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COST OPTIMIZATION OF A T-BEAM UNDER BENDING CONSTRAINTS

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Abstract: This research paper focuses on the cost optimization of a T-beam subjected to bending constraints according to Eurocode 2. The objective of the study is to minimize the cost of the T-beam while ensuring that it meets the specified structural requirements and design limitations outlined in Eurocode 2. The optimization problem is formulated as a nonlinear constrained minimization problem,, taking into account the geometric and material properties of the T-beam, as well as the imposed loading conditions. The Eurocode 2 provisions for structural analysis and design are incorporated into the optimization process to ensure compliance with safety and serviceability requirements. This was solved using the GRG Algorithm. The optimization offered minimal cost savings, with gains reducing from 1.4% to 0.8% as the beam span increased. However, the optimal cost was found to increase with the design moment applied, with gains from 11.96% to 32.46% for a design moment ranging from 200kNm to 500kNm respectively. The results demonstrate the effectiveness of the proposed cost optimization approach, highlighting the potential for significant savings in material usage and construction costs. The findings also provide valuable insights into the trade-off between structural performance and economic considerations in the design of T-beams

Keywords: cost optimization, Eurocode 2, GRG algorithm, moment, t-beam

INTRODUCTION

Reinforced Concrete T-beams are commonly used in industrial construction, particularly in building floors, retaining walls, bridge decks, and in all reinforced concrete construction projects where an appropriate portion of the slab is associated with the resisting section of the supporting beam. Non-linear programming techniques can be used to produce a cost-effective design solution for large-scale utilization of such T-shaped beams, as may be the case for precast reinforced concrete component manufacture. The best-designed beams can be adequately fabricated in a prefabrication facility and then used for their intended purpose. This could result in significant savings in both the superstructure and the foundation elements' expensive construction materials. The overall cost to be reduced is fundamentally divided into the costs of concrete, steel, and formwork. From an economic standpoint, it is also important to include the nonlinear ultimate behavior of the concrete and reinforcing steel in compliance with current design codes throughout the design process optimization of the crucial sections.

The current study falls within this framework and is concerned with the cost-effective design of reinforced concrete T-shaped beams under ultimate stresses. The art of cost effective design entails first formulating a structural optimization model and then solving it with an appropriate mathematical programming technique (Bhalchandra and Adsul, 2012). An objective function and a set of constraints comprise the structural optimization model. The latter often contain search limits for choice variables, structural behavior restrictions, and various stress and strain circumstances and their limits. Ideally, the final design must incorporate compatibility between the geometrical dimensions of the optimized T-cross section and the ultimate loading condition, which includes the T-beam's self-weight. Some of the early investigations paid very little attention to this element. Another important feature of optimal design is the adoption of a proper optimization technique. In structural design optimization, many mathematical programming techniques have been applied (Salim et al., 2018; Bhalchandra and Adsul, 2012; Ildiko et al., 2010). This study uses a suitable mathematical programming technique to formulate and solve the nonlinear minimum cost design issue of reinforced concrete T-beams under bending constraint.

The purpose of a designer is to create an "optimal solution" for the structural design under consideration. An optimal solution typically indicates the most cost-effective construction without jeopardizing the building's intended functional functions. The total cost of the concrete structure is the sum of the costs of its constituent materials, which include at least concrete, reinforcement steel, and formwork. Some properties of reinforced concrete (RC) structures distinguish their design optimization from that of other structures. Several cost items influence the cost of RC constructions.

To address this issue, this study presents a thorough technique for T-beam cost optimization. The project will use advanced computational tools and optimization techniques to identify configurations that minimize material consumption and construction costs while meeting Eurocode 2 safety and performance criteria (Eurocode 2, 2004). This work tries to provide a holistic solution to the problem of cost-efficient T-beam design by using an interdisciplinary approach that merges engineering concepts with economic models.

Optimization is the art of selecting the most cost-effective or highest achievable performance alternative from a set of alternatives by maximizing the desired elements and reducing the undesirable factors. Babiker et al. (2012) employed an Artificial Neural Networks-based model to optimize the cost of simply supported beams by factoring in the cost of concrete, reinforcing, and formwork. The beams were developed in accordance with the American Concrete Institute (ACI) standard ACI 318-08.

The majority of the recent literature on this topic was created utilizing the Genetic Algorithm (GA) optimization technique. Yousif and Najem (2013) presented the use of genetic algorithms (GA) for the optimum cost design of RCC continuous beams based on ACI 318-08 requirements. The solutions to the depicted example problem produced sensible, dependable, economical, and practical designs. Ismail (2017) conducted a comparison study between one of the conventional optimization approaches, Generalized Reduced Gradient (GRG), and one of the heuristic strategies, Genetic Algorithm. The comparison found that the GA outperformed the traditional GRG. Bhalchandra and Adsul (2012) demonstrated the GA technique's superiority over the GRG and Interior Point optimization techniques. The problem of optimum design of simply supported doubly reinforced beams with uniformly distributed and concentrated load has been solved by adding the beam's true self-weight.

Alex and Kottalil (2015) attempted to illustrate the use of the GA to the construction of reinforced concrete cantilever and continuous beams. The design was based on the guidelines provided by the Indian Standard, IS 456. Cost optimization was performed to obtain the most cost-effective concrete section and reinforcements at user-defined intervals. Prakash (2016) investigated the economic considerations of reinforced concrete beam design. Manual and MS-Excel programs were used to design reinforced concrete rectangular and flanged sections. IS 456-2000 code standards were used to design the singly reinforced, doubly reinforced, and flanged sections at a constant imposed load of 25 kN/m. The study also took into account different spans and depth to width ratios. The majority of the works were designed in accordance with international standards such as ACI. The design factors utilized for the optimization issues also differed amongst researchers. The purpose of this work is to determine the best design of a singly reinforced T-beam for a particular imposed load while keeping code and practical constraints in mind. The cost of the beam can be represented as a function of the amount of concrete and steel used, the grade of concrete used, the size of the form work, and so on. This function will be the problem's objective function. The beam must meet the strength and serviceability conditions specified in the EC2 design, which will serve as constraints for the optimization problem. The goal of the optimization is to minimize the total cost of the beam while keeping the limits in mind.

The scope of this project was restricted to the cost of concrete, formwork, and steel. The cost targets were also determined using the generalized reduced gradient approach in Microsoft Excel. This research is justified by its potential to significantly cut construction costs, reduce environmental effect, and improve the level of knowledge in the field of structural engineering and optimization.

The goal of this project was to find the cheapest concrete material, formwork, and steel reinforcement for a reinforced concrete T-beam. This was accomplished by altering the beam spans and the enforced design moment in order to reduce the total cost of construction of a reinforced flanged beam. The methodology used to achieve this goal was the creation of a computer software in Microsoft Excel that allows for the simple selection of design variables that will optimize the overall cost of construction of a reinforced T-Beam in bending.

MATERIALS AND METHODS

Materials

Eurocode 2 (2004) was used to develop a mathematical representation of a concrete structure. An Excel spreadsheet was used to set up the model and the optimization process was executed using Excel's Solver Tool.

Methods

— T-Beams under Bending Constraints

T-Beams are concrete structural members, which have a flange cross-section shaped like a ‘T’.

Their cross-section consists of a central web and a flange on both left and right sides of the web, as shown in Figure 1.

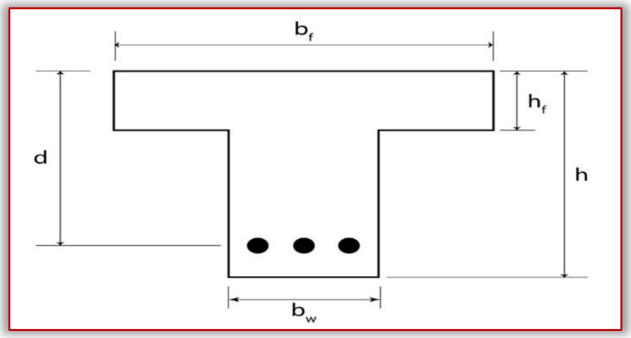

Figure 1: Cross-section of a concrete T-Beam.

The T-Beam, experiences tension at the bottom and compression at the top. However, due to the large surface area provided by the concrete (which is favorable in compression) in the flange, it is usually unnecessary to consider a case where compression reinforcement is needed.

In addition, since this research focuses on T-Beams under bending constraints, the nature of the beams cross-section under flexure was fully considered. Here, there were two cases:

- The stress block lies within the compression flange.
- The stress block extends outside the compression flange.
- Both cases are shown in Figure 2 and Figure 3, respectively.

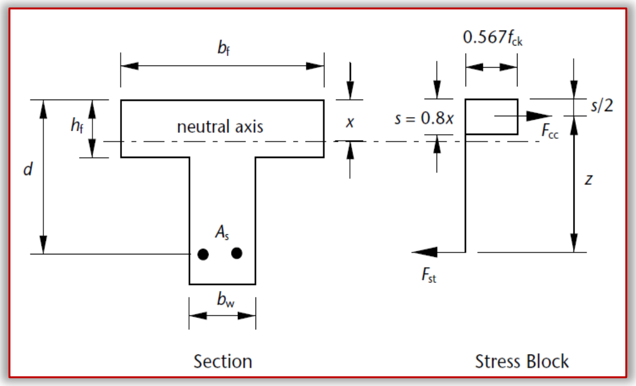

Figure 2: T-section, with stress block within the flange, $s < h_f$

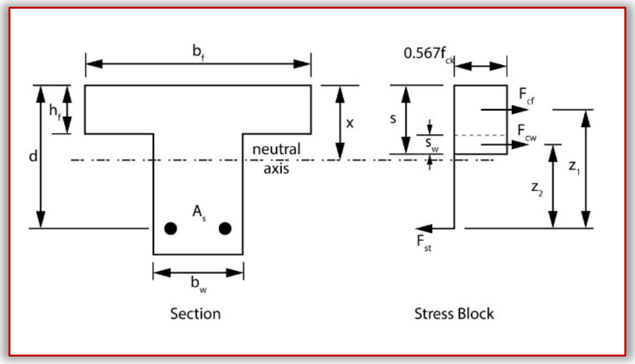

Figure 3: T-section, with stress block beyond the flange, $s > h_f$

In this research, the second case was chosen under the design constraints of Eurocode 2 as the focus of this study.

— **Optimization Technique**

Generalized reduced gradient (GRG) method was the optimization technique used to carry out the cost optimization. The objective function developed for the cost optimization was a non-linear one, with bending constraints derived from Eurocode 2. The optimization problem is a non-linear constrained optimization problem, which the generalized reduced gradient method can resolve.

Microsoft Excel was the preferred software of choice to handle the optimization problem. Being easily affordable and ubiquitous in the software market, it was also chosen for its ease and clarity of usage. An Excel spreadsheet was built to set up the model, before the optimization process was finally executed using Excel's Solver Tool, which possesses the generalized reduced gradient method for non-linear models as one of its solving methods. Values were derived from the spreadsheet and documented as results.

— **Development of Model**

An objective function was derived which related the cost of manufacturing a reinforced concrete T-Beam of specific dimensions to the materials and their sizes needed to construct the beam. This was then subjected to bending constraints under Eurocode 2.

— **Cost Objective Function**

The cost of the T-Beam is the sum of the cost of concrete, steel and formwork components. The quantity of each of these components depends not only on the dimensions of the beam, but also on some of its design properties. For example, the area of reinforced steel is dependent on the applied moment (also known as the design moment) and the dimensions of the stress block.

The cost objective function can be defined as:

Total Cost, C = (cost of concrete) + (cost of rebar) + (cost of formwork)

Which can be rewritten in full as:

$$C = \left[C_c \times \left(\left(b_f h_f + b_w(h - h_f)\right) - A_s\right) \times u_c \times L\right] + [C_s + A_s] + [C_f \times (b_f + 2h)] \quad (1)$$

where:

C = Total cost of manufacturing the T-Beam.

C_c = Cost coefficient of concrete in cost per mass (naira per kg).

C_s = Cost coefficient of reinforcement steel, in cost per cross-sectional area (naira per mm²).

C_f = Cost coefficient of formwork, in cost per length (naira per m).

b_f = Width of the flange (mm).

b_w = Width of the web (mm).
h = Total height of the beam (mm).
h_f = Height of the flange (mm).
A_s = Total area of reinforcement steel (mm^2).
L = Length of the beam (m).
υ_c = Unit weight of concrete (kg/m^3).

— Input and Design Parameters

Given that the cost of manufacturing the T-beam is related to the various parameters listed in the previous section above, further derivations were used to calculate the variables necessary for the calculation of the parameters present in the objective function.

Input parameters were classified into those that could be directly imputed and used in the objective function; those which were needed to compute values of parameters to be used in the objective function; and finally those that would be adjusted in the optimization process to produce an optimal cost of manufacturing the T-beam.

The parameters that were to be adjusted to derive the optimized costs were classified as design variables. Those that needed additional calculations before being used were separated in the Excel spreadsheet as computed values.

The cost coefficients were each calculated based on their necessary dimensions and underlying real-world market prices as follows:

- Cost Coefficient of Concrete (C_c): This is the total cost per mass of concrete (naira per kg). It was found by calculating the total cost of manufacturing a given mass of concrete and dividing that cost by the mass of concrete manufactured.
- Cost Coefficient of Steel (C_s): This is the cost per cross-sectional area of reinforcement steel (naira per mm^2). It was found by dividing the cost of specific sizes of steel bars by their areas. Given that reinforcement bars are manufactured and sold based on their diameter sizes, the bar diameters were used to derive the cross-sectional areas.
- Cost Coefficient of Formwork (C_f): Here, the cost coefficient of formwork is the cost per length of the formwork material used (commonly wood). Its dimensions are in naira per meter.

The material properties of both the concrete and the steel, which were used to compute values in the objective function and in the derivation of some constraints, are:

- Characteristic Strength of Concrete (f_{ck}): This is the compressive strength of 150 mm sized cubes tested at 28 days at which not more than 5% of the test results are expected to fail. It is taken in Eurocode 2 as 25 N/mm^2.
- Characteristic Strength of Steel (f_{yk}): This is the minimum yield stress, at which not over 5% of the test outcomes should fail. Taken as 500 N/mm^2 according to Eurocode 2.
- Unit weight of Concrete (υ_c): This is the ratio of the mass of concrete per unit volume. Taken as 2400 kg/m^3.

The inputs for the geometric dimensions of the beam (as shown in Fig 1):

- length of the beam (l)
- width of the flange (b_f)
- width of the web (b_w)
- total height of the beam (h)
- height of the flange (h_f)
- effective depth of reinforcement bar (d)

The design moment M_d, which is the resulting moment applied on the member as a result of the load conditions on the member was also imputed in the model. This moment would be used to calculate s_w, which is the depth of the stress block into the web of the beam. It would also be used in the derivation of the bending constraints, as shown in the next section.

The area of reinforcement A_s, required in the objective function was calculated from the formula:

$$A_s = \frac{0.567 f_{ck} b_f h_f + 0.567 f_{ck} b_w s_w}{0.87 f_{yk}} \qquad (2)$$

Where s_w was found by deriving the roots of the equation:

$$s_w^2 \left[\frac{0.567 f_{ck} b_w}{2}\right] - [0.567 f_{ck} b_w (d - h_f)] s_w + (M_f - M_d) = 0 \qquad (3)$$

Given that there are two roots to equation 3, additional constraints were developed to ensure that the value of s_w used by the model was an appropriate and mandatorily positive real number. The term M_f in the above equation represents the moment of resistance developed by the flange.

DEVELOPMENT OF CONSTRAINTS

The beam was optimized under bending constraints to Eurocode 2. Hence, the behavioral constraints were limited to only parameters related to flexure. These constraints were derived using structure illustrated in Figure 3. Here, the design moment M_d, is to be constrained by both the moment of resistance in the flange M_f and the moment of resistance of the entire section, M_R.

To ensure that the stress block extends beyond the flange, the design moment is to be greater than the moment of resistance developed by the flange alone:

$$M_f \leq M_d \quad (4)$$

In addition, to ensure that the beam does not fail in bending, the applied moment has to be exceeded by the moment of resistance of the entire section:

$$M_d \leq M_R \quad (5)$$

Mathematically, equation 4 and 5 was combined and restated as:

$$M_f \leq M_d \leq M_R \quad (6)$$

Where,

$$M_f = 0.567 f_{ck} b_f h_f \left(d - \frac{h_f}{2}\right) \quad (7)$$

$$M_R = 0.567 f_{ck} b_f h_f \left(d - \frac{h_f}{2}\right) + 0.567 f_{ck} b_w (s - h_f) \left(d - \frac{s}{2} - \frac{h_f}{2}\right) \quad (8)$$

The term s, from equation 8, is the total height of the stress block and was derived from the formula:

$$s = \frac{0.87 f_{yk} A_s - 0.567 f_{ck} b_f h_f}{0.567 f_{ck} b_w} + h_f \quad (9)$$

Given that in the model, the stress block must extend past the flange and into the web of the beam, a constraint relating s to the depth of the flange h_f was developed:

$$s > h_f \quad (10)$$

In order to ensure that there was no need for compression reinforcement, the depth of the neural axis, x, as shown in Figure 3, must not exceed forty-five percent (45%) of the depth of reinforcement d. Mathematically:

$$x < 0.45d \quad (11)$$

where,

$$x = \frac{s}{0.8} \quad (12)$$

Apart from behavioral constraints, there were geometric constraints placed on the model. These were based off the permissible and real-life dimensions of the beam's possible cross-section.

Behavioral constraints:

$$M_f \leq M_d \leq M_R \quad (13)$$

$$s > h_f \quad (14)$$

$$x < 0.45d \quad (15)$$

Geometric constraints:

$$350 \leq b_f \leq 550 \quad (16)$$

$$100 \leq h_f \leq 150 \quad (17)$$

$$200 \leq b_w \leq 300 \quad (18)$$

$$400 \leq h \leq 600 \quad (19)$$

$$1200 \leq A_s \leq 2500 \quad (20)$$

$$s_w > 0 \quad (21)$$

OPTIMIZATION MODEL

The optimization problem has been described in the previous sections in detail. It can be summarized as:

Minimize:

$$C = \left[C_c \times \left(\left(b_f h_f + b_w (h - h_f)\right) - A_s\right) \times u_c \times L\right] + [C_s + A_s] + [C_f \times (b_f + 2h)] \quad (22)$$

Subject to:

$$M_f \leq M_d \leq M_R \quad (23)$$

$$s > h_f \quad (24)$$

$$x < 0.45d \quad (25)$$

$$350 \leq b_f \leq 550 \quad (26)$$

$$100 \leq h_f \leq 150 \quad (27)$$

$$200 \leq b_w \leq 300 \quad (28)$$

$$400 \leq h \leq 600 \quad (29)$$

$$1200 \leq A_s \leq 2500 \quad (30)$$

$$s_w > 0 \quad (31)$$

To find $X = [X_1 X_2 X_3 X_4 X_5]^T$ which minimizes the objective function while satisfying the constraints stated above.

Let:

$$b_f = X_1$$

$$h_f = X_2$$

$$b_w = X_3$$

$$h = X_4$$

$$A_s = X_5$$

The matrix X, contains the design variables which were to be changed from their initial values to derive an optimum cost, provided that they can satisfy the constraints. The output of the model would include both the design variable and the now optimized cost C, from the objective function.

OPTIMIZATION PROCESS

The cost optimization of T-beam was carried out by replicating the mathematical model in a Microsoft Excel spreadsheet.

Development of Excel Spreadsheet

The objective function, input parameters, design parameters, computed values, constraints and their aforementioned formulas were appropriately placed in the Excel spreadsheet shown in Figure 4.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Cost Optimization of a T-Beam under Bending Constraints to Eurocode 2												
2													
3		Objective Function:			54507.89								
4													
5	Input Parameters:			Design Variables:			Constraints:						
6	C_c	12.91429		b_f	400		Behaviorial Constraints:						
7	C_s	27.73323		b_w	200		M_f <= M_d <= M_R						
8	C_f	218.7227		h	400		s > h_f						
9	L	5		h_f	100		x < 0.45d						
10	U_c	2400		A_s	1397.1788		0.45d =		158				
11	b_f	400					Side Constraints:						
12	b_w	200		Computed values:			350	<=	b_f	<=	550		
13	h	400		s_w	14.381934		100	<=	h_f	<=	150		
14	h_f	100		A_s	1397.1788		200	<=	b_w	<=	300		
15	d	350		s	114.38193		400	<=	h	<=	600		
16	M_d	180		M_f	170.1		1200	<=	A_s	<=	2500		
17	f_{ck}	25		M_R	180								
18	f_{yk}	500		x	142.97742								
19													

Figure 4: Excel spreadsheet set up to evaluate the cost optimization of a T-beam subject to bending constraints.

Use of Excel Solver

Once the spreadsheet was created, the Solver button was selected from the Data tab on the Excel interface. The Solver dialogue box displayed was then filled with pertinent data from the spreadsheet. The constraints were added individually, by clicking the "Add" button. The solving method selected in the Solver dialogue box was the Generalized Reduced Gradient Non-linear algorithm method.

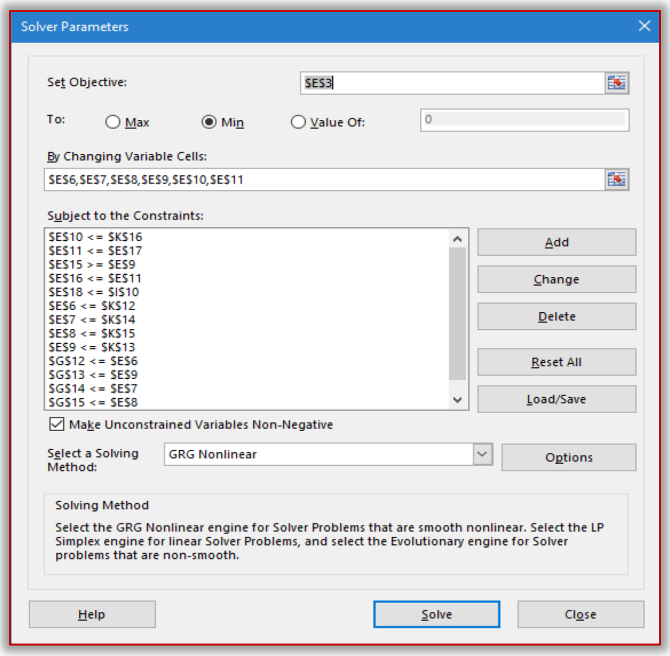

Figure 5: Solver dialogue box with relevant cells filled with information from the spreadsheet.

The "OK" button was then selected, after which a dialogue box reporting the success of the optimization process. The cells containing the design variables were changed due to the success of the operation. This also led to a corresponding change in the cost of the T-beam as represented in the objective function.

RESULTS AND DISCUSSION

Design Example

The developed Excel model was used to optimize a specific case study T-beam. The corresponding preassigned parameters are defined as follows:

Input parameters:

C_c = 12.91429 naira/kg, Cs = 27.73323 naira/mm^2, Cf = 218.7227 naira/m, L = 6 m, U_c = 2400 kg/m^3, M_d = 350 kNm, f_{ck} = 25 N/mm^2, f_{yk} = 500 N/mm^2, d = 475 mm.

Design variables:

b_f = 450 mm, b_w = 250 mm, h = 500 mm, h_f = 125 mm, A_s = 1979.6121 mm^2.

The results of the subsequent optimization is shown in Table 1. A comparison of the design variables and optimal solution is also represented. The degree of decrease in the cost of the beam is shown by the gain, which can be stated mathematically as:

$$\text{Gain (\%)} = \frac{\text{initial cost} - \text{optimal cost}}{\text{initial cost}} \times 100\% \qquad (13)$$

A cost savings of roughly 26% was observed from the design study with the model.

Table 1: Optimization of the design study, showing initial and optimal values.

Design Variables	Initial Design	Optimal Solution
b_f	450	493.8914212
b_w	250	206.3508112
h	500	577.6607185
h_f	125	143
A_s	1979.6121	1200
Cost:	83113.04	61491.88
Gain (%):	26.01416095	

Optimum Cost Due to Varying Span

The span of the beam was incrementally increased from 1 to 10 meters and its cost was optimized at each step. The results from the optimization are show in Table 2.

Table 2: Cost optimization results with varying span lengths.

Span (m)	Original Cost (naira)	Optimized Cost (naira)	Gain (%)
1	36995.14273	36475.86194	1.40365
2	39939.59987	39420.31908	1.30017
3	42884.05701	42364.77622	1.21089
4	45828.51416	45309.23337	1.1331
5	48772.9713	48253.69051	1.06469
6	51717.42844	51198.14765	1.00407
7	54661.88558	54142.6048	0.94999
8	57606.34273	57087.06194	0.90143
9	60550.79987	60031.51908	0.8576
10	63495.25701	62975.97622	0.81783

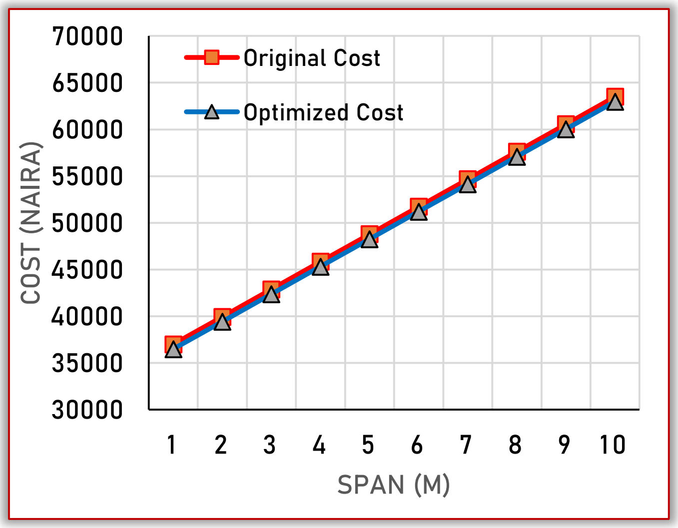

Figure 6: Comparison of costs with the span of the beam.

The resulting optimization offered only very little savings in cost as the difference in the values of the original cost and optimized cost offered maximum gains of 1.4%. From Figure 7, the gains in cost savings reduced from 1.4% to 0.8% as the length of the beams span increased from 1 to 10 meters.

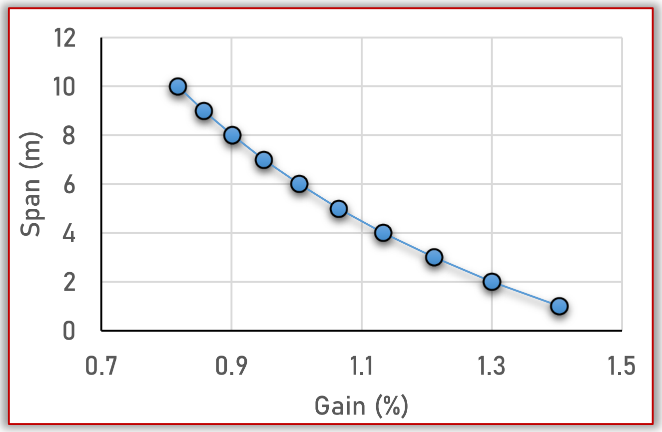

Figure 7: Comparison of beam span with gain

Optimum Cost Due to Varying Design Moment

Unlike the optimization of the beam with increasing span length, there was an increasing difference in the original and optimal costs as the design moment applied on the beam increased. However, when comparing the design moment to the cost gains directly, there is a steady increase in the gains as the imposed moment increases from 200 kNm to 400 kNm. After which the gains reduce as the moment increases to 500 kNm.

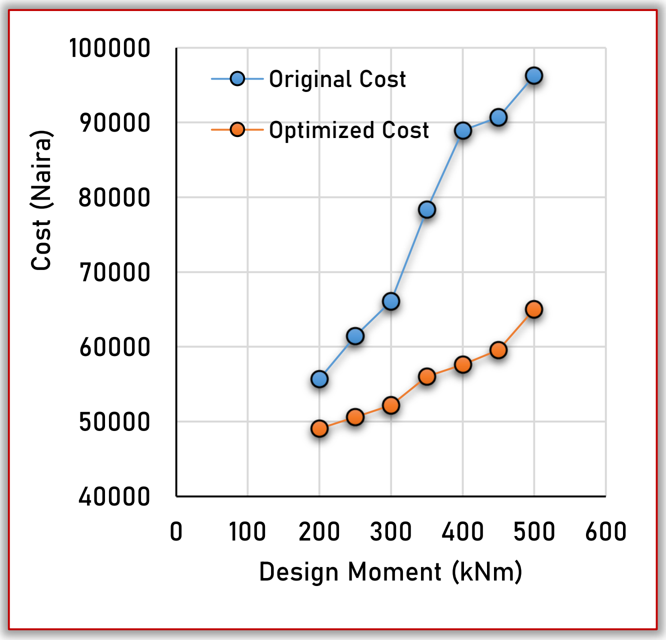

Figure 8: Comparison of costs with the design moment.

Table 3: Cost optimization results with varying design moment loads.

Design Moment (kNm)	Original Cost (naira)	Optimized Cost (naira)	Gain (%)
200	55704.065	49039.484	11.964
250	61432.767	50611.070	17.616
300	66077.004	52182.657	21.028
350	78366.828	56027.879	28.506
400	88953.750	57617.593	35.228
450	90686.835	59576.608	34.305
500	96268.265	65022.480	32.457

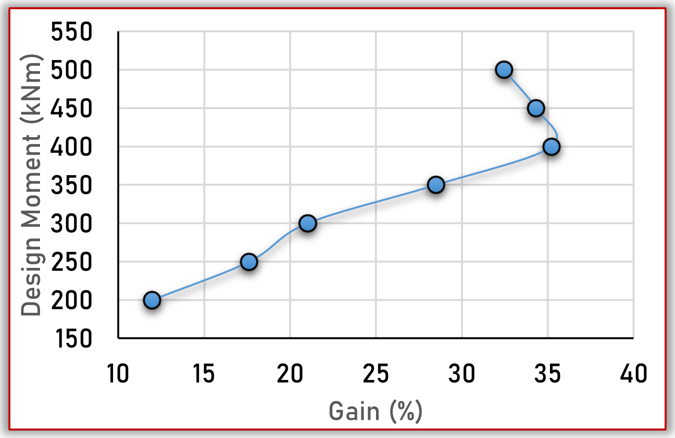

Figure 9: Comparison of design moment with gain.

CONCLUSION

From the procedures developed and results observed, the following can be concluded about the research:

- Minute savings in cost was observed when comparing the optimization of the structure with respect to increasing span. The difference in the values of the original cost and optimized cost offered maximum gains of 1.4%. The gains in cost savings reduced from 1.4% to 0.8% as the length of the beams span increased from 1 to 10 meters.
- Increase in the span of the member led to an increase in the original costs, as well as the optimized costs, even though the latter were smaller than the former.
- There was an increasing difference in the gains as the design moment applied on the beam increased. However, when comparing the design moment to the cost gains directly, there is a steady increase in the gains as the imposed moment increases from 200 kNm to 400 kNm. After which the gains reduce as the moment increases to 500 kNm.

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References

[1] Alex, D. M. and Kottalil, L. (2015). Genetic algorithm Based design of a reinforced concrete cantilever beam. International Research Journal of Engineering and Technology, vol. 2, no.7, pp. 1249 -1252.
[2] Babiker, S. A. , Adam, F. M. and Mohamed, A. E. (2012). Design optimization of reinforced concrete beams using artificial neural network. International Journal of Engineering Inventions, vol. 1, no. 8, pp. 07-13.
[3] Bhalchandra, S. A., and Adsul, P. K. (2012). Cost Optimization of Doubly Reinforced Rectangular Beam Section. International Journal of Modern Engineering Research (IJMER), Vol. 2, Issue. 5, pages 3939-3942.
[4] EuroCode 2 (2004) "Design of concrete structures - Part 1-1: General rules and rules for buildings."

[5] Ildiko, M, Kolbitsch, A., and Kravanja, S. (2010). Cost Optimization of Reinforced Concrete Beams. Proceedings of the Third International Conference on Modelling, Simulation and Applied Optimization Sharjah, U.A.E, January 20-22, 2009.
[6] Ismail, M. A. (2007). Design optimization of structural concrete beams using genetic algorithms. (Master's Thesis). Department of Civil Engineering, Islamic University of Gaza, Gaza.
[7] Salim, T. Y., Ikhlas, S. A., and Saddam, M. A. (2018). Optimum Design of Singly and Doubly Reinforced Concrete Rectangular Beam Sections: Artificial Neural Networks Application. Iraqi Journal of Civil Engineering, Vol. 6, No. 3, pp. 1-19.
[8] Yousif, S. T. and Najem, R. (2013). Optimum cost design of reinforced concrete continuous beams using genetic algorithm. International Journal of Applied Sciences and Engineering Research, vol. 2 no. 1, pp. 79-92.

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