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High-contribution of Strip Glass Waste in Strengthening Slender Glass Reinforced Concrete Columns under Axial Compressive Load

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ABSTRACT

The important thing about axially loading slender columns is buckling stability. However, very limited researches were found, especially using glass-reinforced concrete. An alkali silica reaction (ASR) deterioration problem only occurs when particles are very fine. The utilization of glass as a particle was avoided, and bigger dimension of glass strip waste was utilized instead because cement cannot penetrate deep into the glass piece. A series of axial loading tests of glass-reinforced concrete (GLARC) slim columns were carried out on arrangement types; glass strips, homogenous and randomly pieces reinforced to explore their buckling performance. All axial GLARC columns capacity results were better than glassless columns reinforcement. The best reinforcement was longitudinal horizontal strip arrangement since they have consistent strength contribution hence allow the GLARC columns to resist higher axial loads to avoid buckling failures. The tests results in a good performance and hence GLARC columns have potential chances to be used extensively as structural compression members.

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NOMENCLATURE

EI	Flexural rigidity of column cross section	P_E	Euler buckling load
y	Deflection to the y-axis	N_E	Axial force for slender column
P_c	Critical axial load	$w(x)$	Lateral deflection in x-distance
ℓ	Length of the column	$e(x)$	Imperfection buckling in x-distance
n	number of half-sine waves in the deformed geometry of the column	π	3.14159265359

1. INTRODUCTION

Waste glass contributes significantly to environmental degradation, owing to the inconsistency in waste glass sources. With mounting environmental demand to eliminate solid waste and recycle as much as practicable, the concrete industry has implemented a variety of strategies to accomplish this aim. Research examined the properties of concretes comprising waste glass as fine aggregate was explored by Ismail and Al-Hashmi [1]. Indonesia is expected to generate 64 million tons of waste per year. According to statistics from the Ministry of Environment and Forestry (KLHK), glass waste accounted for 1.7% of overall waste in 2017 [2].

Nearly any form of building involves the use of concrete. Traditionally, concrete was made mainly of cement, water, and aggregates [3]. Additionally, coarse aggregate may be substituted with incinerator bottom ash aggregate and sintered fly ash pellets. The use of recycled glass aggregates (RGA), bottom ash from thermal power plants, and quarry dust as fine aggregates in concrete has considerable potential. RGA has significant potential for the use as a fine aggregate in concrete, including high performance concrete. Research has shown that concrete made with RGA as fine aggregate develops comparable or slightly higher strength and modulus of elasticity than concrete made with natural sand of the same grading, whereas flexural strength, creep, and shrinkage are essentially unaffected. RGA can also be used as a filler

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aggregate in concrete to increase its strength and stiffness [4]. Some of the studies on glass materials, such as that conducted by Martens et al. [5], resulted in the creation of strengthened and prestressed glass beams. Despite fundamental variations in output and methods, the majority demonstrate superior behaviour, which results in increased substantial post-failure strength.

As a concrete composite, Feldmann and Langosch [6] investigated the behavior of structural concrete incorporating glass powder when added to reinforced concrete columns. The results indicated that substituting glass powder for 20% of the cement in a column measured at 28 days postponed cover cracking and marginally improved load-bearing capability and post-peak response.

In contrast to the findings above, a study conducted by Rosso et al. [7] on the properties of concrete incorporating recycled glass aggregates made from exploded lamp materials found that the greater the amount of recycled glass aggregate added, the less benefits the concrete features received from glass involvement. Microscopic research performed to understand this phenomena demonstrates the detrimental impact of the aggregate grain shape produced.

Yu et al. [8], on the other hand, investigated the durability of concrete constructed from steel slag and waste glass. Compressive power, flexural strength, and modulus of elasticity of steel slag concrete are equal to or perhaps greater than those of limestone aggregate concrete. As coarse aggregate was supplemented with up to 17.5% waste glass, there was just a minor influence on the concrete's mechanical properties. Steel slag and waste glass, due to their superior thermal and/or mechanical properties, have the potential to improve the fire resistance of concrete. However, researchers who have studied glass materials, have been left out of the way of applying glass piece reinforcement to concrete structures. This research focuses on the application of reinforcing broken glass piece in columns, which has not been studied well.

2. LIRERATURE REVIEW

2. 1. Column Buckling

Columns are classified as struc-tural members that suffer the majority of their loads in compression. Columns typically include bending moments along one or both of the cross section's axes, and the bending behavior can generate tensile forces across a portion of the cross section. Except in these situations, columns are commonly referred to as compression members due to their predominant action under compression powers. Columns are classified into two different categories: short columns, whose strength is determined by the material's strength and the cross section geometry, and slender columns, whose strength may be greatly diminished by lateral deflections [5]. The majority of structures of slim or slender dimensions that are subjected to compressive force can exhibit buckling instability. Buckling occurs when a structure is unable to retain its initial geometry and must adjust geometry to rebalance. Buckling is essentially a geometric problem in which there is a significant deflection that alters the form of the structure. Equilibrium states occur for the axially loaded column depicted in Figure 1 (left side). When a column is forced laterally at midheight and released, it returns to its original position; and so on. Figure 1 (right side) illustrates a section of a column in neutral equilibrium [5]. The differential equation for this column is:

$$EI\,\frac{d^2y}{dx^2} = -Py \tag{1}$$

In 1744, Leonhard Euler derived Equation (2) and its solution, where:

$$P_c = \frac{n^2\pi^2 EI}{\ell^2} \tag{2}$$

Figure 1 (right side) illustrates the cases of n = 1,2, and 3. For n = 1,0, the lowest value of Pc occurs. This results in what is known as the Euler buckling load:

$$P_E = \frac{\pi^2 EI}{\ell^2} \tag{3}$$

The equation for slender glass columns under an axial force N_E, using sinusoidal imperfection also developed by Feldmann and Langosch [6] as:

$$w''(x) + \frac{N_E}{EI}\cdot w(x) = -\frac{N_E}{EI}e(x)$$

Feldmann and Langosch [6] also derived the theory of imperfection buckling column. Therefore, buckling behaviour is critical to investigate, ever more so when the column geometry is slender and exhibits wall-like behavior, and even more so when subjected to cyclic or seismic loads, as earthquakes such stated in literature [7-10]. While several observation regarding column element or axial member in many research also can be seen in literature [11-15].

Figure 1. Imperfection buckling of a pin-ended column Source: [5]

2. 2. Glass Waste As seen from the lens of physics, glass is a very cold substance. Thus named due to the arrangement of the constituent particles being as far separated as they are in a liquid, but the glass itself being solid. This is because the cooling mechanism is so rapid that the silica particles do not have enough time to assemble themselves properly. Glass is composed of a variety of non-volatile inorganic oxides that are formed through the decomposition and fusion of alkaline and alkaline earth compounds, sand, and numerous other constituents. Glass's distinctive properties are determined by the uniqueness of silica (SiO_2) and the mechanism by which it is formed [10].

The roughness of the glass imparts an abrasion resistance to the concrete that only a few natural aggregates possess. In comparison to other ceramic types, glass exhibits unique characteristics. Typically, the glass is ground first to remove the rough points. Glass powders are generated during the grinding process as a consequence of scraping the outer side of the crushed glass. Typically, glass powder is discarded straight onto the ground, rather than being recycled, since shattered glass may be burned and reprinted [10].

A mix design preparation approach that is suitable is required to create a concrete mix design that satisfies quality standards and has a strong economic benefit [7]. There are several techniques for designing concrete mixes, including the following: (1) the trial and error process, which involves comparing concrete mixtures of varying composing materials in order to achieve a composition of a desired workability; and (2) the fineness modulus scheme. (3) The Department of Environment (DOE) process originated in the United Kingdom and is based on the basic compressive strength of concrete measuring 15 x 15 x 15 cm; (4) American Concrete Institute (ACI) method 61354. This process of developing concrete mixes originated in America and is focused on the compressive power of cylindrical concrete with a diameter of 15 cm and a height of 30 cm; (5) Shacklock's method of high strength concrete mix design, which is used for high strength concrete (> K.350 kg/cm^2).

Environmentally friendly concrete (green concrete) is a kind of concrete that is made from products that are not harmful to the environment. The erosion of rugged hills is an indicator of environmental degradation caused by the use of natural resources. The growing demand for concrete supply results in widespread extraction of rock, one of the constituent materials of concrete in the form of coarse aggregate, reducing the amount of natural resources usable for concrete purposes [16]. Coarse aggregate is the primary component of concrete. In environmentally sustainable concrete (green concrete), broken stone (split) may be substituted for broken tile aggregate derived from clay, synthetic aggregate derived from clay, or aggregate derived from crushed concrete waste [17]. Another research that utilizing waste or recycled glass in concrete was reported in literature [18-21].

2. 3. Alkali-Silica Reaction However, when glass sand or powder is used as a particle aggregate in reinforced concrete, alkali silica reaction (ASR) issues such as those depicted in Figure 2 often occurred in many researches [22-29].

However, an ASR alkali issue exists only with extremely fine particles. To prevent this problem, the use of glass as a particle was avoided; thus, the reinforcement proposed was structural in nature and therefore not material in nature. When the horizontal strip waste remains in the glass shop cutter, the dimension of glass strip waste is large enough. As a result, ASR would not occur here, as cement cannot penetrate deeply into the glass fragment, partial or complete substitution of cement with more environmentally sustainable products during the concrete manufacturing phase is a choice. Green concrete is a movement that seeks to empower building professionals such that while concrete is manufactured, what matters is that the concrete is environmentally safe, in compliance with its status, does not waste natural resources, and is forward-thinking in order to provide an atmosphere conducive to sustainable growth (sustainable development) [22].

3. AXIAL TEST METHODOLOGY

In this study, continuing the previous reseach regarding flexural loads [30, 31], five column specimens of varying glass waste arrangement were used, as shown in Figure 3.

In Figure 3, the first GLARC column specimen was namely as column without glass (CWG), and the second was random glass pieces (RGP), and the third was vertically strip longitudinal (VSL) cut, and the fourth was horizontally strip longitudinal (HSL) cut as uniform 1-2 cm long, and finally was uniformly homogeneous pieces (UHP). While the glass waste and columns specimens were depicted in Figure 4.

Figure 2. View of alkali silica reaction phenomenon

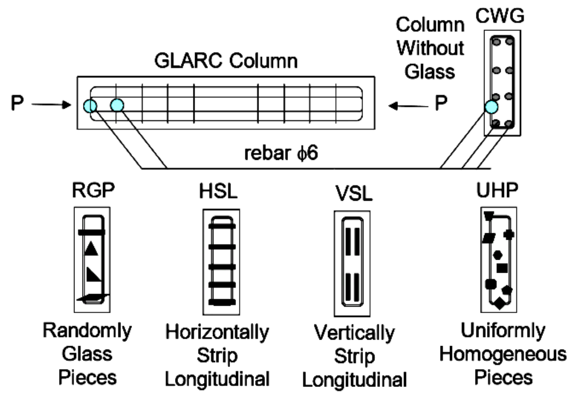


Figure 3. Variation of GLARC column specimens

Figure 4 (a) Glass-waste (b) Slim column specimens

Hydraulic jacking devices such as those depicted in Figure 5(a) and the loading dials are depicted in Figure 5(b), while the holder and clamp for dial mounting, as well as the dial gauge for calculating load and deflection, are depicted in Figure 5(c).

The loading frame used to validate the above structure is a 4m long I-profile steel frame, the details of which are shown in Figure 6(a) and support for dial gauges in Figure 6(b).

The data acquisition device was used to monitor the strain amplifiers' observed values automatically. The PCI expansion board interface used is the PCI-3126 with a 12 bit analog input board that comes with the GPF-3100 driver software. The limitations and requirements apply to relative humidity levels of 20%-90% (non-condensing). Figure 7(a) illustrates the way two wires for this system was mounted, and Figure 7(b) illustrates a PCI-3126 card in a PC machine slot to install.

Figure 5. (a). Hand pump (b) hydraulic jack, (c) Dial gauge, dial holder and clamp

Figure 6. (a) Loading frame; (b) dial gauge support

The auxiliary software is used to configure the test, and all necessary information such as the strain gauge factor, calibration coefficient, and channel gain is input into the software.

A strain gauge is mounted axially on the tensile part (bottom) of the girder in the center section of the flexural test girder specimen, and the strain data is connects by data acquisition that recorded 6 channels simultaneously to the AS1803 strain amplifier shown in Figure 8, followed by a cable that connects to PCI-3126 12 bit analog input board embedded in a PC drivered by GPF-3100, where each line has its own processing unit that can take 8 data per second with a resolution of 16 bits and has 8 different input settings in range 10 V. When the input is increased, the measurement sensitivity rises proportionately, resulting in a smoother curve. Additionally, the strain gauge can be adjusted between + 5V and + 10V.

Strain gauges were used in Figure 9 to determine the strain, which has a factor of 2.09± 1%. This strain gauge

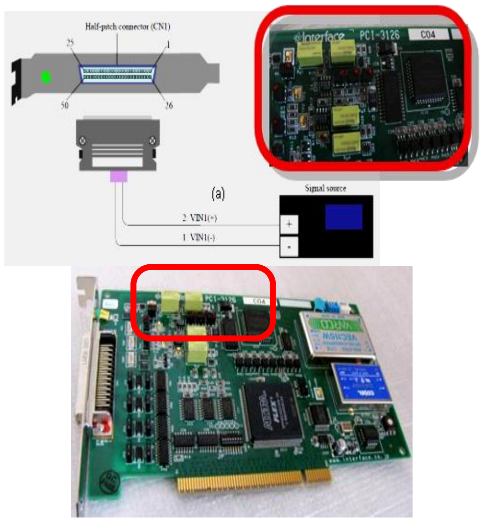


Figure 7. (a) Installation of cables using the two wires connection method; (b) PCI-3126 card that is installed in the computer slot and its inzet

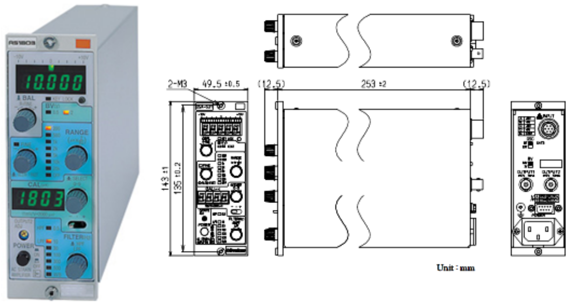


Figure 8. Strain amplifier AS-1803 connected to the PCI-3126 using the GPF-3100 driver software

is designed specifically for plastic materials and operates between 20˚C-80˚ C. It has a gauge length of 3 mm and a resistance of 120±0.3Ω. The strain gauge composite is a Cu-Ni alloy with a strain limit of 3%.

The hydraulic jack was positioned on the upper GLARC column with respect to the compression test specimen. The static load is then applied gradually before ultimate failure occurs (quasi-static). Figure 10 illustrates the configuration of the GLARC column specimen in the loading frame.

4. RESULTS AND DISCUSSION

The compressive axial load test results for CWG or glassless column specimens shown in Figure 11 reflect the initial loads before buckling, as well as the strain gauge location in the center of the glassless column length.

Figure 9. Strain gauge with a resistance of 120 ± 0.3 Ω

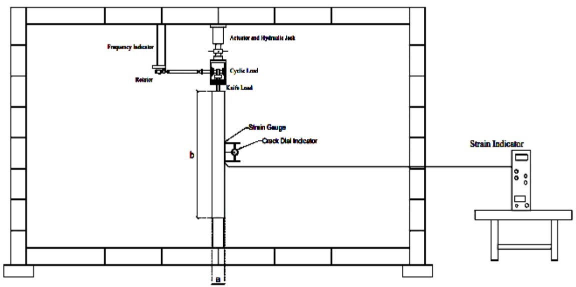


Figure 10. Setup of compressive test on GLARC column

Figure 11. (a) CWG as column without glass due to axial load before buckling occurs (b) position of the glassless column strain gauge

Owing to the large load on the support, the damage was localized. The failure area could not be exactly in the center of the column due to some imperfection in the column during testing.

As shown in Figure 12 a), a local failure occurred at the column support location. As illustrated in Figure 12 b), the location of failure in a CWG or unreinforced glass concrete column seems not on the strain gauge position. The axial test with a GLARC column of RPG or a column of random glass specimen is seen in Figure 12b. The results indicate that buckling is the most common type of failure in concrete columns, followed by tensile and progressive compressive failure such depicted in Figures 13 and 14. RPG specimens tends more ductile than CWG specimens.

The results obtained by the GLARC column with the strengthening of broken glass, RGP (random glass pieces) showed better results, it does not behave brittle but contrary it is more ductile as indicated by the lateral deflection that is larger than the CWG specimen (column without glass), at load 52 kN is 1.15 mm, 4.62 mm, 1.24 mm, 10.40 mm, and 1.2 mm for CWG, RGP-1, RGP-2, RGP-3, and RGP-4, respectively. Additionally, the majority of RGP specimens with corresponding above deflection showed higher peak loads than CWG 59 kN, 79 kN, 102 kN, 52 kN, and 72 kN, respectively.

Figure 12. (a) local collapse on the RPG column support (b) upper RPG column spalling at peak load

The results of axial test for CWG-1 (column without glass) and UHP-1 to UHP-4 (uniformly homogeneous piece) specimens can be seen in Figures 15 and 16, respectively.

Figure 13. RPG column: (a) Buckling failure (b) tensile cracks (c) Progressive compression failure

Figure 14. (a) Loading begin at UHP column before buckling (b) Behaviour of specimen collapse (c) joint support (d) local compressive failure

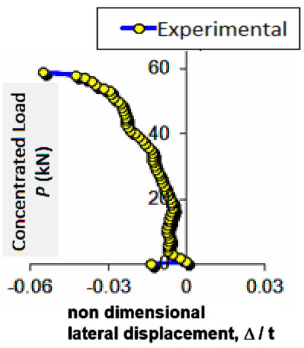
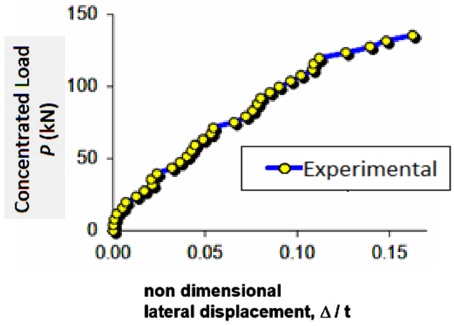
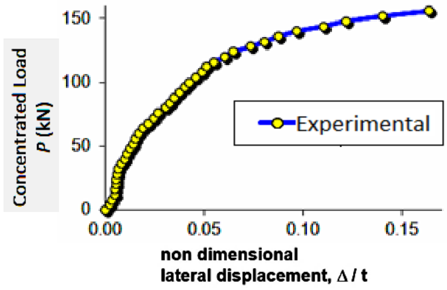


Figure 15. Lateral deflection – axial load relationship of CWG column

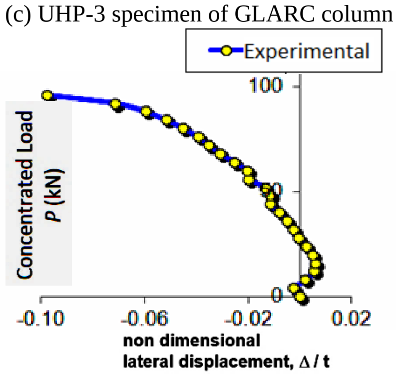
(a) UHP-1 specimen of GLARC column



(b) UHP-2 specimen of GLARC column



(c) UHP-3 specimen of GLARC column



(d) UHP-4 specimen of GLARC column

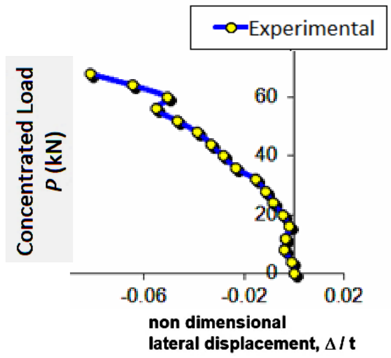


Figure 16. Lateral deflection – axial load relationship of UHP-1 to UHP-4 column specimens

The results of buckling lateral deflection for CWG specimen (column without glass), UHP (uniform glass column) at 56 kN load were 0.92 mm, 2.23 mm, 0.82 mm, 0.88 mm, 2.37 mm and 2.15 mm, for CWG, UHP- 1, UHP-2, UHP-3, UHP-4, and UHP-5, respectively.

The results of the lateral deflection are slightly larger, indicating that the UHP column is more ductile as well as all the compressive capacity is better than the CWG which has a peak load of only 59 kN while the peak load values are 136 kN, 156 kN, 96 kN, 68 kN and 80 kN for UHP-1, UHP- 2, UHP-3, UHP-4, and UHP-5, respectively.

This is probably due to the increased stiffness of the GLARC concrete column due to the glass-concrete composite action. When compared to RGP, UHP is also stiffer hence has less deformation and importantly has higher compressive axial capacity than RGP.

CWG specimens are more brittle than UHP-3 specimens, and the non-dimensional lateral deflection, Δ /t, for CWG column specimens at a load of 56 kN is greater than those UHP-3 column specimens, which are 0.0365 and 0.02 mm, respectively. In addition, the UHP-3 column specimen has a higher peak load of 96 kN than the of CWG's peak load, which is 59 kN.

The GLARC column lateral deflection results of uniformly homogeneous piece UHP-5 and random glass pieces of the RGP-1 specimen can be seen in Figures 17 and 18, respectively.

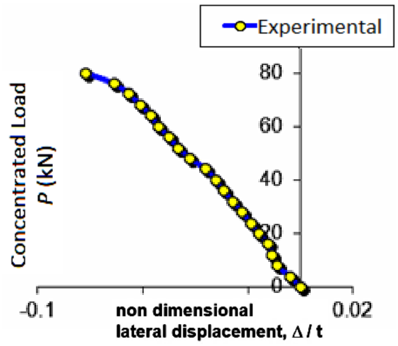


Figure 17. Lateral deflection – axial load relationship of specimen UHP-5 GLARC column

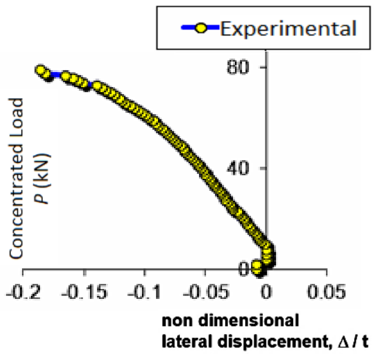
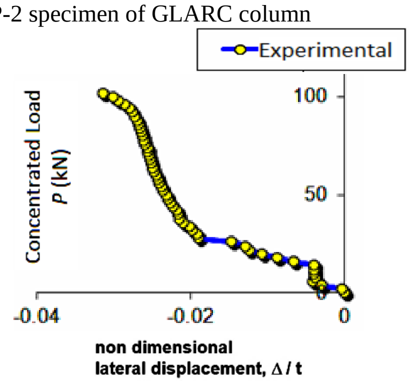


Figure 18. Lateral deflection – axial load relationship of specimen RGP-1 of GLARC column

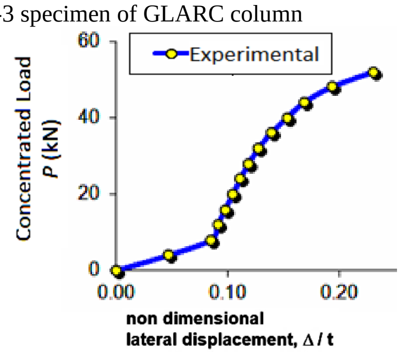
The results of GLARC column specimens with uniform glass reinforcement results in more ductile behavior, even the Δ/t value could be more than 0.15. The UHP-4 specimen showed slightly larger value than CWG-1 for both lateral deflection and load. The effect of uniform glass seems good for the compressive case, this is understandable because the compressive strength of glass specimens is larger than those of non-glass reinforced concrete.

While the results of random glass pieces GLARC column RGP-2, RGP-3 and RGP-4 specimens are depicted in Figure 19.

(a) RGP-2 specimen of GLARC column



(b) RGP-3 specimen of GLARC column



(c) RGP-4 specimen of GLARC column

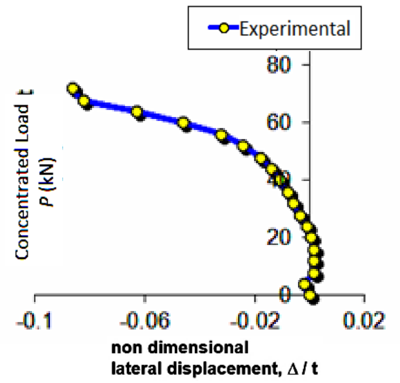


Figure 19. Lateral deflection and axial load on random GLARC column (a) RGP-1; (b) RGP-2 (c) RGP-3; (d) RGP-4

The random glass piece GLARC column specimens showed relatively random results due to the inhomogeneous dispersion even at the same glass amount and the distribution of the direction of the pieces is also very random, that is, the effect of slip on the glass surface is greater, but on the other hand, the sharp edges of the glass give an enough bite, which is more monolithic to ensure a composite action with concrete. These reasons can give an irregular slope of the curve to the column lateral deflection results.

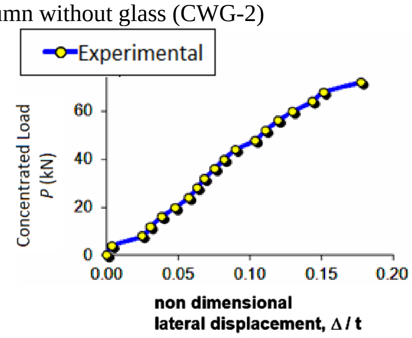
The results of axial compression test for glassless column specimens (CWG-2) and HSL-1 horizontal strip glass GLARC column can be figured out in Figure 20.

The results of the lateral deflection of the HSL-1 column specimens were about three times better in ductility than the CWG-2 specimens, namely 0.06 and 0.018, respectively, meaning that the glassless CWG-2 specimen could deform further than the HSL-1 specimen. But contrary with that, the peak load that the HSL-1 specimen was able to withstand was almost twice as good as that of the CWG-2 specimen, which as 128 kN and 72 kN, respectively.

The results of the GLARC column with horizontal strip glass reinforcement for specimens of HSL-2, HSL-3, HSL-4 and HSL-5 can be seen in Figure 21.

It can be seen in Figure 21 that the GLARC column specimens with horizontal strip glass (HSL) reinforcement shows the best results, with a very significant increase in stiffness as well as excellent ductility.

(a) Column without glass (CWG-2)



(b) Horizontal strip glass column (HSL-1)

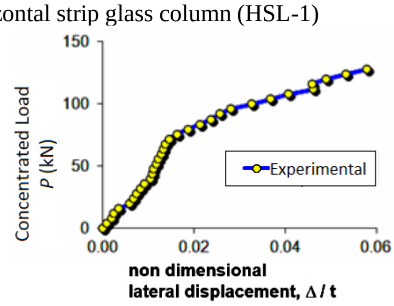
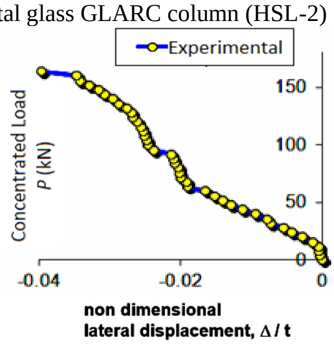


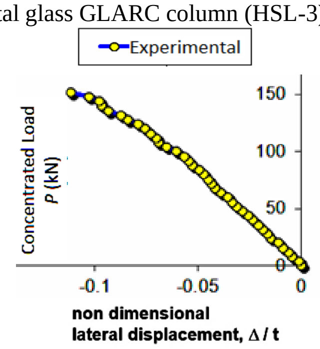
Figure 20. Lateral deflection and axial load on the column (a) CWG-2 column; (b) Column HSL-1

These excellent horizontal strip glass HSL specimens arise due to the higher inertia moment of the horizontal strip glass stiffened the weak axis (thin column geometry in lateral direction). These are not occur in other glass arrangements.

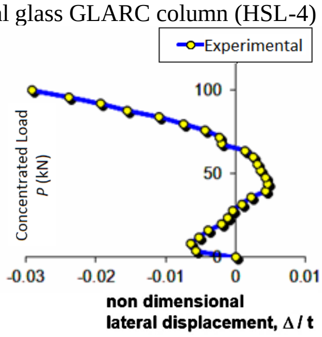
(a) Horizontal glass GLARC column (HSL-2)



(b) Horizontal glass GLARC column (HSL-3)



(c) Horizontal glass GLARC column (HSL-4)



(d) Horizontal glass GLARC column (HSL-5)

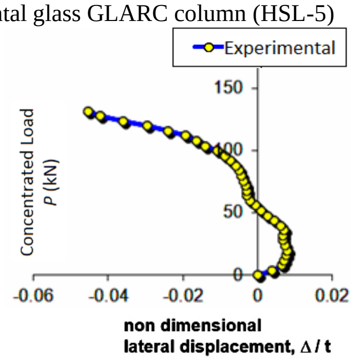
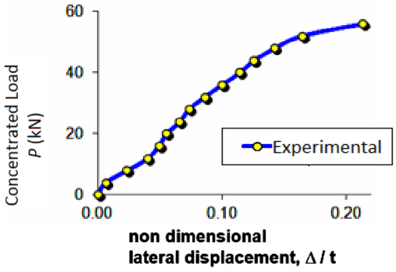
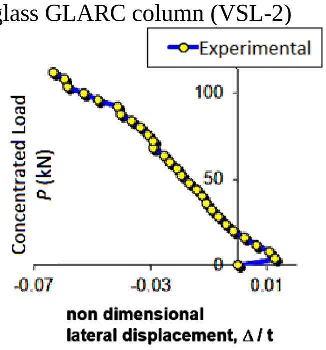


Figure 21. Lateral deflection and axial load on GLARC column with horizontal strip glass (a) HSL-2; (b) HSL-3 (c) HSL-4; (d) HSL-5

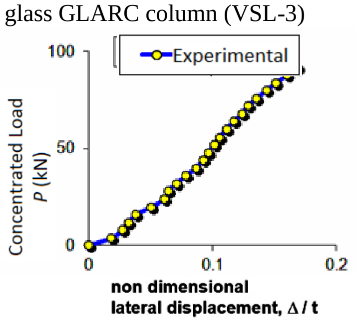
(a) Vertical glass GLARC column (VSL-1)



(b) Vertical glass GLARC column (VSL-2)



(c) Vertical glass GLARC column (VSL-3)



(d) Vertical glass GLARC column (VSL-4)

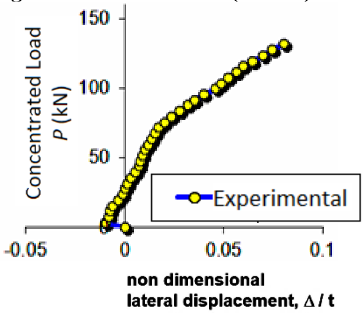


Figure 22. Lateral deflection and axial load on GLARC column with vertical striped glass (a) VSL-1; (b) VSL-2 (c) VSL-3; (d) VSL-4

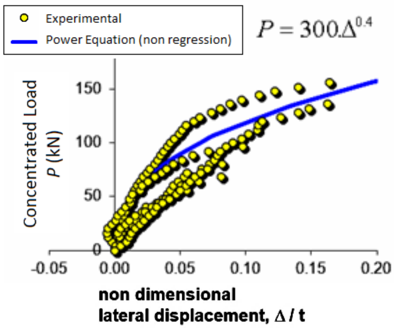
Above in Figure 22 can be seen the results of the GLARC column with the vertical strip glass reinforcement of the VSL-1, VSL-2, VSL-3 and VSL-4 specimens.

With the exception of VSL-1 which has a peak load of only 60 kN, in general the results of GLARC column specimens with vertical glass strip reinforcement from VSL-2 to VSL4 show good results, with high peak loads, some even more than 100 kN. All VSL specimens had good ductility, even the non-dimensional lateral deflection of VSL-1 specimens was more than 0.2. Figure 23 depicts the lateral deflection versus axial load results among the glass piece arrangement HSL, VSL and UHP specimens.

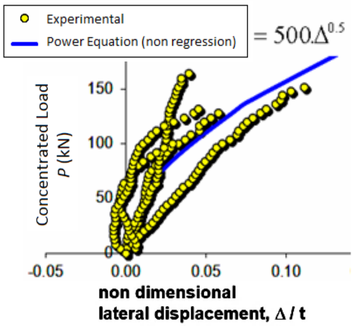
As for all CWG column specimens and GLARC column specimens, namely RGP specimens can be seen in Figure 24.

In general, the results of GLARC column RGP specimens with random glass reinforcement show higher peak load results than those in CWG specimens, some even more than 100 kN, at almost the same lateral deflection as 0.2. In other words RGP tends to show more ductile behavior than CWG.

(a) Uniform homogen GLARC column (UHP)



(b) Horizontal strip GLARC column (HSL)



(c) Vertical strip glass GLARC column (VSL)

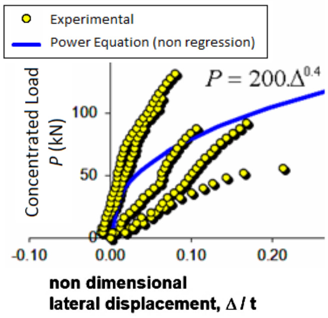


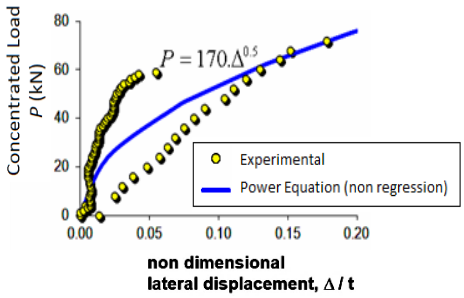
Figure 23. Lateral deflection and axial load on GLARC column of (a) UHP (b) HSL; (c) VSL specimens

Overall, both in detail can be presented in Figure 24 and in the results resumed in Figure 25, GLARC column specimens with any glass reinforcement show better results than CWG or glassless specimens.

It can be seen in Figure 25 that the best results for peak load were obtained specimens of HSL, UHP, VSL, RGP, and CWG respectively from the largest to lowest order. Then for the non-dimensional lateral deflection or ductility, namely Δ/t from the largest value is VSL, RGP, CWG, UHP and HSL respectively.

However, the bending capacity due to axial compressive forces is more important than ductility in the column due to their buckling resistance. They are not like a beams or girders where the ductility is important for their safety because in serviceability of girder structural deflection seems to be more considered.

(a) Column without glass (CWG)



(b) Random glass GLARC column (RGP)

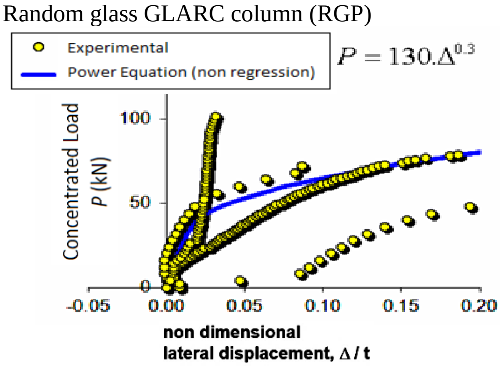


Figure 24. Lateral deflection and axial load on the column (a) CWG; (b) RGP

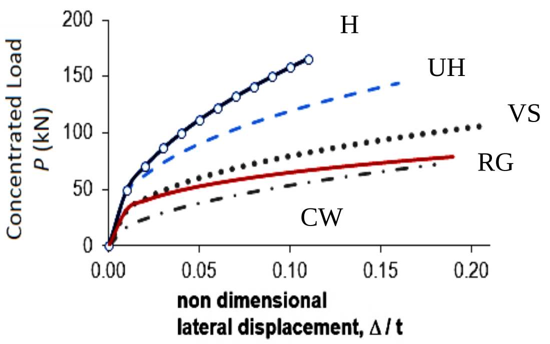


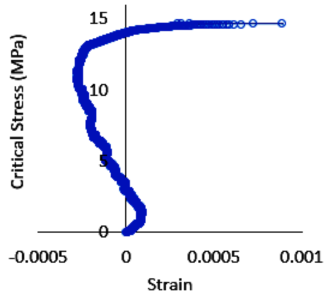
Figure 25. Lateral deflection and axial load in all specimens of glassless columns and GLARC columns in various arrangement of glass reinforcement

While buckling failure in the columns seem more abrupt, especially in slim or thin slender columns [13, 14]; therefore, their resistance to buckling is more crucial to be take into account. Hence, both the highest compressive load capacity and the smallest lateral deflection is the best consideration for columns, while – surely in all research conducted under flexural loads –the highest bending capacity and the largest ductility are the best consideration for the beams or girders.

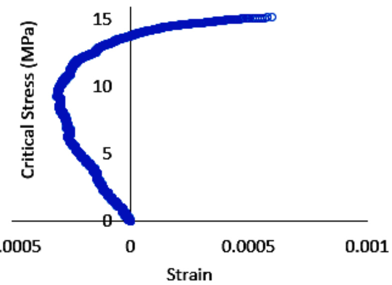
While the stress and strain relationship results can be seen for UHP-1 to UHP-4 (uniformly homogeneous piece) and CWG (column without glass) specimens can be seen in Figures 26 and 27, respectively.

As UHP specimen depicted in Figure 26, almost of them reach high enough critical stress due to capability to experience snap-buckling, hence their rigidity avoid them to reach both displacement and strains. They behave snap buckling rather than enlarge the strain. They

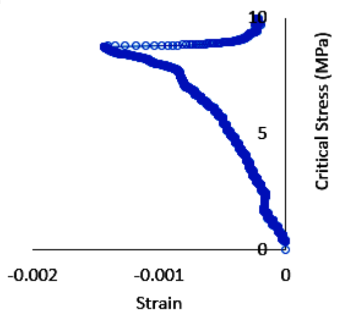
(a) UHP-1 specimen of GLARC column



(b) UHP-2 specimen of GLARC column



(c) UHP-3 specimen of GLARC column



(d) UHP-4 specimen of GLARC column

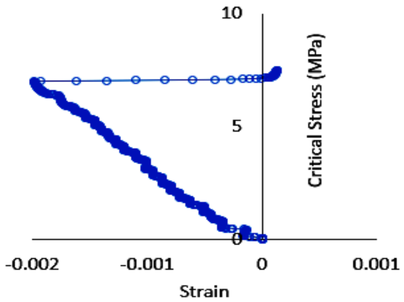


Figure 26. Strain versus critical buckling stress relationship of UHP-1 to UHP-4 column specimens

have quite small strain below 0.002 even some less than 0.001. It can be stated that UHP specimens have certain capability to restore to their original positions.

As seen in CWG (column without glass) as control column buckling test, CWG-1 tends to buckle at the strain of 0.002 before reach concrete failure strain which is around 0.003.

The GLARC column strain versus stress results of random glass pieces of the RGP-1 to RPG-2 specimen can be seen in Figure 28.

While the strain-stress results of random glass pieces GLARC column RPG-3 to RGP-4 specimens can be depicted in Figure 29.

As RGP specimen depicted in Figures 28 and 29, almost of them reach low critical stress below 10 MPa, except RGP-2 little bit larger which is more than 10 MPa. The have no capability to perform snap-buckling. Half of them enlarge the strain approach 0.003 although half result less than 0.0015. It can be stated that RGP specimens have lowest stiffness and tend to get much higher in both of their deflections and strains.

The stress versus strain results for HSL-1 horizontal strip glass GLARC column can be found in Figure 30 and the other HSL in Figure 31.

As seen in HSL-1, it tends very hard to buckle as it have very low strain less than 0.00025 very far from0.003 concrete failure strain. This phenomenon show very high rigidity due to the glass strip direction that strengthen the weak axis.

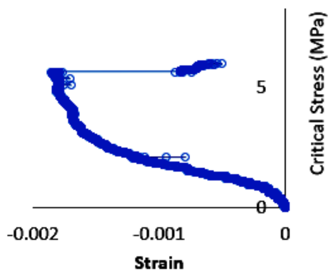
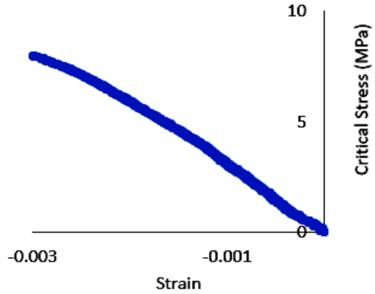


Figure 27. Strain versus critical buckling stress relationship of CWG-1 column

(a) RGP-1 specimen of GLARC column



(b) RGP-2 specimen of GLARC column

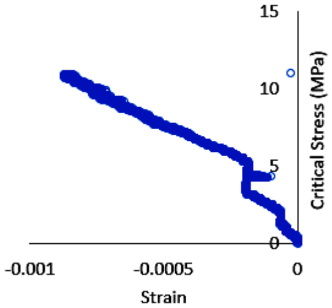
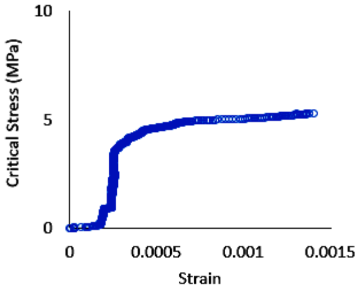


Figure 28. Strain versus critical buckling stress of specimen RGP-1 and RGP-2 of GLARC column

(a) RGP-3 specimen of GLARC column



(b) RGP-4 specimen of GLARC column

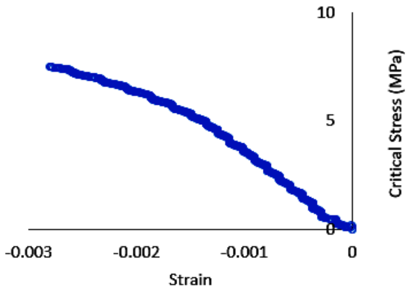


Figure 29. Strain versus critical buckling stress of specimen RGP-3 and RGP-4 of GLARC column

Below in Figure 32 can be seen the strain-stress relationship results of the GLARC column with the vertical strip glass reinforcement of the VSL-1, VSL-2, VSL-3 and VSL-4 specimens.

It can be seen in Figure 33 that the lowest stress are in specimen CWG, the second lowest were RPG due to its random arrangements. The VSL specimens were in medium and moderate results among all.

(a) Horizontal strip glass column (HSL-1)

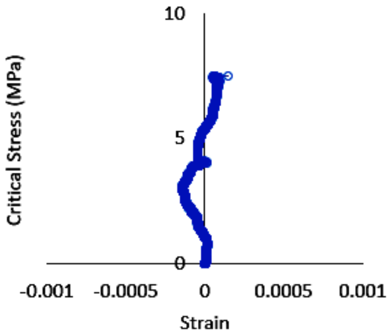
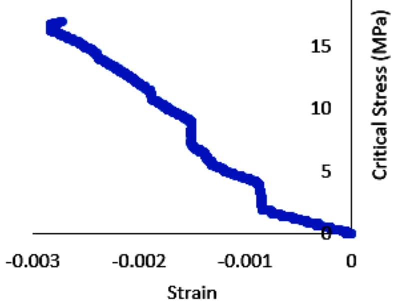
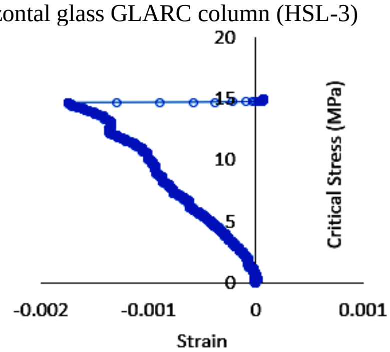


Figure 30. Strain versus critical buckling stress relationship in (a) Column HSL-1

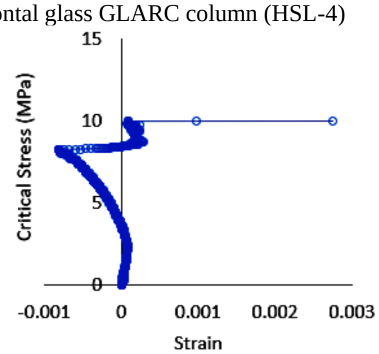
(a) Horizontal glass GLARC column (HSL-2)



(b) Horizontal glass GLARC column (HSL-3)



(c) Horizontal glass GLARC column (HSL-4)



(d) Horizontal glass GLARC column (HSL-5)

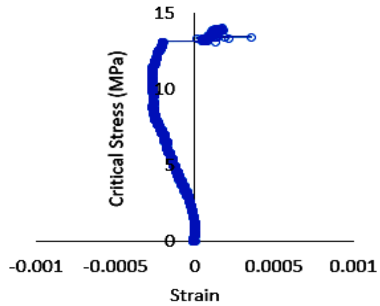
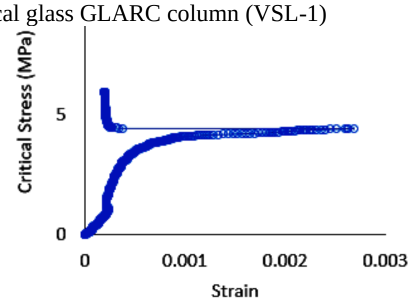


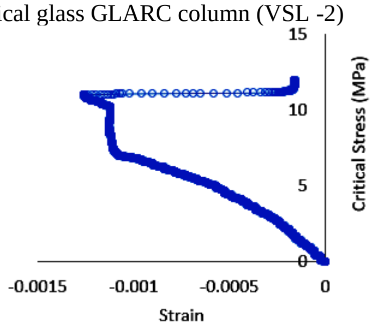
Figure 31. Strain versus critical buckling stress on GLARC column with horizontal strip glass (a) HSL-2; (b) HSL-3 (c) HSL-4; (d) HSL-5

The UHP specimens were read not in consistent stress, but also quite high critical stress due to their capability to snap-buckling and their lowest strain show their excellent rigidity. Finally, the best results for peak critical stress were obtained by HSL specimens from the lowest to largest order.

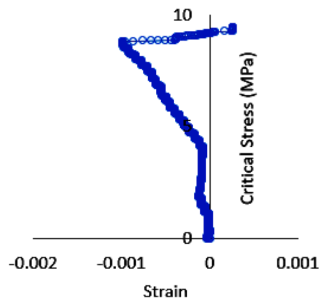
(a) Vertical glass GLARC column (VSL-1)



(b) Vertical glass GLARC column (VSL -2)



(c) Vertical glass GLARC column (VSL -3)



(d) Vertical glass GLARC column (VSL -4)

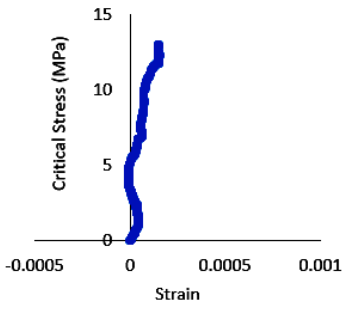


Figure 32. Strain versus critical buckling stress relationships on GLARC column with vertical striped glass (a) VSL-1; (b) VSL-2 (c) VSL-3; (d) VSL-4

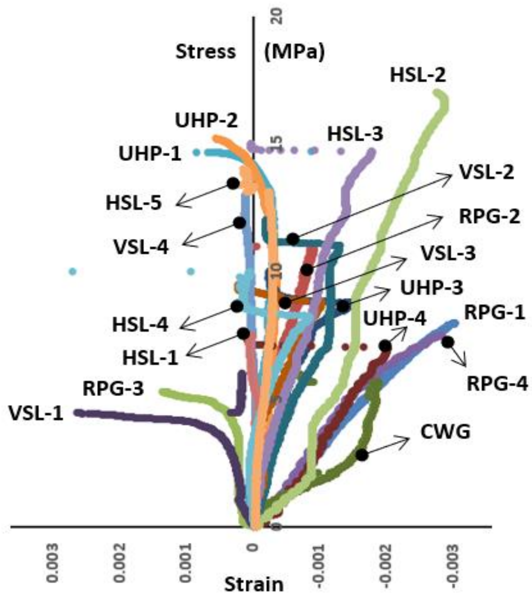


Figure 33. Strain versus critical buckling stress relationships in all specimens of GLARC columns in various arrangement of glass reinforcement

4. CONCLUSION

This discussion demonstrates the influence of the glass waste addition on axial behaviour of reinforced concrete columns. As a result, the following outcomes are obtained:

1. The results describe that compressive test of GLARC (glass reinforced concrete) columns from recycled glass waste, showed good results both in terms of their strength and stiffness over the CWG, glassless one, especially HSL arrangement.
2. Glass waste can be used as an alternative to strengthening reinforced concrete structures, especially precast beams and columns hence that it can overcome glass waste and eventually solved environmental problems. UHP arrangement of glass waste is quite good as a reinforcement material due to cheap and easily to installed and have the lowest strain as below 0.0005, hence to be the stiffest column of GLARC specimen.
3. HSL with a horizontal strip longitudinal arrangement achieved highest peak axial compressive load around 100-150 kN and axial stresses 10-15 MPa under relatively low strain as 0.0005-0.001. This HSL arrangement is the best configuration glass reinforced due to cheap, easy and have the largest compressive capacity and the second most stiffer among others.
4. With roughly neglected parameter such thickness, glass arrangement, glass amount, slenderness ratio and imperfection behaviour the P_{cr} of GLARC column in this dimension is said to be around 60 kN – 150 kN, and considering snap through buckling this P_{cr} value is tend to be lower as 40-60 kN.

The following can be noted to enhanced and give a deeper understanding regarding GLARC columns:

1. The use of glass in GLARC columns have not been done according to certain regulations or valid protocol and codes. This is due to the lack of reinforced concrete design code containing glass waste utilization. These recommendations should be underlined for non-structural column applications for the sake of waste management term.
2. The calculation of critical buckling load and allowable load of GLARC columns have not been conveyed expressly yet because it contain many parameter that should be examined further by another research such as thickness, weight of glass waste, the glass arrangement angle, etc.
3. The structures with stands bending momentum have already investigated but surely concrete and glass alone can not withstand tensile stresses independently cause all specimens containing steel rebar in a small amount and hence, glass, can not replace steel in concrete but indeed they have large contribution under axial compressive loading.
4. The glass amount is set to be constant, because this research focuses on the arrangement on the same amount. Further research is needed to explore how much an optimal glass amount for reinforcement.

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Persian Abstract

چکیده

نکته مهم در بارگذاری محوری ستون های باریک ثبات کمانش است. با این حال ، تحقیقات بسیار محدودی موجود است به ویژه با استفاده از بتن تقویت شده با شیشه. مشکل خرابی واکنش سیلیس قلیایی (ASR)تنها زمانی رخ می دهد که ذرات بسیار ریز باشند. از استفاده شیشه به عنوان ذره اجتناب شد و بجای آن از ابعاد بزرگتری از ضایعات نوار شیشه ای استفاده شد زیرا سیمان نمی تواند به عمق قطعه شیشه نفوذ کند. مجموعه ای از آزمایشهای بارگذاری محوری ستونهای باریک شیشه ای (GLARC)بر روی انواع آرایش انجام شد. نوارهای شیشه ای ، قطعات همگن و تصادفی تقویت شده تا عملکرد کمانش آنها را بررسی کند. همه نتایج ستونهای محوری GLARC بهتر از تقویت ستونهای بدون شیشه بود. بهترین تقویت ، چیدمان نوار افقی طولی بود ، زیرا آنها دارای استحکام ثابتی هستند ، بنابراین به ستون های GLARC اجازه می دهد تا در برابر بارهای محوری بیشتر مقاومت کنند تا از خرابی کمانش جلوگیری شود. نتایج آزمایش ها عملکرد خوبی دارد و بنابراین ستون های GLARC شانس بالقوه ای برای استفاده گسترده به عنوان اعضای فشرده سازی ساختاری دارند.