Novel Ductile Enhancement in the Structural Characteristics of External Beam Column Joint with Potassium Activated Green Concrete Technology: An Artistic Establishment of Seismic Challenging Structures

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Abstract

Ductility and energy dissipation capacity of the beam column joints are the two prominent characteristics which governs the stability of the entire structure constructed in the seismic prone areas. In this paper, the effect of potassium activated geopolymer concrete in the exterior beam column joint application is investigated under low frequency cyclic loading. Numerical analysis has been done by using the finite element software Abaqus and compared with the experimental work. From the load deformation relationship, parametric studies are carried out in the aspects of ductility, stiffness degradation, energy dissipation capacity, drift ratio and cracking pattern. The use of potassium activated geopolymer technology in the exterior beam column joint application resulted in the improved ductility, energy dissipation capacity with superior ultimate load carrying capacity of 1.05% over conventional cement reinforced concrete beam column joints with special confining reinforcement confirmed by IS 13920 due to the enormous polymerisation activated by high molecular potassium ions.2.78% improved energy dissipation capacity of potassium based geopolymer specimen resulted in the lesser number of non structural cracks and 11.26% more deformation under 11.96% enlarged drift ratio than the conventional reinforced concrete specimen. From the observed results it is clearly noted that the implementation potassium activated green polymer technology in the beam column joints possessed enhanced ductility characteristics to protect the structure susceptible to seismic environment and resulted in the innovative, economical and sustainable mode of seismic resistant building construction.

1. Introduction

One of the major challenges in the modern infrastructural development is provision of structural safety in the hazardous environment especially in the seismic prone areas. The building components should be strong enough to withstand the strong ground motion and also the core materials should dissipate the absorbed energy, undergo more deformation without causing any collapse and also should be repairable easily (Constantin E.Chalioris, 2017). On the other hand, the implementation of high strength costlier materials and devices to resist the earthquake load will lead to the uneconomical design (Flora Faleschini, 2017). Global researchers focused on the new ductile material development for the application of seismic prone constructionn. Various studies are carried out all around the world to establish a highly ductile, stronger and economical construction material in the structures subjected to high earthquake risks. The weakest element which is affected more due to the earthquake loads is beam column joints and hence taken for research works.

Maria Teresa De Risi studied the behaviour of exterior beam column joints under cyclic loading by varying the joint aspect ratio and beam longitudinal reinforcement ratio. From the research work it was concluded that the use of deformed bars in the joints resulted in the high level axial load ratio followed by the higher energy dissipation capacity with lower joint aspect ratio (Maria Teresa De Risi, 2017). Y. Wang classified the yielding mode of beam column joints under cyclic loading effect. It was observed that the specimens subjected to high axial forces failed only by the local buckling of the column (Y. Wang, 2019). The retrofitting effect of ultra high performance concrete on the beam column joints are studied by R.

Sharma. It was clearly interpreted from the results that the implementation of ultra high performance on the repairing works enhanced the load carrying capacity along with the greatest improvement in the energy absorption capacity (R. Sharma, 2019). A new type of composite column with geopolymer concrete infilled in the steel tube is developed by Z. Zhou in 2020. Along with this composite system an external supporting geopolymer concrete wall was also framed with the column element. It was observed that the geopolymer composite supporting wall system did not participate in the initial stage load cycles as the elastic deformation was taken care by the geopolymer composite steel tube itself. As the load cycles increased, the resultant deformation caused severe damages to the members. In order to withstand against this deformation without any structural failure the geopolymer supporting walls plays an important role in the higher cycles of loads. It was clear that the participation of this geopolymer supporting wall system enhanced the energy dissipation capacity by 2 to 4 times than the control specimen. The good structural integrity was assured in the geopolymer application (Z. Zhou, 2020). The geopolymer concrete derived from GGBS (Ground Granulated Blast Furnace Slag) and dolomite minerals was proved to dissipate 52% higher amount of energy than the ordinary Portlandcement based beam column joints with special confining reinforcement as per the recommendations of IS13920. Also the ductility was improved by 2.2 times than the cement concrete joints (P. Saranya, 2020).

Generally the detailing of joints is neglected in Indian construction practice. The code solves this problem by just extending its attention for the provision of sufficient anchorage in longitudinal beam reinforcement. But, improvement is highly recommended for understanding behaviour of joint. The joints are critical portion when the structure is subjected to the forces of earthquakes. Repairing these joints is difficult and hence we have to avoid the damage to the structure. Therefore, the reinforced concrete beam column joints design should be done considering the earthquake load. It is advisable to the limit the degradation of joint strength till the beam's ductility capacity reaches its designed capacity (Joshua Daniela, 2017). Hence according to the research work done by Saranya, it is observed that, the use of geopolymer system in the beam column joints efficient energy dissipation medium with high ductility and avoids the difficulty of repairing works as in case of specially confined reinforcement. Geopolymer concrete is emerging composite system which develops strength and durability characteristics by utilizing the aluminum silicate cores of industrial wastes such as fly ash, GGBS and metakaolin etc in the presence of alkaline activators. As industrial wastes are used as construction resources, the disposal issues of those abundant waste materials have been highly reduced. Also the geopolymer does not require cement the resultant global warming effects have been avoided by ensuring zero carbon footprints (Mohammad hossein Saghafi, 2018).

The geopolymers are still not commonly practiced due to the lack of research. In this paper, first time potassium activated geopolymer concrete is introduced in the beam column joint in order to achieve strength, long term durability, ductility to resist the strong vibratory motion without collapse and economy in construction with the help of sustainable construction. The main objective of this paper is to study the behaviour of Exterior Geopolymer beam column joints under Cyclic loading using the finite element software Abaqus and to investigate experimentally on Exterior Geopolymer beam column joints under cyclic loading in the aspects of Load – deformation relationship, Energy dissipation capacity, Ductility behaviour, Stiffness degradation, Drift ratio and Crack pattern. The results of potassium activated geopolymer concrete beam column joint (KGPC) specimens are compared with the control specimen with conventional reinforced cement concrete specimen (CRC) by using experimental and numerical methods.

2. Materials And Methods

2.1 Materials used

2.1.1 Binders

For the conventional concrete specimen, Ordinary Portland Cement (OPC 43) grade 43 confirming to IS 12269:1987 having initial setting time and final setting time as 30 minutes and 453 minutes respectively has been used. For the geopolymer members, Class F fly ash obtained from Thoothukudi thermal power plant has been used as binder. To ensure the better binding effect as that of OPC 43, the fly ash particles are sieved through 45 micron sieve.

2.1.2 Alkaline activators

Potassium based alkaline solutions are used to enhance the strength and durability behaviour of geopolymer concrete. Based on the trail and error process, the concentration of potassium hydroxide solution is confirmed to 10 M. For obtaining 10 molar concentration potassium hydroxide solution, ten times the molecular weight of the potassium hydroxide flakes are taken. The molecular weight of potassium hydroxide 56.1 g/cc. Hence 561 grams of potassium hydroxide flakes are taken and dissolved in one litre of distilled water. The solution is prepared 24 hours prior to casting. Semi solid form of K 66 potassium silicate solution is used to combine the potassium hydroxide solution in order prepare the alkaline activator solution. The potassium silicate solution is mixed with the potassium hydroxide solution 30 minutes before to the casting process.

2.1.3 Fine and Coarse Aggregates

Locally available Natural River sand passing to 4.75 mm sieve confirming to zone II of IS 383-1970 is used as Fine aggregate. The Laboratory tests are conducted for fine aggregate to determine its physical properties confirming to IS: 2386 (Part III). Coarse aggregate used in this paper consists of crushed stone of size passing through 20mm and retained on 12.5mm IS Sieve confirming to the physical requirements of IS: 383-1970. The mix proportion done by using the method proposed by WeenaLokuge (WeenaLokuge, 2018) has been shown in Table 1.

2.1.4 Reinforcement details:

High Yield Strength Deformed Steel bars (Fe500) of 8mm, 12mm and 16mm diameter are used for this work. 12mm and 16mm bars are used as longitudinal reinforcement (beam & column) and 8mm bars are used for lateral ties and stirrups. Spacing of lateral ties and stirrups as per the design are 75mm and 100mm c/c (centre to centre) as shown in Fig 1.

Table 1 Mix Proportions for Geopolymer M30 Grade

S.No	Description	Flyash (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Potassium silicate (kg/m^3)	Potassium hydroxide (kg/m^3)	Super plasticizer (kg/m^3)
1.	Mass of the quantity	444.45	540	1260	103.7	51.85	8.89
2.	Mix ration	1	1.21	2.83	0.233	0.116	0.02

2.2 Testing of specimens

2.2.1 Experimental Investigation

As per the design specifications of ductile detailing code IS 13920:1993, the design of beam-column joint has been done and the special confining reinforcement details are given in Table 2.

Table 2 Special confining reinforcement detailing of beam column joints

S.No	Description	Beam specification	Column specification
1.	Dimension	200 x 300 mm; 1.2 m length	200 x 300 mm; 1.5 m height
2.	Longitudinal reinforcement	4 nos of 12 mm dia bars	4 nos of 16 mm dia bars
3.	Lateral reinforcement	8mm diameter bar @ 75 mm spacing stirrups up to 550 mm (2d distance) and beyond that 100mm spacing	8mm diameter bar @ 75mm spacing as ties up to 450 mm from the face of the column beyond that 100mm spacing

The cyclic behaviour is studied by applying n number of forward and reversal cyclic loadings. The experimental set up of specimen has been shown in Fig 3. The beam specimen is kept vertical and column specimen is kept horizontal. The column specimen is restrained vertically at both ends in Y direction. In the X and Z direction the restraining is achieved by means of strongly built up steel boxes which is connected to reaction floor by using holding anchorages.

The test has been done in Mepco Schlenk Engineering College, Sivakasi. The maximum capacity of the testing frame is 50 Ton and the readings are noted down for each 10kN application of cyclic loading. The hydraulic jacks are placed on both sides of the beam element and the loading is given on either side. In the first cycle, the initial load of 10kN is given from one direction which is taken as positive and the corresponding deflections are measured from the dial gauges. Then the applied load of 10 kN is unloaded and the same magnitude of lateral loading applied in the opposite direction which is taken as negative. The cycle starts from zero, applied load in positive direction, unloading and reloading in the opposite direction and again return to zero. The cycles of loads are applied on the joints by means of two hydraulic jacks placed on either side of the beam in the increasing order of 10 kN upto the joint fails. For the effective application of reversal loading the hydraulic jacks on the either side of the beam component are connected to testing frame by means of mechanical fasteners. The applied lateral load on the vertically placed beam component is transferred to column by means of joints as axial load.

2.2.2 Numerical study using Abaqus

The same beam column joint member has been simulated and analyzed by using the finite element software Abaqus for the further parametric study. The material modeling has been done by assuming the elasto-plastic behaviour. The inelastic properties of concrete are assigned by using Concrete Damage plasticity (CDP) model as explained in Table 3. In this method the combined concept of isotropic damage plasticity and isotropic tensile and compression plasticity is used to assign the inelastic properties of the concrete. The strain hardening definition is allowed in this model. This method is more realistic and sensitive in straining rate. For the cyclic loading having repeated alternative tension and compression and for the seismic loading this method is highly realistic since this modelling allows the stiffness recovery. In order to define the plastic properties of concrete five parameters are used. The first parameter is dilation angle (ψ) which is the sloping angle taken from the plane of pressure invariant Vs second stress invariant. The rate at which hyperbolic flow potential approaches its asymptote is defined by flow potential eccentricity (□) which is taken as second parameter in plastic properties. The third parameter which is taken into account to define the plastic properties of concrete is the ratio between initial compressive yield stress at equibiaxial state and uniaxial state (fb0/fc0). The ratio between the second stress invariant on tensile meridian and compressive meridian is known as yield shape parameter (K) which considered as the fourth parameter. To define the visco plastic regularisation of the concrete constitutive equations in Abaqus / Standard, the viscosity parameter (μ) is used. As per the work done by Goh (Goh, 2014) it was suggested that the plastic parameters explained above cannot be found out from the experimental results. They were assumed using the values from the normal strength concrete. The plastic parameters used in this project are listed in Table 3. Hence the model is assumed to be isotropic model which is explicitly used in case of cyclic load application. By using this property, the failure mode of concrete is ensured by crushing failure of concrete.

Table 3 CDP modeling of beam column joint in Abaqus

S.No	CDP parameter	CRC	KGPC
1.	Dilation angle (in degrees)	35	38
2.	Eccentricity	0.1	0.1
3.	fb0/fc0	1.16	1.17
4.	K	0.67	0.658
5.	Viscosity parameter	0	0
6.	Compressive strength	30 MPa	30 MPa
7.	Poisson's ratio	0.18	0.2
8.	Elastic modulus	27386	385000

To increase the accuracy of the analysis, finer meshes are done by confirming the suitable size of mesh using mesh sensitivity analysis. The bond between steel reinforcement and the concrete mortar is achieved by embedded region in the interaction module. After assigning all material properties, interactions, constraints, boundary conditions and loading condition an analysis job is created and submitted for analysis. The first step for analysis is the submission of input file processer. The input file processer will be completed if there is no error in writing the input file. Then the Abaqus/Standard analysis is submitted for analysis. In this for the specified time increment the load is taken and the time frequencies and the load step frequencies are checked with specified maximum and minimum time increments for each incremental step. If the frequencies are not converging it will iterate for 6 times. If the frequency is still not matching the job will be aborted. Job will be continued if the iteration value converges. The job will be completed when the interval of the step function closes. The analysis is first done for elements in each part instances and from the results of the elements the results of the entire assembly is calculated by Reduced Gauss integration method.

The von mises stress plot due to the application of cyclic loads are taken from the visualization module of Abaqus are shown in Fig 4. When compared to the KGPC specimens, CRC joints are highly affected by the applied loads as indicated by the red colour plots on the upper side. This vulnerable stress formation leads to the structural cracks on these portions.

3. Results And Discussion

3.1 Load carrying capacity

The applied load and the corresponding deflections are measured with the help of load cell and dial gauges. The load deformation behaviour is compared for both CRC and KGPC specimens by using the envelope curves as shown in Fig 5.

Envelope curves are formed by connecting all the peak values of each cycle. The ultimate and the crack load for both the specimen from the experimental and numerical results are shown in Table 4.

Table 4 Load carrying capacity

S.No	Specimen	First crack load (kN)	Ultimate load (kN)			
			Experimental		**Numerical**	
			Forward cycle	**Reverse cycle**	**Forward cycle**	**Reverse cycle**
1.	CRC	50	103.4	101.5	108.9	107.92
2.	KGPC	50	104.5	102.3	109.12	110.73

From the results it was noted that the CRC and KGPC specimens provide greater resistance against applied load slightly higher in forward loading cases. In the load displacement envelope curve, the point at which the curve changes from linearity is known as first crack load and it is observed that both the specimens have the first cracks at the same point as 50kN. With the help of potassium activators, the fly ash compounds generates more bond with the embedded reinforcement which attributed the KGPC specimen to perform equally to CRC specimens and showed similar first crack load (Sayan Kumar Shaw, 2020). The ultimate load carrying capacity of the KGPC specimens is proved to be higher than 1.08% than the CRC specimens. The reaction of potassium ions with the poly carboxylic based super plasticizer caused the fly ash mineral to gain strength in the ambient curing which remove the fluctuation or drop in the hysteresis loop and leads to the enhanced load carrying capacity (Tomas Kovarik, 2021). From the load and displacement relationship obtained from the envelope curve the parametric studies are carried out further by considering the aspects of ductility, energy dissipation capacity, stiffness degradation, drift ratio and cracking behaviour.

3.2 Ductility characteristics

Ductility is the measure on the ability of the specimen to undergo maximum deformation without failure. In order to assess the ductility characteristics maximum displacement carried out by the specimen and the ductility factors are taken into account. The maximum displacement measured on the KGPC specimens are 11.26% higher than the CRC specimens as shown in Table 5.

Table 5 Ductility factor

S.No	Specimen	Average maximum load		Average deflection		Failure deflection	Yield deflection	Ductility factor
		Exp	FEM	Exp	FEM			
1.	CRC	103.4	107.5	52.8	59.93	42.24	17.25	2.448
2.	KGPC	104.5	109.93	59.5	71.05	47.6	19.39	2.455

Presence of potassium activators enhanced the resultant sialate polymers to withstand more deformation due to increased strain rate development (Patcharanat Kaewmee, 2020). Another measure is the ductility factor which is the ratio between failure and yield deflection. The failure deflection can be found out as 80% of the ultimate deflectionin the ascending path of the load deformation curve (Ahmed Sayed Tawfik, 2014). Ductility factor of the KGPC specimens are more than equivalent to CRC specimens. Hence it is evidently proved that the introduction of potassium ions activated aluminium silicate minerals in the beam column joints exhibited greater ductility characteristics than the conventional reinforced cement concrete joints.

3.3 Stiffness degradation

When a structural member is subjected to repetitive loading the stability of the element against the applied load can be ensured by its own relative stiffness. The external load causes the decrease in energy limit which lead to the increased deformation behaviour. The increased deformation of the joints attributes to the stiffness degradation in the member followed by the development of cracks.

Due to the application of cyclic loading the beam column joints exhibits stiffness degradation followed by propagation of cracks. In the experimental results, it is noted that the stiffness of the member is highly reduced at 5th cycle of load application. The initial stiffness is calculated by the ratio of average maximum load to the deflection as shown in Fig 6.

Table 6Stiffness Degradation

S.No	Specimen	Numerical results		Experimental results	
		Initial stiffness (kN/mm)	**After cyclic loading** **stiffness (kN/mm)**	**Initial stiffness (kN/mm)**	**After cyclic loading** **stiffness (kN/mm)**
1.	CRC	3.09	1.567	3.496	1.68
2.	KGPC	3.10	1.796	3.448	1.958

When the structure is subjected to cyclic loading the beam column joint develops inner micro cracks which resulted in reduction of energy limit. The decreased energy limit of the specimen leads to the increased deformation behaviour. Due to this effect, the degradation of stiffness is induced. The application of cyclic loading consists of loading, unloading and reloading effects. The comparison between the initial and final stiffness are given in Table 6. The degradation of stiffness of the KGPC specimens are observed to be gradual and the final stiffness is 12.75% lesser than CRC specimens. The stiffness degradation results confirms to the conclusion drawn by the research work done by S.K. Shaw on flyash (S.K. Shaw, 2020). Due to the initiation of wider open cracks at the joints of CRC specimen the dilapidation of core concrete and the reinforcement grown up fast and led to the rapid stiffness degradation. Whereas, the fly ash particles activated with potassium based alkaline activators only generates minor non structural cracks at the joints and hence the stiffness degrades in the KGPC specimen more gradually.

3.4Drift ratio

The responsible structural parameter for the stability against the ground motion is member drift ratio. The measured deflection along the total length of the member is known as drift ratio. As the load cycles increased, the corresponding increment is observed on the drift ratio. According to the research work carried out by Y.Wang, it was confirmed that, the cyclic load application results in the buckling effect on the beam element. But the existing elastic nature of column still controls the joint from the drift effect (Yandong Wang, 2019). The calculated drift ratio of the CRC and KGPC specimens are shown in Table 7.

Table 7 Comparison of drift ratio from numerical and experimental results

S.No	Specimen	Drift ratio (%) from numerical investigation		Drift ratio (%) from experimental study	
		Forward cycle	**Reverse cycle**	**Forward cycle**	**Reverse cycle**
1.	CRC	3.684	-4.43	3.52	-3.25
2.	KGPC	4.179	-5.294	3.566667	-2.9

The drift ratio variation of CRC and KGPC specimens are compared in Fig 7.It is observed that, the KGPC specimens withstand 11.84% to 16.3% higher drift ratio than the CRC specimens at forward and reversal loading respectively without exhibiting any structural damage. Hence it is evidently proved that the employment of KGPC structural joints in the seismic prone areas will provide safely against the violent storey drift over the specially confined reinforcement in the reinforced concrete beam column joints suggested by IS 13920.

3.5Energy Dissipation Capacity:

During the strong ground motion, the building components also forced to be vibrated along the earth motion. The capacity of the elements to dissipate the absorbed energy by allowing elastic and inelastic deformation without failure decide the stability of the building. Hence the assessment of energy dissipation capacity plays a vital role in the seismic resistant structures. The energy dissipation capacity can be measured as the area under the load deflection curve which is shown in Fig 8.

The displacement variation for each cyclic load application has been showed for both CRC and KGPC specimens separately. The maximum energy dissipated by the joints are calculated from the graph and shown in Table 8. In both the experimental and numerical results, the energy dissipated by the KGPC specimen is higher than the CRC joints by 2.78% and 3.6% respectively.

Table 8 Energy Dissipation Capacity

S.No	Specimen	Energy Dissipation Capacity, kN-mm	
		Experimental	**Numerical**
1.	CRC	6254.25	7313.50
2.	KGPC	6485.86	7515.45

The bridging action developed by the potassium activated ions on the sialate networks attributes the excellent post cracking behaviour (Saranya, 2020) which leads to the increased energy dissipation capacity than the CRC specimens. The application of cyclic load makes the beam component to slightly undergo plastic deformation which is the reason for the minor variation between the numerical and experimental results. Whereas, the column member remains at the elastic stage which is ensured by the large energy dissipation capacity obtained from the hysteresis curve of geopolymer beam column joints (Yandong Wang, 2019).

3.6 Cracking mechanism

The repetitive loading, unloading and reloading applications of the beam column joint specimen causes alternative tensile and compressive stress development. When the generated stresses reached the ultimate strength of the material, the flexural cracks are developed from the highly stressed portion (Sujith Mangalathu, 2018). As the lateral loads are applied and transferred from the vertically placed beam element to the horizontally positioned column members through joints, the flexural cracks are initiated at this junction. The transferred lateral forces are acted as axial forces to the column member. The increase in the number of load cycles increased the rate of axial deformation which resulted in the initiation of shear cracks in the column (Gunasekara, 2016). The developed shear causes diagonal tension and compression along the joints. As the joints are provided with 90^{o} bent anchorage bars to arrest the tension failures, compressive stresses are initiated at the joints.

When the anchorage bars subjected to compressive stresses, the further resistance to applied load is only provided by the bonding between concrete and steel which attributes development of contact pressure under the bend. Induced contact pressure generates diagonal form of compressive shear cracks (Leonardo M.Massone, 2018). To attain the equilibrium in shear the consequent diagonal tension cracks are developed on the joints. The tension ties placed perpendicular to the joints increase the ability to resist the diagonal tension caused by the lateral loads. This tension tie acted as shear panel area of the joint which safely transfers the applied lateral force to the foundation of the building through base plates (Hong Yanga, 2018). The resistance to the diagonal compression and diagonal tension developed on the joints is purely depending upon the strength of the resisting medium. When the CRC specimens are used as core concrete material in the beam column joints, wider open cracks are observed at the joints as shown in Fig 9 a. But in case of KGPC specimens the potassium activated geopolymer column acted as compressive strut which resists the diagonal compression and also serves to resist the diagonal tension by making improved compatible action with the bent up anchorage reinforcement. The flexible mode of shear resistance mechanism offered by the KGPC specimen showed non-structural micro cracks at the joints as shown in Fig 9b. Also the spalling of column cover concrete in these specimens ensures the serviceability of KGPC activated beam column joints under the seismic loading cases.

4. Summary And Conclusion

The effect of potassium activated geopolymer concrete in the beam column application (KGPC) under cyclic loading has been studied and the results are compared with the conventional reinforced concrete beam column joints with special confining reinforcement as per IS 13920 (CRC). From the load deformation characteristics the parametric studies are carried out in the aspects of ductility, stiffness degradation, energy dissipation capacity, drift ratio and cracking pattern. The conclusions made from the results are as follows:

- The use of industrial wastes such as fly ash instead of cement in the beam column joint application in the presence of potassium activators enhanced the strength characteristics and exhibited 1.05% superiority in the cyclic load carrying capacity than the conventional reinforced concrete with IS 13920 recommendations.
- The continuously developed alumino silicate chain networks stimulated with the high molecular potassium activators enable the beam column joints to withstand under higher rate of strain growth in the forward and reversal loading. Hence KGPC specimen undergoes 11.26% more deformation than the CRC specimens.
- Application of cyclic loading resulted in the stiffness degradation property. The enhanced ductility of the KGPC specimen attributes to the gradual reduction rate of stiffness degradation which is 12.75% lesser than the CRC specimens.
- As the KGPC specimens are proved to withstand more deformation, the safety of the exterior joints against cyclic loading has been ensured over CRC specimens even at the 11.96% higher drift ratio.
- Reversal loading causes the development of micro cracks inside the joints and initiates the reduction of energy limits of the materials. The KGPC joints have the tendency to dissipate 2.78% higher energy by producing non structural cracks.
- CRC specimens formulate the wide open cracks in the junction of beam column joint due to flexural failure which results in the crushing mode of concrete failure. Whereas, the KGPC specimen initiates the spalling out of cover concrete by inducing compression strut action in the beam column joints which results in the lesser number of cracks, improvement in the seismic behaviour and also enables easier mode of FRP wrapping repair techniques in order to restore the flexural strength and ductility in the post remedial stage.

Declarations

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Conflicts of interest/Competing interests

The author has no conflicts of interest to declare that are relevant to the content of this article.

Availability of data and material

The data that support the findings of this study are available on request from the corresponding author, [Mohana R].

Code availability

NA

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Figures

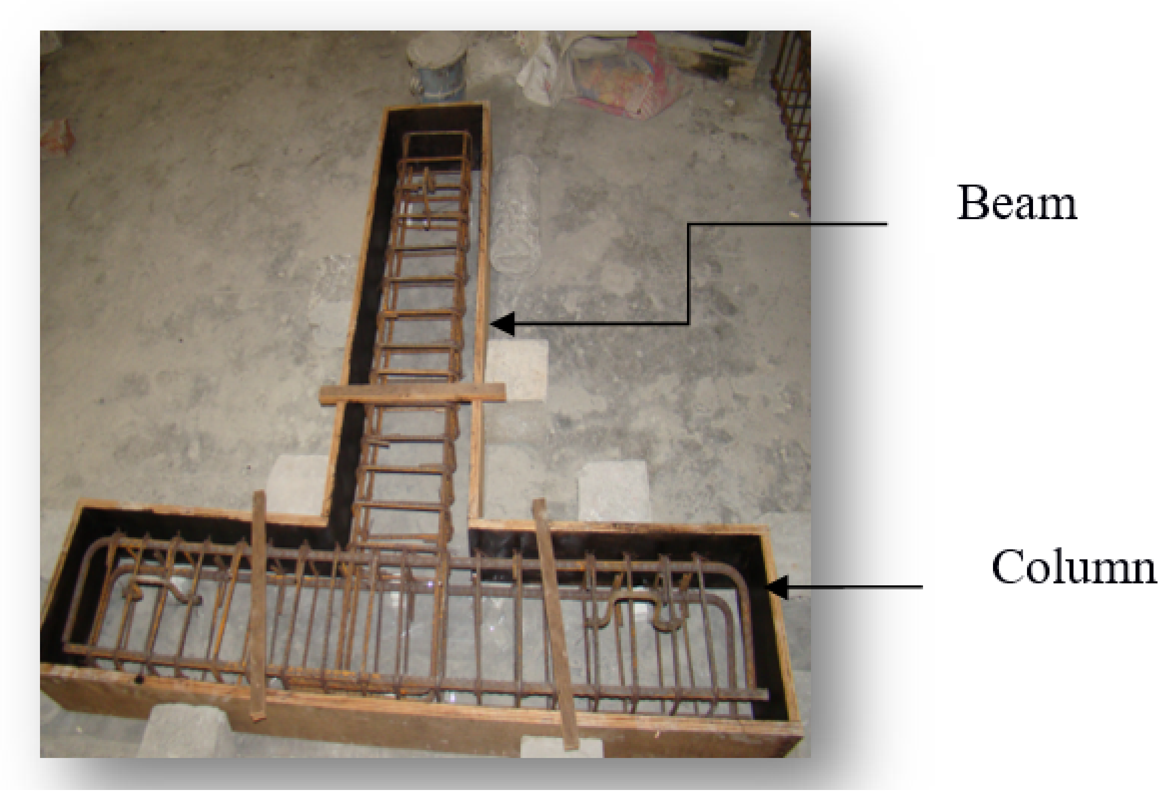


Figure 1

Formwork and reinforcement arrangement

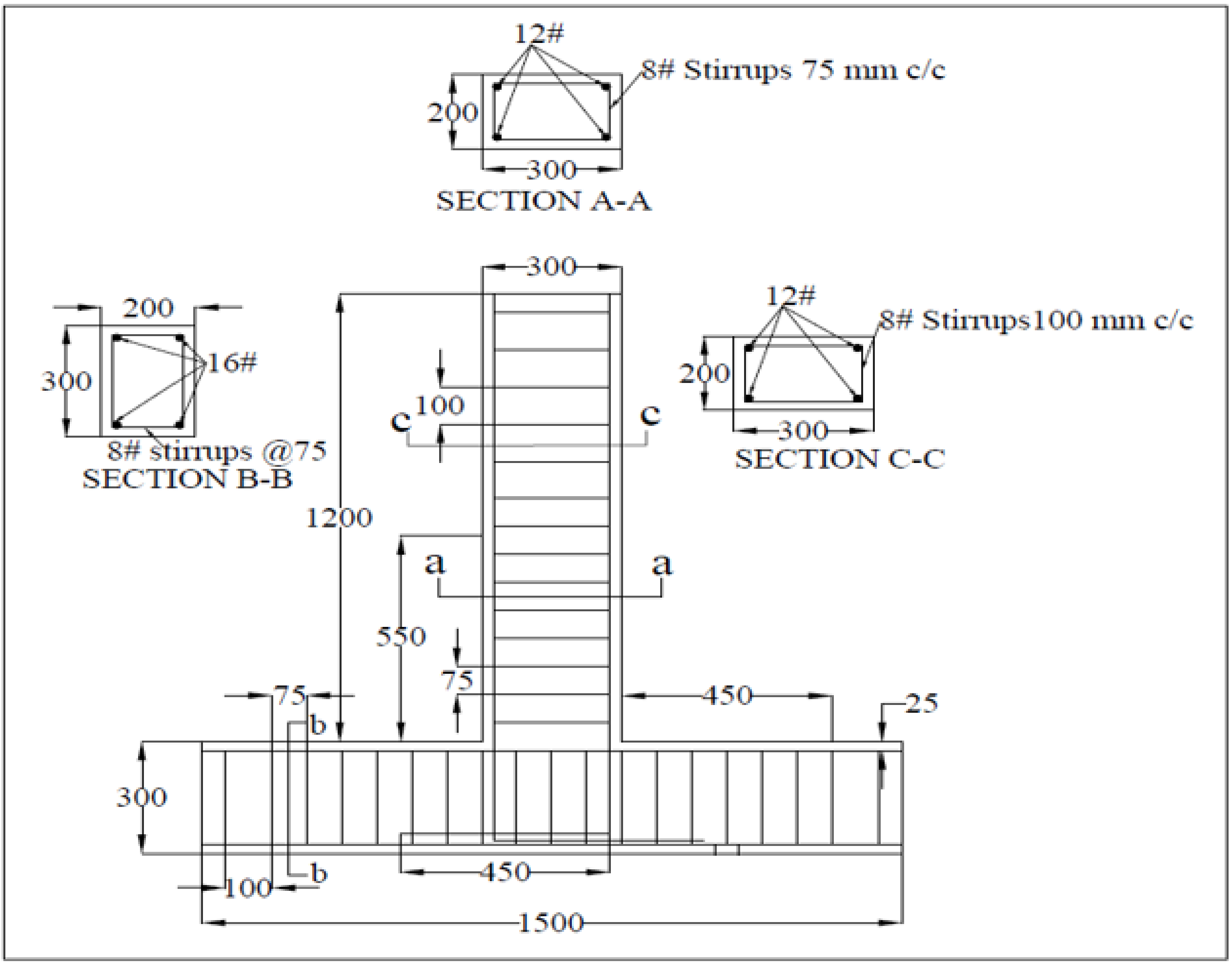
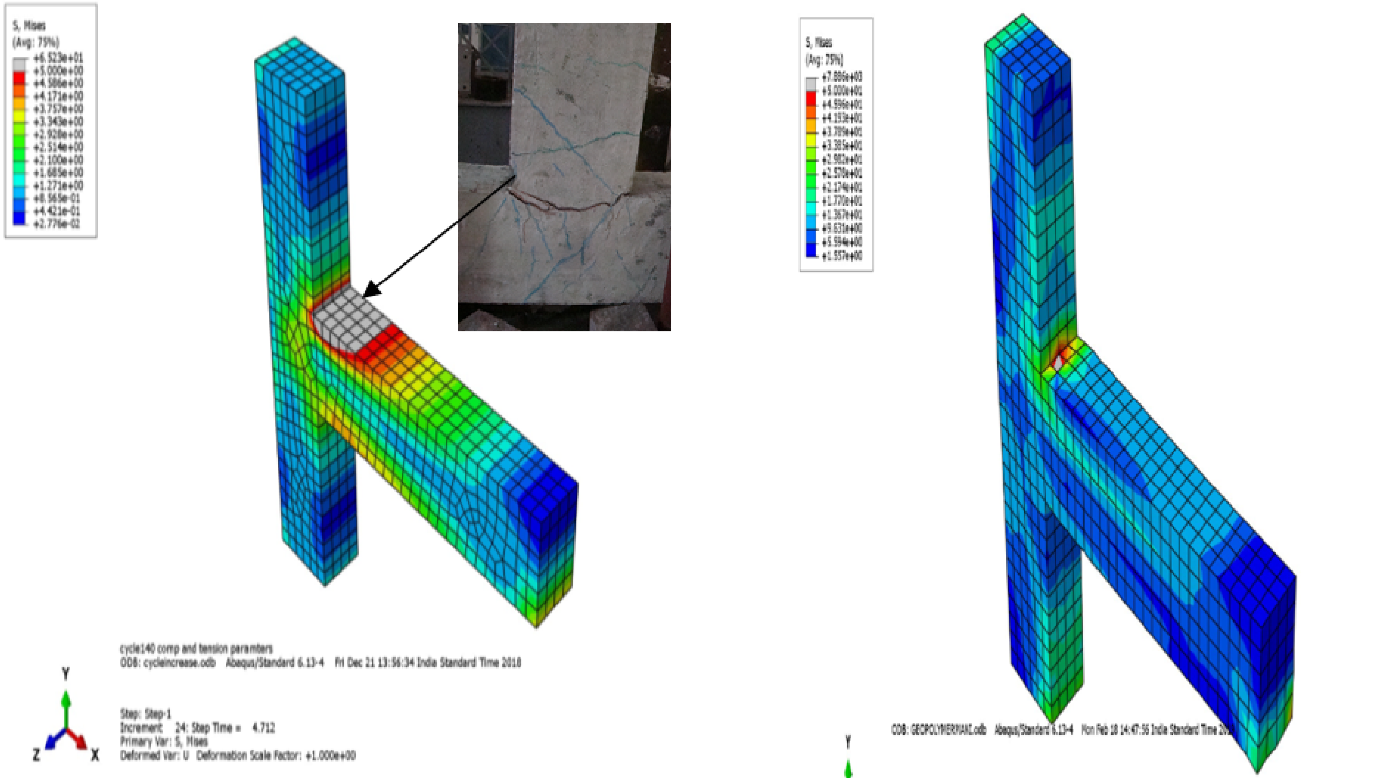


Figure 2

Reinforcement details of exterior beam column joints

Figure 3

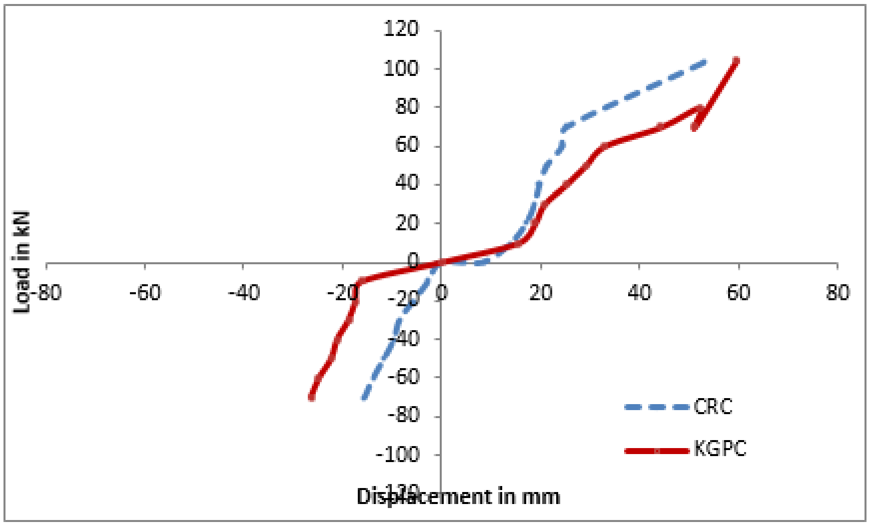
Test setup of geopolymer (KGPC) beam column joint specimen



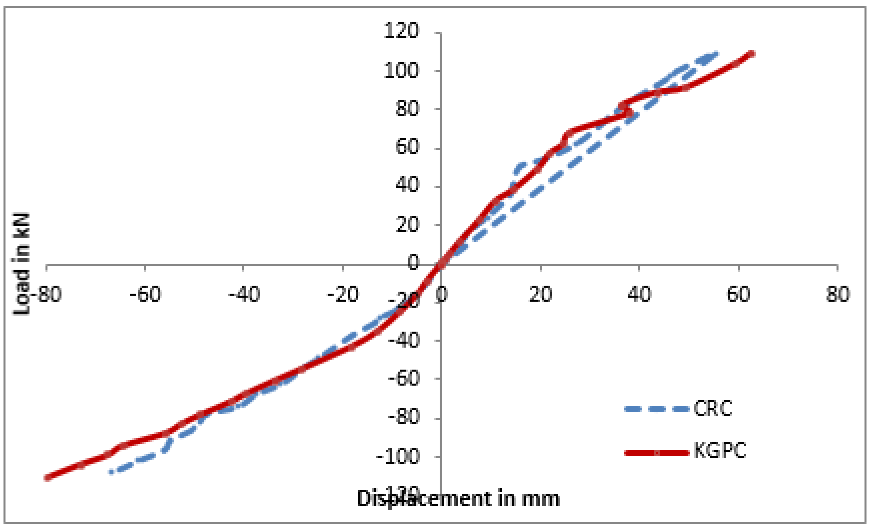
a. CRC **b. KGPC**

Figure 4

Stress distribution on the beam column joint specimens



a. comparison from experimental results



b. comparison from numerical results

Figure 5

Comparison of load displacement characteristics of the CRC and KGPC specimen

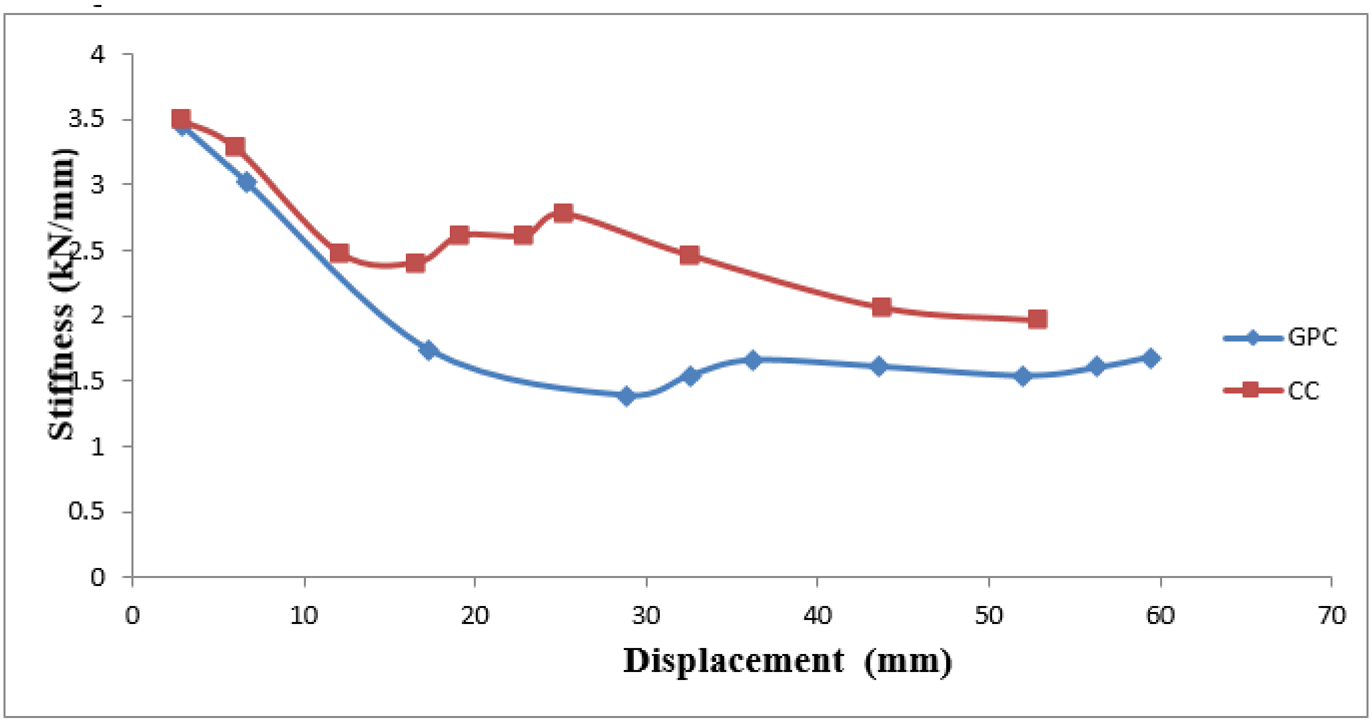


Figure 6

Stiffness comparison of CRC and KGPC beam column joint specimen

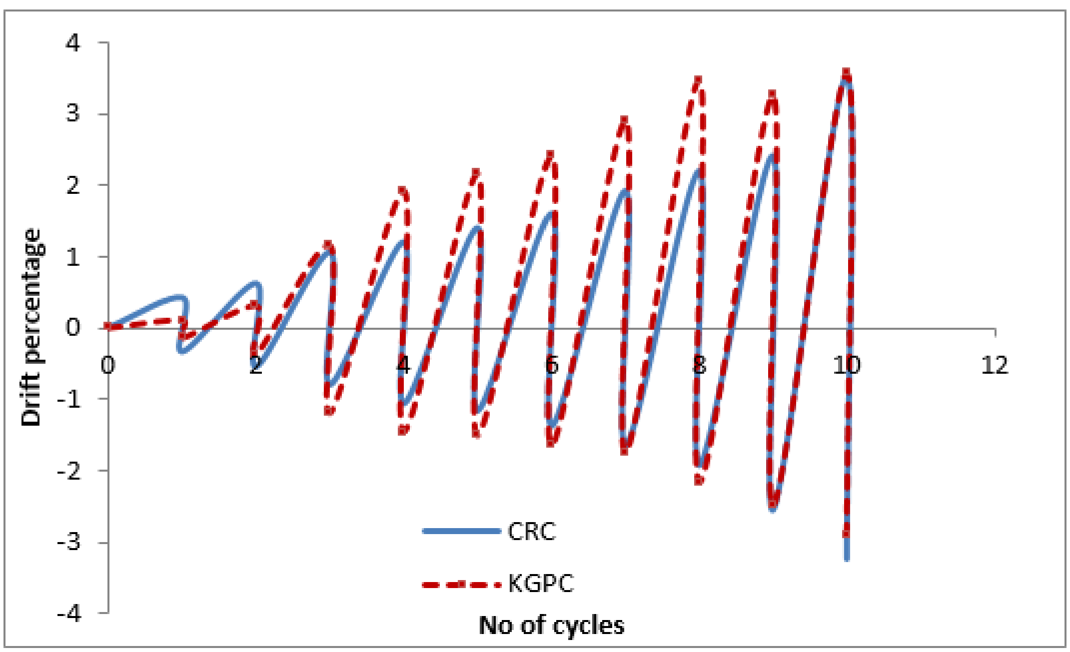


Figure 7

Comparison of drift ratio between the CRC and KGPC specimens

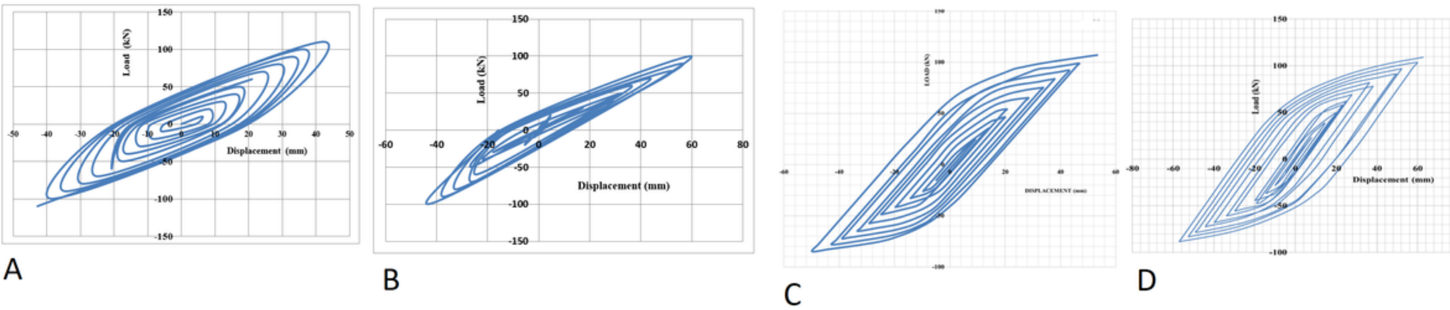


Figure 8

a. Energy dissipation capacity of conventional (CRC) beam column joint specimen b Energy dissipation capacity of geopolymer (KGPC) beam column joint specimen c Energy dissipation capacity of CRC exterior beam column joints (numerical) d Energy dissipation capacity of Geopolymer exterior beam column (KGPC) joints from numerical results

a. CC b.GPC

Figure 9

Cracking pattern in CC and GPC members