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The Effectiveness of Two-Layer Reinforced Concrete Beam with Different Grades of Concrete

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ABSTRACT: *This article examined the effectiveness of two-layer reinforced concrete beam with different grades of concrete. To achieve the research aim, twelve reinforced concrete beams of 1200mm x 100 x 150mm depth (consist of Two 10mm diameter rebars in the tension zone and Two 8mm diameter rebars was used as hanger bars, 6mm diameter rebars spaced at 200mm were used as shear bars) were constructed for this research as specified by BS 1881-109:1983. Three of which were the control reinforced concrete beam formed completely of the higher-grade concrete. (1:2:4 concrete mix). Then, the remaining nine beams were form in different group types as follows: Type-P: Reinforced concrete beams and cubes formed completely of the higher-grade concrete. (1:2:4 concrete mix ratio), Type-E1: The compression layer (half the depth) concrete, is a higher grade (1:2:4 concrete mix ratio), and the tension (half the depth) layer, is lower grade (1:3:6 concrete mix ratio),Type-E2: The compression layer (half the depth) concrete, is a lower grade (1:3:6), and the tension (half the depth) layer, is higher grade (1:2:4 concrete mix ratio), Type-E3: The compression layer (two-third the depth) concrete, is a higher grade (1:2:4 concrete mix ratio), and the tension (one-third the depth) layer, is lower grade (1:3:6 concrete mix ratio), Type-E4: Reinforced concrete beams and cubes formed completely of the lower-grade concrete. (1:3:6 concrete mix ratio). All the different group types reinforced concrete beams were subjected to flexural testing at 28days of curing over a span of 1100mm at two point-load application. Dial Gauge was positioned at the middle point beneath the beam. The load was applied by hydraulic jack, with an increment of 3.66kN throughout the tests. The deflection was recorded in every 3.66kN increment by Dial Gauge. The test results confirmed that the two-layer beam attains almost the same bending resistance as the control reinforced concrete beam formed completely of the higher-grade concrete. But the control reinforced concrete beam formed completely of the higher-grade concrete performed about 3.4, 8.7 and 0.2% better than Type-E1, Type-E2 and Type-E3 respectively. Crack pattern for beam design for flexural failure was observed for Specimen Type P, E1 and E2 while specimen type E2 cracked both in shear and flexure. All specimen type experienced crushing at the compression zone. From Figure 1.0, Type-E1 and Type-E2 deflect significantly more than Type-P and Type-E3 at ultimate failure, this means Type-P and Type-E1 withstand deformation in response to an applied load than Type-E1 and Type-E2. Based on the results, it is recommended that double layer beams with 2/3 depth higher grade concrete at the top layer and 1/3 depth of lower grade concrete at the bottom layer can be used in structural members.*

KEYWORDS: *Two-Layer Beam, Different Grades of Concrete, Moment Capacity, Mode of failure*

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I. INTRODUCTION

Concrete is a man-made building material made up of particle size lesser than 4.75 mm and the particle sizes more than 4.75 mm and a binding material produced from a mixture of cement and water. Additional constituents can also be applied to modify the properties of concrete. The concrete properties so produced are one of a kind from any of its constituent materials, and that makes concrete a composite material. As a construction material, concrete has high strength in compression but vulnerable in tension. To overwhelmed the weak tensile performance, deformed steel bars are placed where it is expected to go into tension. That was the birth of Reinforced cement concrete structure.

The significant material in the construction sector is the reinforced cement concrete. In recent times, there had been an appreciable rise in the application of concrete. This has led to a sudden reduction of raw materials used for its making. In a bid to discover other processes that can be used in concrete, different studies have been done to decrease the usage of cement in concrete. The longer side (tension zone) and shorter side (compression zone) in a simply supported reinforced concrete beam deflecting under load are divided by the neutral axis. Longer side (tension zone) can be seen at the area beneath the neutral axis and shorter side (compression zone) at the upper area of the neutral axis. In a beam, steel rebars are placed at the longer side because concrete is weak or fail in tension. The concrete placed beneath the neutral axis is referred to as sacrificial concrete. It is called sacrificial concrete because it is responsible for moving stress via the compression zone to the tension zone. Concrete strength before the neutral axis is not completely used, the concrete at the upper region of the neutral axis is also not stressed while the concrete beneath the neutral axis acts as a means of transferring shear. In the neutral axis zone concrete with a lower grade can be utilized.

Ataria and Wang [1], present the outcome of an analytical, numerical and experimental research of bending and shear performance of reinforced concrete beams supported at both ends with two-layers of various grades of concrete. The compression layer (1/3rd) concrete, is a higher grade, and the tension (2/3rd) layer, is lower grade the usage of rubber recycled aggregate concrete. The test results showed that the two-layer beam attains the same bending resistance as the control reinforced concrete beam formed completely of the higher-grade concrete. In concrete beams short of shear reinforcement, the two-layer beam confirmed lower shear strength than the control beam. Finite Element simulations disclose that the compression layer higher grade concrete does not affect the beam's shear resistance. Therefore, the lower concrete grade should be used when computing shear resistance of two-layer beam.

Iskhakov and Ribakov [2] stated that double-layer fibered concrete beams can be analyzed through traditional methods for composite elements. The authors showed that the key disadvantage of high strength concrete is their low ductility. Fibres were introduced to solve the low ductility problem in the HSC layer.

Iskhakov et al [3] researched on two-layer beams, comprising of steel fibered high strength concrete in the compression zone and conventional strength concrete in the tensile zone, are researched experimentally. Three identical samples with incessant fibre proportion, conforming to the suitable ductility level, were produced and tested by four-point loading. The results reveal the function of fibres in a high strength concrete layer and develop a basis for the formation of two-layer beams design provisions.

Gara et al., [4] suggested different numerical techniques of the solution to handle beams with a larger class of loading and support conditions.

Schnabl et al. [5] explained the solution technique of the equations governing the model and carried out a parametric study to research the effect of shear deformation on the behaviour of simply supported two-layer beams loaded uniformly.

It has been tested from researches conducted in previous times that the global stiffness and strength of a composite beam has a better effect than the sum of the global stiffness and strength of the various layers obtain individually, [6].

A composite beam is a beam that has two layers, which may be made of the same or different materials, having the same or different dimension, and can be connected either by mechanical means or with the aid of adhesive, [7].

In this article, the authors aim to study the bending and failure mode of a double layer rectangular reinforced concrete beam with different concrete grades.

II. MATERIALS AND METHOD

Materials

Cement-The cement used in the research was Portland Limestone Cement of Grade 42.5. It conformed to [8]. **Fine Aggregate-**The fine aggregate used was sourced from river sand at Wilberforce Island, Amassoma, a neighborhood of Yenagoa, Capital of Bayelsa State, Nigeria. Scums were removed and it confirmed to [9]. **Coarse Aggregate-**Coarse aggregate used was crushed stones having rough-textured sourced from Yenagoa, Capital of Bayelsa State, Nigeria. The maximum size was 12mm. It conformed to [9]. **Water-**Water used was sourced from the Civil Engineering Laboratory of the Niger Delta University. It conformed to [10]. **Formwork-**High-Density Polyethylene Marine Board was used for the construction of the formworks. It conformed to [11]. **Steel Reinforcement-**The internal reinforcement used was a deformed bar, which is categorized by ribbed protrusions rolled onto their surfaces during the production process. It conformed to [12].

Method

Test Beam Specimens-Twelve reinforced concrete beams of 1200mm x 100 x 150mm depth (consist of Two 10mm diameter rebars in the tension zone and Two 8mm diameter rebars was used as hanger bars, 6mm diameter rebars spaced at 200mm were used as shear bars) were constructed for this research as specified by BS

1881-109:1983. Three of which were the control reinforced concrete beam formed completely of the higher-grade concrete. (1:2:4 concrete mix). Then, the remaining nine beams were form in different group types as follows:
Type-P: Reinforced concrete beams and cubes formed completely of the higher-grade concrete. (1:2:4 concrete mix ratio)
Type-E1: The compression layer (half the depth) concrete, is a higher grade (1:2:4 concrete mix ratio), and the tension (half the depth) layer, is lower grade (1:3:6 concrete mix ratio)
Type-E2: The compression layer (half the depth) concrete, is a lower grade (1:3:6), and the tension (half the depth) layer, is higher grade (1:2:4 concrete mix ratio)
Type-E3: The compression layer (two-third the depth) concrete, is a higher grade (1:2:4 concrete mix ratio), and the tension (one-third the depth) layer, is lower grade (1:3:6 concrete mix ratio)
Type-E4: Reinforced concrete beams and cubes formed completely of the lower-grade concrete. (1:3:6 concrete mix ratio).
All the different group types reinforced concrete beams were subjected to flexural testing at 28days of curing over a span of 1100mm at two point-load application. Dial Gauge was positioned at the middle point beneath the beam. The load was applied by hydraulic jack, with an increment of 3.66kN throughout the tests. The deflection was recorded in every 3.66kN increment by Dial Gauge.

Test cube Specimens-Fifteen (15) 150mm x 150mm concrete cubes samples were cast in different group types as stated above in this research. The concrete cube samples were cured and were safeguarded against dehydration. Compressive strength values were determined for all specimens by means of a compression testing machine. Samples were tested to failure at 28 days.

III. RESULTS AND DISCUSSION

Test results on the compressive strength, failure load, bending capacity of a two-layer reinforced concrete beam with different grades of concrete specimen types P, E1, E2, E3 and E4 are presented in both tabulated and graphical forms. Table 1 shows the direct test results and mode of failures of specimen types P, E1, E2, E3 respectively. Table 5 shows 28-days compressive strength of concrete specimen's types P, E1, E2, E3. Table 2,3 and 4 shows the computed results of cracking capacity, tensile stress and bending capacity of test beams.

Table 1: Direct Test Results

Specimen Type	Number of Samples	First Crack Load (kN)	Failure Load (kN)	Deflection at Failure (mm)	Failure Mode
Type P	Sample 1	29.31	36.64	4.69	Flexure/Crushing
	Sample 2	29.31	32.97	2.88	Flexure/Crushing
	Sample 3	27.48	36.64	4.05	Flexure/Crushing
Type-E1	Sample 1	21.98	34.80	6.57	Flexure/Crushing
	Sample 2	21.98	32.97	5.80	Flexure/Crushing
	Sample 3	21.98	33.89	6.19	Flexure/Crushing
Type-E2	Sample 1	21.98	29.31	3.65	Flexure/Shear/Crushing
	Sample 2	21.98	34.80	8.51	Flexure/Shear/Crushing
	Sample 3	21.98	32.06	6.08	Flexure/Shear/Crushing
Type-E3	Sample 1	18.32	32.97	4.25	Flexure/Crushing
	Sample 2	25.65	37.37	4.80	Flexure/Crushing
	Sample 3	21.99	35.17	4.53	Flexure/Crushing

Table 2: Cracking Capacity of Beams

Specimen Type	Number of Samples	First Crack Load (kN)	Cracking Capacity (kNm)
Type P	Sample 1	29.31	5.37
	Sample 2	29.31	5.37
	Sample 3	27.48	5.03
Type E1	Sample 1	21.98	4.03
	Sample 2	21.98	4.03
	Sample 3	21.98	4.03
Type E2	Sample 1	21.98	4.03
	Sample 2	21.98	4.03
	Sample 3	21.98	4.03
Type E3	Sample 1	18.32	3.36
	Sample 2	25.65	4.70
	Sample 3	21.99	4.03

Table 3: Tensile Stress of Beams

Specimen Type	Number of Samples	First Crack Load (kN)	Tensile Stress (N/mm2)
Type P	Sample 1	29.31	14.33
	Sample 2	29.31	14.33
	Sample 3	27.48	13.43
Type E1	Sample 1	21.98	10.75
	Sample 2	21.98	10.75
	Sample 3	21.98	10.75
Type E2	Sample 1	21.98	10.75
	Sample 2	21.98	10.75
	Sample 3	21.98	10.75
Type E3	Sample 1	18.32	8.96
	Sample 2	25.65	12.54
	Sample 3	21.99	10.75

Table 4: Bending Capacity of Beams

Specimen Type	Number of Samples	Failure Load (kN)	Bending Capacity (kNm)
Type P	Sample 1	36.64	6.71
	Sample 2	32	5.87
	Sample 3	36.64	6.72
Type E1	Sample 1	34.80	6.38
	Sample 2	32.97	6.04
	Sample 3	33.89	6.21
Type E2	Sample 1	29.31	5.37
	Sample 2	34.80	6.38
	Sample 3	32.06	5.88
Type E3	Sample 1	32.97	6.04
	Sample 2	37.37	6.85
	Sample 3	35.17	6.45

Table 5: 28-Days Compressive Strength

Specimen Type	Size of Cube (mm)	Weight of Specimen (kg)	Applied Compressive Load (kN)	28-Day Compressive Strength (N/mm^2)
Type-P	150x150x150	8	643.3	28.60
Type-E1	150x150x150	8	470.0	20.89
Type-E2	150x150x150	8	453.3	20.81
Type-E3	150x150x150	8	473.3	21.04
Type-E4	150x150x150	8.5	400.0	17.78

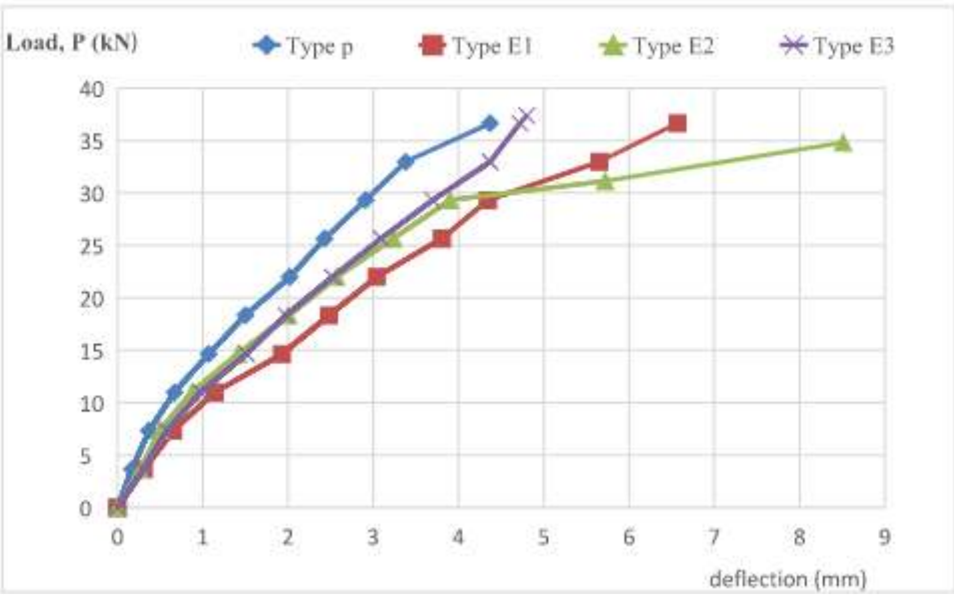

Fig. 1. Load against deflection of test specimen Type P, E1, E2, E3

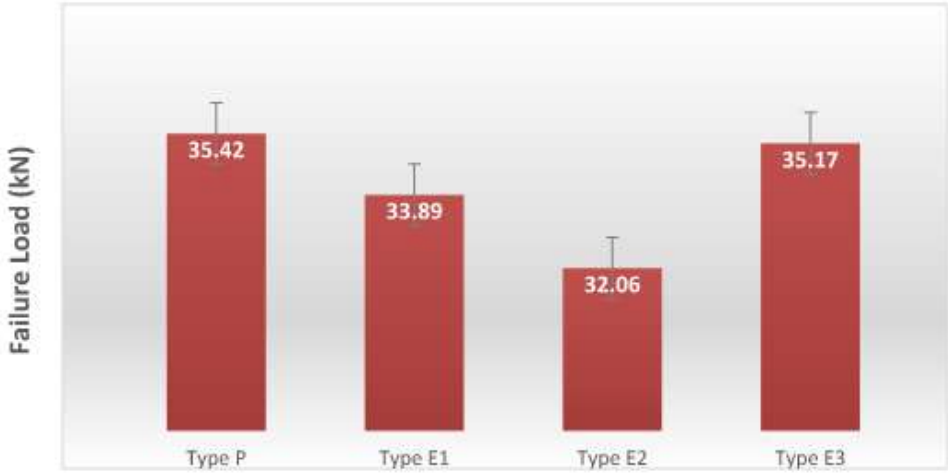

Fig. 2. Pictorial view showing the performance of each beam type

IV. DISCUSSION

First Crack Load

From Table 1, it is understood that the two-layer beams (Type E1, E2 and E3) observed first crack at an average load of 21.98kN which is lower than the average first crack load of the beams formed completely of the higher-grade concrete. (1:2:4 concrete mix ratio, Type-P) which is 28.7kN. This show that the double layer beam (Type E1, E2 and E3) due to the variation in the concrete grade at various layers.

Bending capacity

From Table 4, it is observed that the two-layer beam attains almost the same bending resistance as the control reinforced concrete beam formed completely of the higher-grade concrete. But the control reinforced concrete beam formed completely of the higher-grade concrete performed about 3.4, 8.7 and 0.2% better than Type-E1, Type-E2 and Type-E3 respectively.

Mode of Failure

Table 1 presents the failure modes, cracking loads and failure loads of the two-layer reinforced concrete beam with different grades of concrete specimen types P, E1, E2, E3 and E4 based on experimental results. Crack pattern for beam design for flexural failure was observed for Specimen Type P, E1 and E2 while specimen type E2 failed in both shear and flexure. All specimen type experienced crushing at the compression zone.

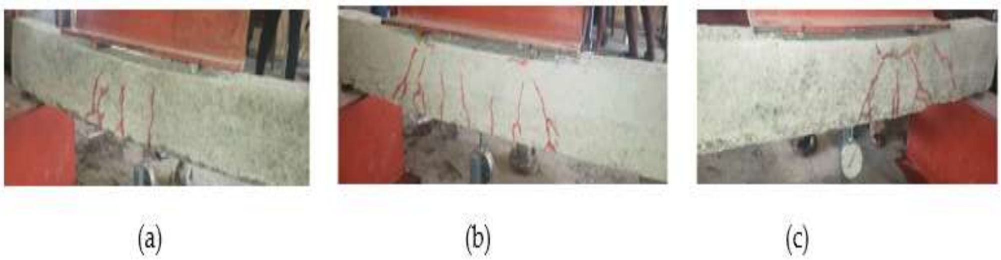

Fig. 3. Failure mode of test specimen: (a) Type-E1, (b) Type-E2, (C) Type-E3,

Deflection of beams

The load against deflection curves established on the experimental outcomes of beams types P, E1, E2, E3 and E4 are illustrated in Fig. 1. Figure. 1 shows that all the test beams samples presented linear, elastic segments of the curves at the early phases. From Figure 1.0, Type-E1 and Type-E2 deflect significantly more than Type-P and Type-E3 at ultimate failure, this means Type-P and Type-E1 withstand deformation in response to an applied load than Type-E1 and Type-E2. From the results, it is confirmed that Increase in lower concrete grade layer leads to decrease in toughness and ductility of tested specimens.

Cracking capacity and Tensile Stress

From Table 2, control (Type-P) reinforced concrete beam samples produced completely of the higher-grade concrete (1:2:4) confirmed higher **Cracking capacity and Tensile Stress** than two-layer beams (Type-E1, Type-E2 and Type-E3).

Cost Effectiveness

The cost comparison between the double layer beams and the beams formed completely of the higher-grade concrete shows that Type E1 and E2 are 4.3% lesser than the cost of constructing Type-P while Type-E3 is 3% lesser than the cost of constructing Type-P therefore indicating that the double layer beam is more cost effective than the control beam.

V. CONCLUSION

Conclusion

Experimental research was carried out on two-layer rectangular reinforced concrete beam with different concrete grades to study the effectiveness of its structural performance. From the outcomes of experiments, the following conclusions can be drawn:

- The double layer beams with half the depth of higher-grade concrete at the top layer and half the depth of lower grade concrete at the bottom layer is affective and structurally satisfactory
- The double beams with half the depth of higher-grade concrete at the bottom layer and half the depth of lower grade concrete at the top layer can be encourage in construction industries to reduce cost.
- The double layer with 2/3 depth of higher-grade concrete at the top layer and 1/3 depth of lower grade concrete at the bottom layer performed at the same range with the control beam.
- Concrete beam formed completely of the higher-grade concrete withstand deformation in response to an applied load and tougher than two-layer reinforced concrete beam with different grades of concrete
- Two-layer reinforced concrete beam with different grades of concrete are cheaper than Concrete beam formed completely of the higher-grade concrete

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