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RESEARCH ARTICLE / НАУЧНАЯ СТАТЬЯ

Analysis for the efficiency of additional dispersed reinforcement using coconut fiber for a concrete beam with traditional steel bar reinforcement

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Abstract. Concrete is widely used as a building material throughout the world. However, its use in building structures is limited due to its low tensile strength. This problem can be partially solved using steel bars reinforcement, as well as using dispersed reinforcement with various types of fibers. The authors propose the simultaneous traditional reinforcement of a concrete structure with steel bars with additional dispersed reinforcement with natural coconut fibers, relatively cheap and widely available in many countries in Africa, Asia and Latin America. The purpose of this study is to analyze the effectiveness of the proposed solution by comparing the required amount of steel reinforcement (by weight) for a beam made of traditional concrete and a similar beam with additional dispersed reinforcement with coconut fibers. Deflections and cracking in beams were investigated. The analysis was carried out using Autodesk Robot Structural Analysis Professional 2022 software. The results showed that a beam additionally reinforced with coconut fiber requires 11% less steel reinforcement (by weight) compared to a similar beam made of traditional reinforced concrete. In addition, the coconut fiber reinforced beam experienced 6% less deflection and significantly less stress cracking compared to a simple concrete beam. These results proved that the approach proposed in the work noticeably improves the performance of reinforced concrete in the structure, and also makes it possible to obtain significant savings in reinforcing steel.

Keywords: steel reinforcement, plain concrete, additional disperse reinforcement, coconut fiber concrete, concrete beam, comparative analysis

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Анализ эффективности дополнительного дисперсного армирования кокосовым волокном для бетонной балки с традиционным армированием стальными стержнями

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Аннотация. Бетон широко используется в качестве строительного материала во всем мире. Однако его применение в строительных конструкциях ограничено по причине его низкой прочности на растяжение. Эта проблема частично решается использованием стальной стержневой арматуры и применением дисперсного армирования различными типами волокон. В исследовании предлагается одновременное традиционное армирование бетонной конструкции стальными стержнями с дополнительным дисперсным армированием натуральными кокосовыми волокнами, относительно дешевыми и широкодоступными во многих странах Африки, Азии и Латинской Америки. Цель исследования – анализ эффективности предложенного решения путем сравнения необходимого количества стальной арматуры (по массе) для балки из традиционного бетона и аналогичной балки с дополнительным дисперсным армированием кокосовыми волокнами. Изучены прогибы и трещинообразование в балках. Применялось программное обеспечение Autodesk Robot Structural Analysis Professional 2022. Результаты показали, что балка, дополнительно армированная кокосовым волокном, требует меньшего на 11 % количества стальной арматуры (по массе) по сравнению с аналогичной балкой из традиционного железобетона. Кроме того, балка, армированная кокосовым волокном, испытывала на 6 % меньший прогиб, а также наблюдалось существенно меньшее образование трещин под действием нагрузки по сравнению с простой бетонной балкой. Доказано, что предложенный в работе подход заметно улучшает работу железобетона в конструкции, что в том числе позволяет получить существенную экономию арматурной стали.

Ключевые слова: стальная арматура, традиционный железобетон, дополнительное дисперсное армирование, бетон, добавка, кокосовые волокна, железобетонная балка, сравнительный анализ

Introduction

Concrete is one building material that is widely used in everyday life. Its strength is greatly influenced by the composition and quality of the ingredients mixing. But one of the main problems of this material is its low tensile strength: the value of concrete tensile strength has range from 9–15% of its compressive strength. In line with the development of today's concrete technology, various attempts were made to improve the unfavorable character of concrete. One of these methods is to add some type of fibers into the concrete mixture to enhance the tensile and compressive properties of concrete [1].

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The properties of concrete are influenced by many factors mainly due to mix proportion of cement, sand, aggregates and water. The various properties of the produced concrete hugely depend on the mix ratios of these main materials. We are going to discuss the main properties of traditional concrete.

Concrete is known by its grade which is designated as M15, M20, etc. in which letter "M" refers to concrete mix and number 15 or 20 denotes the specified compressive strength (f_{ck}) of 150 mm cube at 28 days, expressed in N/mm^2. Thus, concrete is known by its compressive strength. M20 and M25 are the most common grades of concrete, and higher grades of concrete should be used for severe, very severe and extreme environments [2].

The characteristic strength of concrete in flexural member is taken as 0.67 times the strength of concrete cube. The strength to be taken for the purpose of design is known is known as design strength and is given by design strength (f_d) = characteristic strength/partial safety factor for material strength. The value of partial safety factor depends upon the type of material and upon the type of limit state. According to IS code, partial safety factor is taken as 1.5 for concrete and 1.15 for steel. Design strength of concrete in member is equal to $0.45f_{ck}$ [3].

The tensile strength of concrete is one of the basic and important properties which greatly affect the extent and size of cracking in structures. Moreover, the concrete is very weak in tension due to its brittle nature. Hence, it is not expected to resist the direct tension. So, concrete develops cracks when tensile forces exceed its tensile strength. The brittleness of lightweight concrete has developed concern among structural engineers [4].

Therefore, it is necessary to determine the tensile strength of concrete to find out the load at which the concrete members may crack. The question of increasing the reliability and durability of reinforced concrete structures is a priority [5]. Furthermore, splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. The procedure is based on the ASTM C496 (Standard Test Method of Cylindrical Concrete Specimen) which is similar to the other codes like IS 5816 1999 [6].

Short term modular ratio is the modulus of elasticity of steel to the modulus of elasticity of concrete. Short term modular ratio = E_s / E_c, where E_s is the modulus of elasticity of steel ($2 \cdot 10^5$ N/mm^2), E_c is modulus of elasticity of concrete ($5000 \cdot \mathrm{SQRT}_{(fck)}$ N/mm^2). As the modulus of elasticity of concrete changes with time, age at loading, etc., the modular ratio also changes accordingly. Considering the effects of creep and shrinkage partially, IS code gives the following expression for the long-term modular ratio. Long term modular ratio (m) is equal to $280/(3f_{cbc})$, where f_{cbc} is the permissible compressive stress due to bending in concrete in N/mm^2 [3].

Different types of fibers can be used for additional disperse reinforcement of concrete, for example, basalt fibers [7]. But it is very promising to use for this purpose different types of organic fibers which are widely available in some regions. Natural fibers are a great solution because they are more sustainable and environmentally friendly. There is a wide range of natural fibers which can be utilized in concrete as reinforcement. In this research, the natural fiber that was considered was coconut fiber because it showed more consistent results during the literature review.

Coconut fiber reinforced concrete

Coconut fiber is extracted from the outer shell of a coconut. Its scientific name and the plant family of the coconut fiber is *Cocos nucifera* and *Arecaceae* (Palm) respectively, while it is commonly referred to as "Coir". The cultivation of coconut is concentrated in the tropical belts of Asia and East Africa. There are currently two types of coconut fibres: white fibres and brown fibres. The white fibres are extracted from immature coconuts, whereas the brown fibres are extracted from already matured coconuts. Coconut fibres have a very low conductivity and high toughness. Coconuts are widely available in many west African countries. The fibres from concrete have a young modulus of 4–6 GPa and a tensile strength of 131–175 MPa. The addition of fibers to the concrete mix can improve its mechanical properties including flexure, deformation, toughness, ductility, and cracks [8]. Natural fibers were used by researchers as alternatives to synthetic fibers in composites like concrete [9].

Several experimental studies have been done on coconut fiber reinforced concrete (CFRC). Compressive and flexural strength of coconut fibre reinforced concrete using destructive and non-destructive test methods was studied in [10]. Conventional compression tests and Schmidt Hammer Rebounds on cube specimens and two-point bending test on short beam specimens with different coconut fibre content were conducted. From the results and analysis of this research work it was concluded that the addition of a 0.5% coconut husk fibre as a constitutive material of concrete affected the rheological properties of the fresh concrete, increased the compressive and flexural strength of concrete by 35.8 and 22.15% respectively.

Also, mechanical properties of coir fiber reinforced concrete were studied in [11]. The authors tried to determine coir fibers' length and volume in the concrete composition affect the general physical and mechanical properties of the resulting concrete. As the basis, plain concrete (PC) with the mix ratio of 1:2:2 for cement, sand and aggregate respectively was used. The water to cement ratio was 0.48. For preparing CFRC (the mixture of the same composition with additives of coconut fibers) it was necessary to add a little more water to make the mix more workable as the coir fiber caused the concrete to be less workable and possibly the increase in the overall porosity of the concrete. It was found that with an increase in fibre content and length, the static modulus of elasticity of the various CFRCs reduced. For CFRC with fiber's length of 25 mm, the values of static modulus of elasticity were larger than that of PC. Compared with the PC, the coir fiber inclusion either increased or reduced the static modulus of elasticity depending on the fiber's content and length used.

From the laboratory experiments carried out, it was reported that cubes with volume fraction of 1% and fibre length of 5cm had an average compressive strength of 42 MPa in comparison to other fibre lengths and fraction volumes and plain concrete mixture of 35 MPa.

Design of fiber-reinforced composite of minimum material consumption at guaranteed reliability and durability requires consideration of cases when cracks may appear in the binder [12].

In [13] a behavioural study of coconut in a concrete structure was conducted. The experiment was made based on high strength concrete with the addition of fiber with 5 mix proportions (1, 2, 3, 4, and 5%) by the weight of cement. The compressive strength and split tensile strength of cured concrete evaluated for 3, 7, 28 days. The study revealed that the compressive strength of the cubes differed depending on the percentage of fibre content. Maximum compressive strength was discovered in the cube with the volume fraction of 1% with a value of 66.52 MPa. The compressive strength dropped upon adding more fibres to the concrete.

For the split tensile strength test, cylinders with varying volume fractions of coconut fibres were examined. It was also found that the maximum tensile strength of the samples was at the fibre volume fraction of 1% at the value of 4.54 MPa. Further increase in the fibre volume led to a decrease in the split tensile strength of the samples.

In [13] the following conclusion were made:

– coconut fiber being low in density reduces the weight of the fiber reinforced concrete;

– the compressive strength and split tensile strength of the concrete gets the maximum value at the mix of fibre fraction of 1%;

– since by addition of fibers in the concrete the strengths of the specimens get decreasing and it can be concluded that the fibre should not be used beyond 1%.

In [14; 15] it was concluded that ductility of dispersed basalt fiber reinforced concrete depends not only in the percentage of basalt fiber in the concrete but also on the length and diameter of the basalt fiber. Increase in the percentage of basalt fiber in the concrete yielded an increase in the concrete ductility. Similar results might be found for coconut fiber reinforced concrete.

Methods

The analysis in this research was conducted in the Autodesk Robot Structural Analysis Professional 2022. A simply supported beam of length 6000 mm and cross section of 300×650 mm was the structural element that was analysed. It was loaded with a uniformly distributed live load and dead of magnitudes 7 and 20 kN/m respectively. The self-weight of the beam was also considered.

There is a great need of incorporating BIM technology in modern-day construction [16]. The simulations will basically compare how a concrete beam from coconut fiber reinforced concrete would perform in real life loading conditions as compared to a plain concrete beam of the same design mix. The demands in steel bar reinforcements, crack formation and depth and deflection for both beams will also be assessed. The software calculations are done in accordance with the Eurocode 1.

Building structural element model

The structural element to be used for our analysis is a simple pinned on both supports rectangular beam. The construction and analysis of the model was done in Autodesk Robot Structural Analysis Professional 2022.

The beam is supported on two identical rectangular columns with dimensions 400×300 mm. The rectangular beam has the cross-section dimensions 300×650 mm and of length 6000 mm and was loaded with two uniformly distributed loads. One UDL is a dead load while the other one is a live load. The self-weight of the beam is also put into consideration in the calculations. The beam's calculation scheme is shown in Figure 1. Table 1 shows different loads and their meanings acting on the rectangular beam.

Figure 1. Loading on the rectangular beam

Table 1

Loads acting on the beam

No.	Case number	Distributed load	Nature	Sub-nature	*gf*-load factor	p1, kN/m
1	SW	Self-weight	Dead load	Structural	1.35	–
2	DL1	Uniform	Dead load	Structural	1.35	20.00
3	LL1	Uniform	Live load	Category A	1.5	7.00

Both the plain concrete and coconut fiber reinforced concrete beams were loaded with the same load pattern and quantity.

The following are the material properties of the plain concrete and coconut fiber reinforced concrete respectively.

1. Plain concrete beam

● Concrete: PC 20, f_{ck} = 20.00 MPa.
Rectangular stress distribution [3.1.7(3)].
Density: 2447.32 kG/m^3.
Aggregate size: 20.0 mm.

● Longitudinal reinforcement: B500C, f_{yk} = 500.00 MPa.
Horizontal branch of the stress-strain diagram.
Ductility class: C.

● Transversal reinforcement : B500C, f_{yk} = 500.00 MPa.
Horizontal branch of the stress-strain diagram.
Ductility class: C.

● Additional reinforcement: B500C, f_{yk} = 500.00 MPa.
Horizontal branch of the stress-strain diagram.

2. Coconut fiber reinforced concrete beam

● Concrete: CFRC20, f_{ck} = 26.40 MPa.
Rectangular stress distribution [3.1.7(3)].
Density: 2447.32 kG/m^3.
Aggregate size: 20.0 mm.
Coconut fibre length: 60 mm.
Coconut fibre fraction volume: 0.5%.

● Longitudinal reinforcement: B500C, f_{yk} = 500.00 MPa.
Horizontal branch of the stress-strain diagram.
Ductility class: C.

● Transversal reinforcement: B500C, f_{yk} = 500.00 MPa.
Horizontal branch of the stress-strain diagram.
Ductility class: C.
● Additional reinforcement: B500C, f_{yk} = 500.00 MPa.
Horizontal branch of the stress-strain diagram.

Methodology for calculation

The following were the calculation options which were put into consideration when running the software simulation for both beams.

● Regulation of combinations: EN 1990:2002.
● Calculations according to: EN 1992-1-1:2004/A1:2014.
● Seismic dispositions: no requirements.
● Precast beam: no.
● Cover: bottom c = 5.0 cm; side c_1= 5.0 cm; top c_2= 5.0 cm.
● Cover deviations: C_{dev} = 1.0 cm; C_{dur} = 0.0 cm.
● Coefficient b_2 =0.50: long-term or cyclic load.
Method of shear calculations: strut inclination.

Calculation results

After running the calculations in the Robot Structural Analysis Professional software, the following results were obtained for the plain concrete and coconut fibre reinforced concrete beam respectively.

PC and CFRC internal forces results

Since the PC and CFRC beams had the same dimensions and were both equally loaded, the internal forces in both the beams were the same and are displayed Table 2.

From the values in the Table 2, the maximum moment in ultimate limit state (ULS) in the beam was 224.35 kN·m in the middle of the span. Bending moments at both ends of the beam were zero. The shear forces were maximum at the supports. They were of the same value, 131.45 and –131.45 kN respectively. The ultimate limit state shows values of internal forces beyond which the structure will collapse and loose its integrity.

Table 3 displays the values of the internal forces in the beam in the serviceability limit state (SLS). Serviceability limit state means checking the structure for service conditions such as stability analysis, check for deflection, stress checks in normal conditions. Like in the ultimate limit state, the maximum bending moment is in the middle of the span and the maximum shear force values are at the supports of the beam.

Table 2

Internal forces in ULS

Span	*Mt* max, kN·m	*Mt* min, kN·m	*Ml*, kN·m	*Mr*, kN·m	*Ql*, kN	*Qr*, kN
P1	224.35	–0.00	58.46	58.46	131.45	–131.45

Table 3

Internal forces in SLS

Span	*Mt* max, kN·m	*Mt* min, kN·m	*Ml*, kN·m	*Mr*, kN·m	*Ql*, kN	*Qr*, kN
P1	162.20	0.00	–24.33	–24.33	95.04	–95.04

Required reinforcement area, deflection, cracking and material survey

1. Plain concrete beam. Now that we have the internal forces values in both ultimate limit state and serviceability limit state for both beams, we can now go on to compute the required reinforcement area, deflection values, cracking and finally do the material survey for both beams.

Computations will first be done for the plain concrete beam. We shall start with required reinforcement area. Table 4 shows the values of total reinforcement area required in the top and bottom sections of the beam.

Table 4 shows the required reinforcement areas for the middle span, left support and right support of the plain concrete beam respectively. As clearly visible in the table, the middle span bottom section of the beam requires a larger area of reinforcement due to the maximum bending moments putting the beam under tension. The top part of the middle span requires almost no reinforcement because it is under compression. The left and right supports' bottom and top sections require a lesser area of reinforcement as shown in the table.

Table 5 is showing the deflection parameters of the plain concrete beam. From the table it can be observed that after the simulation, the perpendicular cracks formed were 0.4 mm in width and the total quasi-permanent combination *wt*(*QP*) was 1.7 cm.

Table 4

Required reinforcement area for PC beam

Span	Span, cm^2		Left support, cm^2		Right support, cm^2	
	Bottom	Top	Bottom	Top	Bottom	Top
P1	9.80	0.00	2.29	1.31	2.29	1.31

Table 5

Deflection parameters of PC beam

Span	*wt*(*QP*), cm	*wt*(*QP*)*dop*, cm	*Dwt*(*QP*), cm	*Dwt*(*QP*)*dop*, cm	*wk*, mm
P1	1.7	2.6	0.2	1.3	0.4

We shall now look at the computations of the required reinforcement for the plain concrete in all the sections in detail.

P1: span from 0.40 to 6.40 m.

Longitudinal reinforcement:

● bottom (B500C):

3 d16 l = 6.59 from 0.11 to 6.69;

2 d16 l = 4.74 from 1.03 to 5.77;

● assembling (top) (B500C):

3 d14 l = 5.77 from 0.51 to 6.29;

● support (B500C):

3 d14 l = 2.03 from 0.05 to 1.78;

3 d14 l = 2.03 from 5.02 to 6.75.

Transversal reinforcement:

● main (B500C):

stirrups 32 d8 l = 1.43;

$e = 4\cdot 0.30 + 9\cdot 0.40 + 3\cdot 0.30$ m.

Material survey:

● Concrete volume = 1.33 m^3.

● Formwork = 11.03 m^2.

● Steel B500C.

● Total weight = 99.87 kG.

● Density = 75.32 kG/m^3.

● Average diameter = 11.9 mm.

● Survey according to diameters.

Table 6

Table of steel reinforcement for PC

Diameter, mm	Length, m	Weight, kg	Number	Total weight
8	1.43	0.56	32	18.04
14	2.03	2.45	6	14.71
14	5.77	6.98	3	20.93
16	4.79	7.49	2	14.98
16	6.59	10.40	3	31.21

Table 6 summarizes the steel bar reinforcement in terms of the diameter, length, weight, number of bars and total weight for each bar diameter in the plain concrete beam span. This includes the main longitudinal reinforcement bars, support bars, assembling bars and stirrups. The main longitudinal bars, diameter 16 mm in the middle of the span are the heaviest as displayed in the table.

2. Coconut fiber reinforced concrete beam. We shall now look at and analyze the results for coconut fiber reinforced concrete beam analysis.

Table 7 shows the required reinforcement areas for the middle span, left support and right support of the coconut fiber reinforced concrete beam respectively. As clearly visible in the table, the middle span bottom section of the beam requires a larger area of reinforcement due to the maximum bending moments putting the beam under tension. The top part of the middle span requires almost no reinforcement because it is under compression. The left and right supports' bottom and top sections require a lesser area of reinforcement as shown in the table. Comparing these values to the values of the required reinforcement areas for the plain concrete, the coconut fiber reinforced concrete beam has a slightly lesser requirement for reinforcement in the middle span and at the left and right supports.

In Table 8, we can see the total quasi-permanent combination *wt*(*QP*), allowable due to quasi-permanent combination deflection *wt*(*QP*)*dop*, deflection due to quasi-permanent load combination after erecting a structure *Dwt*(*QP*), the admissible deflection increment from the quasi-permanent load combination after erecting a structure *Dwt*(*QP*)*dop* and the width of the perpendicular cracks formed *wk*. After being loaded, the maximum perpendicular deflection cracks in the span of the CFRC beam was 0.4 mm as well.

Table 7

Required reinforcement area for CFRC

Span	Span, cm^2		Left support, cm^2		Right support, cm^2	
	Bottom	Top	Bottom	Top	Bottom	Top
P1	9.54	0.00	2.25	1.29	2.25	1.29

Table 8

Deflection parameters of CFRC beam

Span	*wt*(*QP*), cm	*wt*(*QP*)*dop*, cm	*Dwt*(*QP*), cm	*Dwt*(*QP*)*dop*, cm	*wk*, mm
P1	1.6	2.6	0.2	1.3	0.4

The next step is to make computations of the required reinforcement for the plain concrete in all the sections in detail (the number of bars, placement and length of each bar diameter in the CFRC beam).

P1: span from 0.40 to 6.40 m.

Longitudinal reinforcement:

- bottom (B500C):

3 d16 *l* = 6.50 from 0.15 to 6.65;

2 d16 *l* = 4.61 from 1.09 to 5.71;

- assembling (top) (B500C):

2 d14 *l* = 5.40 from 0.70 to 6.10;

- support (B500C):

3 d14 *l* = 1.66 from 0.05 to 1.71;

3 d14 *l* = 1.66 from 5.09 to 6.75.

Transversal reinforcement:

- main (B500C):

stirrups 29 d8 *l* = 1.60;

$e = 1·0.04 + 8·0.16 + 12·0.28 + 8·0.16$ m.

Material survey:

- Concrete volume = 1.33 m^3.
- Formwork = 11.03 m^2.
- Steel B500C.
- Total weight = 88.73 kG.
- Density = 66.92 kG/m^3.
- Average diameter = 11.7 mm.

Table 9 summarizes the steel bar reinforcement in terms of the diameter, length, weight, number of bars and total weight for each bar diameter in the CFRC beam span. This includes the main longitudinal reinforcement bars, support bars, assembling bars and stirrups. The main longitudinal bars, diameter 16 mm in the middle of the span are the heaviest as displayed in the table.

Table 9

Steel reinforcement material survey for CFRC

Diameter	Length	Weight	Number	Weight
8	1.60	0.63	29	18.27
14	1.66	2.01	6	12.07
14	5.40	6.52	2	13.05
16	4.61	7.28	2	14.57
16	6.50	10.26	3	30.77

Results and discussion

After running the structural analysis on the plain concrete and coconut fibre reinforced concrete beam, results were obtained. We are now going to analyse, compare the results obtained from the tests.

Internal forces in the beam

As earlier stated, both beams were loaded with the same amount and form of external loads. The beams also had the same geometrical properties (cross-section width, height and length). Due to this, the results for the support reactions, shear forces and bending moments were identical. The beams were loaded with a dead and live uniformly distributed load. The lead to having the maximum shear forces at the supports and the maximum bending moment in the centre of the beam. The Table 10 shows the results from the calculation in detail.

Table 10

Detailed theoretical results (ULS and SLS)

Abscissa, m	ULS			SLS		
	M max, kN·m	*M* min, kN·m	*V* max, kN	*M* max, kN·m	*M* min, kN·m	*V* max, kN
0.40	58.46	–33.65	131.45	18.25	–24.33	95.04
0.84	106.60	–20.13	112.17	58.39	0.00	81.10
1.48	162.04	–0.00	84.13	103.81	0.00	60.83
2.12	199.53	–0.00	56.09	136.25	0.00	40.55
2.76	219.07	–0.00	28.04	155.71	0.00	20.28
3.40	224.35	0.00	0.00	162.20	0.00	0.00
4.04	219.07	–0.00	–28.04	155.71	0.00	–20.28
4.68	199.53	–0.00	–56.09	136.25	0.00	–40.55
5.32	162.04	–0.00	–84.13	103.81	0.00	–60.83
5.96	106.60	–20.13	–112.17	58.39	0.00	–81.10
6.40	58.46	–33.65	–131.45	18.25	–24.33	–95.04

From the values of the bending moments in both ULS and SLS we can notice the need for horizontal beam steel bar reinforcements to absorb the flexural forces as a result of these bending moments in the beam. The supports of the beam are also in need of transverse reinforcements to prevent crack formation due to shear forces. We shall analyse the quantity of steel bar reinforcements for each beam in the sub-heading of reinforcements later in this chapter.

Deflection and cracking

When both beams were subjected to the uniformly distributed loads, they both underwent deflection and cracking. Through the help of the software, we were able to calculate deflections and cracking in both cases. We shall now look at and analyse them. Table 11 summarizes the findings.

Table 11

Table of deflection and cracking for PC and CFRC beams

Beam	Span	***wt*(*QP*), cm**	***wt*(*QP*)dop, cm**	***Dwt*(*QP*), cm**	***Dwt*(*QP*)*dop*, cm**	***wk*, mm**
PC	P1	1.7	2.6	0.2	1.3	0.4
CFRC	P1	1.6	2.6	0.2	1.3	0.4

wt(*QP*) – total due to quasi-permanent combination; *wt*(*QP*)*dop* – allowable due to quasi-permanent combination; *Dwt*(*QP*) – deflection increment from the quasi-permanent load combination after erecting a structure; *Dwt*(*QP*)*dop* – admissible deflection increment from the quasi-permanent load combination after erecting a structure.

As clearly indicated in Table 11 the plain concrete beam has a higher value of deflection from the loading as compared to the coconut fibre reinforced concrete beam under the same loading.

Reinforcement

As earlier stated, there is need for steel bar reinforcement in both beams as a result of the shear and bending moment forces which occurred in the beam due to the loading. We shall analyse the amount of steel reinforcement needed in each case and find where more steel reinforcement was needed. The reinforcement is in the span P1 from 0.4 to 6.4 m.

For the PC beam. Figure 2 graphically shows the placement of the different steel bars in the plain concrete beam. It clearly shows the positions of the main horizontal bars, assembling bars, support bars and stirrups. Let's break down the placement of the bars below for a better understanding.

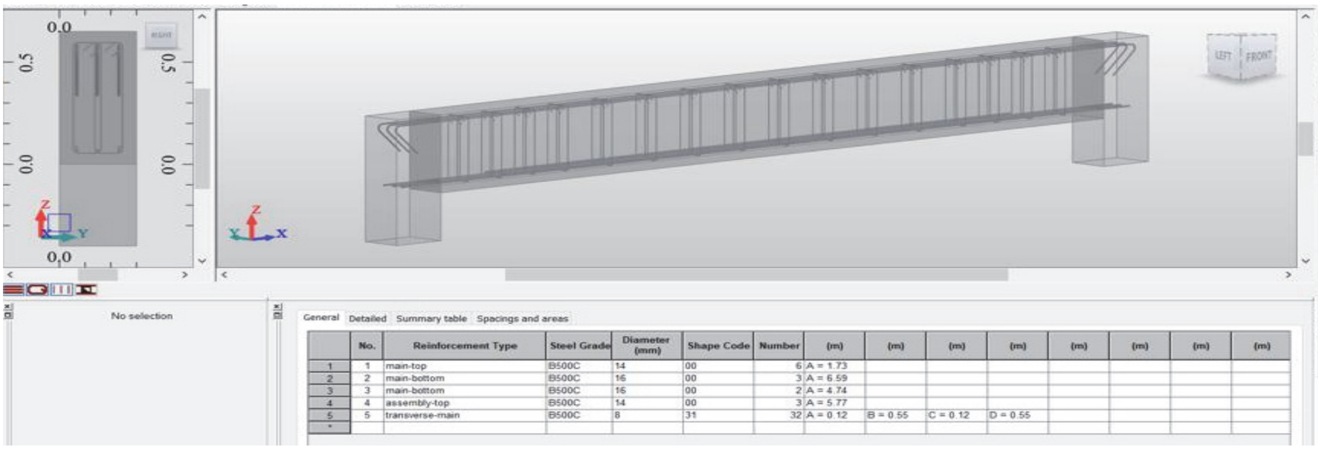

Figure 2. PC steel reinforcement diagram

Longitudinal reinforcement:
- bottom (B500C):

3 d16 l = 6.59 from 0.11 to 6.69;
2 d16 l = 4.74 from 1.03 to 5.77;
- assembling (top) (B500C):

3 d14 l = 5.77 from 0.51 to 6.29;
- support (B500C):

3 d14 l = 2.03 from 0.05 to 1.78;
3 d14 l = 2.03 from 5.02 to 6.75.

Transversal reinforcement:
- main (B500C):

stirrups 32 d8 l = 1.43;
$e = 4\cdot0.30 + 9\cdot0.40 + 3\cdot0.30$ m.

For the CFRC beam. Figure 3 on the other hand also graphically shows the placement of the different steel bars in the plain concrete beam. It clearly shows the positions of the main horizontal bars, assembling bars, support bars and stirrups. Below is the breakdown of the placement of steel bars in the beam.

Longitudinal reinforcement:
● bottom (B500C):
3 d16 l = 6.50 from 0.15 to 6.65;
2 d16 l = 4.61 from 1.09 to 5.71;
● assembling (top) (B500C):
2 d14 l = 5.40 from 0.70 to 6.10;
● support (B500C):
3 d14 l = 1.66 from 0.05 to 1.71;
3 d14 l = 1.66 from 5.09 to 6.75.
Transversal reinforcement:
● main (B500C):
stirrups 29 d8 l = 1.40;
e = 1·0.04 + 8·0.16 + 12·0.28 + 8·0.16 m.

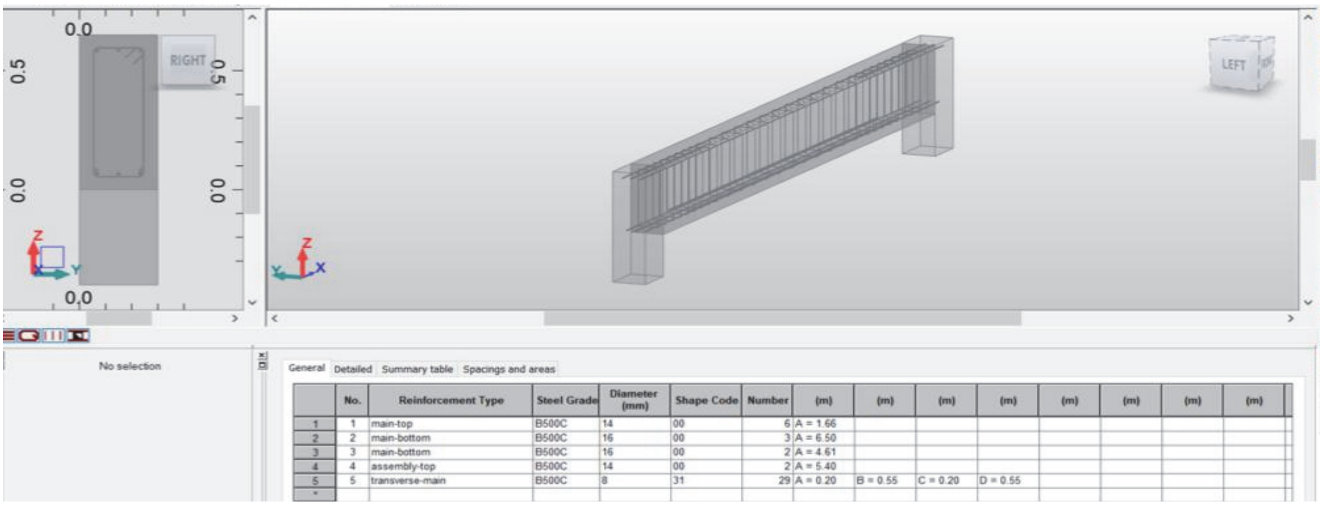

Figure 3. Steel bar reinforcement diagram for CFRC beam

After the analysis, the software generated the type and amount of steel needed for each beam type. Table 12 summarizes the results from the analysis. From the table, it can be seen that plain concrete beam required more bars of steel reinforcements in number and in length despite both beams requiring steels bars of the same diameters.

Table 12

Steel bar reinforcements in PC and CFRC beams

Type of concrete beam		Longitudinal reinforcement			Transverse reinforcement		
		Bottom (B500C)		Assembling (top) (B500C)	Support (B500C)		Main stirrups (B500C)
PC beam	Number	3	2	3	3	3	32
	Diameter	16	16	14	14	14	8
	Length	6.59	4.74	5.77	2.03	2.03	1.43
CFRC beam	Number	3	2	2	3	3	29
	Diameter	16	16	14	14	14	8
	Length	6.50	4.61	5.40	1.66	1.66	1.40

Material analysis

We shall now summarize the overall material requirements for the beams. This will summarize the concrete, formwork and steel material survey for erecting a 6000×300×650 beam from PC and CFRC.

Table 13

Total material survey for PC and CFRC

Type of concrete	Concrete volume, m^3	Formwork, m^2	Steel B500C		
			Total weight, kg	Density, kg/m^3	Average diameter, mm
PC	1.33	11.03	99.87	75.32	11.90
CFRC	1.33	11.03	88.73	66.92	11.70

Table 13 draws a clear conclusive distinction in the material survey between the plain concrete and coconut fibre reinforced concrete beam. Since the two beams were of the same dimensions, there was hardly any difference in the concrete volume and formwork area needed to erect them. However, there was a reasonable difference in the total weight, density and average diameter of the steel bar reinforcement. The PC beam had larger values for total weight, density and average steel reinforcement bar diameter.

Conclusion

The experimental structural analysis in the Autodesk Robot Structural Analysis Professional 2022 software was carried out to determine the differences in material demands for a plain concrete beam and a coconut fibre reinforced concrete beam. Both beams were of the same geometrical characteristics and were loaded with the same uniformly distributed load (form and quantity).

The mechanical properties of the coconut fibre reinforced concrete were gotten from experimental researches from reviewed and published scientific articles from our literature review. The CFRC beam had a fraction volume of 0.5% of coconut fibre of length 6cm. After running the analysis in the software, the internal forces in the beams came out of the same value.

During the analysis of results, it was found that the PC beam had a greater deflection and cracking as compared to the CFRC beam. The PC beam also showed results of having a greater required reinforcement area as compared to the CFRC. This meant that the PC beam was in need of more steel reinforcement.

The results of the analysis also included the material survey for both beams. From the survey it was discovered that the both the PC and CFRC were of the same concrete volume and formwork area. However, there was a significant difference in the steel reinforcement total weight, density and average diameter of the bars. The PC beam requires a total weight of 99.87 kg of steel bar reinforcement while the CFRC beam of the same geometric dimensions requires 88.73 kg of steel bar reinforcement.

Based on this software analysis, it was found the following:

1) the CFRC beam experiences 6% less deflection and crack formation when loaded with a flexural force;

2) the PC beam requires a greater area of reinforcement as compared to the CFRC;

3) the material survey showed that CFRC requires 11% less of steel bars in weight as compared to the PC.

This makes the CFRC a light construction material and more economical in terms of steel reinforcement. From the results obtained from the research, the beam made from coconut fibre reinforced concrete showed better performance under the given loads. It also showed less deflection, crack formation and less steel bar reinforcement. This makes it a better and more sustainable material as compared to the plain concrete. However, more research is needed on the incorporation of natural fibres in concrete as there are no existing standards and code for their use as reinforcement in concrete.

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