen of 110mm diameter, a mix of 80% percent replacement and a length of 900m with the 1 denoting the first specimen of the same mix. PVC tubes available in the lab were taken. Typical properties of the specimen are as follows:

Table 2 Sizes of the specimens used

Specimen	D x t x L mm
T110P100-300	110 x 4 x 300
T140P100-300	140 x 5.1 x 300
T160P100-300	160 x 6 x 300
T110P80-300	110 x 4 x900
T140P80-900	140 x 6 x 900
T160P80-900	160 6 x 900

Two different mix designs of 100% replacement of fly-ash by GGBS and 80% replacement of fly-ash were made. The alkaline solution, which is a mixture of NaOH and sodium silicate was used as the alkaline activator responsible for Geo-polymerisation. Two different molarities were used for the two different mixes. A 14 molar solution was used for 100% replacement and an 8 molar solution was used for 80% replacement. The PVC tubes were first cut out from larger pipes upto the required length.

Preparation of alkaline solution

Alkaline solution is cast 24 hours prior to the casting date. Sodium silicate solution is available directly from the shop while sodium hydroxide has to be made using pellets according to the molarity which is required.

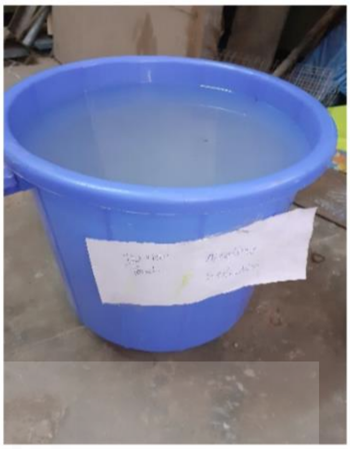


Plate 13 Alkaline solution of NaOH and sodium silicate

Making the mix

Two mix of geopolymer concrete with fly-ash and GGBS were cast with alkaline solution as the activator. Aggregates were mixed with GGBS and fly-ash in dry state first and thereafter the alkaline solution was added into it. The aggregates were mixed in a drum mixer.

Plate 14 Mixing of concrete

Filling PVC with concrete

Two different sizes of concrete of 300 mm and 900 mm with two different mix as infill concrete. Three different specimens of 300mm were cast and nine specimens were cast with 3 specimens each for 110mm, 140mm and 160mm with a length of 900mm. Two different mix were cast to see the variation in the load carrying capacity. Lengths were changed to study the parametric effect on the ductility, energy absorption capacity and load carrying capacity. Various parameters such as ductility ratio and energy ratio were calculated to ascertain ductility and energy absorption capacities.

Plate 15 Preparation of specimens of 300mm length

Plate 16 Specimens of 110mm specimens of 900mm length

Plate 17 Specimens of 140 and 160mm diameter of 900mm length

Grinding of specimens

Before testing the specimens under INSTRON machine for the load-compression behaviour, the surface is smoothened out by the process of grinding. This is done to prevent the loading to come out to be eccentric. If the surface is not smoothened, then consequently the load becomes a load with some eccentricity, load carrying capacity in such a case gets reduced.

Plate 18 Grinding of specimens

Testing of PVC filled Geopolymer concrete

Plate 19 Instron testing machine

The test setup for experimentation was done on INSTRON make UTM machine is shown in plate 17. It has a capacity of 2500 KN. The experiment was performed using a displacement-controlled method with a rate of 1 mm/minute. The upper jaw is moved down while the bottom jaw kept stationary. The rate was applied continuously without any jerk. Loads and displacements were measured continuously by data collection computer system. The frequency of the data collection is 0.4 Hz.

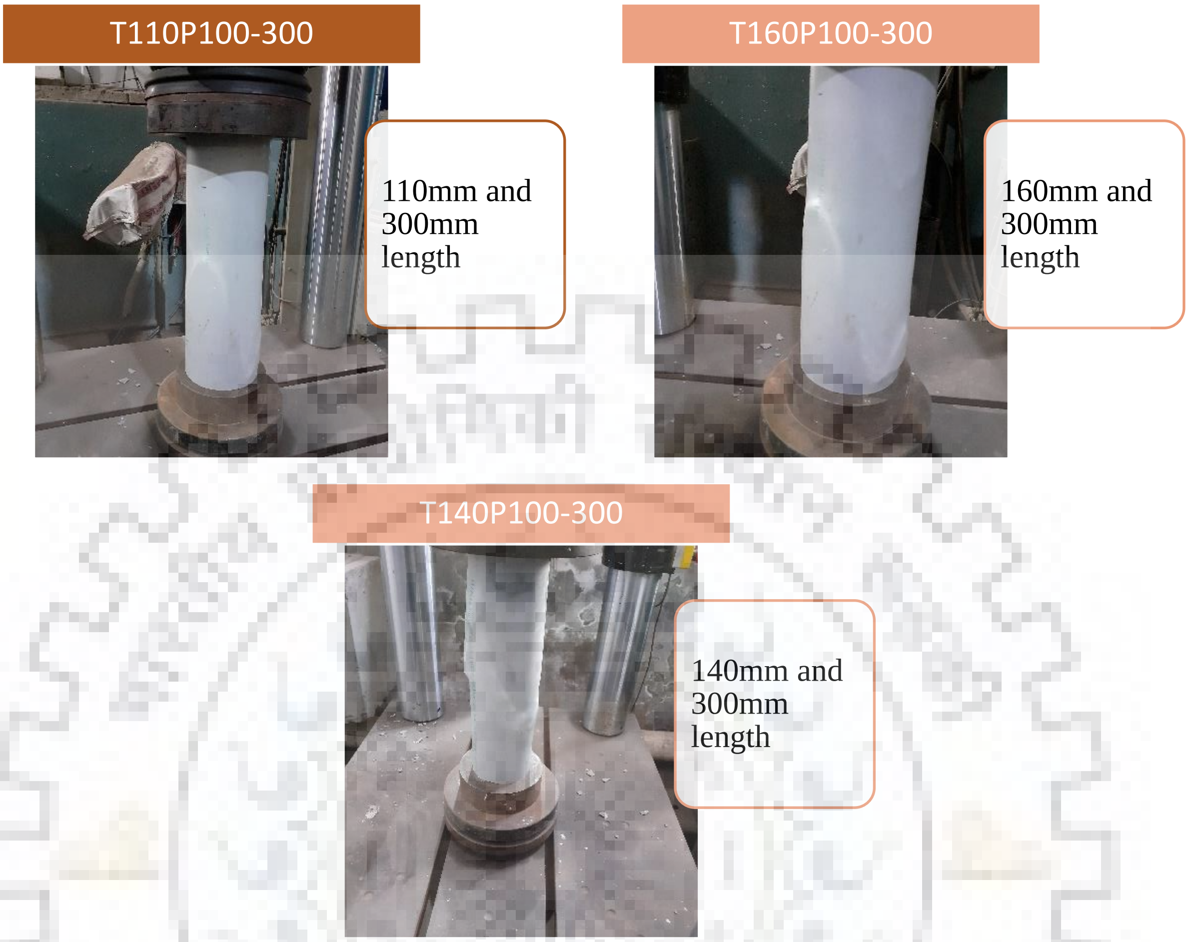


Plate 20 Testing of 300mm specimens

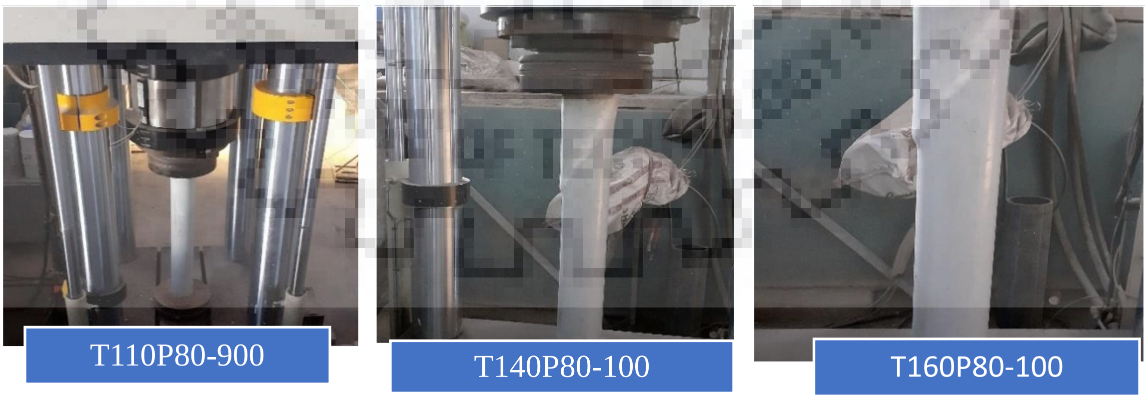
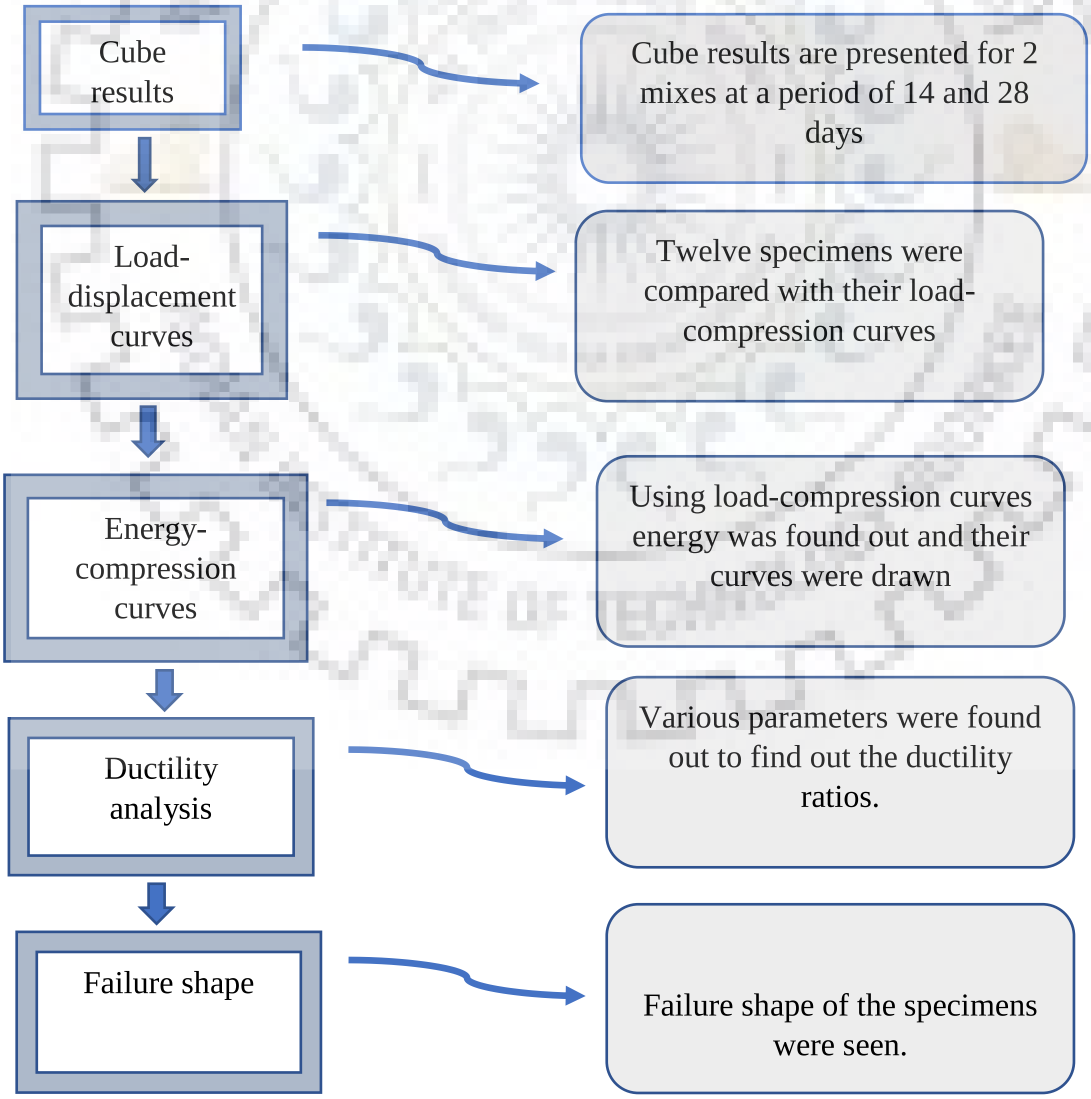


Plate 21 Testing of 900mm specimens

5.1 General

There are two mix namely P100 and P80 where the amount of fly-ash is completely replaced and 80% replaced by GGBS. The test results for the cube cast are presented for 14 and 28 days. Twelve PVC tube confined Geopolymer concrete were cast with 3 specimens with P100 and the rest 9 specimens filled with P80. The three specimens were of 300 mm length and the rest nine were of 900 mm length. The PVC confined Geopolymer concrete were tested under INSTRON testing machine. The data for load-compression of all the specimens were obtained and graphs were drawn using excel. Comparisons were made between different specimens. The area under the load-compression curves were found out using mid-ordinate formula on various data points on excel. Various parameters are defined to make an analysis of the ductility. A bi-linear approximation was also done for finding out ductility parameters.



5.2 Cube results

The two different mix designs are P100 and P20. Six cubes were cast for each mix design and three cubes each were tested at 14 and 28 days. Various quantities used for the mix are shown in the following table.

Table 3 Mix design values for different components

Mix	T100	T80
Coarse aggregate	1193 kg/m^3	1193 kg/m^3
Fine aggregate	642 kg/m^3	642 kg/m^3
GGBS	453 kg/m^3	362.4 kg/m^3
Fly-ash	-	90.6 kg/m^3
Alkaline solution	159 kg/m^3	159 kg/m^3

Table 4 Test results for cube

Mix-type	Compressive strength					
	14 days		Average	28 days		Average
T100	173 ton	75.43 N/mm^2	65.25 N/mm^2	173 ton	75.43 N/mm^2	72.81 N/mm^2
	164 ton	71.50 N/mm^2		161 ton	70.19 N/mm^2	
	112 ton	48.83 N/mm^2		167 ton	72.81 N/mm^2	
T80	165 ton	71.94 N/mm^2	64.10 N/mm^2	174 ton	75.86 N/mm^2	69.32 N/mm^2
	119 ton	51.88 N/mm^2		163 ton	71.07 N/mm^2	
	157 ton	68.45 N/mm^2		140 ton	61.04 N/mm^2	

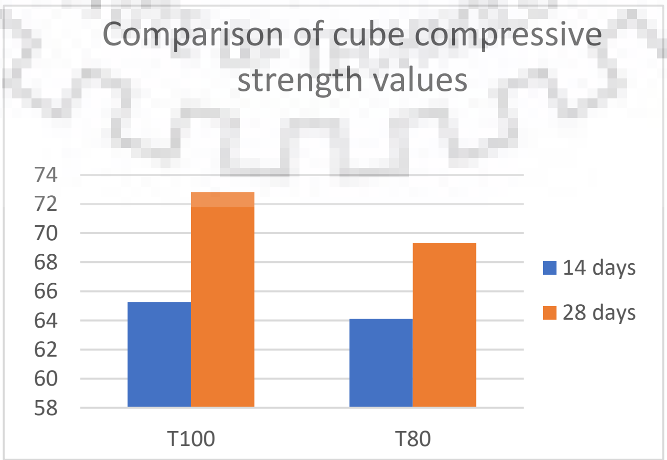


Figure 2 Cube compressive strength comparison for different mix

It can be seen that the cube compressive strength for P80 were lesser than P100 for both 14 days and 28 days duration. It is seen that the concrete mix of both P100 and P80 achieved 90% of their 28-day strength in 14 days. The increased strength of P100 was supposedly due to the internal heat produced by GGBS which led to the increased value of strength of P100. The column graph of figure 21 presents a graphical presentation of the values.

5.3 Load-compression curves

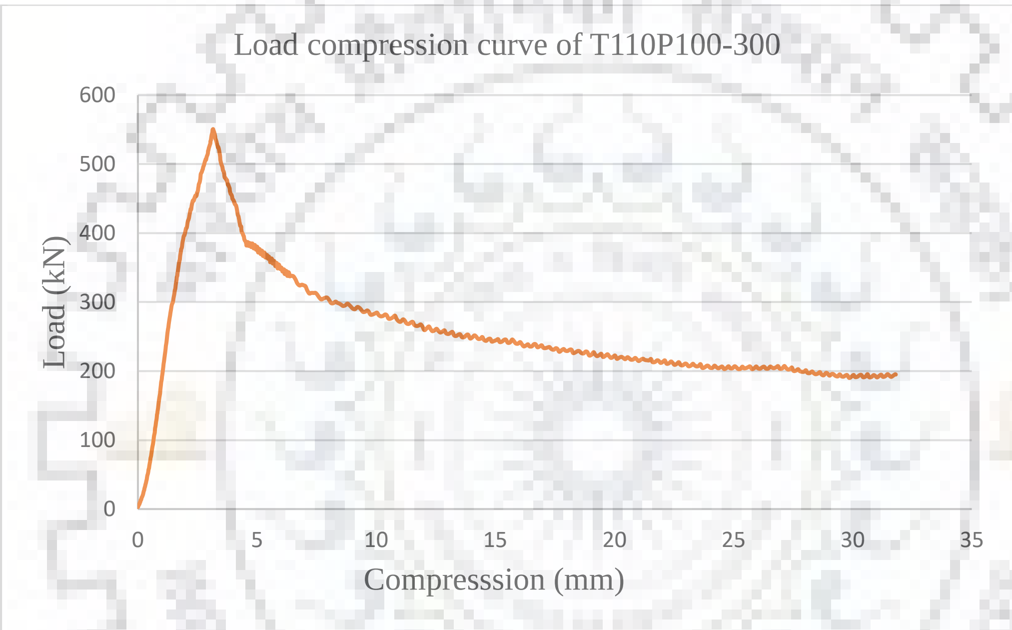


Figure 3 Load compression graph of T110P100-300

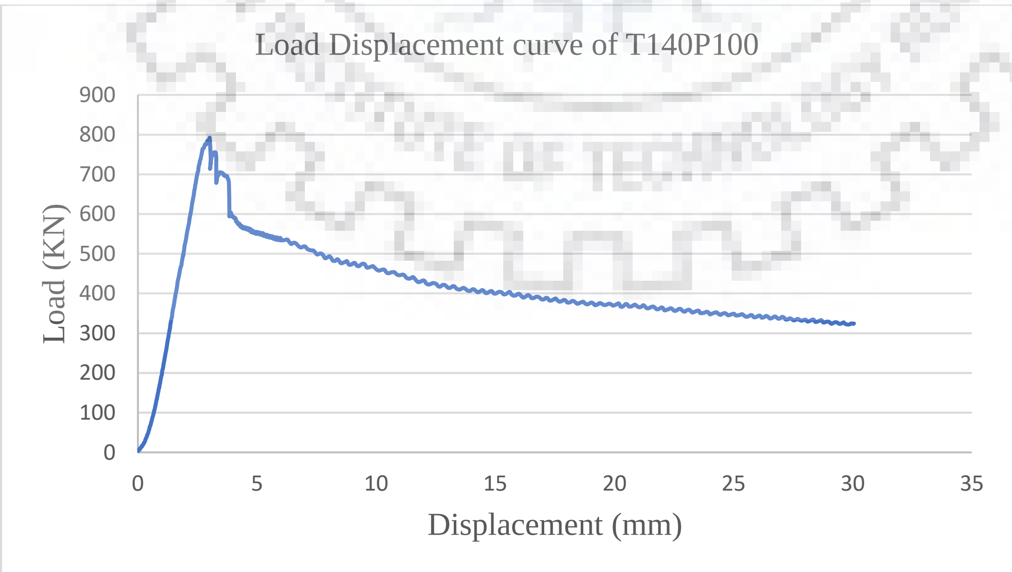


Figure 4 Load-compression curve of T140P100-300

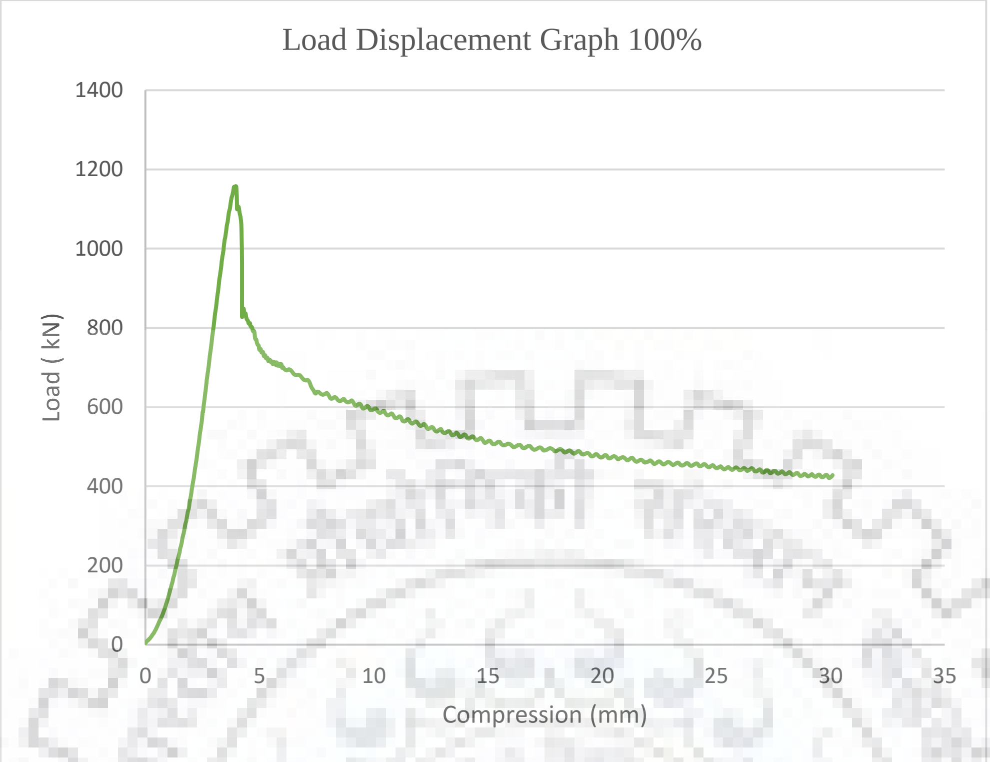


Figure 5 Load-compression curve for T160P100-300

Table 5 Various parameters for 300 mm specimens

Specimen	D x t x L mm	D/t ratio	Ultimate load	Residual load	Residual Load as percent peak load
T110P100-300	110 x 4 x 300	27.5	550.79	194.99	35.4
T140P100-300	140 x 5.1 x300	27.45	791.87	324.38	40.96
T160P100-300	160 x 6 x 300	26.66	1157.78	428.01	36.96

The ultimate loads as shown in Table 5 show a trend of increment with the increase in diameter from 110 mm to 160 mm. The trend increase in load is due to the confinement effect of PVC tubes with increase in thickness of the tubes. The graph has been plotted with max compression of 30 mm. Residual strength is defined as the load at 30 mm compression which is also represented as a percentage of peak load in the table. The residual load for all the specimens of 300 mm varied between 35 to 40 percent of the peak load.

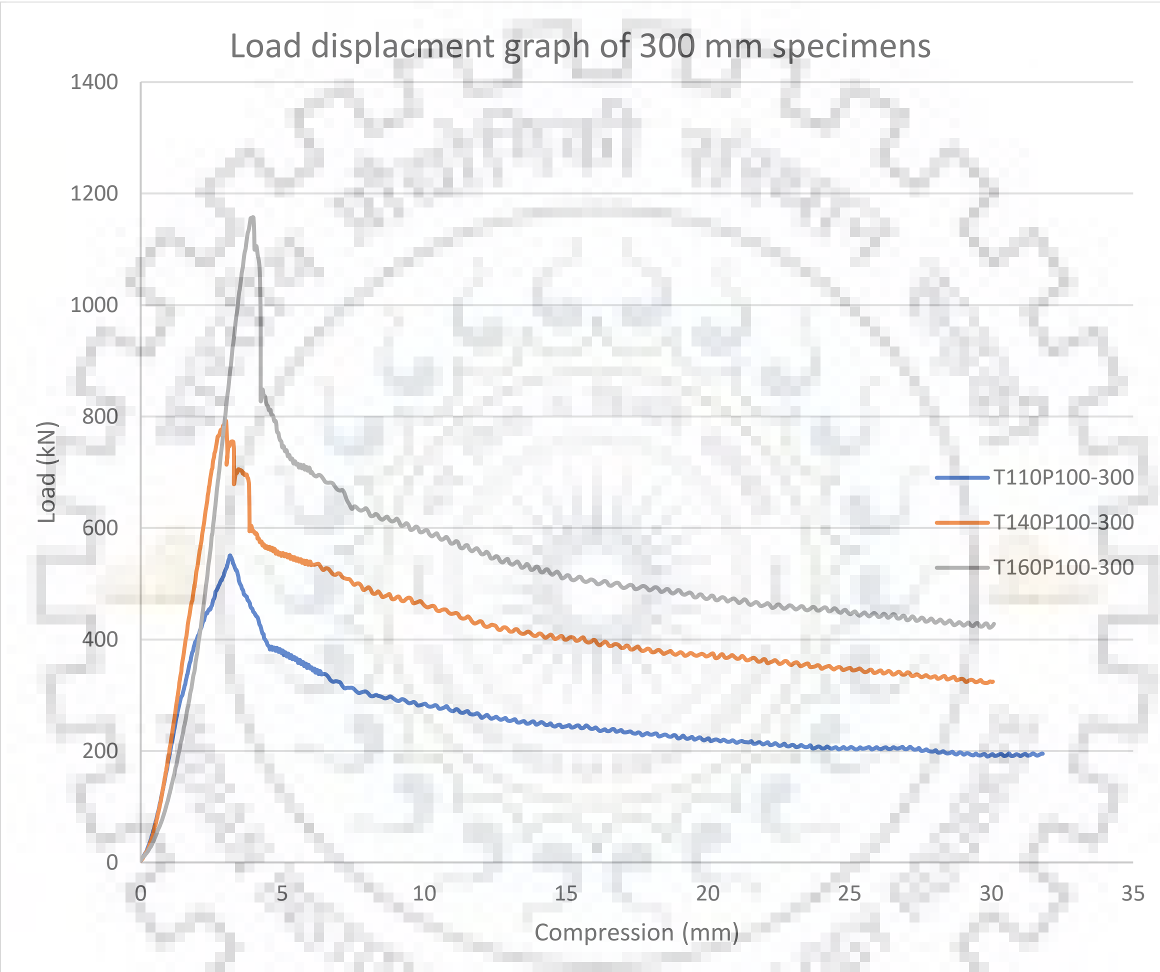


Figure 6 Comparison of load-compression behaviour of 300 mm specimens.

The specimens named T110P100-300, T140P100-300 and T160P100-300 have a D/t ratio of 27.5, 27.45 and 26.66 respectively as presented in Table 5. From figure 25, it can be seen that the slope of onset curve of the graphs decreases with decrease in D/t ratio meaning that the slope of T140P100-300 is highest while that of T160P100-300 is the lowest. The difference can be attributed to the difference of the elastic modulus of PVC and core concrete.

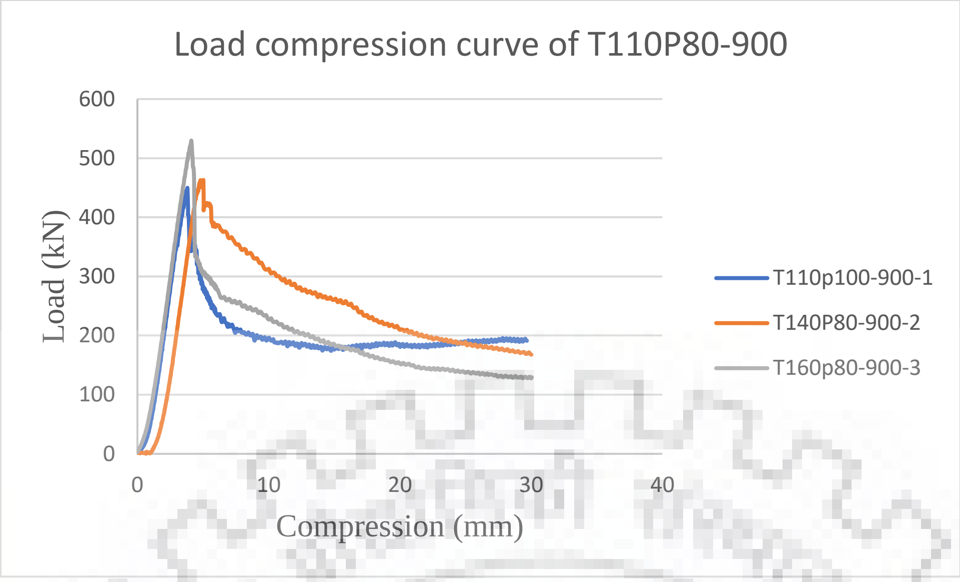


Figure 7 Load-compression curve of all specimens of T110P80-900

The ultimate load for the three specimens are 449.42 kN, 463.14 kN and 529.82 kN. The slope of the onset curve is almost the same for the specimens. The variation of the ultimate load values was within 11% of the average value of 480.79 kN.

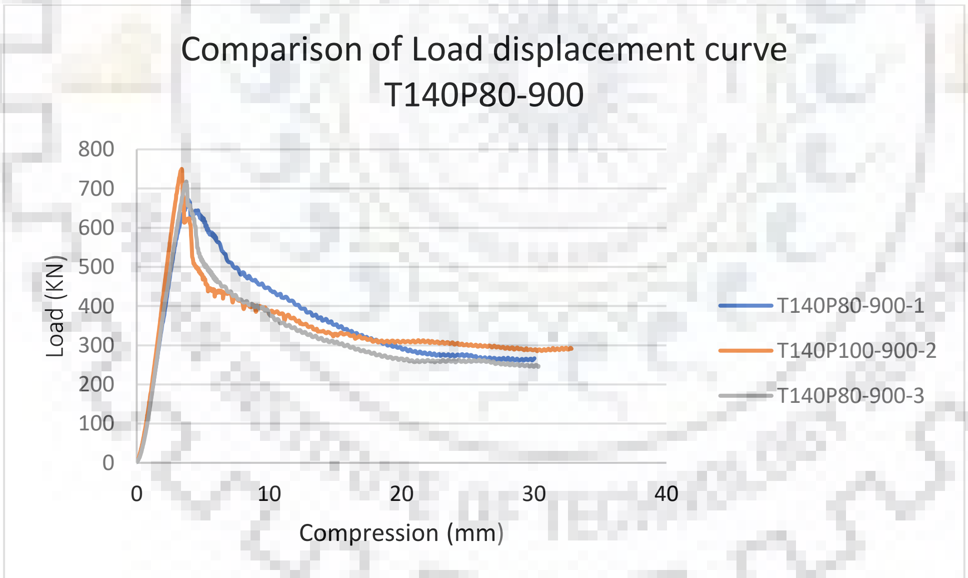


Figure 8 Comparison of Load displacement curve T140P80-900

The ultimate load for the three specimens of T140P80-900 is 670.87 kN, 749.98 kN and 717.88 kN. The onset of the curve almost overlaps. The variation of ultimate load values was within 6% of the average value of 712.91.

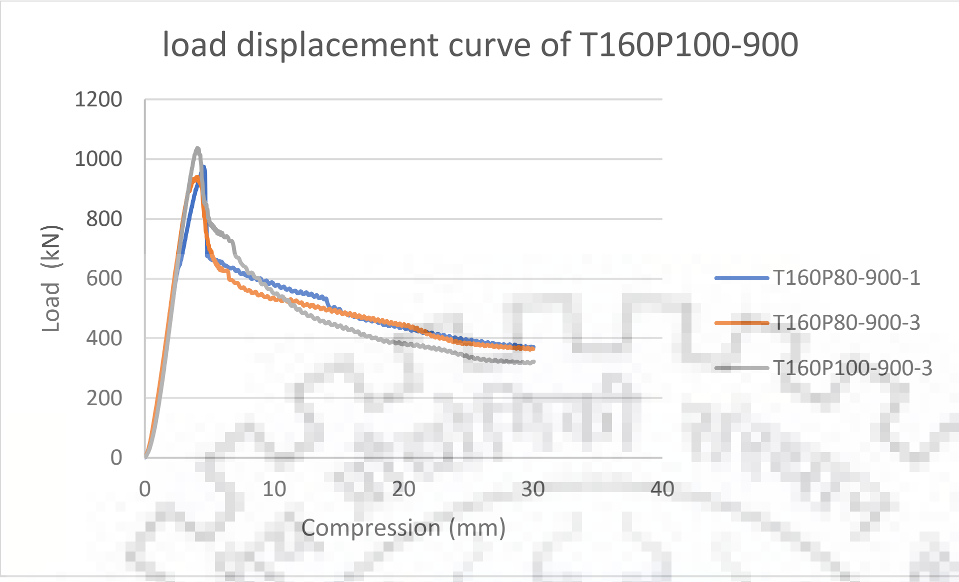


Figure 9 load displacement curve of T160P100-900

The ultimate load values for the three specimens of T160P80-900 are 974.98 kN, 940.95 kN and 1037.48 kN. The variation of ultimate load values was with 6% of the average value. Average value was found out to be 984.47 kN. The initial onset curves were overlapping at the beginning while the descending curve deviated after the peak load.

Table 6 Various parameters for 900 mm specimen length

	Ultimate load	Average Ultimate load	Residual strength	Average Residual strength	% Residual strength to peak load
T110P80-900-1	670.87 kN	480.79 kN	191.15 kN	162.84 kN	33.86
T110P80-900-2	749.98 kN		167.86 kN		
T110P80-900-3	717.88 kN		129.51 kN		
T140P80-900-1	974.98 kN	984.47 kN	266.69 kN	268.25 kN	27.24
T140P80-900-2	940.95 kN		291.08 kN		

T140P80-900-3	1037.48 kN		246.98 kN		
T160P80-900-1	974.98 kN	984.47 kN	371.38 kN	352.61 kN	35.81
T160P80-900-2	940.95 kN		364.01 kN		
T160P80-900-3	1037.48 kN		322.44 kN		

Table 7 Properties of various specimens of 900 mm

Specimen	D x t x L	D/t ratio	Average ultimate load	Average Residual Load	% Residual Strength
T110P80-900-1	110 x 4 x900	27.5	480.79 kN	162.84 kN	33.86
T110P80-900-2	110 x 4 x900				
T110P80-900-3	110 x 4 x900				
T140P80-900-1	140x 6x900	23.33	984.47 kN	268.25 kN	27.24
T140P80-900-2	140x 6x900				
T140P80-900-3	140x 6x900				
T160P80-900-1	160x6x900	26.66	984.47 kN	352.61 kN	35.81
T160P80-900-2	160x6x900				
T160P80-900-3	160x6x900				

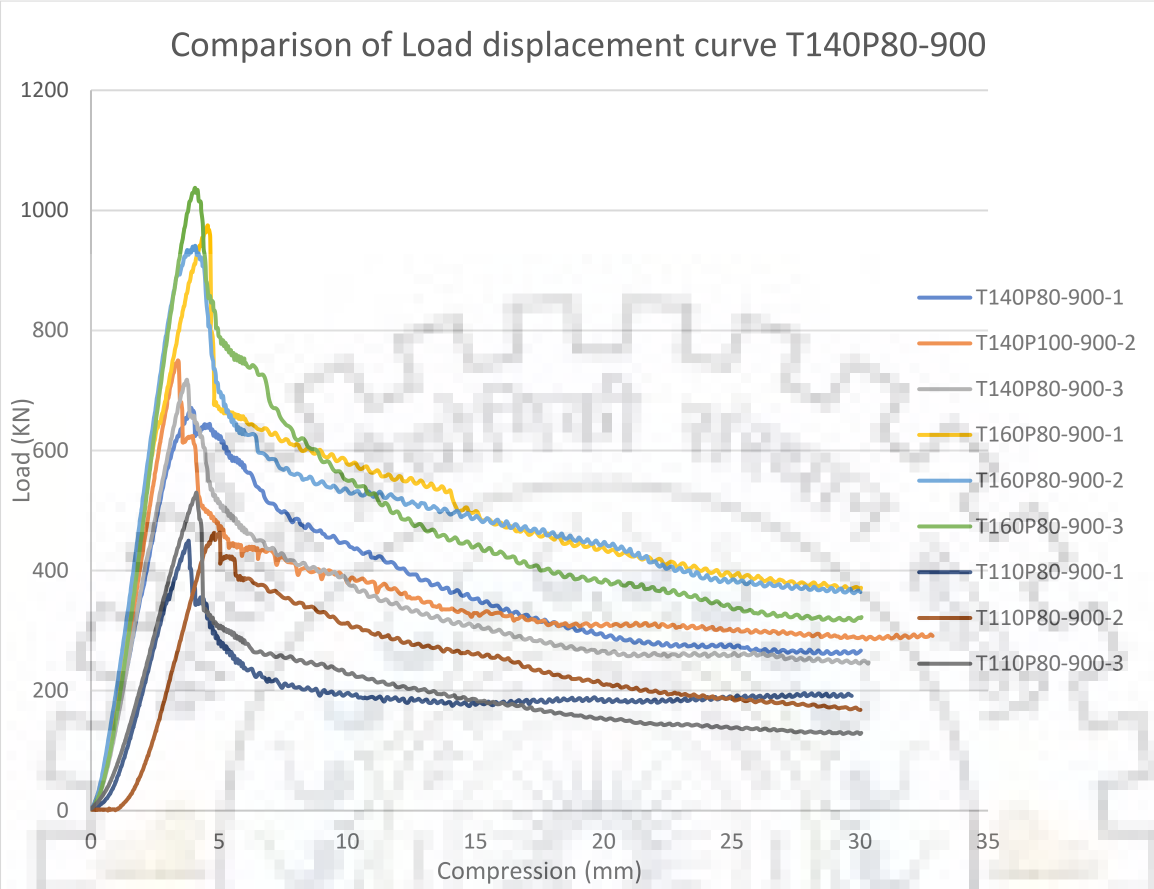


Figure 10 Comparison of load-compression curve of 900 mm specimens

From the comparison of figure 6 and figure 7, it can be seen that the ultimate load of T110P100-300 is more than that of T110P80-900 due to richer mix and the similar trend can also be seen for the other specimens. It can be seen from table 7 that T110P80-900 has the highest value of D/t ratio of 27.5 and has the lowest slope as can be seen from figure 7. While the slope of T140P80-900 is the highest and its corresponding D/t ratio is 23.33 lowest of the three different specimens of the same mix. Hence, it can be concluded that the slope decreases with increase in D/t ratio. It can also be seen that the percentage residual strength decreased with decrease in grade of concrete for the same specimen size.

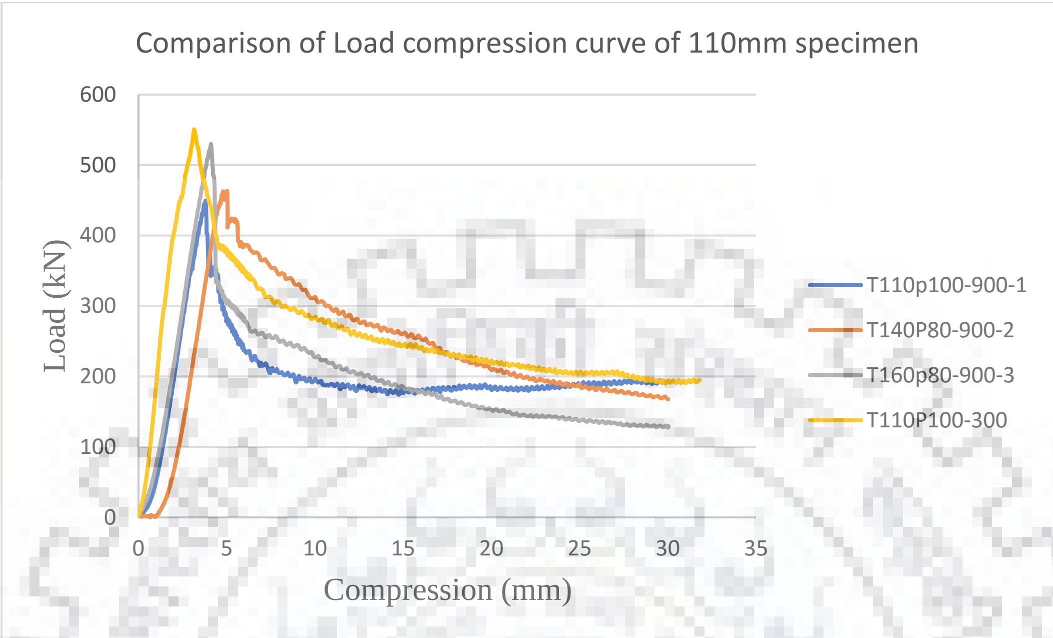


Figure 11 Comparison of load compression curves of 110 mm diameter specimens

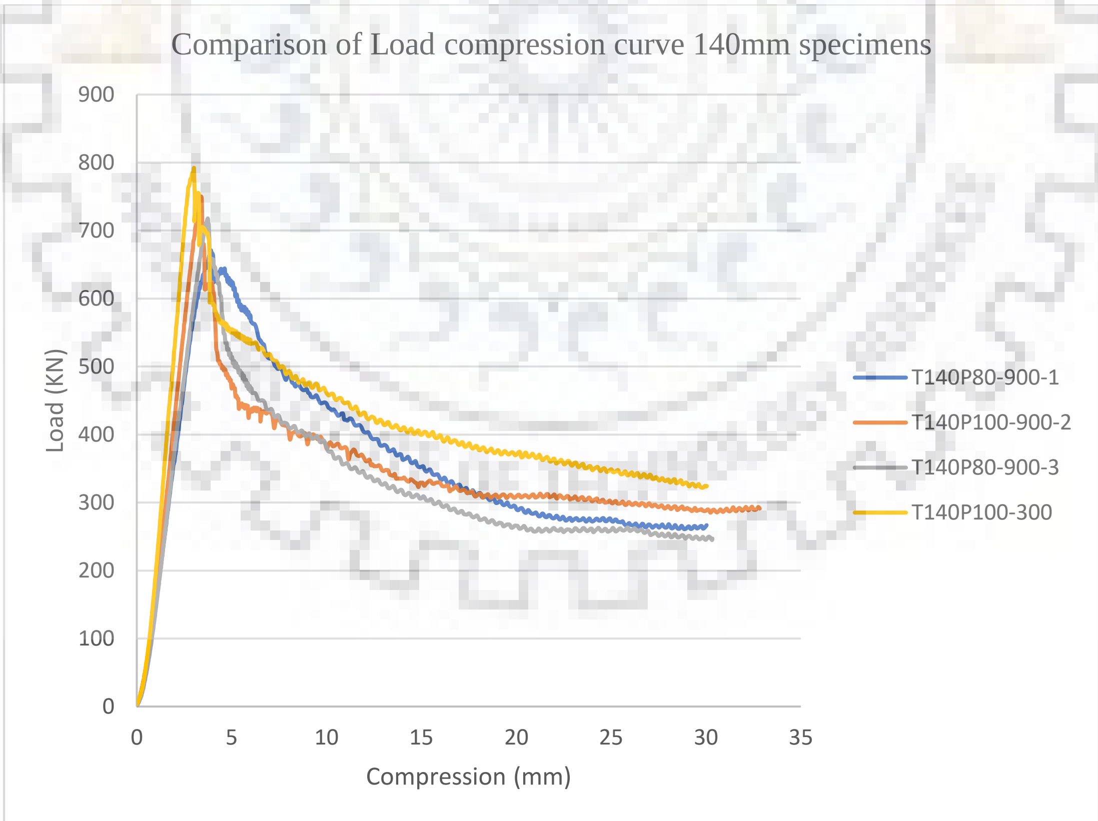


Figure 12 Comparison of load compression curve of 140 mm diameter specimens

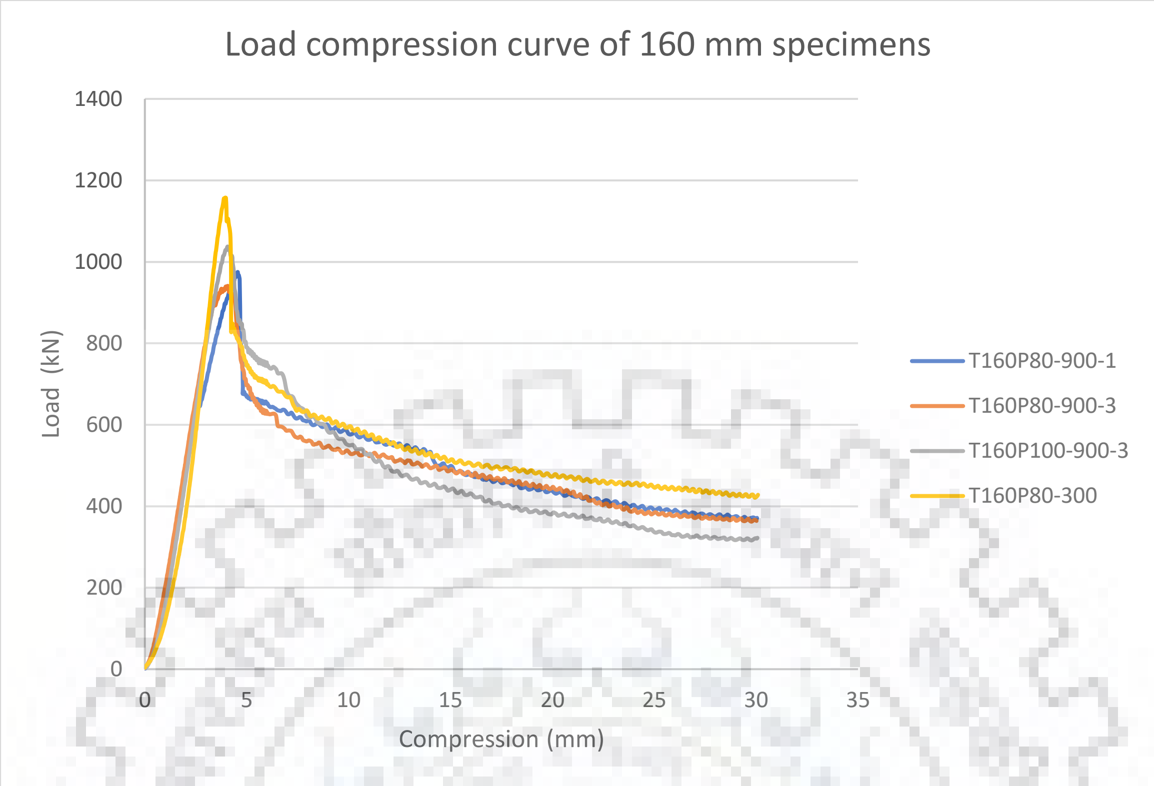


Figure 13 Comparison of load compression curve of 160 mm diameter specimens

The graphs drawn above in figure 11, figure 12 and figure 13 depict the comparison of same diameter specimens with different mix and different length. It can be clearly seen that the slope of the onset graph decreases with decrease in grade of concrete. In our case P100 and P80 are the two grades with higher value of cube compressive strength of P100. It can also be observed that the value of ultimate load decreased with decrease in the grade of concrete.

5.4 Energy-compression curves

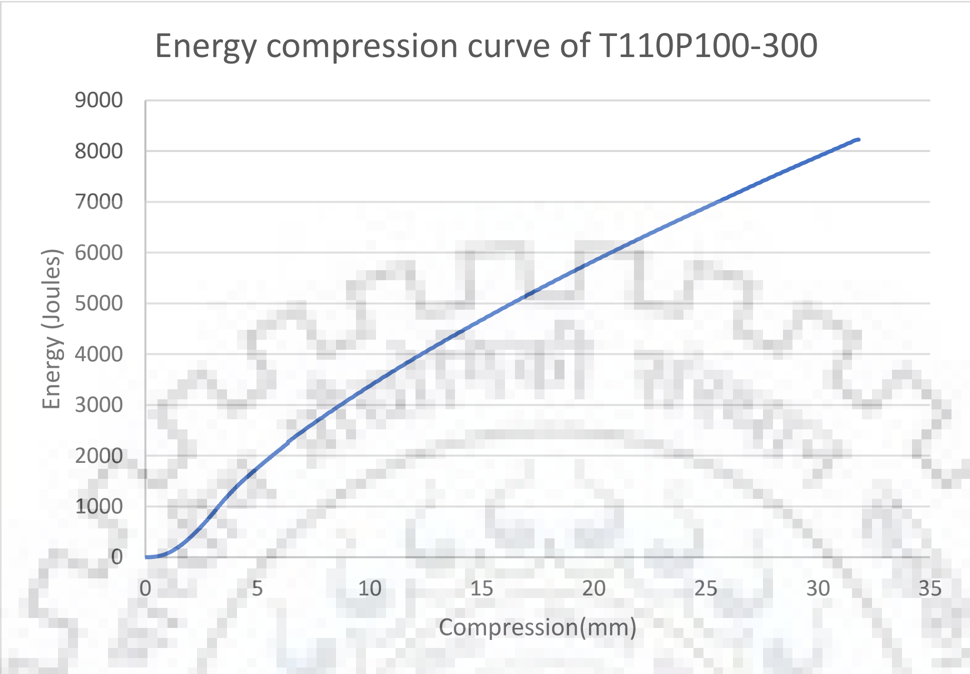


Figure 14 Energy compression curve of T110P100-300

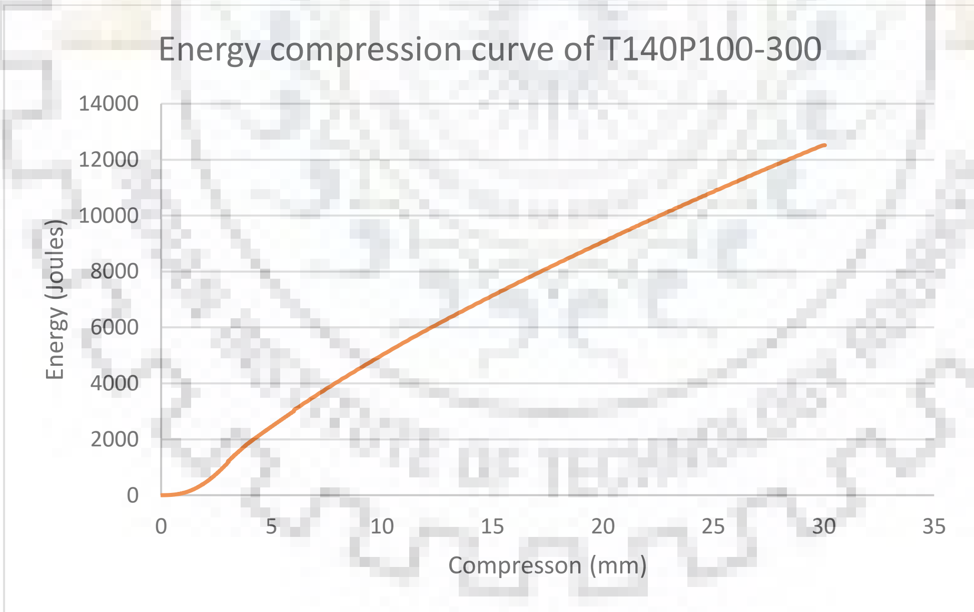


Figure 15 Energy compression curve of T140P100-300

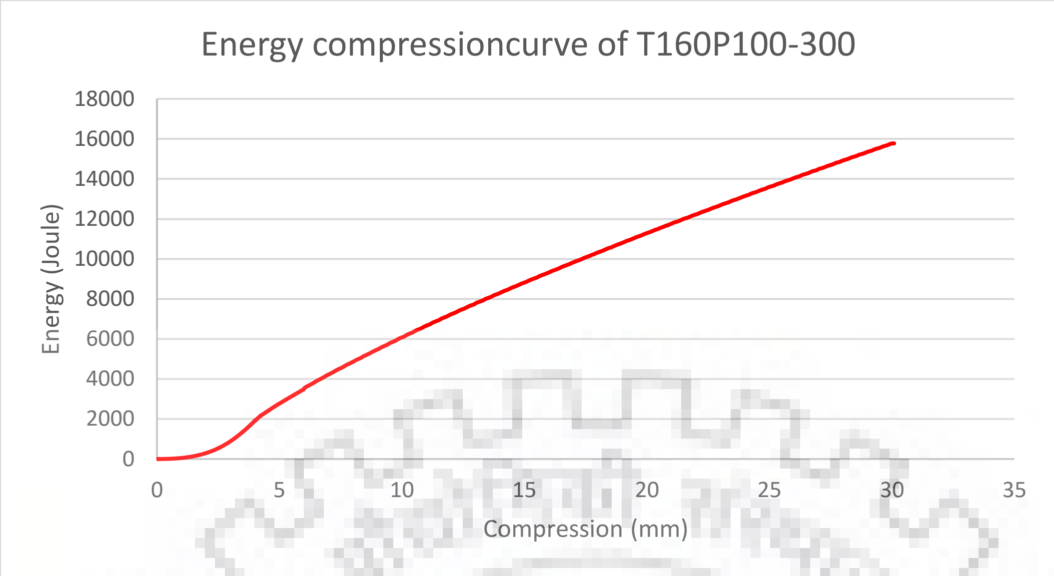


Figure 16 Energy compression curve of T140P100-300

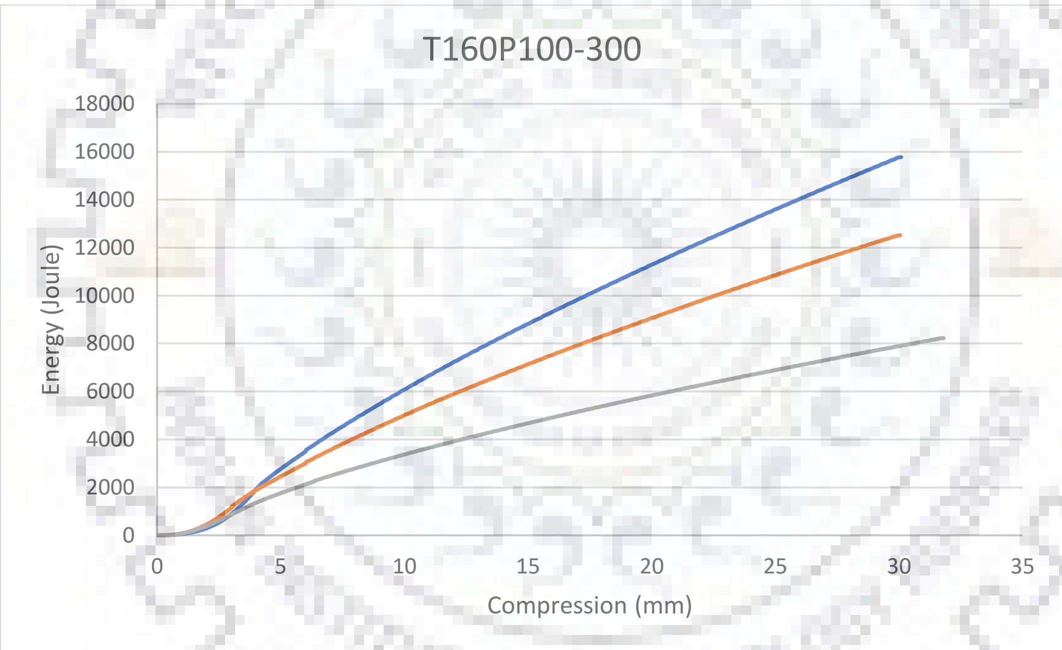


Figure 17 comparison of energy compression curve of specimens of 300 mm

One of the problems of structures are their energy absorbing capacity. Area under load compression curves was calculated to ascertain the energy absorbing capacities of the PVC tube infill Geopolymer concrete which provides an increased energy when confined by the tubes. In the specimens of 300 mm it can be seen that the energy absorbing capacity of highest diameter is highest which could be due to its increased thickness than the other two.

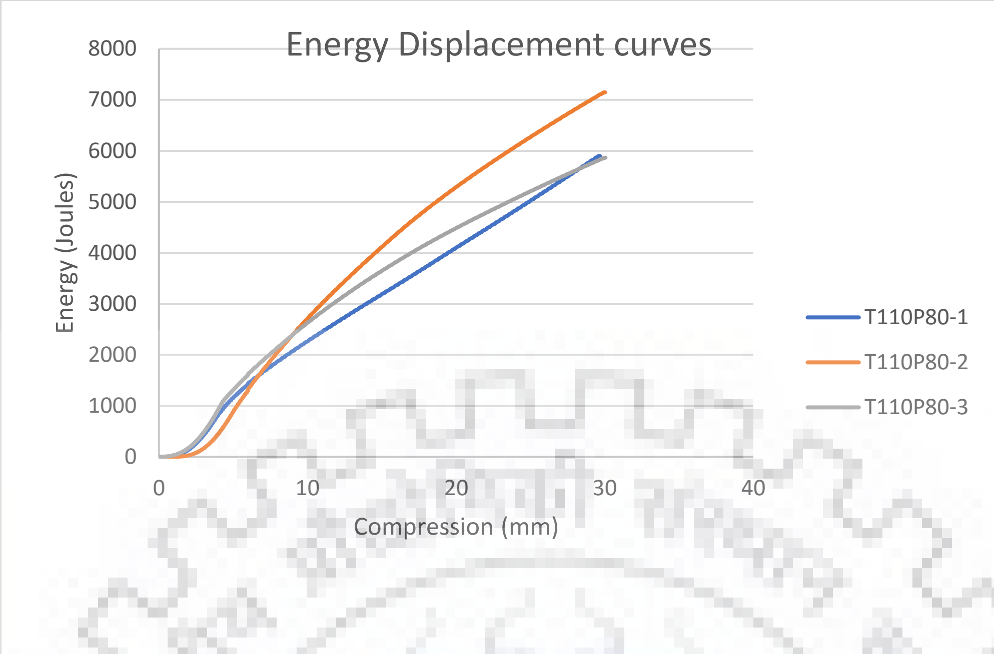


Figure 18 Energy compression curves of T110P80-900

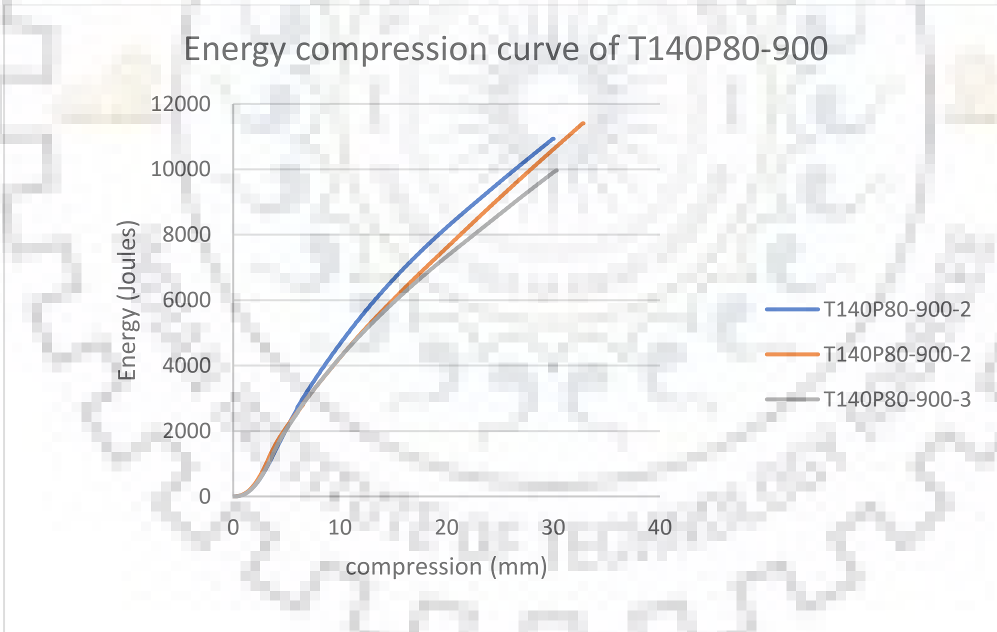


Figure 19 Energy compression curve of T140P100-900

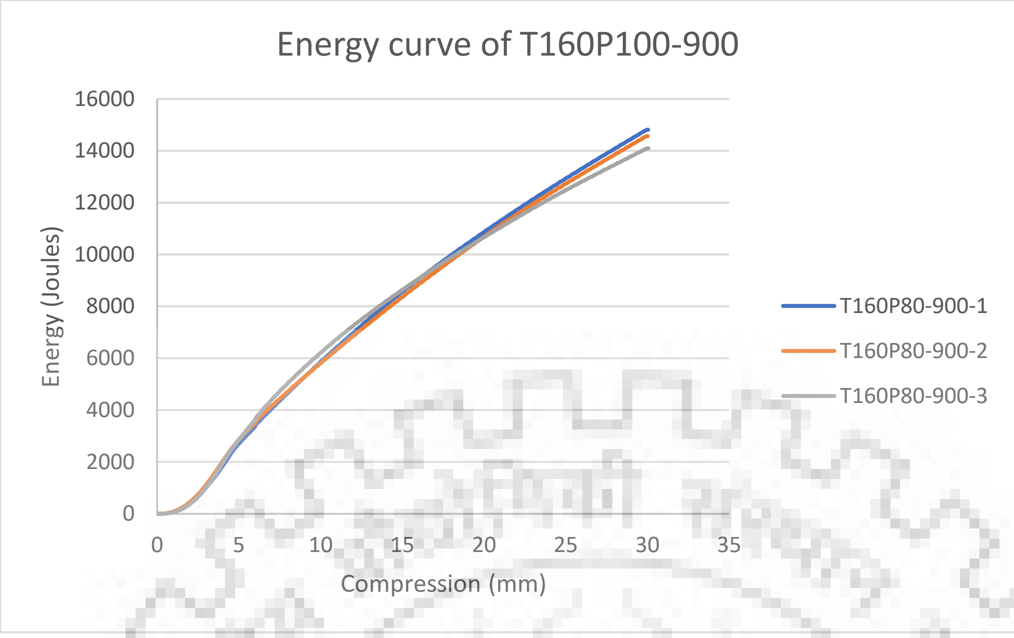


Figure 20 Energy compression curve of T160P80-900

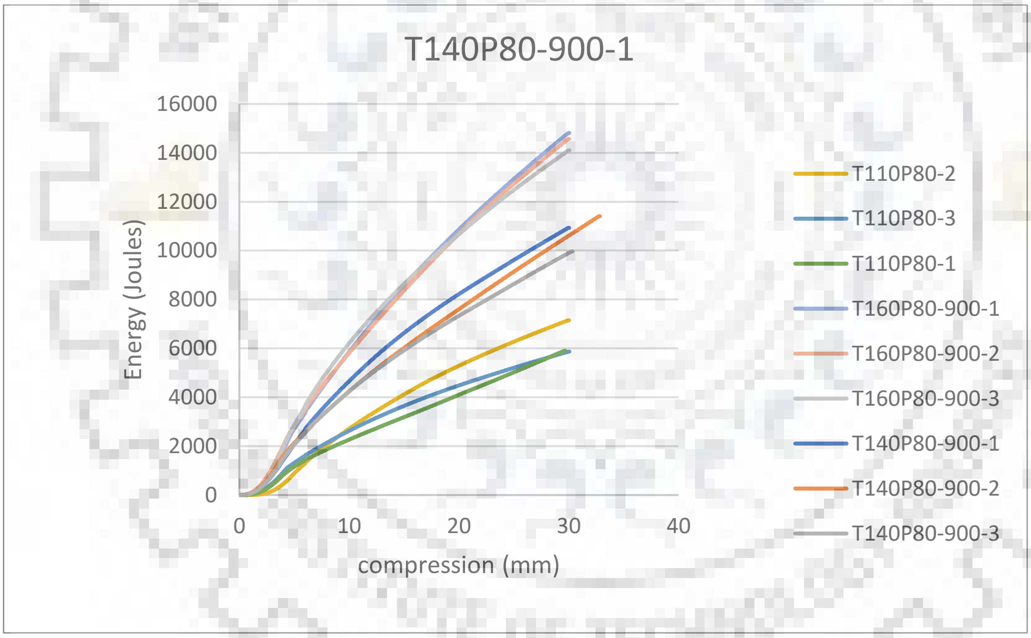


Figure 21 Energy compression curve of all specimens of same mix P80

Comparison graphs shows that the energy absorption values tend to increase with increase with diameter. The increase in energy absorption indicates that the specimen will behave better in a situation where there is sudden need for energy absorption like in an earthquake. Also, there are times when there is sudden increment of load in a structure, in that situation the structure which has a confinement will perform better than a one which has not.

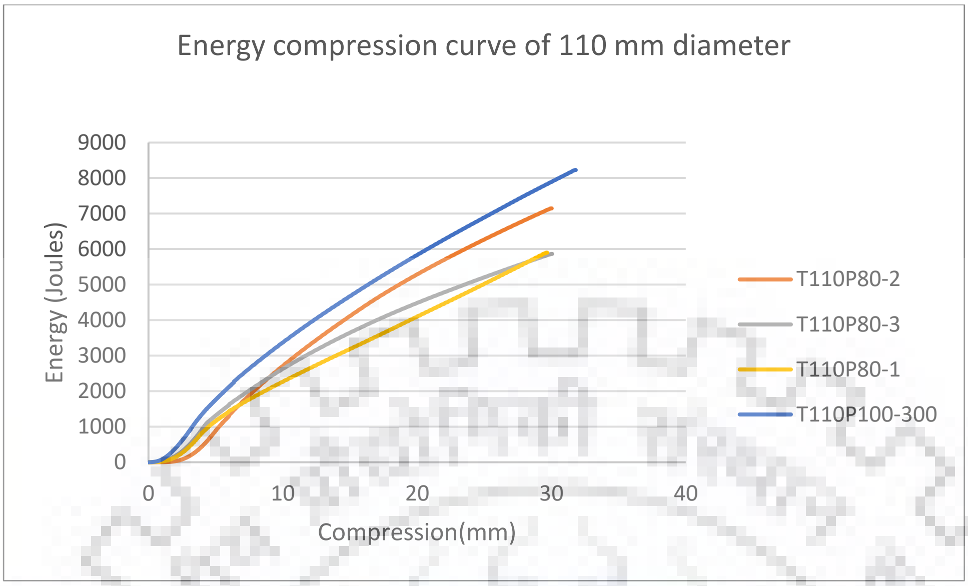


Figure 22 Energy compression graph of 110 mm diameter specimens.

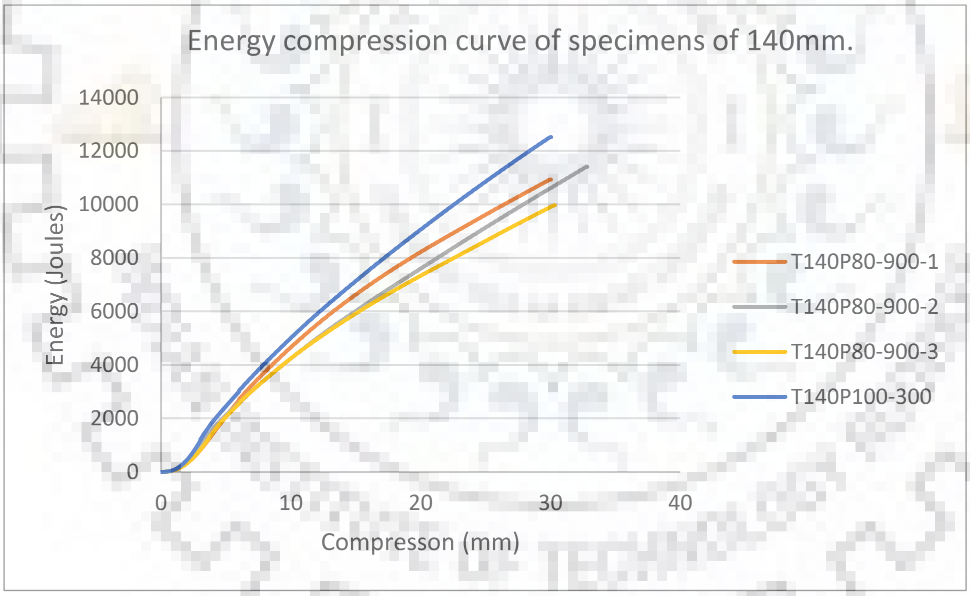


Figure 23 Energy compression curve of specimens of 140mm.

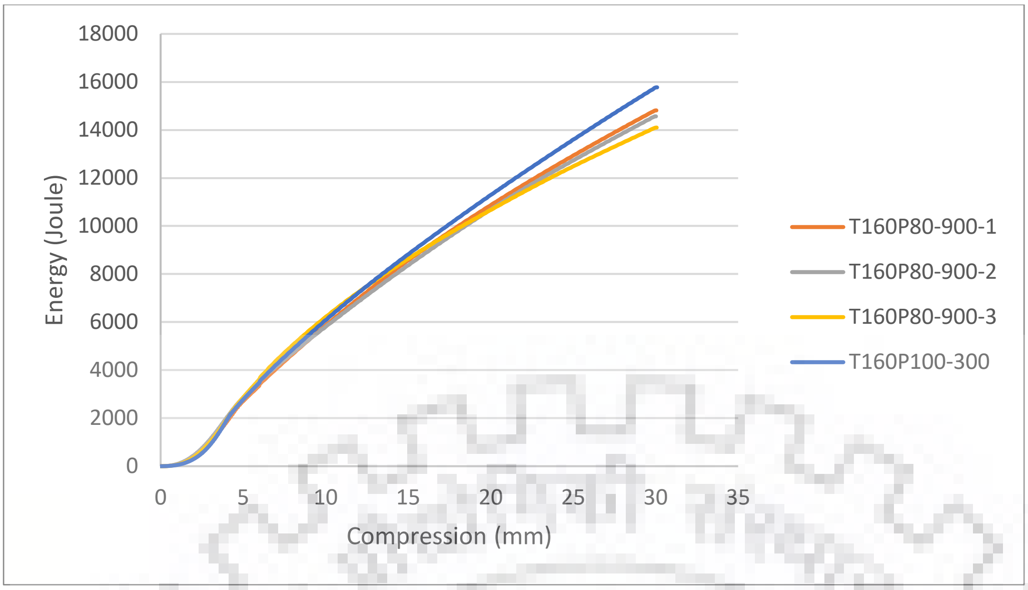


Figure 24 Energy compression curve of specimens of 160 mm

The increase in ductility ratios is much lesser in comparison to increment in energy when the diameter was changed. The richer mix P100 in the 300 mm specimens tends to increase the energy absorption capacity of all the specimens with P100 mix which are T110P100-300, T140P100-300 and T160P100-300. The length of P80 mix specimens is also 900 mm which is more than P100 specimens which also contributes to lesser energy absorption.

5.5 Bilinear Analysis

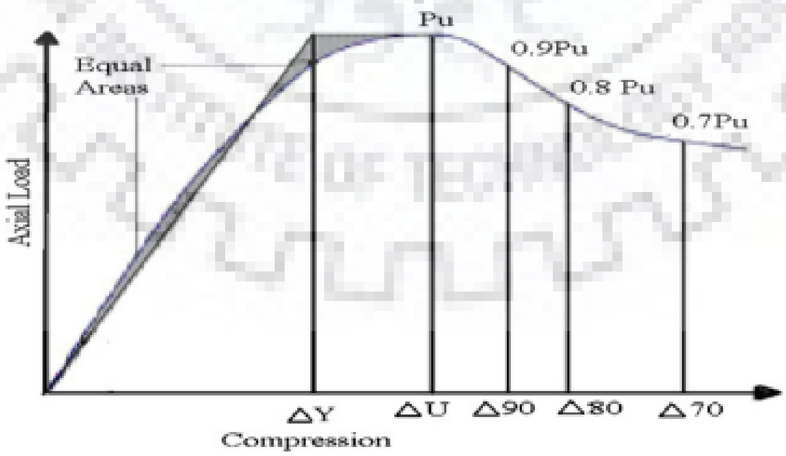


Figure 25 Sample load *compression curve for bilinear analysis*

A typical load compression curve is shown in figure 25 in which an equivalent linear graph is plotted such that the linear graph it divides the curves in two equal areas. The point of intersection gives the value of Δ_y. To assess ductility and energy absorption capacity of all the specimens, ductility ratio and energy absorption ratios were calculated. According to (Wu, 2004), ductility can be assessed by ductility ratio μ, which is defined as the ratio of compression values at different points. The values of ductility ratio and energy ratios were calculated at different stages of the load-compression curve to have an idea about the behaviour of specimens during axial compression.

$$\mu_0 = \frac{\Delta U}{\Delta Y} \qquad \mu_{90} = \frac{\Delta 90}{\Delta Y}, \qquad \mu_{80} = \frac{\Delta 90}{\Delta Y} \qquad \mu_{70} = \frac{\Delta 70}{\Delta Y}$$

where ΔU is the ultimate compression at ultimate strength and ΔY is the yield displacement at yield point. The ultimate compression ΔU is the compression at the point of max load which is denoted as P_u. The other load levels are defined at 90%, 80% and 70% of maximum load and are designated as $0.9P_u$, $0.8P_u$ and $0.7\ P_u$. The compressions corresponding to these levels are Δ90, Δ80 and Δ70. The yield point is ΔY is the yield point of an equivalent bilinear response curve which gives an equal area of the envelope curve as shown in figure 25.

The energy absorption capacity of the PVC confined tubes indicates the effectiveness of the PVC confinement. The energy absorption in joules was calculated by finding out the area under the load-compression curve upto different load levels. E_u is the energy of the curve upto ultimate load point. E_{90}, E_{80}, and E_{70} are the area of the load-displacement curve i.e. the energy of the of the specimen upto 90%, 80% and 70% of the ultimate load. E_y is the energy upto the yield point obtained by the bilinear graph. The energy ratios are defined as follows,

$$\varepsilon = \frac{Eu}{Ey} \qquad \varepsilon_{70} = \frac{E70}{Ey}$$

Table 8 Details of experimental results in terms of ductility ratio

specimen	Ultimate Load	Axial displacement(mm)					Ductility Ratio	
		ΔU	Δ90	Δ80	Δ70	ΔY	$\mu_0 = \frac{\Delta U}{\Delta Y}$	$\mu_{70} = \frac{\Delta 70}{\Delta Y}$
T110P100-300	550.79	3.15	3.54	4.10	4.54	2.38	1.32	1.90
T140P100-300	791.87	3.013	3.44	3.83	4.67	2.30	1.31	2.03
T160P100-300	1157.78	3.95	4.20	4.23	4.54	3.03	1.30	1.49
T110P80-900-1	449.42	3.81	3.87	3.95	4.62	3.31	1.15	1.39
T110P80-900-2	463.14	5.02	5.07	6.84	9.44	3.87	1.29	2.43
T110P80-900-3	529.82	4.10	4.28	4.33	4.37	3.09	1.32	1.41
T140P80-900-1	670.87	3.91	5.20	6.52	8.68	2.97	1.31	2.92
T140P80-900-2	749.98	3.38	3.54	4.09	4.19	2.62	1.29	1.59
T140P80-900-3	717.88	3.74	4.11	4.51	5.15	2.86	1.30	1.79
T160P80-900-2	974.98	4.55	4.68	4.75	4.85	3.49	1.30	1.38
T160P80-900-3	940.95	4.06	4.50	4.74	5.42	3.14	1.29	1.72
T160P80-900-3	1037.48	4.06	4.39	4.84	6.61	3.16	1.28	2.08

Table 9 Details of experimental results in terms of energy ratio

specimen	Ultimate Load	Energy absorbed					Energy Ratio	
		E_u	E_{90}	E_{80}	E_{70}	E_y	$\varepsilon = \frac{Eu}{Ey}$	$\varepsilon_{70} = \frac{E70}{Ey}$
T110P100-300	550.79	943.37	1144.31	1403.41	1580.47	558.41	1.63	2.83
T140P100-300	791.87	1172.5	1518.81	1779.82	2277.42	623.33	1.88	3.65
T160P100-300	1157.78	1866.83	2128.49	2143.56	2414.68	910.46	2.05	2.65
T110P80-900-1	449.42	759.46	787.05	813.34	1045.47	543.22	1.39	1.92
T110P80-900-2	463.14	896.69	928.77	1643.59	2478.8	407.76	2.19	6.07
T110P80-900-3	529.82	985.65	1082.9	1096.4	1112.45	512.99	1.92	2.16
T140P80-900-1	670.87	1371.9	2192.1	2999.3	4063.7	783.5	1.75	5.18
T140P80-900-2	749.98	1220.9	1322.2	1660.4	1726.54	685.11	1.78	2.52
T140P80-900-3	717.88	1302.04	1557.6	1802.7	2129.72	735.81	1.76	2.89
T160P80-900-2	974.98	2358.1	2453.4	2543.05	2617.32	1408.9	1.67	1.85
T160P80-900-3	940.95	2077.6	2480.2	2670.2	3140.92	1230.07	1.68	2.55
T160P80-900-3	1037.48	2001.3	2348.6	2734.05	4134.12	1156.67	1.73	3.57

The ductility ratios and energy ratios were calculated in table 8 and table 9 as shown using the values of ΔY, Δ90, Δ80, Δ70, ΔY and E_U, E_{90}, E_{70}, E_Y respectively. The values of μ_0 and μ_{70} are higher for richer mix P100 when compared with the average values of the specimens containing leaner mix P80. For example, the values of μ_0 and μ_{70} are higher for T110P100-300, T140P80-300, T140P100-300 when compared correspondingly with T110P80-900, T140P80-300 and T160P80-900 are higher. In the same manner, the energy ratios, ε and ε_{70}, of T110P100-300, T140P80-300, T140P100-300 when compared correspondingly with T110P80-900, T140P80-300 and T160P80-900 were found to be higher implying that the energy capacity of richer mix of P100 were higher than leaner mix of P80. The ductility ratios are also higher meaning that the richer mix provided a better ductility. The bigger diameter specimen provided more resistance to the applied load and hence a better load carrying capacity.

The values of E_u, E_{90}, E_{80}, E_{70} and E_y are following an ascending trend in the same order. It is because they have more areas under the load compression curve as is evident from figure 25. The 90%, 80%, 70% load points were defined beyond the peak load hence their areas are greater. The values of ΔU, Δ90, Δ80 and Δ70 were also in the ascending order due to the same reason. The value of μ_0 varied between 1.28 to 1.32 while that of μ_{70} varied between 1.38 to 2.92. The values of ε varied between 1.39 to 2.39 while that of ε_{70} varied between 1.85 to 6.07. Hence, the variations in ductility ratios were less in comparison to energy ratios. The energy enhancement is higher than ductility enhancement for the same parameter change.

Failure shape

Plate 22 Failure shape of 300 mm specimens

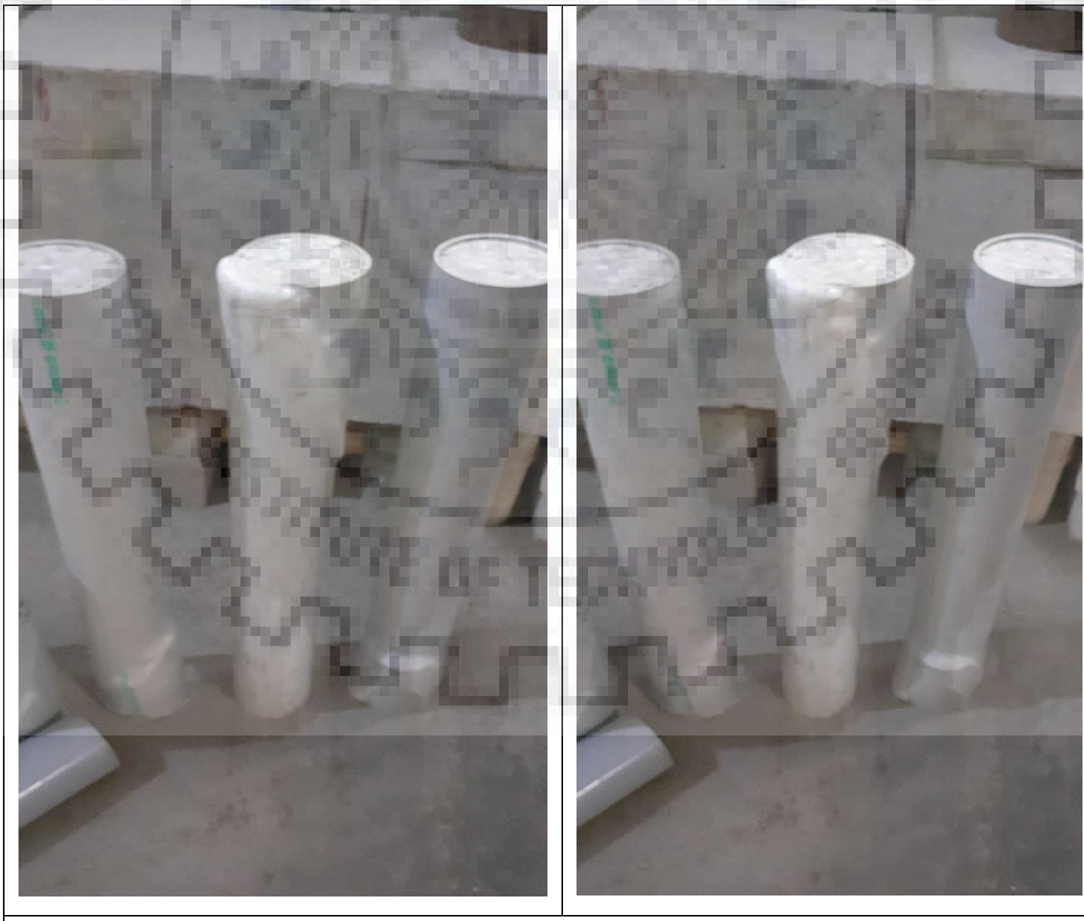


Plate 23 Failure shape of 900 mm specimens

Plate 24 Failure surface after removing a portion of the pipe

The failure of the specimens was shear failure as is evident from the above figures. Plate 24 is obtained by removing a portion of the PVC pipe to check the failure surface of the confined concrete.

1. It was seen that the cube compressive strength for P80 were lesser than P100 for both 14 days and 28 days duration. It can be concluded that the more the amount of GGBS, the better the strength.
2. The mix achieved 90% of its 28-day strength in 14 days which is clear from the cube compressive strength values.
3. The ultimate loads show a trend of increment with the increase in diameter from 110 mm to 160 mm. The trend increase in load is due to the confinement effect of PVC tubes with increase in thickness of the tubes
4. The residual load for all the specimens of 300 mm varied between 35 to 40 percent of the peak load.
5. It was seen that the slope of onset curve of the graphs decreases with decrease in D/t ratio meaning that the slope of T140P100-300 is highest while that of T160P100-300 is the lowest
6. The ultimate load increase with increase in diameter of the specimens.
7. it can be concluded that the slope of the onset curve decreases with increase in D/t ratio.
8. It was seen that the percentage residual strength decreased with decrease in grade of concrete for the same specimen size
9. It was concluded that the slope of the onset graph decreases with decrease in grade of concrete.
10. It can also be observed that the value of ultimate load decreased with decrease in the grade of concrete.
11. It was observed that the energy absorbing capacity of highest diameter is highest which could be due to its higher thickness.
12. The increase in ductility ratios is much lesser in comparison to increment in energy when the physical parameters such as sizes, and length and grade of concrete were changed.

13. The values of energy ratios were found to be higher for richer mix of P100 in comparison of leaner mix of P80.
14. The energy enhancement is higher than ductility enhancement for the same parameter change.

Scope of further studies

There has been a debate going on all around the world about climate change and every step is looked upon as a possibility. Considering that cement production contributes greatly to global carbon dioxide emissions, any alternative can present a promising future. In the same context, Geopolymer concrete provides a promising future. There has been some research available about the same but few researches are available about GGBS-Flyash combination. Also, at the same time retrofitting is a big market value in the present times. So, there is a lot of research going on enhancing the columns and other structural elements. In the present study both Confinement and Geopolymer concrete has been used. There are some researches available on steel confined Geopolymer concrete. But there is a big knowledge gap available in PVC confined Geopolymer concrete. There is a lot of scope in this direction. The future studies can include different type of mixes with more variations in the amount of GGBS. Other cementitious materials like metakaolin, rise-husk can also be used as a replacement to GGBS and fly-ash.

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