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Experimental Study on Single Bay Reinforced Coconut Shell Concrete Portal Frame under Lateral and Cyclic Load

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ABSTRACT

As a natural stone aggregate, resources are reducing at a high rate due to the large concrete use. For the search of substitute material for natural aggregates, in recent years coconut shells are used in the concrete field. Reinforced cement concrete (RCC) portal frames are a very common structural element and used for resisting lateral loads. In this research single bay, RCC portal frames made with coconut shell concrete (CSC) are tested under lateral load and cyclic push-pull load. The results are compared with frames made with conventional concrete (CC). Four prototype bare frames cast in that two frames made with CSC and two with CC. Behavior and characteristics like load capacity, deflection, crack formation, concrete strain, stiffness, and ductility are studied. It was found that under cyclic push-pull load CSC frames are comparable with CC frames rather than under lateral load. The amount of deflection and strains are observed in the CSC frame is comparatively more than in CC frames. Stiffness and ductility also observed more in CSC frames than CC frames.

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1. INTRODUCTION

In recent times lightweight concrete has a great impact on the concrete production field and has been used in reinforced concrete. By using lightweight concrete (LWC) cost can save up to 15-20 % of that of normal weight concrete. As a result of the growing population and industrialization, the use of concrete is increasing at a high rate. This caused a drastic reduction in natural stone recourses, as aggregate plays a significant role in concrete production. In this situation search for a substitute material for crushed stone aggregate (CSA) is significant. Many agriculture wastes and by-products are already in use as aggregate in the concrete field. Recently in LWC production lightweight aggregates (LWA) used are pumice, perlite, expanded clay, coal slag, sintered fly ash, rice husk, straw, sawdust, cork granules, wheat husk, oil palm shell, and coconut shell (CS) [1-4]. With the help of these LWAs, LWC with the required strength can be produced [5]. Studies found that the basic properties of coconut shell concrete (CSC), mechanical properties of CSC, bond properties of CSC [2] and long term performance of CSC are coming in the similar range as required for the structural applications of LWC [3]. In previous researches behaviors of reinforced CSC beam under flexure, shear, and torsion had been already studied [6-8], hence this study investigated an experimental study of reinforced CSC portal frames under lateral and cyclic load, then compared with the conventional concrete (CC). Reinforced cement concrete (RCC) portal frames are a very commonly used structure in the construction field. RCC frames generally consist of two structural element beams and columns, in which beams are fixed to the columns, and columns are strongly made that they can give stability to the entire portal frame [9]. In the case of framed structures, lateral loads are having more effects than the gravity loadings like dead load and vertical imposed loadings [10].

It is found that in previous studies the use of many structural elements were analyzed using CSC but none of them have used CSC in portal frames. Therefore, the study on CSC used portal frame is found to be very

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limited. In that case study, the analyzing the characteristics of single bay reinforced portal frame by using CSC under lateral loads is the need of the hour. This research is focusing on the use of CS as a suitable replacement material to substitute the natural stone as coarse aggregate in the case of concrete portal frames. This includes the comparisons of behavioral characteristics such as deflection, strain characteristics, stiffness, and ductility of CSC frame with CC frame under lateral and cyclic loads. This analysis can provide significant insight into the performance of bare portal frame structure.

1. 1. Coconut Shell Aggregate

The making process of aggregate from CS, which is thrown as an environmental waste is already discussed and presented in earlier researches and studies [2-3]. Some of the important properties of CS aggregates have been found in previous studies. The CS having average moisture content and water absorption were 04.20% and 24.00%, respectively. The average specific gravity of CS found as 1.05-1.20 respectively, it is comparatively less than the normal aggregates. This justified that, if CS as aggregate is used in concrete it will fall in the LWC category. The average bulk densities of CS in loose and compacted conditions are 550 kg/m^3 and 650 kg/m^3, respectively. CS aggregates will produce concrete of less unit weight compared to normal weight aggregate concrete and that falls under the category of producing LWC [2-3].

1. 2. Coconut Shell Concrete

In the making of two types of concrete, ordinary Portland cement, river sand, water, and crushed granites are the ingredients for making CC. But for making CSC crushed granites are replaced by CS as coarse aggregates. The concrete grade is selected as M25 concrete, for both CC and CSC. CS are collected and crushed by the crushing machine available on the University premises. Figure 1 showing the process pictures of CSC from the collection of CS to cast specimen under curing. Trail mix proportions are collected from previous studies [6-8]. Table 1 showing the trail mixes and properties of the CC and CSC found in preliminary tests.

2. EXPERIMENTAL TEST

2. 1. Frame Size and Detailing

The overall portal frame size was decided with respect to the feasibility of accommodating the same into the loading from provision available to apply both static and push-pull load in the structural testing laboratory of the university premises.

Since the maximum size in height is 1650 mm and the provision to hold the base is 1500 mm and hence the maximum base width of 1400 mm and the column height of 1500 mm were fixed. The sectional detailing is provided based on the Indian Standard IS 456: 2000 [11] (i.e) it recommended for column minimum diameter of reinforcement bar should be 12 mm and the

(a) Collected

(b) CS crusher

(c) CS size segregation

(d) Crushed CS

(e) Material batching

(f) Materials loading

(g) CSC

(h) Specimen before casting

(i) Specimen after casting

Figure 1. Process pictures of CSC

TABLE 1. Trail mixes and cocnrete proterties

Description	Conventional concrete (CC)	Coconut shell concrete (CSC)
Mix ratio	1:2.22:3.66 (cement: sand: CSA)	1:1.47:0.65 (cement: sand: CS)
Water/Cement	0.55	0.42
Cement content	320 kg/m^3	510 kg/m^3
Slump	11 mm	7 mm
Compaction factor	0.89	0.93
28 days dry density	2496 kg/m^3	1982 kg/m^3
28 days compressive strength	27.85 N/mm^2	26.16 N/mm^2

CS minimum four number bars should be provided. In this aspect, it was adopted. Since most of the research studies on structural elements size, shape, and reinforcement detailing are fixed at first and tested for their capacity and behavior rather than designed for resisting particular applied load [12-15] which is normally adopted for field execution. Therefore, the size of the beam ((150 × 150 × 1000 mm), size of the column (150 × 150 × 1500 mm), and size of the base (200 × 300 × 1400 mm) is adopted for the prototype frames, in this study.

Totally four frames were cast in that two for CC and two for CSC. Four numbers of steel bars having a diameter of 12 mm are provided for the beam, column, and base of the frames. The schematic diagram of the cross-section and reinforcement detailing are showing in Figure 2 and Figure 3, respectively.

2. 2. Casting Process For casting process the plywood moulds and the reinforcement are made as per the size and detailing. Before placing the reinforcements a thin coat of crude oil was coated inside of the frames. All materials are collected and mixed. Concretes are placed into the moulds very carefully and compacted using a needle vibrator. Right after the casting frames are covered with plastic sheets. Only after 24 h moulds are removed from the frames and the curing process is started for the next 28 days**.**

2. 3. Loading Setup The testing of the frames was carried out in a self-straining loading frame of a capacity of 200 kN. Only after 28 days of curing the frames are placed and rigidly fixed to the frame base with clamps and bolt nuts for avoiding any kind of displacement during testing. The setup is showing in Figure 4, where a hydraulic jack of 200 kN is fixed in such a way it can give the loading to the beam-column joint of the frame. A linear variable displacement transducer (LVDT) was placed to the opposite beam-column connection for measuring deflection to the

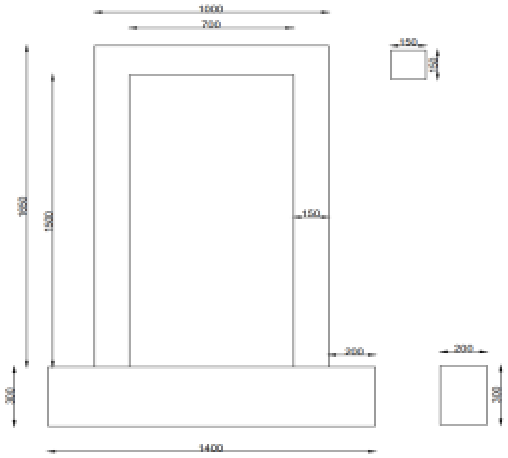

Figure 2. Cross section of frame

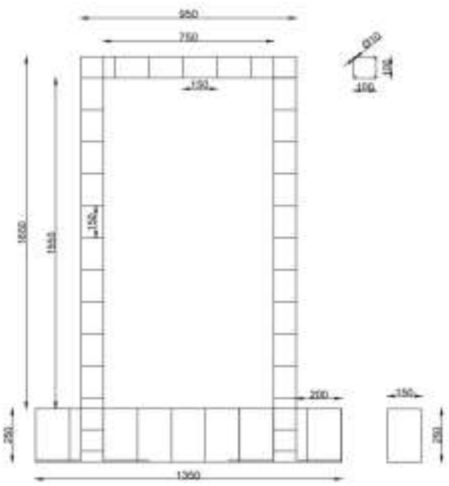

Figure 3. Reinforcement detailing of frame

(1) Hydraulic jack 200 kN capacity, (2) LVDT, (3) Deflection indicator, (4) Load indicator, (5) Multi-channel data logger, and (6) Strain gauges on the surface

Figure 4. Loading set-up

corresponding load. Strain gauges were pasted to the frame surface and connected to the multi-channel data logger for concrete strain readings.

2. 4. Loading Protocol In the case of lateral static loading, a load applied on the increment of 2 kN. But in the case of cyclic loading because of the application of load in both push and pull to minimize the number of cycles it was applied in 4 kN increment. That is, it was applied to one direction positive (push) 4 kN, then brought to neutral position and then applied to the opposite direction negative (pull) 4 kN for the first cycle. The same way was followed for cycle two for 8 kN and then 12 kN for cycle three and so on till the ultimate. This is how the loading protocol was followed for both lateral and cyclic load application in this study.

3. RESULTS AND DISCUSSIONS

3. 1. Ultimate Loads In lateral loading the ultimate failure load for the CC portal frame was found to be 62 kN and for the CSC frame, it was 40 kN. For cyclic push load the ultimate failure load for CC portal frame was found to be 40 kN and for the CSC frame, it was 38 kN. Similarly, for cyclic pull load, the ultimate failure load for the CC portal frame was found to be 40 kN and for the CSC frame, it was 38 kN.

The ultimate failure load in lateral loading is found less in CSC frame compared to CC frame. It's approximately 34% lesser in CSC than the CC portal frame. But in the case of cyclic push-pull loading, the ultimate loads are much more same in both CC and CSC frames. It's only 5% lesser in CSC compared to the CC portal frame. It shows that CSC frames are having similar strength as CC frames under cyclic loads rather than lateral loading.

3. 2. Load vs Deletion Behavior The load-deflection patterns are much more similar in both CC and CSC portal frames. In both cases, CC and CSC portal frames, the pattern of load-deflection the curve is similar parabolic type. But it was found that the CSC portal frames are showing more deflection than CC portal frames for a similar amount of aping load. This is happening because of the porous nature, low density of CS that results in lower elastic modulus of CSC as found in previous works CSC [10].

In both CC and CSC the deflection curve is initially linear than it's followed by a parabolic curve. During lateral loading, there is no deflection up to 10 kN for both CC and CSC. But in the case of cyclic loading deflection was started from the initial load of 4 kN. But in both loading cases deflection was found more in the CSC frame compared to the CC portal frame on a similar amount of load. Figures 5, 6 and 7 are showing the load versus deflection curve for both CC and CSC frames of experimental investigations. Figures 8 and 9 are showing hysteristic curve of cylic loads of CC and CSC frames, respectively.

In case of lateral load CC frame has ultimate load capacity of 60 kN with 18.9 mm defection and CSC frame has ultimate load capacity of 40 kN with 50.1 mm defection. Under lateral load CC performance was better than CSC frame. For cyclic push load CC and CSC frame has ultimate load capacity of 40 kN and 38 kN and maximum deflection 53.72 mm and 52.59 mm, respectively. For cyclic push load CC and CSC frame

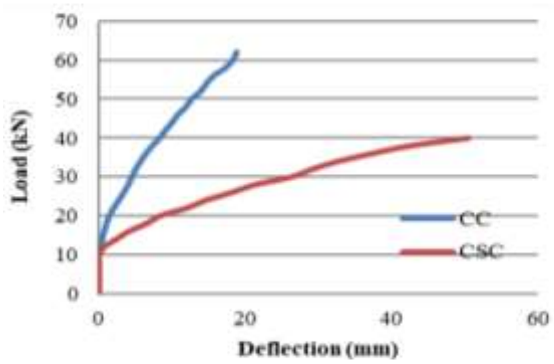

Figure 5. Load-deflection curve under a lateral load

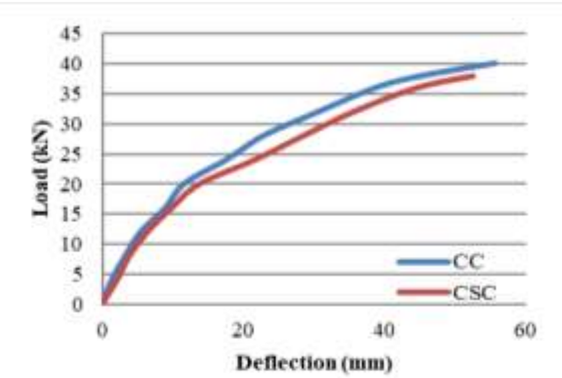

Figure 6. Load-deflection curve under a cyclic push load

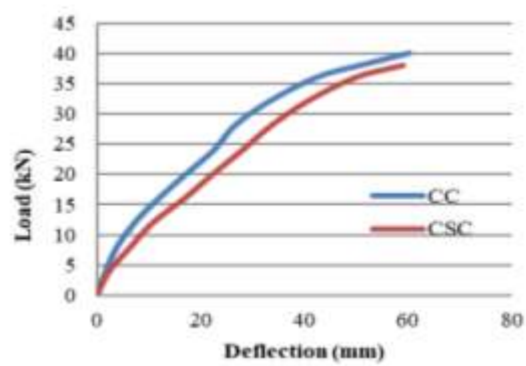

Figure 7. Load-deflection curve under a cyclic pull load

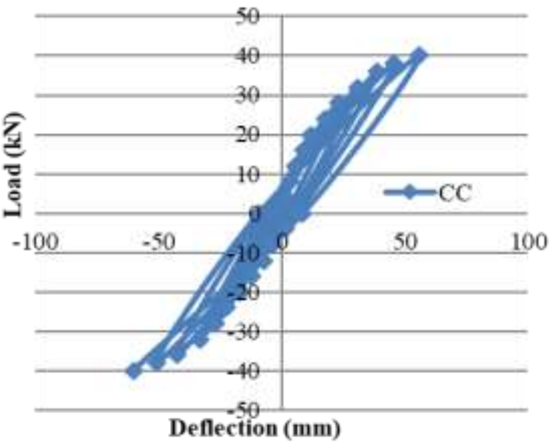

Figure 8. Hysteretic curves of cyclic load (CC)

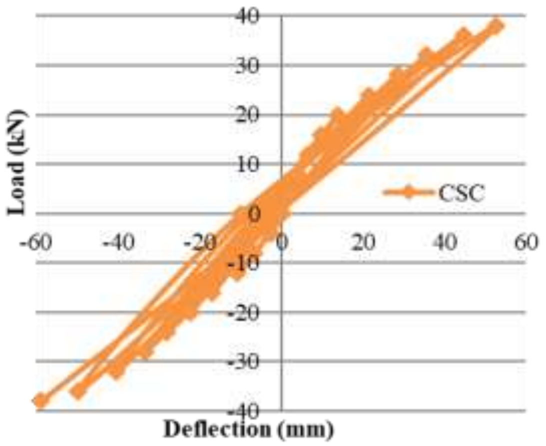

Figure 9. Hysteretic curves of cyclic load (CSC)

has ultimate load capacity of 40 kN and 38 kN and maximum deflection 60.18 mm and 50.72 mm, respectively. Cyclic loading ultimate load for CSC is 5% lesser compared to CC portal frame. It shows that CSC frames are having similar behviour like CC frames under cyclic loads. But in both loading cases deflection was found more in CSC frame compared to the CC portal frame at the same amount of load. CSC frames are showing more deflection than CC frames and hence more ductility. There are some advantages and disadvantages of the coconut shell concrete mix compared to the traditional concrete mix. The advantage is coconut shell concrete density is less compared to conventional concrete density because of less coconut shell density (550-650 kg/m^3) compared to the conventional stone aggregate density (1600-1800 kg/m^3). Also, due to the fibrous nature of coconut shell aggregate compared to conventional stone aggregate, naturally, the ductility of coconut shell concrete is more compared to conventional concrete and it is more advantageous especially in the case of seismic resistance. A disadvantage of using coconut shells in urban areas is transportation cost. Therefore, it is most advantageous the coconut shell is used in rural areas where it is dumped as waste.

3. 3. Cracking Patterns Cracks are formed in frames after certain application loads. Loads are noted when the corresponding cracks occur and marking was done during the start to the end of the test. The cracks usually form on the beam-column joint and column base junctions. Initial cracks are formed in the column joints than mostly cracks occur in the upper and lower portion of the columns of the frame. In the case of the lateral load, an initial crack occurs in CC portal frame at the load of 16 kN which is 26% of its ultimate failure load. In the CSC portal frame initial crack occurs at the load of 14 kN which is 35% of its ultimate failure load. Figure 10 shows of cracks occurred in the CC frame on both side of the columns and beam at the load of 14, 18, 24, 26, 28, 34, 38, 42, 48, 54, 60, and 62 kN, and cracks occur in the CSC frame on both sides of the columns and beam at the load of 10,16,22,26,28,34,38, and 40 kN. Similarly, like the CC frame, the ultimate cracks have occurred in the beam-column connection.

Most of the cracks are formed in the horizontal and vertical directions both in CC and CSC frames in column and beam components, respectively. This shows that the bonding between the reinforcement and the coconut shell concrete is also similar to that of conventional concrete. Because if there is no bonding exist between the reinforcement and the concrete then along the length of the reinforcement crack will form. In this study, column reinforcement is normally placed vertical and beam reinforcement is placed horizontally which shows that the good compatibility exists between CSC and reinforcements is essential for any kind of structural element.

In the case of the cyclic push-pull load, an initial crack occurs in the CC portal frame at the pull load of 12 kN which is 30% of its ultimate failure load. Similarly for the CSC portal frame, the initial crack occurs at the load of 10 kN which is 26% of its ultimate failure load. Figure 11 shows of cracks are occurred in the CC frame on both side of the columns and beam at the load of 16 kN then 16 to 40 kN at the interval of 4 kN. Figure 12 shows of cracks occur in the CSC frame on both side of the columns and beam at the load of 12 kN and then 16 to 40 kN at the interval of 4 kN.

3. 4. Strains Strain values are measured for every increment of load. Figures 13, 14 and 15 are showing the tension and compression strain values for both CC and CSC frames for each load type. Concrete surface strains for CSC frames are found more than CC frames.

Figure 10. Cracks in CC and CSC frames after lateral load

Figure 11. Cracks in CC frame after cyclic load

Figure 12. Cracks in CSC frame after cyclic load

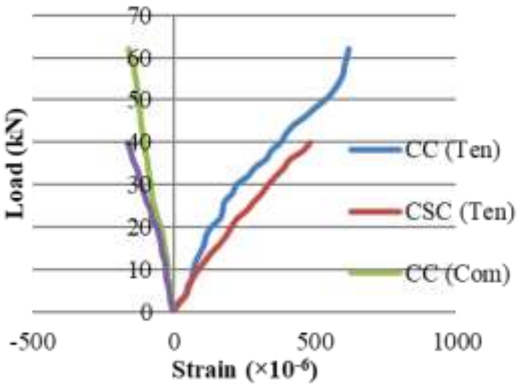

Figure 13. Load - strain curve under lateral

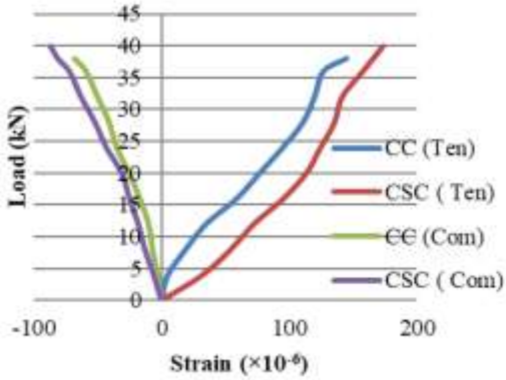

Figure 14. Load - strain curve under cyclic push load

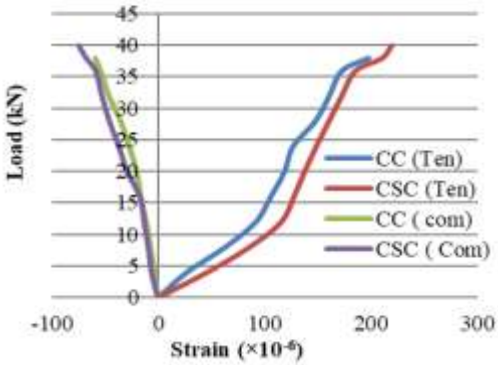

Figure 15. Load - strain curve under cyclic pull load

It is because of the replacement of coarse aggregate as coconut shell, and coconut shells having less strength and stiffness as compared to crushed granite. Granite aggregates are having more characteristics and properties then coconut shells And hence there is more deflection in CSC frame compared to CC frame. These obtained strain values are similar to the previous work done on CSC [11]. From this study we can say CSC is efficient to attain its strain capacity.

3. 5. Stiffness Stiffness for both CC and CSC frames are calculated and compared with each other. The stiffness characteristics of both bare frames at the beam-column joint level calculated as a ratio of the difference of yield point load, ultimate load and the difference of yield point deflection and ultimate load deflection [16]. Figure 16 showing the stiffness for both CC and CSC frames. The stiffness at the beam-column joint of the frame under lateral loading for CC and CSC are 2.6 kN/mm, 0.56 kN/mm, respectively. Stiffness under cyclic push load for CC and CSC are 0.51 kN/mm, 0.56 kN/mm, respectively. Similarly, stiffness under cyclic push load for CC and CSC is 0.49 kN/mm, 0.54 kN/mm, respectively. In the case of lateral load, CSC frames are showing less stiffness than CC frames. For cyclic push-pull load, CSC frames are showing more stiffness than CC frames.

3. 6. Ductility Factor Ductility factors of both portal frames are calculated as the ratio between displacement at ultimate load and displacement at yield load and compared as recommended in the literature [16]. The ductility factor at the beam-column joint of CC and CSC frames under lateral loading are 23.63 and 20.16, respectively. Ductility factors for CC and CSC frame under cyclic push-load are 6.03, 8.4, and under cyclic pull-load is 5.03, and 5.5, respectively. In the case of lateral load, CSC is a little less ductile than CSC frames. But it is found that under cyclic push-pull load CSC frames are a little bit more ductile compared to CC frames. In Figure 17 ductility factors for both CSC and CC frames are shown for both types of loading.

4. CONCLUSIONS

The ultimate failure load in lateral loading is found approximately 34% lesser in CSC than CC portal frame.

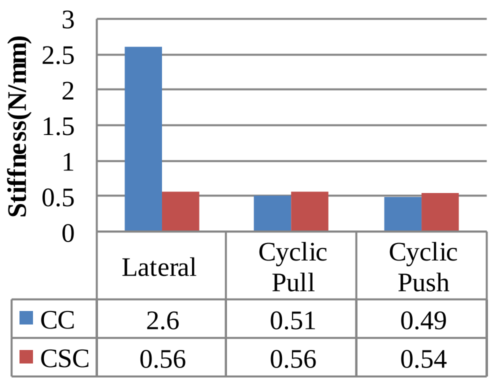

Figure 16. Stiffness in CC and CSC frames

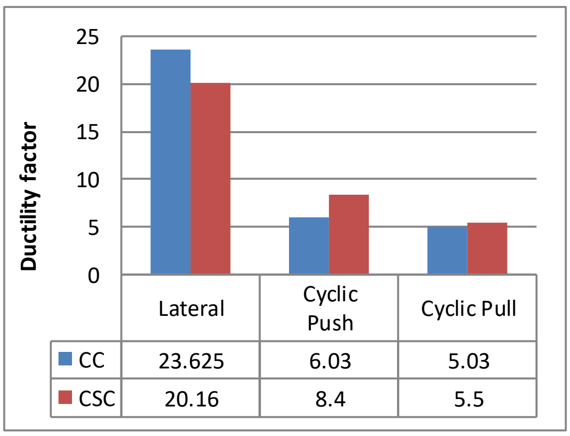

Figure 17. Ductility factor of in CC and CSC frames

Under lateral load, CC performance was better than CSC frame. Cyclic loading ultimate load for CSC is 5% lesser compared to the CC portal frame. It shows that CSC frames are having similar strength as CC frames under cyclic loads rather than lateral loading. But in both loading cases deflection was found more in the CSC frame compared to the CC portal frame on a similar amount of load. CSC frames are showing more deflection than CC frames. Concrete surface strains to the corresponding loads for CSC frames are found more than CC frames. It is because CS, and CS having less strength and stiffness as compared to CSA. Hence there is more deflection in the CSC frame compared to the CC frame. In the case of lateral load, CC frames are showing more stiffness than CSC frames. But for cyclic push-pull CSC frames are showing more stiffness than CC frames. In the case of lateral load, CSC is a little less ductile than CSC frames. But It is found that under cyclic push-pull load CSC frames are a little bit more ductile compared to CC frames. Overall it was observed that in the case of cyclic loads performance of CSC frames is preferable as a structural element and has a reliable comparison with CC frames.

CSC frames are showing more deflection than CC frames and hence more ductility. coconut shell concrete density is less compared to conventional concrete density because of less coconut shell density (550-650 kg/m^3) compared to the conventional stone aggregate density (1600-1800 kg/m^3). The use of coconut shells in urban areas would lead to higher transportation cost compared to conventional aggregate. Therefore, it is most advantageous the coconut shell is used in rural areas where it is dumped as waste. The crack pattern formed on CSC frames shows that the good compatibility of CSC exists with reinforcements like conventional concrete which is essential for any kind of structural element.

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Persian Abstract

چکیده

به عنوان یک سنگ دانه سنگ طبیعی ، منابع به دلیل استفاده زیاد از بتن ، با سرعت بالایی کاهش می یابند. برای جستجوی مواد جایگزین برای سنگدانه های طبیعی ، در سال های اخیر از پوسته های نارگیل در زمینه بتن استفاده می شود. قاب های پورتال بتن سیمان مسلح (RCC) یک عنصر ساختاری بسیار رایج است و برای مقاومت در برابر بارهای جانبی استفاده می شود. در این خلیج تحقیقاتی ، قابهای پورتال RCC ساخته شده با بتن پوسته نارگیل (CSC) تحت بار جانبی و فشار فشار کششی چرخشی آزمایش می شوند. نتایج با فریم های ساخته شده با بتن معمولی (CC) مقایسه می شود. چهار قاب اولیه لخت در دو قاب ساخته شده با CSC و دو قاب با CC ساخته شده است. رفتار و خصوصیاتی مانند ظرفیت بار ، انحراف ، تشکیل ترک ، کرنش بتن ، سختی و شکل پذیری مورد مطالعه قرار می گیرد. مشخص شد که در زیر فشار فشار کششی چرخه های CSCبا فریم های CC قابل مقایسه هستند تا زیر بار جانبی. میزان انحراف و فشارهای مشاهده شده در قاب CSC نسبتاً بیشتر از فریم های CC است. سختی و شکل پذیری نیز در فریم های CSC بیشتر از فریم های CC مشاهده شده است.