

Optimum Depth of a Lower Concrete Grade at the Tension Zone in a Two-Layer Reinforced Concrete Beam



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ABSTRACT: This paper presents the results of an investigation into the optimum depth of the lower concrete grade (LCG) at the tension region in a two-layer reinforced concrete beam. A total of nine (9) simply supported two-layer RC beams (1100 x100 x150 mm) were studied. Two 8 mm and two 6 mm diameter rods were used as reinforcement at the bottom and top of each two-layer beam, respectively. The beam samples were grouped into two: the first group comprises two-layer RC beams produced with 1:2:4 as the higher grade and 1:3:6 as the lower grade; the second group comprises two-layer RC beams cast with 1:2:4 as the higher grade and 1:4:8 as the lower grade. The depth of LCG adopted for each group is 25 mm to 100 mm at a step of 25 mm out of the total beam depth of 150 mm. The beams were subjected to two-point static loading to evaluate the load resistance and deflection. The results show that the greater the depth of the layer under compression, the stiffer the beam. The two-layer RC beam has an equal loading carrying capacity as the beam made entirely of higher grade. The depth of the layer of RC beam under tension in two-layer beams should be kept between 40 and 50% of the overall beam depth, which would be desirable structurally.

KEYWORDS: Bending resistance, Beam, Optimum depth, Shear resistance, Stiffness two-layer.

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I. INTRODUCTION

Beams are structural members that support slabs and vertical walls. A beam is usually split into two parts by a neutral axis; the zone that is under tension or bottom (tension zone) and the part that is under compression at the top (compression zone). As reported in Tarak and Vincy (2019) and Amadise *et al* (2020), concrete has low tensile strength. Therefore, rebars are provided in the zone that is under tension to improve the weak tensile properties of concrete. Irrespective of low tensile strength, concrete ought to be provided at the tension zone to serve as a medium for transferring strain to rebar and is referred to as sacrificial concrete. If the tensile stresses developed at the TZ are resisted by the rebar, then why use a high grade of concrete in that zone? This simple question led to the concept of reducing the concrete grade in the TZ for reinforced concrete (RC) structural members to reduce construction costs. According to Tarak and Vincy (2019), the strength of concrete located close to the neutral axis is not completely used in steel-reinforced concrete beams.

Concrete, which was first utilized by the Romans and Egyptians between 1400 and 1200 BC, then again between 300 and 476 A.D. by combining fragmented stones with a mortar and, occasionally, volcanic ash, has evolved over time and with advances in scientific technology to become what

the construction sector is today. Being dissatisfied with the material at that time, Joseph Monier developed reinforced cement concrete in the year 1849 and then patented it in 1875 (Kim and Irving, 2010). With an innovative touch of Ernest L. Rensome and William Ward, the design and proper placement of reinforcements in concrete were actualized (Kim and Irving, 2010). Since then, various structural elements have been developed to help give a framed structure, and without reinforcement, constructing modern structures with concrete material would not be possible. The second most used composite material in the construction sector, according to the Cement Association of Canada (CAC, 2008), is concrete. The rate of concrete production was estimated to be one person per 1000 kg annually (CAC, 2008). The tensile resistance of concrete is only around 10% of its compressive strength (Mosley *et al*, 2007). As a result, practically all RC elements are engineered with the concept that concrete will not resist tensile stress (Mosley *et al*, 2007). In their investigation, John *et al* (2019) revealed the feasibility of two-layer reinforced concrete beams and concluded that the two-layer steel-reinforced concrete beams had almost the same load resistance as the steel-reinforced concrete beams made single layer of higher concrete grade (HCG). According to John *et al* (2020), two-layer reinforced concrete beams with two thirds of the top layer of higher grade and one third of the bottom layer of lower grade can be structurally desirable. Ataria and Wang (2019) reported the

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findings of their research into the shear and bending resistance of two-layer steel RC beams of varying grades. A compression layer one third of that is a higher grade (HG), and a tension layer two thirds that is a lower grade (LG), of rubber recycled aggregate concrete. According to the results, the two-layer RC beam has an equal bending resistance as the beam made entirely of HG. The two-layer beam demonstrated lower shear resistance than the single layer beam made entirely of HG. According to finite element models, the compression layer of HG concrete has no influence on the shear strength of the beam. Schnabl *et al* (2007) presented a mathematical equation for two-layer beams that takes into consideration, shear deflection and interlayer slip. An exact solution for a two-layer beam with uplift and interlayer slip was reported by Kroflic *et al* (2010). Foraboschi (2009) examined a two-layer beam mathematical approach accounting for nonlinear interlayer slip. Nguyen *et al* (2011) developed an exact stiffness matrix for a double-layer Timoshenko beam member with partial interaction. Findings of a numerical and analytical investigation of multi-layered beam elements with interlayer slip were reported by Sousa and da-Silva (2010). A double-layer beam member with uplift and interlayer slip was subjected to a non-linear analysis by Kroflic *et al* (2011). Findings from an analytical solution of multi-layer beam members with compliant interfaces were described by Skec *et al* (2012).

In order to investigate the feasibility of using the weak effect of the concrete at the tension zone of a beam that lies in this zone, Zena *et al* (2019) conducted an empirical investigation of the layered beam. By employing lightweight concrete in the tension zone; they were able to form a beam that was lighter relative to a homogenous reinforced concrete beam.

The findings of an investigation into the effects of concrete grades (CG) on the strength properties of slender RC beams were presented by Olanitori and Gbadamosi (2019). The findings demonstrate that there was a comparable reduction in shear and load resistance with a drop in CG. Beam strength decreased by approximately 10.5, 21.79, and 32.75% for CG drops of 16.67%, 38.67%, and 62%, respectively. As a result, the strength properties of beams do not fall by the same proportion when the CG is reduced. Results of increasing the load, shear, and bending strength of RC 2-layer beams using crushed ceramic tile as a layer are presented by Amadise *et al* (2020). John *et al* (2022) study on Agro-waste as coarse aggregate in triple-layer RCC beams. This research is geared towards defining the structurally acceptable depth a lower grade of concrete will occupy in a two-layer reinforced concrete beam without affecting its structural performance negatively.

Table 1: Beam sample descriptions

SAMPLE ID	Beam Dimensions			Depth Of Top Layer (mm)	Depth Of Bottom Layer (mm)	Top Layer Mix Ratio	Bottom Layer Mix Ratio
	Beam Depth (mm)	Beam Width (mm)	Beam Length (mm)				
SG1	150	100	1200	150	-	1:2:4	1:2:4
SG2T	150	100	1200	125	25	1:2:4	1:3:6
SG3T	150	100	1200	100	50	1:2:4	1:3:6
SG4T	150	100	1200	75	75	1:2:4	1:3:6
SG5T	150	100	1200	50	100	1:2:4	1:3:6
SG2W	150	100	1200	125	25	1:2:4	1:4:8
SG3W	150	100	1200	100	50	1:2:4	1:4:8
SG4W	150	100	1200	75	75	1:2:4	1:4:8
SG5W	150	100	1200	50	100	1:2:4	1:4:8

II. MATERIALS AND METHODS

A. Material Properties

The Portland limestone cement of the 42.5 N grade specified by BS EN 197-1 (2011), fine aggregate and coarse aggregate of bulk specific gravity of 2.67 and 2.72, respectively, were considered in the production of the two-layer RC beams. Nine (9) simply supported 2-layer RC beams (1100x100x150 mm) were subjected to laboratory study. Two 8 mm and two 6 mm diameter rods were provided as reinforcement at each 2-layer beam specimen's bottom and top, respectively. The reinforcements had a yield of strength of 410 N/mm².

B. Preparation of the Beam

The concrete mix proportion used in preparing the two-layer concrete beams were 1:2:4, 1:3:6, and 1:4:8. The two-layer RC beam samples were grouped into two (2): the first group is made up of 2-layer RC beams cast with 1:2:4 as higher grade (HG) and 1:3:6 as lower grade (LG). These beams were identified as SG2T, SG3T, SG4T, and SG5T for depth of top to bottom layer ratio of 125/25, 100/50, 75/75 and 100/50, respectively. The second group is made up of 2-layer RC beams cast with 1:2:4 as higher grade (HG) and 1:4:8 as lower grade (LG). These beams were identified as SG2W, SG3W, SG4W, and SG5W for a depth of top to bottom layer ratio of 125/25, 100/50, 75/75, and 100/50, respectively, as presented in Table 1.

Beam SG1, a single-layer beam having an overall depth of 150 mm, was used as a reference beam that was constructed with a single concrete mix (SCM) of 1:2:4 as shown in Figure 1a. Beam SG2T is a two-layer concrete beam with an overall depth of 150 mm. The top layer had a depth of 125 mm and is made up of a concrete mix ratio of 1:2:4 which constitute 83.33% of overall beam depth while the second layer with a depth of 25 mm is made up of a concrete mix ratio of 1:3:6 which constitute 16.67% of overall beam depth as depicted in Figure 1b. See Table 1 and Figures 1(c to e) for other beam sample descriptions.

C. Instrumentation

The beam samples were subjected to one-third point load application to evaluate the load resistance and deflection as shown in Figure 1 and were evaluated for their strength to support a load over a span of 1.1 m after 28 days of curing. A dial gauge was positioned at the mid-span under the beam. The deflection of the beams was recorded by a dial gauge for every 9.81 kN load increment. The maximum bending resistance was determined by taking a moment at the loading point.

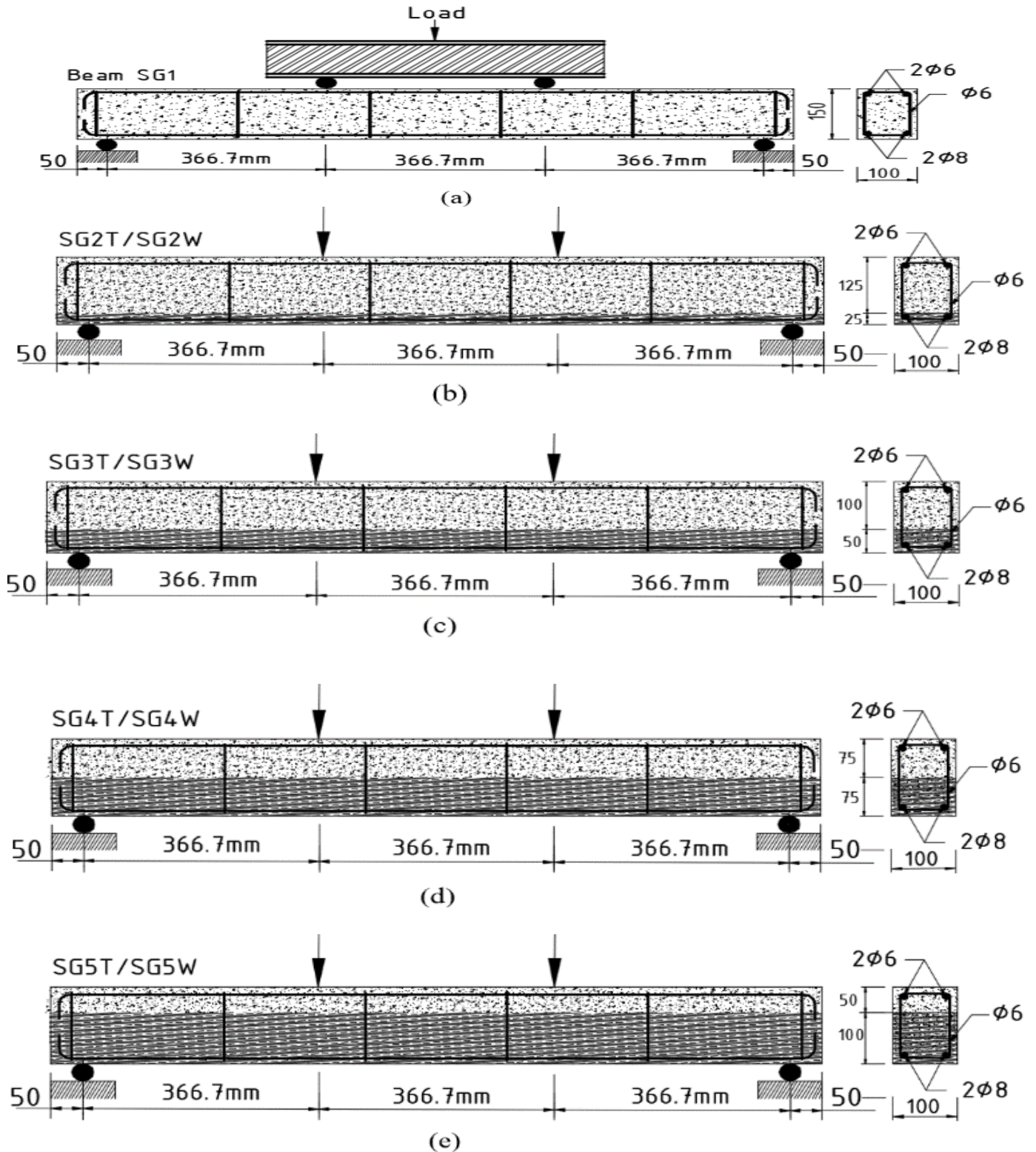


Figure 1: Beam details and configurations

II. RESULTS AND DISCUSSION

The experimental results on the determination of the optimum depth of the lower concrete grade at the tension zone in a two-layer reinforced concrete beam are presented below. The results of the study are presented and discussed

in two groups; the first group is SG1, SG2T, SG3T, SG4T, and SG5T, while the second group is SG1, SG2W, SG3W, SG4W, and SG5W.

A. Beam Samples SG1, SG2T, SG3T, SG4T, and SG5T

These are two-layer RC beams cast with 1:2:4 as HG and 1:3:6 as LG and were conducted to examine the optimum

depth of the lower concrete grade at the TZ in a two-layer reinforced concrete beam. The load steps against deflection are shown in Figure 3. The yield load, ultimate failure loads, and deflections were measured and given in Table 2.

two-layer reinforced concrete beams with two thirds of the top layer of higher grade and one third of the bottom layer of lower grade can be structurally desirable. It is clear from Figure 2 that beam SG4T had the maximum load resistance.

During the test of beam SG5T, the initial crack was observed at 9.6 kN with a corresponding deflection of 0.60 mm. The beam yielded and finally failed at a load of 29.5 kN and 37.20 kN, respectively, as a result of flexural stresses. It can be observed from Figure 2 that beam SG5T is 5.38% higher than SG1.

Table 2: Results Beams SG1, SG2T, SG3T, SG4T, and SG5T

Sample ID	Yield Load (kN)	Deflection at yield Load (mm)	Failure Load P, (KN)	Deflection at Failure Load (mm)	Bending Capacity $M=PL/6$, (kNm)	Failure Mode
SG 1	29.50	4.20	35.20	7.65	6.45	Flexure
SG2T	34.50	6.0	34.50	6.00	6.29	Flexure
SG3T	29.70	4.84	37.00	9.20	6.84	Flexure
SG4T	39.20	6.02	41.00	7.20	7.55	Flexure
SG5T	29.50	5.01	37.20	8.92	6.84	Flexure

1) Ultimate failure loads

Beam SG1 is a reference beam that was constructed with a single concrete mix (SCM) of 1:2:4. During testing, at a load of 9.12 kN, the initial crack (IC) was noticed at the mid-span of the beam with an initial deflection of 0.59 mm. The initial crack was found to be a result of flexural stresses (FS). The SG1 had a yield load of 29.50 kN with a corresponding deflection of 4.2 mm. The beam SG1 failed at a load of 35.20 kN as a result of flexural stresses. SG1 was found to be lower than SG3T, SG4T, and SG5T.

In the course of testing beam SG2T, the initial crack was observed at a load of 9.45 kN. The IC was noticed with a corresponding deflection of 0.63 mm. As loading steps increased, flexural cracks became visible. The beam yielded at a load of 34.5 kN with a 6.0 mm deflection and failed at a load of 34.5 kN. The beam completely failed due to flexural stresses resisting deflection of 6.0 mm. The SG2T had almost the same load-carrying capacity as the sample type SG1 with a 1.98% difference. Referring to the bending moments values presented in Table 2, these findings are similar to Ataria and Wang (2019), which found that the two-layer RC beam had almost equal bending resistance as a single-layer beam made entirely of HG of concrete.

During loading beam SG3T, the initial visible crack was seen at a load of 8.94 kN with a corresponding deflection of 0.59 mm. The beam yielded at a load of 29.70 kN with a deflection of 4.84 mm and at a load of 37.0 kN, the beam finally failed due to flexure. This beam is 4.86% higher than the SG1. Figure 2 shows the load-carrying capacity of SG3T. This result validates John *et al* (2019) findings, which reported that the two-layer steel-reinforced concrete beams had almost the same load resistance as the steel-reinforced concrete beams made entirely of HCG.

While testing beam SG4T, the beam deformed at 0.64 mm with a corresponding initial crack load of 9.9 kN. The beam yielded at a load of 39.20 kN with a deflection of 6.02 and at a load of 41.0 kN, the final deflection of the beam was recorded at 7.20 mm which failed due to flexure. It can be seen from Figure 2 that beam SG4T is 14.2% higher than SG1. This validates John *et al* (2020) results which states that

2) Load versus deflection behaviour

From the study results given in Table 2 and Figure 3, it can be observed from the load against deflection graph that beam SG2T is stiffer than other 2-layer beams (SG3T, SG4T, and SG5T), including the reference beam, SG1. Beam SG4T performed remarkably well by sustaining a final deflection of 7.20 mm at an ultimate failure load of 41.0 kN, which is 14.15% higher than beam SG1. The beam SG4T was approximately 0.45 times stiffer than the sample type SG1. The highest deflection was recorded in sample type SG3T. It was, however, observed from Table 2 that the higher the failure load, the higher the deflection, with the exception of SG4T.

3) Bending capacity

The bending resistance of beam SG4T was 7.55 kNm, which was higher than that of the other sample types SG1, SG2T, SG3T, and SG5T (Table 2). Additionally, the bending capacity of the beams SG3T and SG5T was higher than that of the control beam, beam SG1. The bending capacity of beam SG2T, however, was lower than that of beam SG1.

B. Beam Samples SG2W, SG3W, SG4W, and SG5W

1) Ultimate failure Loads

These beams were made up of 2-layer RC beams cast with 1:2:4 as HG and 1:4:8 as lower grade LG. The load steps against deflection are shown in Figure 5. The yield load, ultimate failure loads, and deflections were measured and given in Table 3.

During loading, it was observed that the beam SG2W yielded at a 28.45 kN load and the developed crack pattern was observed to be flexural. As the loading of the beam continues, shear cracks develop and become noticeable. The beam SG2W failed completely at 31.4 kN. The load-carrying capacity of SG2W is 11.12% less than that of SG1. The yield load, failure load, and mode of failure are shown in Table 3.

During loading beam SG3W, the initial crack developed at 9.81 kN load. Beam SG3W yielded at a load of 29.60 kN. Compression stresses were detected as the load steps

increased. Flexural cracks occurred and propagated towards the loading

kN with a deflection of 8.5 mm. The results are presented in Table 3. This finding supports John *et al* (2020) which state that two-layer reinforced concrete beams with 2/3rds of the top layer of higher grade and 1/3rd of the bottom layer of lower

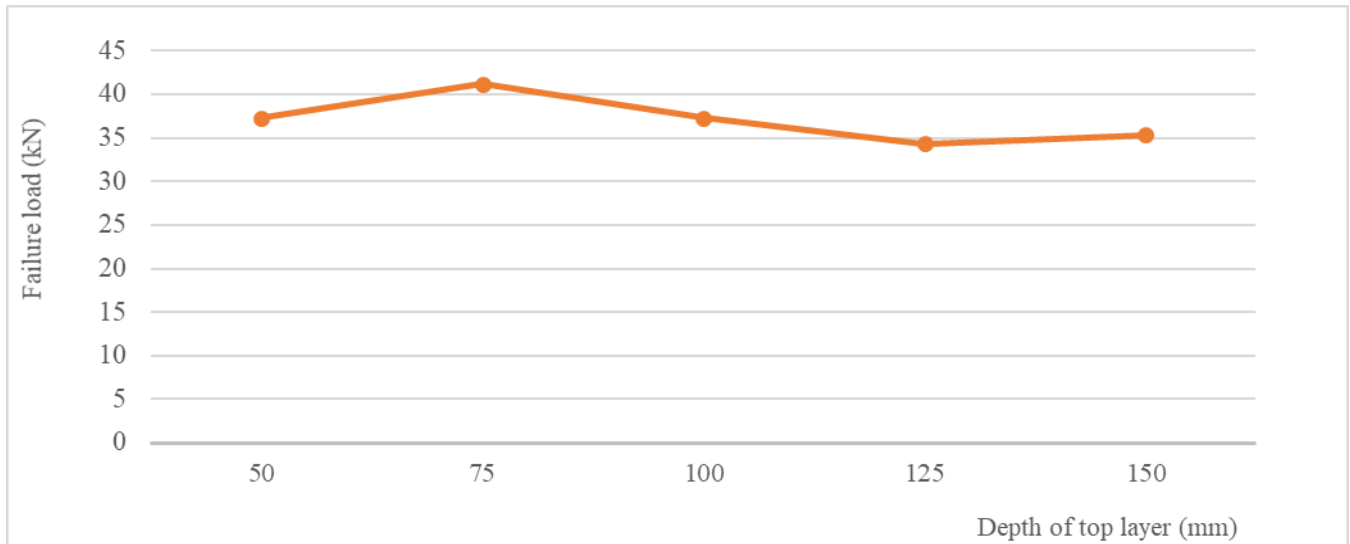


Figure 2: Failure load against top layer depth for SG1, SG2T, SG3T, SG4T and SG5T

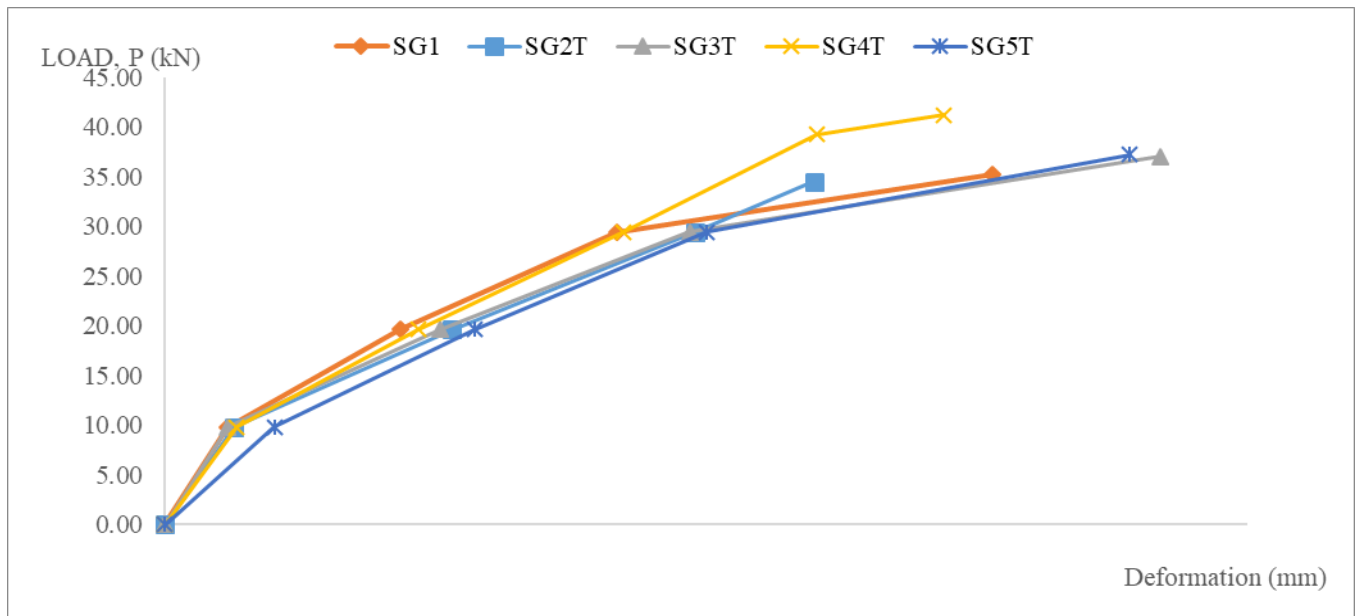


Figure 3: Failure load versus deflection for SG1, SG2T, SG3T, SG4T and SG5T

points. The SG3W failed completely at a load of 36 kN with a corresponding deflection of 8.62 mm. Considering the bending capacities presented in Table 3, the results are similar to Ataria and Wang (2019) findings, where the two-layer RC beam had almost equal bending resistance as a single-layer beam made entirely of HG of concrete.

During loading beam SG4W, it was observed that beam yielded at 29.43 kN with an initial crack load of 9.56 kN. The cracks were observed due to flexural stresses. As loading continued, the cracks became visible and shear cracks were also developed. The beam completely failed at a load of 36.5

grade can be structurally desirable. It is clear from Figure 4 that beam SG4T had the maximum load resistance.

During loading beam SG5W, it was seen that the beam yielded at a load of 19.62 kN with an initial crack of 9.8 kN. The beam completely failed at a load of 34.5 kN with a deflection value of 6.4 mm. The beam failed as a result of flexural stresses that occurred within the beam. A comparison of Beam SG5W and control beam SG1 confirms the validation of Ataria and Wang (2019), which states that the two-layer RC beam has an equal bending resistance as a beam made entirely of HG of concrete. Figure 4 shows the effect of

compression layer depth on the load resistance of two-layer RC beams.

2) *Load versus deflection behaviour*

The load- deflection records of beam samples were observed. The deflections of the two-layer beams were compared with the single-layer beam produced completely from a 1:2:4 mix of concrete. Similarly, the load- deflection behavior was compared between two-layer beams. It can be

Table 3: Results Beams SG2W, SG3W, SG4W, and SG5W

Sample ID	Yield Load (kN)	Deflection at Yield Load (mm)	Failure Load P _f (kN)	Deflection at Failure Load (mm)	Bending Capacity M=PL/6, (kNm)	Failure Mode
SG 1	29.50	4.20	35.20	7.65	6.45	Flexure
SG2W	28.45	5.30	31.40	6.39	5.76	Flexure/Shear
SG3W	29.60	5.80	36.00	8.62	6.60	Flexure/Shear
SG4W	29.43	5.35	36.50	8.5	6.69	Flexure/Shear
SG5W	19.62	5.30	34.50	6.4	6.33	Flexure

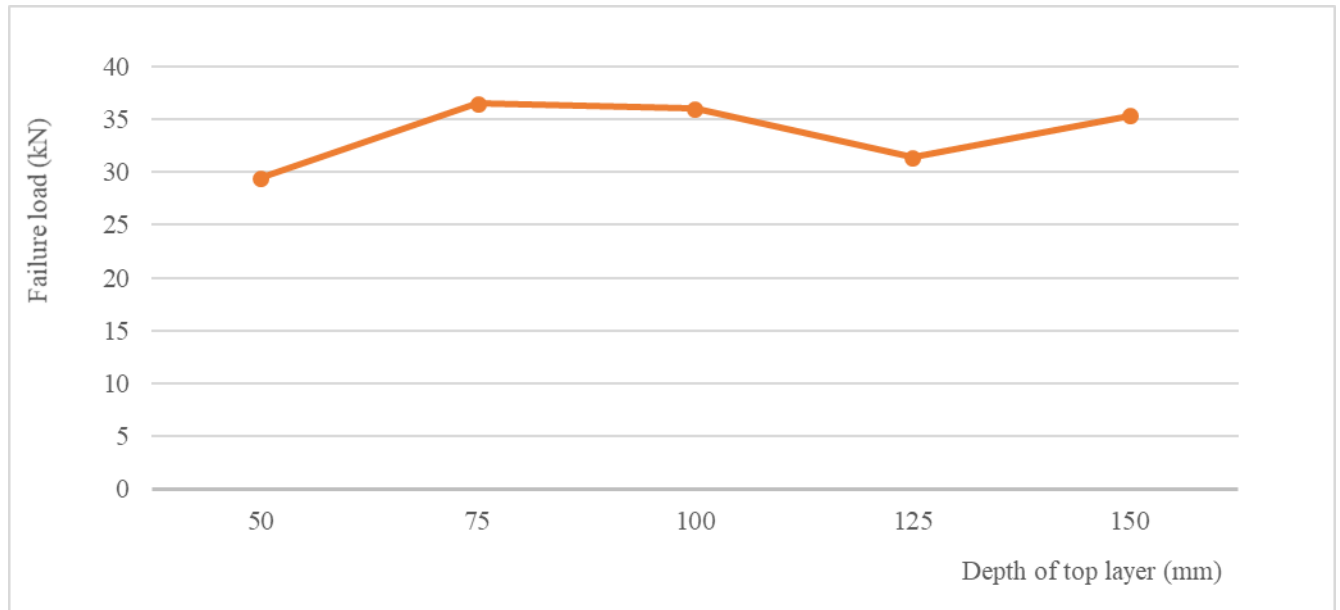


Figure 4: Failure load versus depth of top layer for SG1, SG2W, SG3W, SG4W, and SG5W

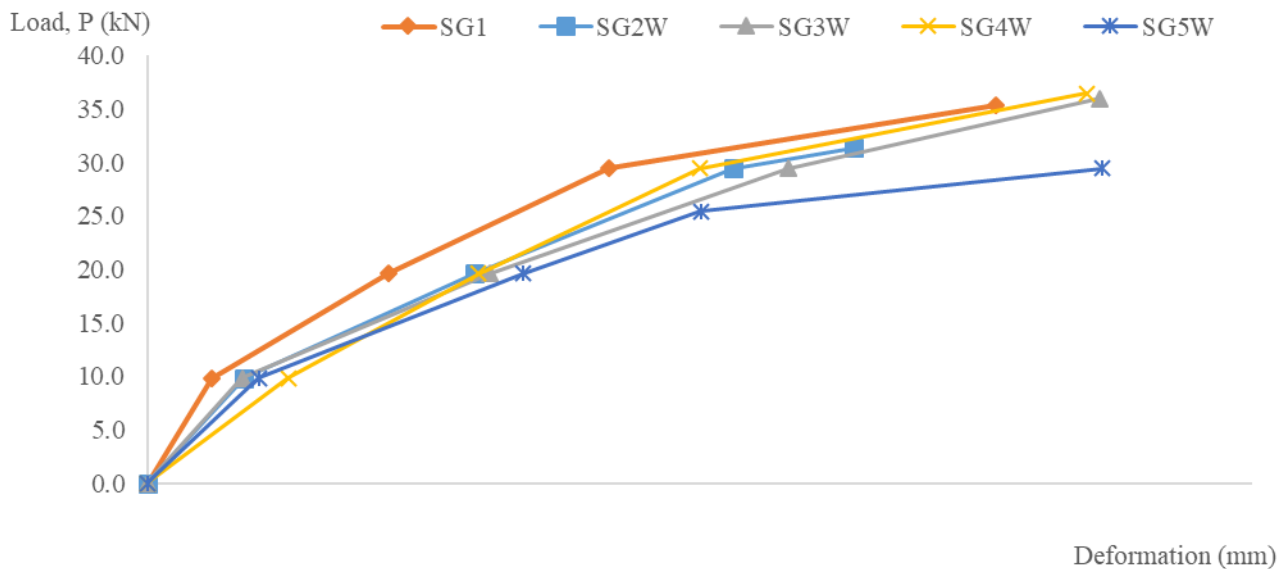


Figure 5: Failure load versus deflection for SG1, SG2W, SG3W, SG4W, and SG5W

seen from Figure 5 that the higher the depth of the compression layer, the stiffer it becomes. The maximum deflection (8.62 mm) was recorded on beam SG3W. During loading, it was noticed that SG1, SG2W, SG3W, SG4W, and SG5W showed ductile failure.

3) *Bending capacity*

From Table 3, it is seen that beam SG4W had a higher bending capacity of 6.69 kNm than the other specimens. Also, the results depicted that the beam SG2W had the lowest bending capacity of 5.75 kNm. This finding supports Ataria and Wang (2019), which states that the two-layer RC beam has an equal bending resistance as a beam made entirely of HG of concrete.

C. *Data Analysis*

As a result of the influence of countless factors, the data obtained from the laboratory shows fluctuations, and the reason for these fluctuations is grouped into two categories. One is due to various experimental conditions; the second category is a result of random error. An Analysis of variance (ANOVA) is suitable to study the significance of the variation in a sample mean and the factors said to be influenced by laboratory results. ANOVA was carried out on the test results using Design Expert.

1) *ANOVA of two-layer beams*

Table 4 provides an overview of the ANOVA for the response surface cubic mathematical model. The mathematical model F-value of 110.51, as shown in Table 4, suggests that the model is credible. An F-value of this magnitude could only occur due to noise in 0.01% of cases; those whose P-values are lower than 0.0500. A, A², and A³ are important model terms in this instance. Parameters are not significant if the value is higher than 0.1000. According to Table 5, the predicted R² of 0.9162 and the adjusted R² of 0.9648 are reasonably in agreement, meaning that the difference is less than 0.2. Signal-to-noise ratio data is logged by Adeq Precision. A ratio of at least 4 is preferred. The ratio of 34.014 indicates a strong enough signal.

Table 4: ANOVA for Cubic model

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	39.39	3	13.13	110.51	< 0.0001	Significant
A-Depth of tension layer	28.01	1	28.01	235.77	< 0.0001	
A ²	4.14	1	4.14	34.84	0.0002	
A ³	19.29	1	19.29	162.32	< 0.0001	
Residual	1.07	9	0.1188			
Lack of Fit	1.07	1	1.07			
Pure Error	0.0000	8	0.0000			
Cor Total	40.46	12				

Table 5: Fit Statistics

Std. Dev.	0.3447	R ²	0.9736
Mean	36.65	Adjusted R ²	0.9648
C.V. %	0.9405	Predicted R ²	0.9162
		Adeq Precision	34.0144

2) *Optimization of beam samples*

The expression for failure load (P_u) values as dependent variables and lower concrete grade depth (β) as independent from the statistical analysis is of the form Eqn. (1). The Eqn. (1) can be used to make predictions of the failure load for given levels of two-layer beam depths.

$$P_u = 35.26 - 0.22\beta + 0.0082\beta^2 - 0.000058\beta^3 \quad (1)$$

Upon evaluation of Table 6, it can be observed that the mathematical model prediction of Failure load is significant for beams considered for this study. Values in Tables 6 shows that the failure load predicted by Eqn. 1 are conservative.

Table 6: Analytical model for load-carrying capacity

Specimen Type	Experiment Failure Load (kN)	Predicted Failure Load (kN) Equation (1)
SG1	35.20	35.26
SG2W	31.40	33.99
SG3W	36.00	37.58
SG4W	36.50	40.61
SG5W	34.50	37.60
SG2T	34.50	33.99
SG3T	37.00	37.58
SG4T	41.00	40.61
SG5T	37.20	37.60

III. CONCLUSION

The optimal depth of the lower concrete grade at the tension zone in a two-layer reinforced concrete beam is investigated in this study. All of the RC beams were subjected to a one-third point load application and the necessary data was collected. Based on the findings, the following conclusions were reached:

- i. The greater the depth of the layer under compression, the stiffer the two-layer RC beam becomes.
- ii. The two-layer RC beams can be encouraged in the construction industry to reduce costs.
- iii. A two-layer RC beam is effective and structurally satisfactory. There was no feasible reduction in bending and load-carrying capacity with a drop in lower concrete grade layer depth.

- iv. The depth of the layer of RC beam under tension in two-layer beams should be kept between 40 and 50% of the overall beam depth.

AUTHOR CONTRIBUTIONS

J. A. TrustGod: Conceptualization, Software, Validation, Writing – original draft. **B. T. Blessing:** Conceptualization, Methodology, Data analysis, Software

REFERENCES

- Amadise, S. O.; A. T. John and G. Banje. (2020).** Improving The Bending and Load Carrying Capacity of Reinforced Crushed Stone Concrete Beams using Waste Ceramic Tiles Aggregate Concrete as a Layer. *International Journal for Innovative Research in the Multidisciplinary Field*, 6 (5): 291-297.
- Mosley B.; J. Bungey and R. Hulse (2007).** Reinforced Concrete Design to Eurocode 2. Palgrave Macmillan, 6th Ed.
- EN, B. S. (2011).** 197-1. Cement-Part 1: Composition, Specifications, and Conformity Criteria for Common Cements. London: European Committee for Standardisation.
- Cement Association of Canada (CAC) (2008).** Canadian Cement Industry Sustainability Report. Cement Association of Canada, Ottawa-Ontario.
- Foraboschi, P. (2009).** Analytical Solution of Two-Layer Beam Taking into Account Nonlinear Interlayer Slip. *Journal of Engineering Mechanics*, 135 (10): 1129-1146.
- John, A. T.; S. T. Orumu and O. E. Perezimo. (2019).** The Effectiveness of Two-Layer Reinforced Concrete Beam with Different Grades of Concrete, *American Journal of Engineering Research*, 9 (1):107-112.
- John, A. T.; S. O. Amadise and E. Ebieride. (2022).** An Empirical Study of Agro-Waste as Coarse Aggregate in Triple-Layer RCC Beams. *International Journal of Engineering and applied computer science*, 4 (5): 1-6.
- John, A. T.; E. K. Kenneth and O. E. Rita. (2020).** The Use of Periwinkle Shell Aggregate Concrete in Two-Layer Reinforced Concrete Beam. *American Journal of Sustainable Cities and Society*, 1(9): 2319-7277.
- Kim, S. Y. and Irving, K. E. (2010).** History of science as an instructional context: Student learning in genetics and nature of science. *Science and Education*, 19:187-215.
- Kroflič, A.; M. Saje and I. Planinc. (2011).** Non-Linear Analysis of Two-Layer Beams with Interlayer Slip and Uplift. *Computers and Structures*, 89 (23-24): 2414-2424.
- Krofljic, A.; I. Planinc; M. Saje and B. Cas. (2010).** Analytical Solution of Two-Layer Beam including Interlayer Slip and Uplift. *Struct. Eng. Mech*, 34 (6): 667-683.
- Olanitori, L. M. and Gbadamosi, I. A. (2019).** Effects of Concrete Grades on Strength Characteristics of Reinforced Concrete Slender Beams. *Journal of Applied Sciences and Environmental Management*, 23 (5): 847-850.
- Nguyen, Q. H.; E. Martinelli and M. Hjjaj. (2011).** Derivation of the Exact Stiffness Matrix for a Two-Layer Timoshenko Beam Element with Partial Interaction. *Engineering Structures*, 33(2): 298-307.
- Ataria, R. B. and Wang, Y. C. (2019).** Bending and Shear Behaviour of Two Layer Beams with One Layer of Rubber Recycled Aggregate Concrete in Tension. *Structures* 20: 214-225.
- Schnabl, S.; M. Saje.; G. Turk and I. Planinc. (2007).** Analytical Solution of Two-Layer Beam taking into account Interlayer Slip and Shear Deformation. *Journal of Structural Engineering*, 133(6): 886-894.
- Skec, L.; S. Schnabl; I. Planinc and G. Jelenic (2012).** Analytical Modelling of Multilayer Beams with Compliant Interfaces. *Structural Engineering and Mechanics*, 44 (4): 465-485.
- Sousa Jr, J. B. M., and da Silva, A. R. (2010).** Analytical and Numerical Analysis of Multilayered Beams with Interlayer Slip. *Engineering Structures*, 32 (6): 1671-1680.
- Tarak M. G. and Vincy, K. (2017).** Flexural Behaviour of High Strength RCC Beams with Lower Grade Concrete in the Neutral Axis. *International Research Journal of Engineering and Technology*, 4 (5): 1970-1975.
- Zena, J.; A. M. Lateef and A. Saleem. (2019).** Mechanical Behaviour of Simple Supported Two Layers Reinforced Concrete Beam. *International Journal of Civil Engineering and Technology*, 10 (1): 1122-1132.