IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 23, Issue 5 Ser. III (Sep. – Oct. 2026), PP 13-31
www.iosrjournals.org

Investigation On the Bending Resistance of Double Layer Reinforced Concrete Beam Using River Gravel and Crush Granite

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Abstract
This investigation focused on studying the bending capacity of double-layer reinforced concrete beam using river gravel and crushed granite. The primary objective is to determine the factors influencing the bending capacity of double-layer beams and analyze their behavior under different loading conditions. By understanding the factors influencing bending capacity, a prototype beam was design to enhance the overall strength and performance of the reinforced concrete beam. The production of this double layer RC beams. Ten (10) simply supported RC prototype beams (1000x75x112 mm) were subjected to laboratory study. Two 8 mm rebar in the tension zone and two 6mm diameter were provided as hanger bars 4mm diameter rebar spaced at 200 mm were used as shear bars and constructed for this research as specified EN1990, EN1991, EN1992. Preparation of the Beams, the concrete mix proportion used in preparing the concrete beams M15(1:2:4). The Reinforced concrete beam samples were grouped into six (6): the first group is made up of SCG as single layer of crushed granite 100%CG, the second group is made of SRG as single layer of river gravel 100%RG. The third group is made of double layer RC beams. These beams are identified as CG, RG for depth of top to bottom layer ratio 50CG/50RG, 50RG/50CG, 30RG/70CG and 70CG/30RG, respectively. The beam samples were subjected to a point load application to evaluate the load resistance and deflections were evaluated for their strength to support a load over a span of 900 mm after 28 days of curing. A dial gauge was positioned at the mid-span under the beam. The result showed that, the control beam for crushed granite SCG had ultimate failure load of 20.41kN with a corresponding deflection of 4.43 mm and bending capacity of 4.59 kNm the next inline was double layer beam, the compression layer (half depth of crushed granite) and the tension (half depth river gravel) 50%CG/50%RG, which failed at a load of 18.59 kN, with a corresponding deflection of 3.82 mm and a bending capacity of 4.65 kN the beam finally failed due to flexure. This beam is 9.03% less than the SCG. The double layer reinforced concrete beams had a similar load resistance as the reinforced concrete beams made entirely with SCG. Based on the experimental test result in the laboratory, it's recommended that placing the weaker concrete (river gravel) in a double layer reinforced concrete beam at the tension zone enhance a desirable bending capacity which is similar to the control beam SCG.
Key words*: River gravel, cement, concrete beam, bending capacity.*

Date of Submission: 17-10-2026 Date of Acceptance: 30-10-2026

I. INTRODUCTION

Concrete is a composite material consisting mainly of cementitious binder, water, fine aggregate and coarse aggregate. Its performance depends on the interaction of these constituents, their proportions, curing conditions and the resulting microstructure (John & Lothenbach, 2023; Li et al., 2021). Aggregate occupies most of the concrete volume and therefore has a major influence on workability, strength, stiffness and durability (Wang et al., 2021; Naderi & Kaboudan, 2021).

Aggregates

Aggregate characteristics such as particle size, grading, shape, angularity, surface texture and mineralogy influence concrete packing and the interfacial transition zone. Recent studies show that angular and rough particles can improve mechanical interlock, although they may increase water demand and reduce workability compared with rounded particles (Lee et al., 2020; Güçlüer, 2020; Wang et al., 2021). Aggregate morphology is therefore important when comparing crushed granite with naturally rounded river gravel.

Crushed Granite Aggregate

Quarried rock is crushed into graded particles to create crushed granite. When the mix is balanced correctly, its angular shape and rough surface can produce a better mechanical interlock with cement paste than

smooth natural aggregates, thus increasing concrete strength. According to experimental data, the type of coarse aggregate can have a major impact on durability, shrinkage, and compressive and flexural strength (Wang et al., 2021). According to Eziefula et al. (2020), under similar mix circumstances, concrete manufactured with crushed granite in Nigeria typically had a better compressive strength than concrete prepared with river stone.

River Gravel

River gravel is naturally rounded aggregate formed through weathering and transportation by water. Its smooth surface generally improves workability, but its rounded shape may provide less mechanical interlock than angular crushed aggregate. Nigerian experimental evidence indicates that river-stone concrete can achieve useful structural strengths, although performance depends strongly on source, grading, cement content and water-cement ratio (Eziefula et al., 2020). The suitability of river gravel should therefore be established through aggregate characterization and concrete testing.

Fine Aggregate

Fine aggregate fills voids between coarse particles and contributes to particle packing, workability and strength. Its grading, cleanliness, particle shape and surface texture influence water demand and paste requirement. Recent studies emphasize that aggregate morphology and grading affect both fresh and hardened concrete properties (Lee et al., 2020; Sun et al., 2020). Fine aggregate should therefore be well graded and free from excessive deleterious materials.

Cement and Water

Cement hydration controls the formation of the cementitious matrix and affects the strength and durability of concrete. Recent reviews (Zhao et al., 2021; John & Lothenbach, 2023) state that hydration is a time-dependent process that includes reaction, dissolution, and the production of hydration products that progressively change the mechanical properties and pore structure. Water is essential for hydration and workability, but the water-to-cement ratio must be controlled since changes in water content impact porosity and strength. Eziefula et al. (2020) discovered that when the water-to-cement ratio dropped in Nigerian aggregate settings, concrete strength rose.

Strength of Concrete

Concrete strength is influenced by curing, aggregate characteristics, water-to-cement ratio, and component quality and ratios. Compressive strength is often used as the main measure of concrete quality, even if tensile and flexural strengths are important for reinforced concrete parts. Wang et al. (2021) found that coarse-aggregate type had an impact on both compressive and flexural strengths, similar to how Naderi and Kaboudan (2021) found that aggregate type can considerably affect concrete strength and permeability. Therefore, the aggregate used in a structural beam should be considered as part of the overall strength development process.

Concrete Grades and Mix Proportioning

Concrete grade is a representation of the specified strength class used in structural design. Modern technique emphasizes regulated mix proportioning rather than solely relying on nominal volumetric ratios. ACI 318-19 outlines requirements for structural concrete materials, design, and detailing, whereas ASTM C33/C33M-16 establishes specifications for concrete aggregates. According to experimental results, achieved strength is also influenced by the interaction of cement content, water-cement ratio, and aggregate source (Eziefula et al., 2020). In experimental beam research, consistent batching, mixing, positioning, and curing are essential for meaningful comparison.

Reinforced Concrete Beams and Flexural Behaviour

The tensile resistance of reinforcement and the compressive resistance of concrete are combined in reinforced concrete. Cracking often appears in the tension region under flexural loading, which is followed by increasing tensile-stress transfer to the reinforcement and concrete compression in the opposite zone. According to recent research on reinforced concrete beams, aggregate type and concrete quality affect ultimate capacity, stiffness, cracking, and load-deflection response (Kolo et al., 2021; Aziz & Abdulkadir, 2022). Because it offers deformation prior to final failure, a ductile flexural response is typically favored.

Two-Layer Reinforced Concrete Beams

In two-layer reinforced concrete beams, which employ different concrete kinds or grades within the same cross-section, stronger concrete is often positioned in the compression zone and lower-strength concrete in the tension zone. According to Ataria and Wang (2019), a two-layer beam with lower-grade concrete in tension and higher-grade concrete in compression could produce bending resistance similar to an all-high-grade control beam.

However, when the lower-strength layer is heavily involved in shear, shear resistance may be reduced. Related layered-beam research indicates that adequate contact between the concrete layers is necessary for structural performance (Nematzadeh & Fallah-Valukolaee, 2021; AL-Farttoosi et al., 2021; AL-Farttoosi et al., 2022).

Flexural and Shear Failure

Flexural failure is associated with tensile reinforcement cracking and yielding as the end state draws near, followed by compression-zone crushing. Shear failure, on the other hand, can happen more rapidly and through diagonal cracking. Recent studies on two-layer beams have shown that the thickness or strength of specific layers can alter the flexural and shear resistance (Ataria & Wang, 2019; AL-Farttoosi et al., 2022). Therefore, in addition to flexural capacity, layer position, thickness, bond, and shear transfer should be considered while assessing a multilayer beam.

Previous Studies

In their investigation of two-layer reinforced concrete beams with varying concrete grades, TrustGod et al. (2020) found that using higher-grade concrete in the compression region and lower-grade concrete in the tension region produced satisfactory structural performance. Similar bending resistance was discovered by Ataria and Wang (2019) between an all-high-grade control beam and a two-layer beam. Nematzadeh and Fallah-Valukolaee (2021) demonstrated that the position of fiber-reinforced concrete, reinforcing type, and concrete strength all had an impact on the flexural response of multilayer beams. Iskhakov et al. (2023) also showed that actual prestressed parts can retain sufficient interaction between concrete layers.

The current study is particularly relevant to recent research carried out in Nigeria. Eziefula et al. (2020) found that the water-to-cement ratio and aggregate source had a significant impact on the compressive strength of concrete constructed from river stone, crushed granite, and other local materials. John and Blessing (2023) investigated the optimal depth of lower-grade concrete in the tension zone of two-layer reinforced concrete beams and verified that stiffness and load-carrying capacity are influenced by the thickness and placement of the lower-grade layer. These findings support the need to investigate the specific combination of river gravel and crushed granite used in this project.

Further study on modified aggregate concrete indicates that changes in coarse aggregate may affect structural performance. Aziz and Abdulkadir (2022) discovered that the strength and stiffness of the beam varied when some of the coarse aggregate was replaced with alternative materials. Sagheer et al. (2023) found that the structural response of reinforced concrete beams using recycled aggregates was influenced by the quantity and quality of aggregate replacement. More recent studies continue to examine the flexural performance of aggregate-modified reinforced concrete beams, emphasizing the importance of experimentally confirming material combinations before structural application (Nguyen et al., 2024; Özkılıç et al., 2025; Taha et al., 2025).

Research Gap

The reviewed literature establishes that aggregate type, particle morphology, water-cement ratio, concrete strength and layer configuration can influence reinforced concrete beam behaviour. However, relatively few studies have directly examined double-layer reinforced concrete beams in which crushed granite and river gravel are combined as separate layers, particularly under locally available Nigerian material conditions. Existing two-layer studies have largely considered different concrete grades, lightweight concrete, recycled aggregates or fiber-reinforced concrete rather than the specific crushed-granite/river-gravel arrangement investigated here. The present study therefore addresses this gap by experimentally evaluating the bending resistance, deflection and failure behaviour of double-layer reinforced concrete beams using different proportions and positions of river gravel and crushed granite.

METHODOLGY

This chapter outlines the procedures and methods used in the research to investigate the bending capacity of double-layer reinforced concrete beams using river gravel and crushed granite. The study employed both experimental and theoretical approaches to achieve the main objectives of the research. The experimental approach involved conducting physical tests and measurements to obtain data and results, while the theoretical approach involved using mathematical models and calculations to analyze and interpret the data. By combining these methods, the study aimed to gain a comprehensive understanding of the bending capacity of double-layer reinforced concrete beams with different coarse aggregates.

Materials Binder (Cement)

Lime stone cement of grade 42.5 was used in producing (150 x 150 x 150) mm concrete cubes and (1000 x 112 x 75) mm rectangular beams confirming to EN 1996-1-1:2004

Fine Aggregate

Sand from Silver River was used. It consisted quartzite the grading properties confirming to BS882:1992

Coarse Aggregate

Particle sizes caught in No. 4 sieve was used as coarse aggregate for this research.

River Gravel:



Figure 1. River gravel



Figure 3.6 Coarse Aggregate



Figure 2. Fine Aggregate

Water

Portable drinking water was used as specified by BS 3148:1980.

Timber

Marine ply boards were utilized for the construction of the beam formworks.it conforms to BS 1881.part 109(1983)

Concrete cube

As specified by BS 1881-108:1983, 12 standard concrete cubes (150 x 150 x150 mm) were made in accordance to each sample type of the beams to obtain an average 28-days compressive strength for the various samples. The cubes were cured in the same condition as the beams. Each cube was tested using compressive loading apparatus. The maximum value for cubes was added together to obtain an average concrete compressive strength for the various samples.

Steel Reinforcement

Deformed bars were used as internal reinforcement both in bending and shear. It conformed to EN 1992-1-1; 2004 Figure 3.7



Steel Reinforcement

Figure 3. Steel Reinforcement

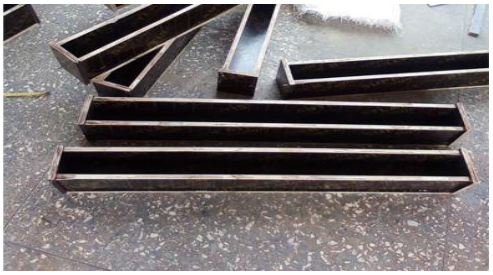


Figure 4. Timber Formwork

Methods

Construction of test results Specimen

The study focused on investigating the bending capacity of double-layer reinforced concrete beams using different materials. The materials used in the study were Portland limestone cement of 42.5 N grade specified by BS EN 197-1 (2011), fine aggregate, coarse aggregate, and river gravel. The bulk specific gravity of these materials was measured as 2.55, 2.62, and 2.59, respectively.

Ten prototype beams with dimensions of 1000x75x112 mm were prepared and subjected to laboratory testing. Each beam had two 8 mm diameter rods and two 6 mm diameter rods as reinforcement at the bottom and top, respectively, with a yield strength of 400 N/mm2.

The concrete mix proportion used for preparing the beams was M15(1:2:4). The beams were grouped into six categories: single layer beams with 100% crushed granite (SCG) and 100% river gravel (SRG), and double layer beams with various depth ratios of SCG and SRG layers (50CG/50RG, 50RG/50CG, 30RG/70CG, and 70CG/30RG).

The beams were instrumented with a dial gauge at the mid-span to measure deflection under point load application. Load resistance and deflection were recorded for each beam at 5 kN load increments. The maximum bending resistance was determined by analyzing the moment at the loading point. After 28 days of curing, the compressive strength of the concrete cubes was tested according to BS1881-3:1970.

The study aimed to evaluate the strength and load-carrying capacity of the double-layer reinforced concrete beams with different material combinations after the specified curing period.

II. RESULTS

Table 1. Physical Properties of Aggregates

Test conducted	Results	Code referenced	Code Specification	Remark
Coarse Aggregate				
Specific gravity	2.62	ASTM C128, (2001)	2.55 - 2.75	Ok
Water absorption (%)	0.1	BS 812 part 2, (1995)	< 3.5%	Ok
River Aggregate				
Specific gravity	2.59	ASTM C128, (2001)	2.95	Ok
Water absorption (%)	1.9	BS 812 part 2, (1995)	< 3.5%	Ok
Fine Aggregate				
Specific gravity	2.55	ASTM C128, (2001)	2.55 - 2.75	Ok
Water absorption (%)	0.5	BS 812 part 2, (1995)	< 15%	Ok

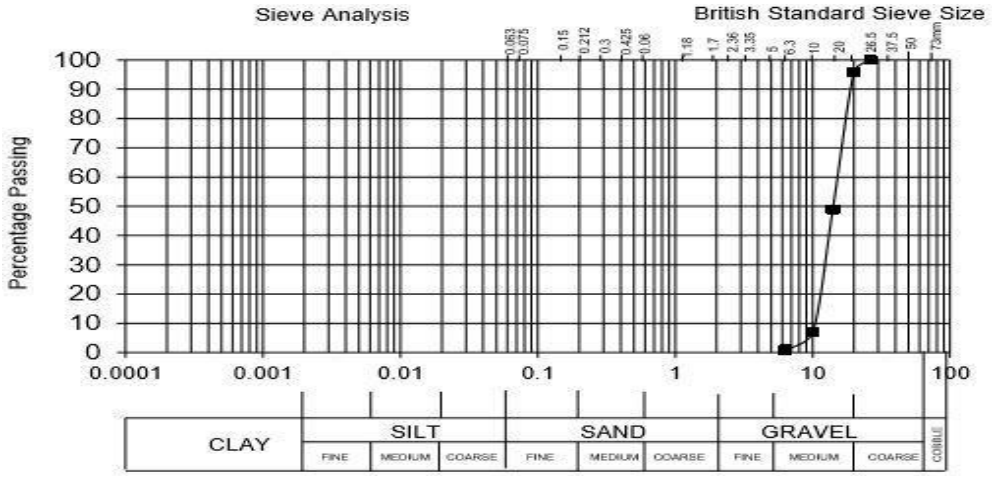


Figure 5. Coarse Aggregate Chart

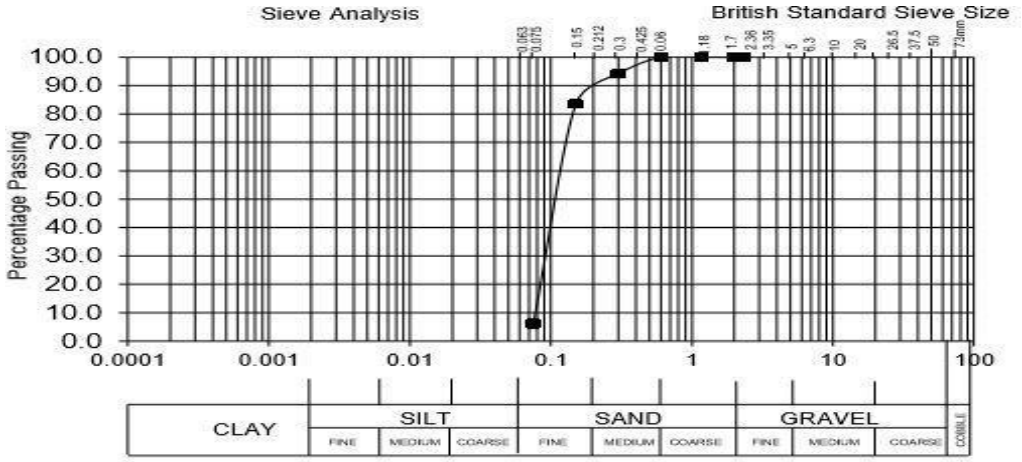


Figure 6. Fine Aggregate Chart

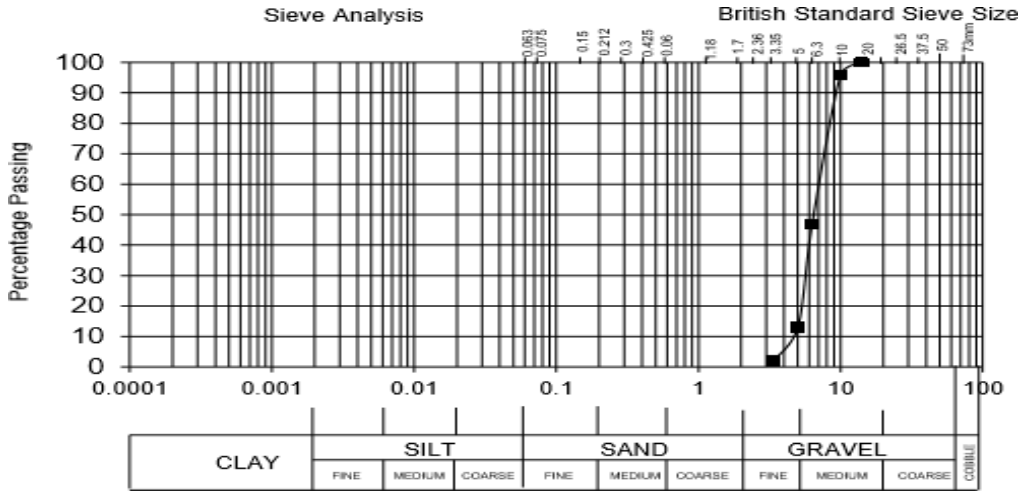


Figure 7. River Gravel Chart

Table 2. Test Result Showing First Crack Load and Failure Load deflection and bending moment

Results of Beams SCG, SRG, 50%CG/50%RG, 50%RG/50%CG, 30%CG/70%RG, 30%RG/70%CG								
Sample ID	Weight of beams (Kg)	Yield Load (KN)	Deflection at Yield Load(mm)	Failure Load P, (KN)	Deflection at Failure Load (mm)	Bending capacity M=PL/4 (KN.m)	Ductility Index	Failure Mode
SCG	25	18.59	3.82	20.41	4.43	5.10	1.16	Flexure

SRG	25	5.55	0.94	14.92	3.28	3.73	1.59	Flexure

50CG/50RG	25	9.42	1.63	18.59	3.82	4.65	2.85	Flexure
50RG/50CG	25	7.58	1.42	14.92	3.76	3.73	2.65	Flexure
30CG/70RG	25	9.42	2.1	16.75	4.75	4.19	2.26	Flexure
30RG/70CG	25	9.42	2.29	14.92	4.2	3.73	1.83	Flexure

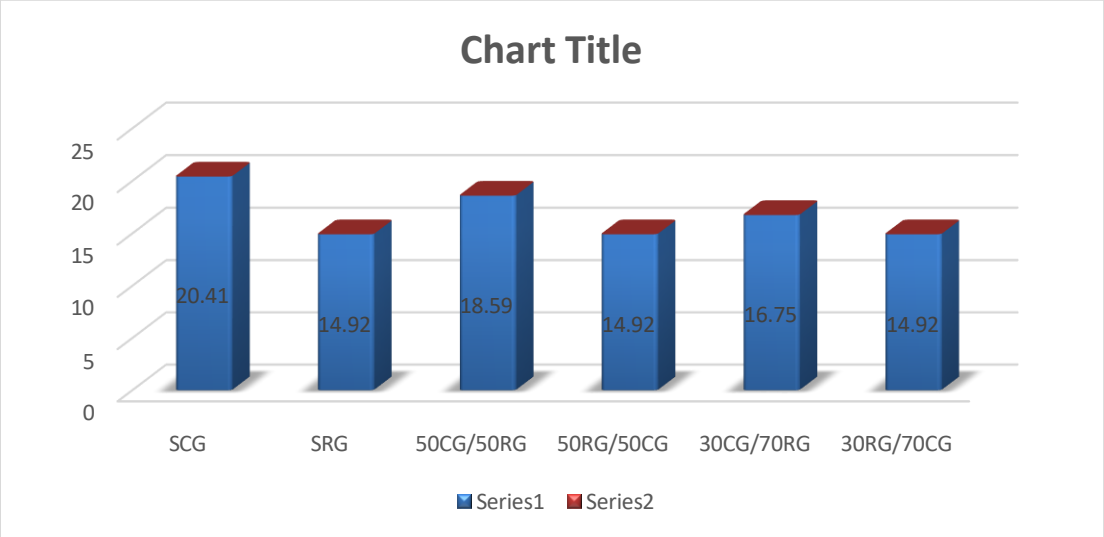


Figure 8. Load P, (KN) VS Sample ID

Table 3. Description of prototype model Beam dimensions

Beam Description						
Sample ID	Beam Depth (mm)	Beam width (mm)	Beam Length (mm)	Depth of Top Layer(mm)	Depth of Bottom Layer (mm)	Top and Bottom Layer Mix Ratio
SCG	112	75	1000	112	0	1:2:4
SRG	112	75	1000	112	0	1:2:4
50CG/50RG	112	75	1000	56	56	1:2:4
50RG/50CG	112	75	1000	56	56	1:2:4
30CG/70RG	112	75	1000	33.6	78.4	1:2:4
30RG/70CG	112	75	1000	33.6	78.4	1:2:4

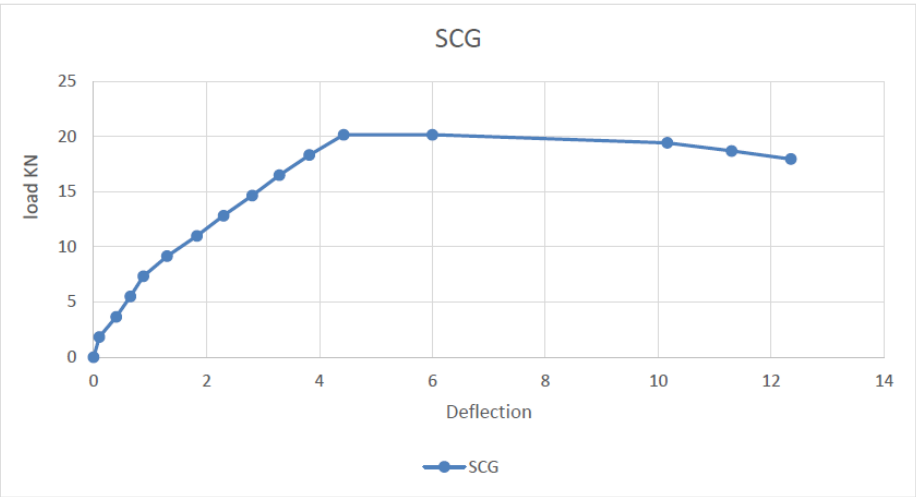


Figure 9. Failure Load vs Deformation for SCG

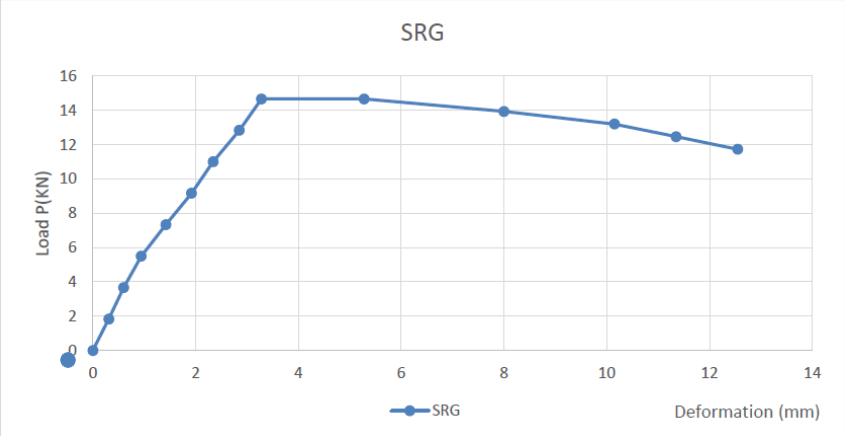


Figure 10. Failure Load vs Deformation for SRG

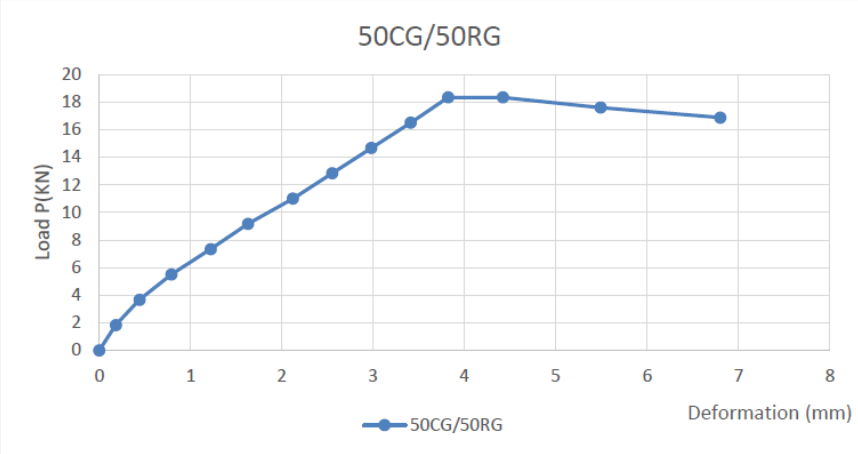


Figure 11. Failure Load vs Deformation for 50%CG/50%RG

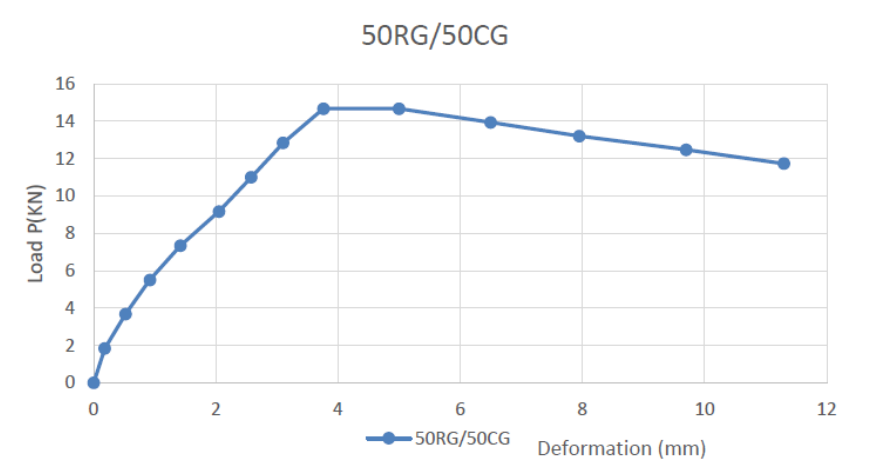


Figure 12. Failure Load vs Deformation for 50%RG/50%CG

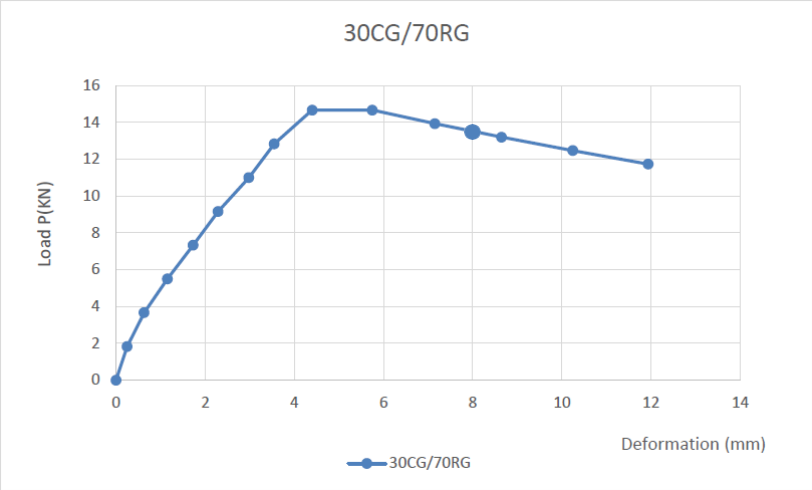


Figure 13. Failure Load vs Deformation for 30%CG/70%RG

Table 4. Cracking Capacity of the Beams

Sample ID	First Crack Load (KN)	Cracking Capacity (KNm)
SCG	18.59	3.40
SRG	11.25	2.06
50CG/50RG	9.42	1.72
50RG/50CG	7.58	1.39
30CG/70RG	9.42	1.72
30RG/70CG	9.42	1.72

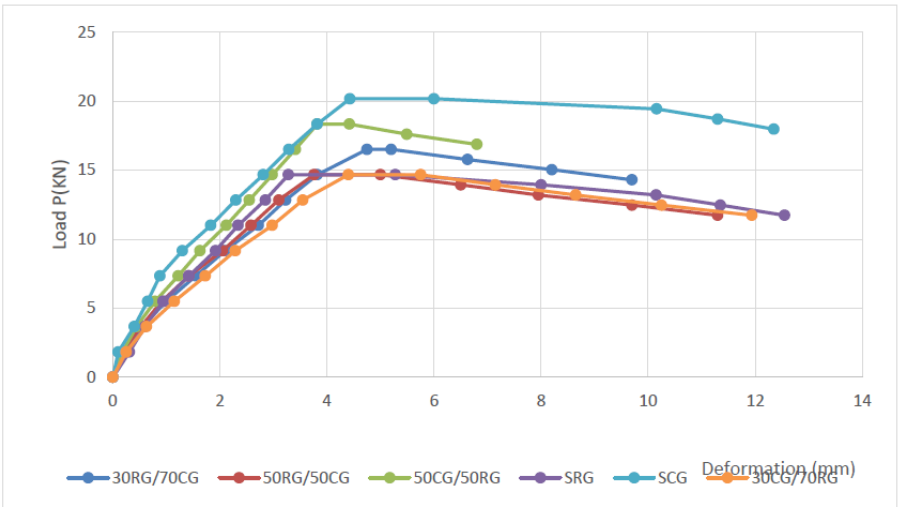


Figure 14. Failure Load vs Deformation for SCG, SRG, 30%RG/70%CG, 50%RG/50%CG, 50%CG/50%RG, 30%CG/70%RG

Table 5. Bending Capacity of the Beams

Sample ID	Failure Load (KN)	Bending Capacity (KNm)
SCG	20.41	5.10
SRG	14.92	3.73
50CG/50RG	18.59	4.65
50RG/50CG	14.92	3.73
30CG/70RG	16.75	4.19

30RG/70CG	14.92	3.73

Table 6. Test Result Showing Ductility Index of the beams

Sample ID	Deflection at Yield Load (mm)	Deflection at Failure Load (mm)	Ductility Index
SCG	3.82	4.43	1.16
SRG	2.34	3.28	1.59
50CG/50RG	1.63	3.82	2.85
50RG/50CG	1.42	3.76	2.65
30CG/70RG	2.1	4.75	2.26
30RG/70CG	2.29	4.2	1.83

Table 7. Tensile Stress of the Beams

Sample ID	First Crack Load (KN)	Tensile stress (MPa)
SCG	18.59	9.30
SRG	11.25	5.63
50CG/50RG	9.42	4.71
50RG/50CG	7.58	3.79
30CG/70RG	9.42	4.71
30RG/70CG	9.42	4.71

Table 8. Shear strength of the beams

Sample ID	Failure Load (KN)	shear strength (MPa)
SCG	20.41	10.21
SRG	14.92	7.46
50CG/50RG	18.59	9.30
50RG/50CG	14.92	7.46
30CG/70RG	16.75	8.38
30RG/70CG	14.92	7.46

Table 9. 28-Days Compressive Strength

Sample ID	Mixed Grade M15	Size of Cubes (mm)	Weight of Beams (Kg)	Applied Compressive Load (kN)	28-Days Compressive Strength (MPa)	Average Strength (MPa)
Cube 1 SCG	1:2:4	150x150x150	10	685	30.44	34
Cube 2 SCG	1:2:4	150x150x151	10	760	33.78	
Cube 3 SCG	1:2:4	150x150x152	10	850	37.78	
cube 4 SRG	1:2:4	150x150x153	10	465	20.67	18.67
cube 5 S RG	1:2:4	150x150x154	10	360	16	
cube 6 SRG	1:2:4	150x150x155	10	435	19.33	

III. CONCLUSION

From the experimental test results, it is observed that placing the weaker concrete (river gravel) in the tension zone of a double layer reinforced concrete beam enhances a desirable bending capacity, similar to the control beam SCG. This finding supports the results of John et al. (2020) that state that double layer reinforced concrete beams with 50% higher strength concrete at the top layer (SCG) and 50% lower strength at the bottom layer (SRG) can be structurally desirable.

The investigation of the bending capacity of double layer reinforced concrete beams using crushed granite and river gravel led to the following conclusions:

i. The greater the depth of the layer under compression, the stiffer the two-layer RC beam becomes.

ii. Double layer RC beams can be encouraged in the construction industry to reduce costs.

iii. Double layer RC beams are effective and structurally satisfactory, as there was no feasible reduction in bending and load-carrying capacity observed so far.

Overall, the results suggest that the use of double layer reinforced concrete beams with different proportions of crushed granite and river gravel can offer advantages in terms of structural performance and cost-effectiveness in construction projects.

IV. RECOMMENDATION

Based on the research work and its findings, it is recommended that the construction industry should consider adopting the use of double layer reinforced concrete beams using river gravel and crushed granite. Placing the weaker concrete (river gravel) in the tension zone of the beam enhances desirable results, similar to the control beam made entirely with crushed granite.

By using double layer reinforced concrete beams, construction projects can potentially reduce costs of coarse aggregate while still achieving desirable structural performance. This cost-saving approach can be beneficial for various construction applications and projects, where the use of locally available materials like river gravel can be advantageous.

However, it is essential to ensure proper design and quality control during the construction process to ensure the overall structural integrity and performance of the double layer reinforced concrete beams. As with any new construction technique, further research and experimentation are also encouraged to explore the full potential and applicability of this approach in different contexts.

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APPENDIX

Design Procedure for Prototype Beam

The following equations have been derived for single reinforced uniform rectangular section under pure bending. The layout in figure 3.2 was extracted from a residential building located at Yenagoa Bayelsa State. The design of the prototype beam was done with limit state design.

Design Information Intended use of structure	**Residential Building**
Residential Building Relevant Codes	EN1990, EN1991, EN1992
Design Stresses Concrete,	fck = 25N/mm2, Steel, fy k= 400N/mm2
Fire Exposure	R60 Exposure Class XC1
Nominal Cover	30mm
General Loading Conditins	
Live Load	2.0KN/m2
Finishes/Scree dings	1.2KN/m2
Portion Allowance	1.0KN/m2

Design Data

$$K = \frac{M}{0.87 fykZ}$$

$$K' = 0.207$$

$$beffi = beff + bw \leq b$$

$$Beff = 0.2bi + 0.1l_o \leq 0.2l_o$$

$$bi = \frac{(L - bw)}{2}$$

Lo = 0.85l for end span

$$Z = d[0.5 + \sqrt{0.25 - \frac{K}{1.134}}] \leq 0.95d$$

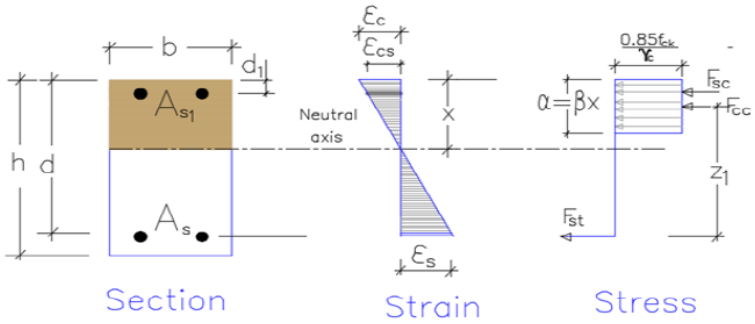


Figure 3.1 Neutral axis Diagrams

considering the strain diagram above and applying similar triangle

$$\frac{\varepsilon_c}{x} = \frac{\varepsilon_s}{d-x} \tag{3.1}$$

where $\varepsilon_c =$ *strain of concrete* $= 0.0035$

where $\varepsilon_s =$ *strain of steel* $= 0.002$

substituting into equ (2.11)

$$\frac{0.0035}{x} = \frac{0.002}{d-x}$$

$$\frac{d-x}{x} = \frac{0.002}{0.0035}$$

$$\frac{d-x}{x} = 0.571$$

$$d - x = 0.571x$$

$$0.571x + x = d$$

$$x(0.571 + 1) = d$$

$$1.571x = d$$

$x = 0.636d$ *(reducing to* $x = 0.6d$ *for safety)*

$x = 0.6d$

$d = 329$

$x = 0.6 \times 329$

$x = 197.4$

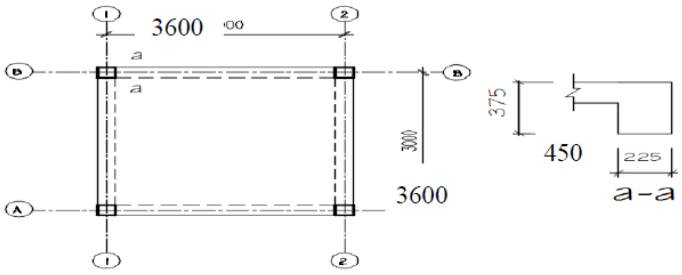


Figure 3.2 Beam layout

3.1.1 Prototype/Full Scale Design

Design procedures and information

Prototype/full scale Design

Design procedure and information

Slab thickness	150 mm
Width of Beam	300 mm
Total beam height	450 mm
Block wall height	2775 mm
fck	25 N/mm2
fyk	400 N/mm2
Density of the concrete	24.5 KN/m3
Density of wall load	3.47 KN/m3
Concrete cover	30 mm
Determination of slab load slab self-weight	0.15 x 24.5 = 3.68 KN/m2
Partition allowance	1.0 KN/m2
Finishes	1.2 KN/m2
Totally permanent load Gk	5.88 KN/m2
Variable Load Qk	2.0 KN/m2
Determine the self-weight of Beam	(0.45-0.15) x 24.5 x 0.3 =2.29 KN/m
Wall Load	3.47 x 2.775 =9.63 kN/m^2

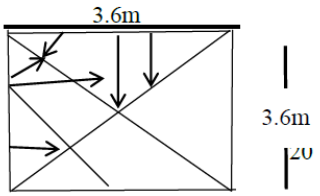


Figure 3.3 Beam Load distribution section

Since it's a single span

Area of triangle

Area = $\frac{1}{4}(Lx^2)$

Area = $\frac{1}{4}(3.6^2) = 3.24m^2$

$W1 = \frac{Area\ x\ Slab\ Load}{Span}$

Proportion of permanent slab load

W1Gk = $\frac{A\ x\ permanent\ Load}{Span}$

W1Gk = $\frac{3.42\ x\ 5.88}{3.6} = 5.29kN/m$

Proportion of Live load

W1Qk = $\frac{3.24\ x\ 2}{3.6} = 1.8\ kN/m$

Total factored permanent load for the span = proportion of slab load + Beam self-weight + Block wall load

Gk = 5.29 + 2.21 + 9.63 = 17.13 kN/m

Total factored Variable load

Qk= 1.8kN/m

Combine Loading

W1 = 1.35Gk + 1.5Qk

W1 = 1.35 x 17.13 + 1.5 x 1.8 = 25.83 kN/m

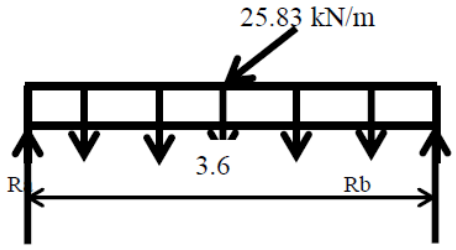


Figure 3.4 Beam FBD

Ra = Rb = $\frac{WL}{2} = \frac{25.83\ x\ 3.6}{2} = 46.49\ kN$

Ved = 46.49kN

Max = $\frac{WL^2}{8} = \frac{25.83\ x\ 3.6^2}{8} = 41.84\ kN/m$

Med = 41.84 kNm

Effective depth d = h - c - $\frac{\Phi}{2}$ - link

d = 450 - 30 - $\frac{16}{2}$ - 8 = 404 mm

d = 404 mm

b = 300 mm

fck = 25 N/mm^2

fyk= 400 N/mm^2

Span Reinforcement

Maximum span moment Med = 41.84kNm

The span is flange beam (L-Beam)

Beffi = $\sum beffi + bw \leq b$

beffi = 0.2bi + 0.11○ ≤ 0.21○

0.21○ = 0.2 x 0.85 x 3600 = 612mm

beffi =$0.2\ x\ \left(\frac{3600-300}{2}\right) + 0.1\ x\ 0.85\ x\ 3600 = 636mm$

beffi = 636mm

Use beff = 612mm

$K = \frac{M}{beffi\ x\ d^2\ x\ fck} = \frac{41.84\ x10^6}{612\ x\ 404^2\ x25} = 0.02$

K' = 0.207 K < K' Compression steel reinforcement not require

$Z = d[\ 0.5 + \sqrt{0.25 - \frac{K}{1.134}} \leq 0.95d$

$Z = 404\ x\ [0.5 + \sqrt{0.25 - \frac{0.02}{1.134}} = 396.74mm$

0.95 x404 =384mm

Use Z = 384mmAsreq = $\frac{M}{0.87\ x\ fyk\ x\ Z}$

Asreq = $\frac{41.84\ x\ 10^6}{0.87\ x\ 400\ x\ 384} =$ 313.1mm2

Provide 2Y16 bot [Aspro = 402mm2]

Minimum and Maximum Reinforcement Area

Asmin = $\frac{0.26fctm}{fyk}\ x\ Ac$ but not less than 0.0013Ac

Fctm = $0.3\ x\ fck^{\frac{2}{3}} = 0.3\ x\ 25^{\frac{2}{3}} = 2.56$

Ac = b x h = 300 x 450 = 135000mm
0.0013Ac = 0.0013 x 135000 = 175.5mm

Asmin = $\frac{0.26\ x\ 2.56}{400}\ x\ 135000 = 225mm^2$

$0.0013Ac = 0.0013 \times 135000 = 175.5mm$

Use Asmin = $225mm^2$ $Asmin = \frac{0.26\ x\ 2.56}{400} x\ 135000 = 225mm^2$

$Asmax = 0.04Ac = 0.04 \times 13500 = 5400mm^2$

$Asmin = \frac{0.26\ x\ 2.56}{400} x\ 135000 = 225mm^2$

$Asmin < Asprov < Asmax \quad 225 < 402 < 5400$ $Asmin = \frac{0.26\ x\ 2.56}{400} x\ 135000 = 225mm^2$

Check for deflection

Percentage required tension Reinforcement [L-Beam]

$$p = \frac{Asreq}{Ac} = \frac{Asreq}{[d\ x\ bw + (beffi - bw)\ x\ tf]}$$

$$p = \frac{313.1}{[404\ x\ 300 + (612 - 300)\ x 150]} = 0.0019$$

Reference Reinforcement Ratio

$$p\circ = (fct)^{\frac{1}{2}}\ x\ 10^{-3}$$

$$p\circ = (25)^{\frac{1}{2}}\ x\ 10^{-3} = 0.005$$

$$p \leq p\circ$$

$$\frac{L}{d} = k[11 + 1.5\sqrt{fck}\ x\ \frac{p_0}{p} + 3.2\sqrt{fck}\ x(\frac{p_0}{p} - 1)^{\frac{3}{2}}]$$

Factor for structural system

k = 1.0

$$\frac{L}{d} = 1.0\ x\ [11 + 1.5\sqrt{25}\ x\ \frac{0.005}{0.0019} + 3.2\sqrt{25}\ x\ (\frac{0.005}{0.0019} - 1)^{\frac{3}{2}}]$$

$$\frac{L}{d} = 64.1$$

Determine factor 1 f1 = $\frac{beffi}{bw} = \frac{612}{300} = 2.04$

Flange section where the ratio of the flange breadth to the rib breadth exceed 3m = 0.8

Determine factor 2 (for beam with span exceeding 7m) = 1

Modification factor for steel stress other than 310MPa = $\frac{310}{Qs}$

$$\frac{310}{Qs} = \frac{500\ x\ Asprov}{fyk\ x\ Asreq} = \frac{500\ x\ 402}{400\ x\ 313.1} = 1.6$$

Since 1.6 > 1.5

Use $1.5 \leq as\ \frac{310}{Qs}$

Therefore, allowable span effective depth ratio

$$\frac{L}{d} = 61.54$$

$\left(\frac{L}{do}\right) = \frac{3600}{404} = 8.91$

Actual span effective depth ratio

Shear Reinforcement from the analysis, the maximum design shear force

$Ved = 46.49\ KN$

Determine the design shear force at the face of support VEd,f

VED, f = 46.49 – (25.83 x 0.5 x 0.3) = 42.62 KN
VED, f = 42.62 KN

Calculate the shear stress at the face of the support VRd, sf = $\frac{\text{VED,f}}{(bw\ x\ 0.9d)}$

VRd, sf = $\frac{42.62 \times 10^3}{(300\ x\ 0.9\ x\ 404)} = 0.40N/mm$

VEd, sf = 0.40N/mm2

Determine the design shear force at (depth of beam) distance from the face of the support.VED,d

VEd,d = Ved,f - Udl x the depth of beam

VEd, d = 42.62 − 25.83 x 0.404 = 32.2KN

VEd, d = 2.2KN

Calculate the shear stress at the distance from the face of the support,VRd,sd

VRd,sd = $\frac{\text{VEd,d}}{(bw\ x\ 0.9d)}$

VRd, sd = $\frac{32.2 \times 10^3}{(300\ x\ 0.9\ x\ 404)}$

VRd,sd = 0.3N/mm^2

Determine the concrete strut capacity in terms of stress at the face of support VRd,max

VRd,max when $\Theta = 22^o$

VRd,max = $0.138\ x\ \left(1 - \frac{fct}{250}\right)\ x\ fct$

VRd,max = $0.138\ x\ \left(1 - \frac{25}{250}\right)\ x\ 25$

VRd,max = 3.11N/mm^2

Since VRd,max ≥ VRd,sf (3.11≥0.40)

Use Θ as 22^o

Shear reinforcement required can be determined as follow

$\frac{Asw}{S} = \frac{VRd,sd}{0.87\ x\ fyk\ x\ cot\Theta}$

$\frac{Asw}{S} = \frac{0.30\ x\ 300}{0.87\ x\ 400\ x\ \cot 22} = 0.1$

The maximum longitudinal spacing between shear assemblies by using the express

Smax = 0.75d 0.75 x 404 = 303mm

try ϕ8mm Links with 2 legs

Area of ϕ8mm = $\frac{\Pi x d^2}{4} = \frac{\Pi x 8^2}{4} = 50.3mm^2$

For 2 legs of ϕ8mm 2 x 50.3 = 101mm^2

try spacing of 300mm

Provide ϕ8 Link @300mm [$\frac{Asw}{S} = 0.3$]