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Optimization of Singly Reinforced Beam Design Using Genetic Algorithm

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Abstract. Achieving an optimized design for the RC beams using the Genetic Algorithm is the main objective of this paper. Cost is saved in the design of RC elements through optimization. Reducing the total cost of the beam is the objective function. Reinforcement, concrete cost, and formwork constitute the cost of each beam. MATLAB's (The Math Works. Inc.) Software was used for the optimization process. A nonlinear constrained minimization problem was formed from the optimization problem and solved using the SQP Algorithm. It was discovered that the resultant outcomes produce a cost-effective design. Hence, the optimization of singly reinforced beam design can be effectively achieved using the genetic algorithm process. it is evident that the genetic algorithm is an efficient tool to accomplish design optimization of structural elements. The variables are minimized but none variable constant is not picked up by the algorithm.

Key words: Optimization, Genetic Algorithm, SQP Algorithm Efficiency, Reinforced Concrete Beam.

1. Introduction

Resistance to fire and water damage, durability, high compressive strength, and adaptability are some of the reasons why RC beams are now being broadly adopted in several structural constructions. The conservative method of design of RC elements comprises the steel ratio required, checks and repetitive design commencing with a trail section for both steel area required and sectional dimensions where beam depth is picked as a result of the deflection control criterion. Flexural resistance is checked in relation to the applied bending moment putting into consideration self- weight impacts. Shear resistance, deflection checks, and other basic requirements as stipulated by the codes are then checked. Although, the design most often than none complies with the code's specifications, it is by no means an optimized one asides the enormous amount of time and repetitive procedures engaged during the design. Technological advancement and analysis have resulted in the production of modern systems of generating cost-effective design techniques of RC elements and structures. Researchers to date from the early 1960s adopted diverse means of generating optimized solutions, design constraints, objective function, etc. due to limited access to machine computing as at the time the study of design optimization was evolving. RC beams design involves the ultimate strength design procedure globally as stipulated by most design codes i.e. ACI 31805 (American Concrete Institute 2005), CSA A23.3-04 (Canadian Standards Association) and Eurocode 2 (British Standards Association 2004). Nonlinear materials properties are accounted for in this method. It also acknowledges differing loads kinds, factors of safety for loads and materials, etc. the design system is well grounded but that of optimized one required objective definition, design variables, and the codes' constraints. The method of determining the least and the extreme point of a description depending on some restraints is termed optimization. The systems of optimization are vital in the design of structures that require the most economical and safe solutions out of which the best set of advantages can be obtained. The numerous requirements of the structures must be valid as per the goal of adequate design. A countless number of designs might be obtained but the mandate is to select the optimum from these available options as regard cost-effectiveness, weight efficiency, maximum services, or the addition of one or two of these.

The optimum cost design of various R.C. elements have been investigated by several authors. A search method of a genetic algorithm was used for the optimization of R.C beams [1]. Several design codes were used in investigating the optimal design of T-shaped RC beams according to Ferreira et.al. [2].

Leps and Sejnoha adopted the virtual strengthening algorithm to establish the optimum reinforcement amount in continuous RC beams [3]. Barros et.al. [4] researched on singly and doubly RC beams cost optimization. A comprehensive study was carried out by Govindaraj and Ramasamy [5] on design optimization of RC beams using the Genetic Algorithm method to examine output with the most economical value from several categories of steel reinforcement used for the study. Stency Mariam Thomas, and Prince Arulraj. G. [6] investigated the optimum value for the RC beam. Different standards of cost of steel reinforcement, formwork, and concrete were examined under total cost as the main function. Different standards of reinforcement, the impact of diameters, and concrete were optimized. Constrained Nonlinear Minimization (CNM) problem was the optimization problem established. Fmincon SQP Algorithm of MATLAB was used in resolving the challenge. All provisions of the IS 456-2000 were carefully followed while generating the appropriate constraints for the design of RC beams. MATLAB Algorithm was adopted in the optimization of several singly RC beams. SQP Algorithm efficiency was investigated to be adequate. Optimized construction cost was established from all the resolved problems.

The optimization problem in a generalized format comprises of the following procedures. Design constraints identification

- Objective function establishment
- Constraints design
- Appropriate Algorithm selection
- Solution

Some of the constraints are regarded as pre- allocated while other are regarded as design constraints. The design constraints are established in a manner which suggests that the value of an objective function which most often being structure cost assume a minimum value. Certain constraints otherwise known as design constraints may impair on the acceptability of the design variables values. The same principle was employed by [7] to study the optimized design of a reinforced concrete flat slab using BS8110.

1.1 Design variables

Dimensions, steel reinforcement area are the commonly used variables for optimization of RC beams. According to [8], the strength of materials, though rarely used can also be regarded as variables. [9] Considered shape optimization of RC beams. They argued that the due to cracking, RC design overlook the important concrete strength in the tension zone. Hence, they adopted a trapezoidal shape for the RC beam. They concluded that trapezoidal beams tend to be more cost-effective compared with the conventional ones.

1.2 Optimization Objectives

Though the design optimization of structures is mainly influenced by the economy, there are several methods of establishing the objective function of RC beams optimization according to numerous authors. Overall weight minimization of the beam was assumed as the objective according to [10]. Having established the fact that weight does not suitably epitomize the material cost, a proportional research was conducted using three ratios for cost per unit weight of concrete to that of steel. Optimum cost reduction was discovered where the concrete cost was ten times compared to steel reinforcement.

1.3 Design Constraints

The functional and structural requirements of the RC beam written as equality or inequality equations are its Optimization constraints. These constraints can either be established by practical limitations as stipulated by the various design codes of practice.

2. Materials and Methods

The purpose of optimization is the minimization of the objective function subjected to certain constraints for constrained case. This can be presented as

Min f(x) subjected to constraints g(x)

In case of reinforced concrete beam, the cost of the reinforced concrete beam production is the objective function to be minimized subjected to both the flexural and geometric constraints. Thus, the objective function is given as

$$f(x_1, x_2) = (x_1 x_2 - A_s)C_c + A_s C_s + (2x_2 + x_1)C_f \quad (1)$$

Where
The width of the beam *b* is x_1
The depth of the beam *h is* x_2
Cc is the cost/unit length of concrete
Cs is the cost unit/length of steel
C_f is the cost /unit area of the formwork

Representing the steel area as the ratio of the beam cross sectional area$A_s = \rho x_1 x_2$. Replacing steel in equation (1) leads to

$$f(x_1, x_2) = x_1 x_2 (1 - \rho)C_c + x_1 x_2 \rho C_s + (2x_1 + x_2)C_f \quad (2)$$

The design constraints are

$$\frac{M}{f_{ck} + 0.134x_1} - x_2^2 \leq 0$$
$$230 - x_1 \leq 0$$

The objective function and the constraint equations are programmed in MATLAB using a genetic algorithm (GA) function. The coding is pretty straight forward and the parametric study can easily be accomplished. The limited results of such are presented in the next section.

3. Results and Discussion

The results presented in this section are the variation of width, depth, and cost with the steel ratio at given bending moments and also the variation of the same at a given steel ratio. Figure 1 is that of the width with the steel ratio. The minimum reinforcement for 75, 100 and 150 kNm are 0.018, 0.019 and 0.025 respectively with the corresponding width of 235 mm for all. Although their local minimal points with higher width hut the global minimized width is limited to 235mm.

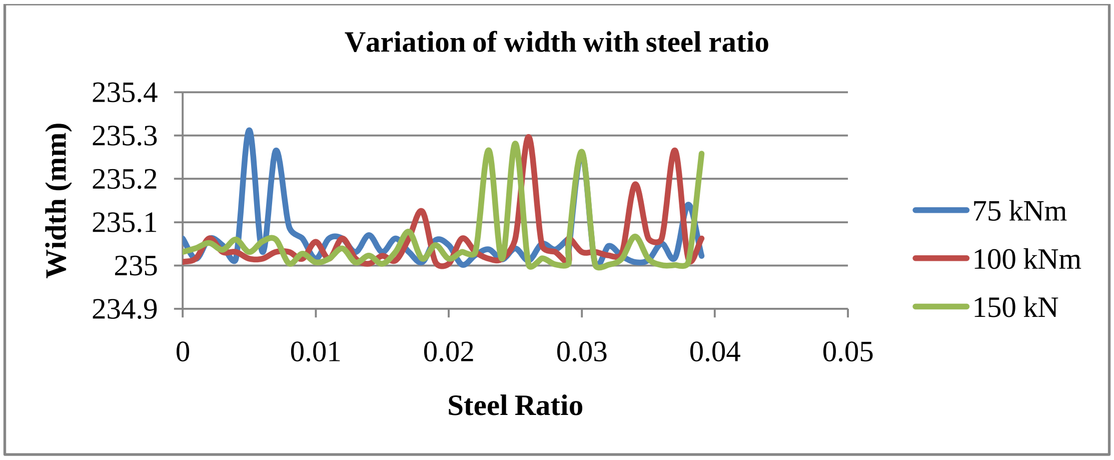

Figure 1. Variation of width with steel ratio

Figure 2 shows the variation of depth with steel ratio at various moments of 75, 100 and 150 kNm The minimum depth of about 389mm at 0.036 steel ratio for 75 kNm, For 100 kNm, the minimum steel ratio of 0.024 at about 400 mm depth. For 150 kNm, the minimum steel ratio of 0.035 at the depth of 450 mm.

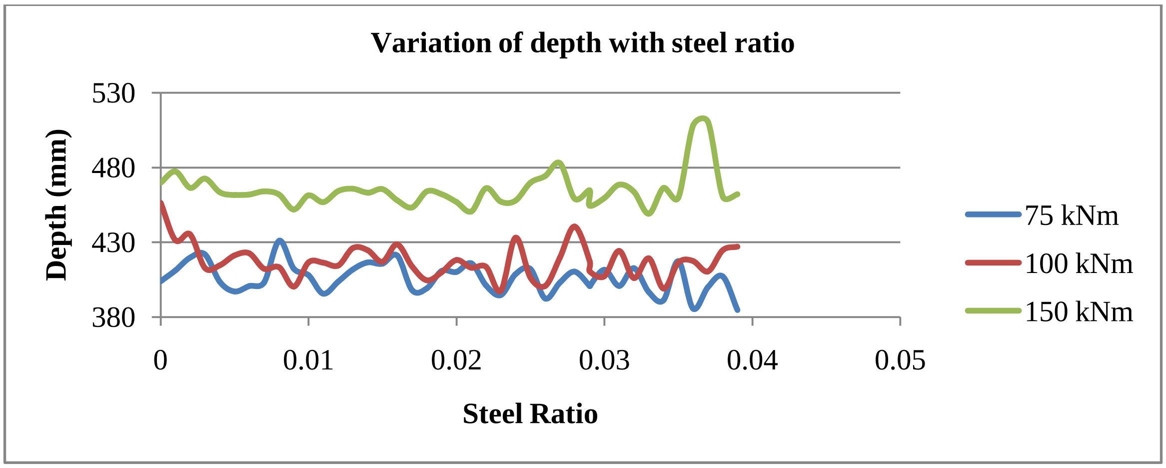

Figure 2. Variation of depth with steel ratio

With the cost, there is a steady increase with steel ratio for all the moments considered. However, the lesser the moment the lesser the cost for any given steel. This clearly indicates that steel quantity drives the cost up irrespective of the moments. This phenomenon is clear because the steel ratio is a constant and variables minimized are the width and depth of the beam.

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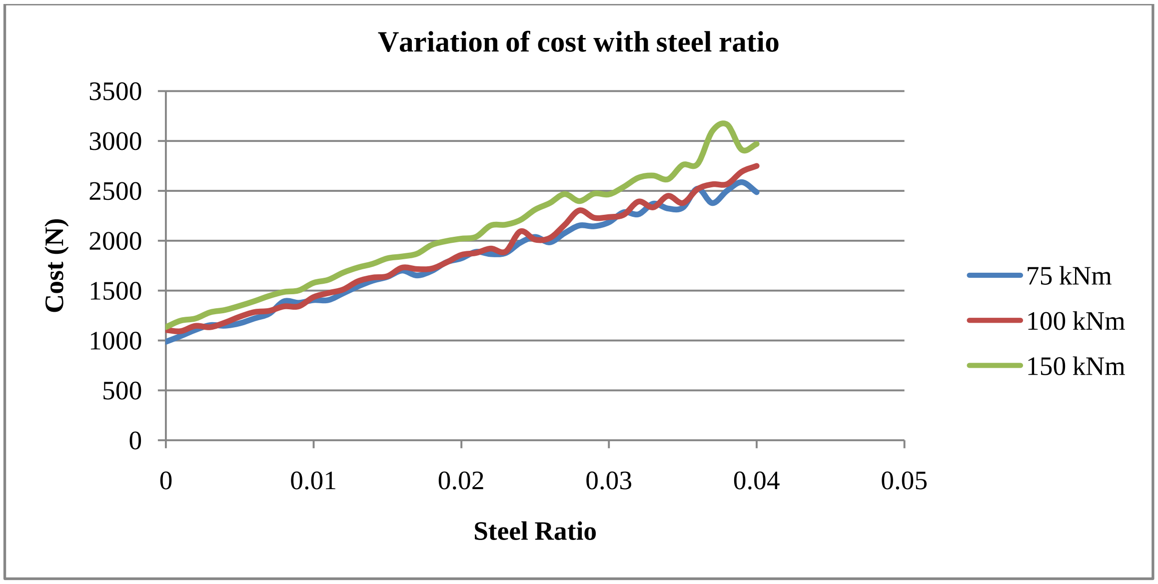

Figure 3. Variation of cost with steel ratio

Figures 4 to 6 are other computational results showing the same trend as the variation of the steel ratio. It is clear that the steel ratio simply shifts the cost as the moment increases. This is clearly shown in figure 6.

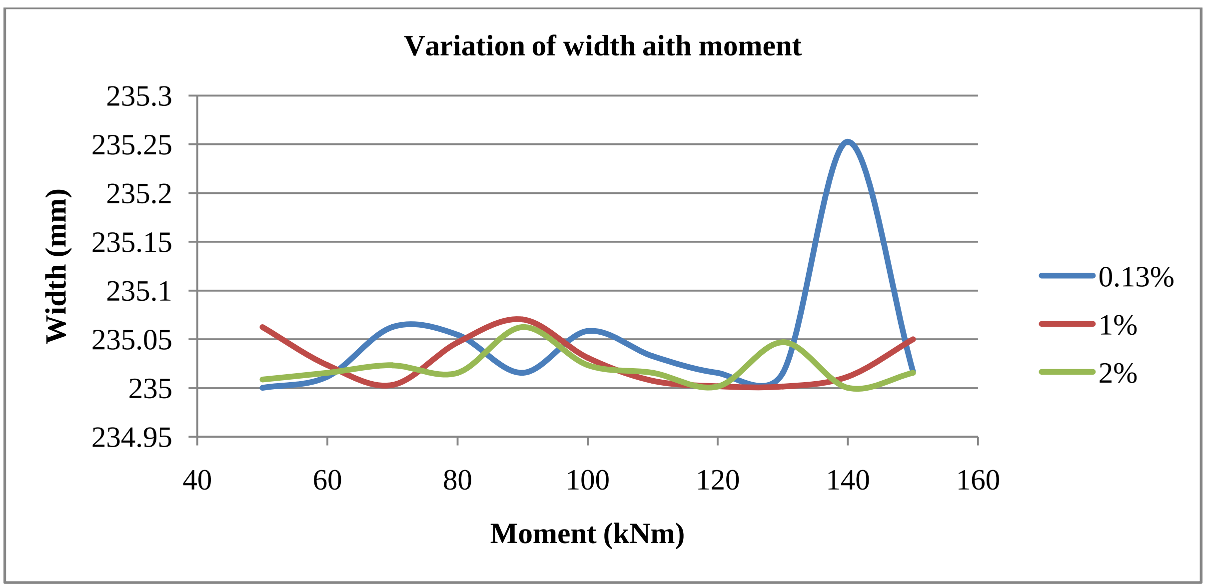

Figure 4. Variation of width with moment

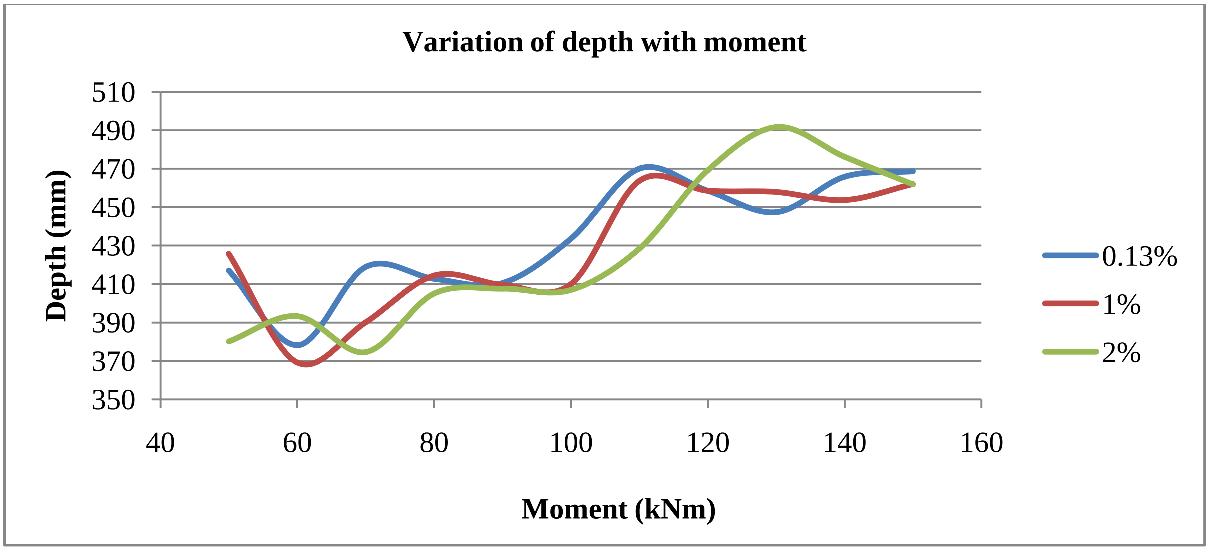

Figure 5. Variation of depth with moment

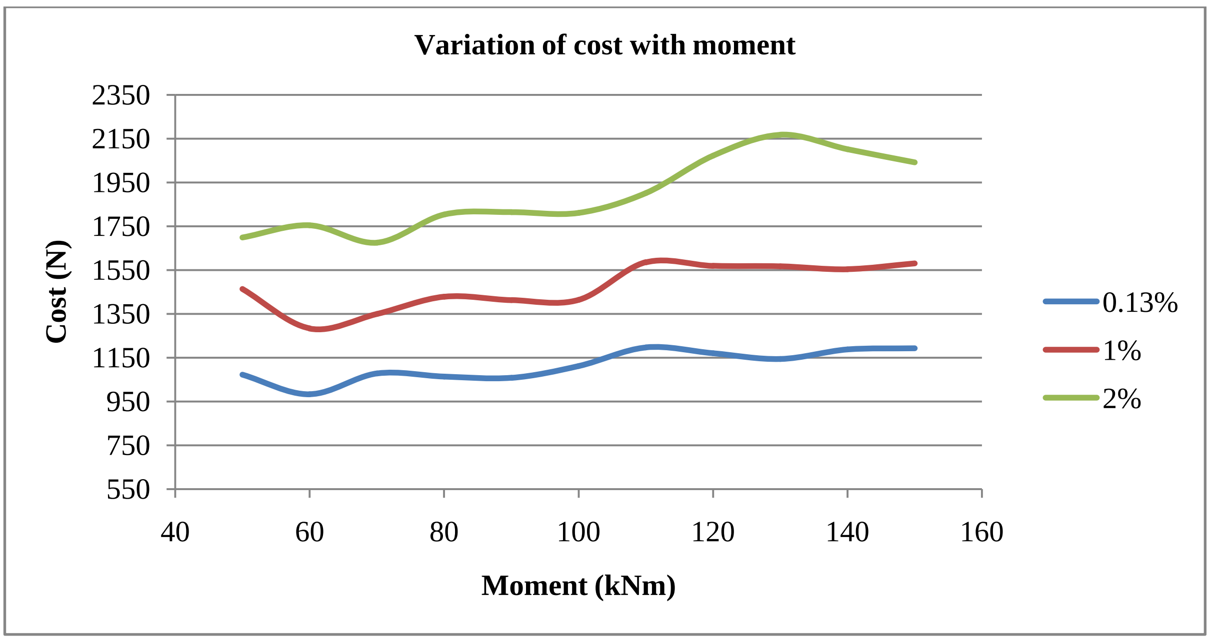

Figure 6. Variation of cost with moment

4. Conclusion

From the above discussion it is evident that the genetic algorithm is an efficient tool to accomplish design optimization of structural elements. The variables are minimized but none variable constant is not picked up by the algorithm. To include any item in the optimization, it is desirable to make it a variable.

References

[1] Coello, C.C, Hernandez, F.S and Farrera, F. A. (1997). Optimal Design of Reinforced Concrete Beams Using Genetic Algorithms, *Expert Systems with Applications*, **12**, 101-108.

[2] Ferreira, C. C, Barros. M. H. F. M and Barros A. F. M. (2003). Optimal design of reinforced concrete T-Sections in Bending, *Engineering Structures*. **25**, 951-964.

[3] Leps, M., and Sejnoha, M. (2003). New Approach to Optimization of Reinforced Concrete Beams, *Computers and Structures*, **81**, 1957–1966.

[4] Barros, M. H. F. M, Martins, R. A. F and Barros, A. F. M. (2005). Cost optimization of singly and doubly Reinforced Concrete Beams with EC2-2001, *Structural and Multidisciplinary Optimization*, **30**, 236–242.
[5] Govindaraj, V and Ramasamy, J. V. (2005). Optimum Detailed Design of Reinforced Concrete Continuous Beams Using Genetic Algorithms, *Computers and Structures*, **84**, 34–48.
[6] Stency Mariam Thomas, and Prince Arulraj. G. (2017). Optimization of Singly Reinforced RC Beams. *International Journal of Research*, Granthaalayah, **5**(2), 199-207. doi.org/10.5281/zenodo.345658.
[7] Olawale, S.O.A., Tijani, M.A., Kareem, M.A., Ogungbire, A.M, and Alabi. O. (2019). Cost optimisation of the design of reinforced concrete flat slab to BS8110. *Materials Science and Engineering*, **640,** 1- 14, doi:10.1088/1757-899X/640/1/012052.
[8] Goble, G.G. and Moses, F. (1975). Practical applications of structural optimization, *J. Struct. Div*., **101**(4), 635-648.
[9] Narayan, K.S.B. and Venkataramana, K. (2007), Shape optimization of steel reinforced concrete beams, *Comput. Concrete*, **4**(4), 317-330.
[10] Chung, T.T. and Sun, T.C. (1994), Weight optimization for flexural reinforced concrete beams with static nonlinear response, *Struct. Optim.*, **8**(2), 174-180.