OPTIMIZATION OF RC COLUMN AND FOOTINGS USING GENETIC ALGORITHM

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Abstract - *In the design and development of the structural configuration, many design engineers put extra time for repeated and well-defined tasks. The development of optimization approach which could be used to reduce such laborious jobs will increase the productivity of the organization. This approach intends to reduce the computational costs normally associated with structural design problem. The optimization techniques in general enable designer to find the best design for the structures under consideration. In this particular case, the principal design objective is to minimize cost of Rc column and footings. The resulting structure, not only give optimum size but also it give optimum cost with all strength & serviceability requirements for a given applied load. In this study the design of RC column and footing is carried out in Visual Basic Application and the optimization is carried out in MATLAB software. Genetic algorithm is used as optimization technique. The present dissertation provides the comparison between optimum results and books results.*

Key Words*: *Optimization, Column, Footing, MATLAB, VBA, Genetic Algorithm

1. INTRODUCTION

The Structural Engineering involves understanding the natural phenomenon, material properties, intuition, past experience in design field. The modern technology can bring various advantages like speed, accuracy, efficiency in the field of Structural Engineering. Design is iterative process initially the cross sections and percentage of reinforcement is assumed then the design is done. The design is to be carried out as per codes and specifications, the Structural engineer experience and knowledge plays an important role to achieve the economic and efficient design. Designer makes the prediction about probable optimum solutions by his experience, knowledge, constraints and requirements.

Optimum design of structures has been theme of many researches in the structural field. An optimal result normally involves the most cost-effective structure without harming the functional purposes the structure is made-up to assist. RC structures optimization is mainly depends on the cost concession between the consumption of concrete, reinforcement which decreases the total price of the structure and fulfills the design necessities. In the design optimization of RC structures the sectional dimensions of elements and detailing of reinforcement such as size and number of steel bars, need to be determined. The number of design variables that are need to be optimized depends on the durability requirements. These requirements increases the number of constraints.

1.1 Need For Optimization

For single design problem there are many acceptable designs, among all these designs one which is economical will satisfy both Engineering and Structural standards as well as economical need. The process of finding best and economic results with maximum benefit at minimum cost is called optimization.

Due to recent advances in Structural designing field it is easy to get a safe design but it is difficult to find the economical design, hence optimization technique is necessary to get most economical design. Which is advantageous in many ways such as material saving, reducing the concrete usage. Hence optimization gained good scope in Structural Engineering. In this project the optimization of column and footing are carried out.

2. PROPOSED METHODOLOGY

a. Defining Structural problem.

b. Determination of Objective Function, Design Variables and Constraints.

c. Development of VBA (visual basic application) code for design.

d. Development of MATLAB programme.

e. Solving problem Using Optimization Technique.

3. DESIGN PROCEDURE

A code (syntax) for design of RC column and footings has been coded in MS Excel VBA. For RC short column and isolated footing the inputs has to be provided in Excal sheet. The inputs required for column design are factored load (P_u), moment along both X and Y direction (M_{ux}, M_{uy}), effective length of column, grade of concrete (f_{ck}), grade of steel (f_y), clear cover (d'), diameter of main bars and tie bars. Inputs required for footing are Axial load (P), column size (b and d), cover (d'), diameter of bars, grade of concrete (f_{ck}), footing size and safe bearing capacity of soil.

A. RC COLUMNS

Following equations have been used for the design of RC Columns in the form of VB syntax in MS Excel VBA.

1. Effective cover is calculated from table 16 and 16A of IS 456:2000[9], and based on Maximum Diameter of Bar to be used.

   Eff.cover = clear cover + Diameter of bar/2

2. Effective length is calculated for columns from Table 28 of IS 456:2000

3. Slenderness ratio is calculated from Short and Slender (long) column from clause 25.1.2 of IS 456:2000[9].

$$\frac{lex}{D} \text{ and } \frac{ley}{b} \leq 12.0$$

4. Check for minimum eccentricity:
   Applied eccentricity

$$e_x = \frac{Mux}{Pu} \text{ and } e_y = \frac{Muy}{Pu}$$

   Minimum eccentricities as per Code (IS 456: 2000 Clause 25.4)

$$e_{min.x} = \frac{lex}{500} + \frac{D}{30} \geq 20mm$$

5. Trial section: Longitudinal Reinforcement
   For the first trial assume % of reinforcement (p) Uniaxial moment capacity of the section about xx-axis
   Calculate $\frac{d'}{D}$ and $\frac{Pu}{fck \times b \times D}$ Referring SP 16 charts for $\frac{Mu}{fck \times b \times D \times D}$ and calculate M_{ux1} Similarly calculate about yy-axis i.e M_{uy1}
6. Calculation of P_{uz}

Referring to Chart number 63 corresponding to % of steel, fck and fy $\frac{Puz}{Ag}$ Where Ag=b ×D Calculate $\frac{pu}{Puz}$ Calculation of αn

$$\alpha n = \frac{2}{3} \times (1+(\frac{5}{2}) \times \frac{pu}{puz})$$

7. Check for safety under biaxial bending

$$\left(\frac{Mux}{Mux1}\right)^{\alpha n} + \left(\frac{Muy}{Muy1}\right)^{\alpha n} \leq 1.0$$

8. Transverse reinforcement
   Tie diameter ≥ $\frac{\text{Main bar diameter}}{4}$ and 6 mm, Tie bar

spacing ≤ (D,16 × main dia of bar, 300mm)

B. ISOLATED FOOTING

Following equations have been used for the design of Isolated footing in the form of VB syntax in MS Excel VBA.

1. Assume self-weight of footing as 10% of Pu

Self-weight $= 0.1 \times Pu$

Total load, $P = \frac{Pu \times 1.1}{1.5}$

2. Area of footing required,

$$A = \frac{P}{SBC}$$

   a. If square footing, then size of footing:

$$B \text{ or } L = \sqrt{A_{reqd}}$$

   b. If rectangular footing, assume one side L Then,

$$B = \frac{A}{L}$$

3. Upward soil pressure:

$$P_{uplift} = \frac{P}{A} + \frac{M}{1.5Zx}$$

Were, sectional modulus

$$Zx = \frac{bd^2}{A}$$

4. BM calculations:
   a. Moment along x-x passing:

$$Muyy = PuB\left(\frac{L-l}{2}\right)\left(\frac{L-l}{4}\right)$$

   b. Moment along y-y passing:

$$Muxx = PuL\left(\frac{B-b}{2}\right)\left(\frac{B-b}{4}\right)$$

5. Calculation of depth required:

The maximum moment (M_{umax}) is considered for further design and the depth required according to IS 456:2000 will be [9].

$$Mu\lim = 0.36\frac{Xu\max}{d}\left(1-0.42\frac{Xu\max}{d}\right)Fckbd^2$$

6. Area of tensile reinforcement [8]:

$$A_{st} = \frac{0.5 f_{ck}}{f_y}\left(1-\sqrt{1-\left(\frac{4.6M_u}{f_{ck}bd^2}\right)}\right)bd$$

Minimum tensile reinforcement,

$$A_{st\min} = 0.0012BD$$

Area of one bar, ast $ast = \frac{\pi d^2}{4}$

Spacing for the reinforcement, Sv

$$s_v = \frac{ast}{Ast}$$

7. Check for one-way shear:

Shear force, V_u

$$V_u = P_{uplift} B\left(\left(\frac{L-D}{2}\right) - d\right)$$

shear stress, τ_v $\tau_v = \dfrac{V_u}{bD}$

Percentage of steel provided, p_t $p_t = \dfrac{100A_{st}}{bd}$

The design shear is calculated according to SP16 will be [9]

$$\tau_c = \frac{0.85\sqrt{0.8 f_{ck}}\left(\sqrt{1+5\beta}-1\right)}{6\beta}$$

Condition for one-way shear check: If, τv < τc, safe in one-way shear.

8. Check for two way shear:

The critical section will lie at a distance of d from the face of the column

$$V_u = P_{uplift} B\left(A - (D+d)^2\right)$$

Nominal shear stress, τ_v

$$\tau_v = \frac{V_u}{b_o D}$$

Where, b_o = perimeter:

$$b_o = 2(D+d) + 2(B+b)$$

$$\tau_c = 0.25F_{ck}$$

Condition for two-way shear check:

If, τv < τc, safe in two-way shear.

9. Development length of bar is calculated from clause 26.2.1 of IS-456-2000 [8].

$$L_d = \frac{\phi\sigma_s}{4\tau_{bd}}$$

4. OPTIMIZATION

Over last few years' many mathematical programming methods have been developed to solve the optimization problem. The calculus methods depends on the derivatives, constraints and objective function but in real world the problems are discontinuous and noisy space. The numerical method is effective when number of possible solutions are very small, in high dimensional space it's difficult to find the optimum values. Due to this type of disadvantages the random search method became more popular. They have been widely applied to a lot of continuous and discrete global optimization problems. Genetic algorithms, one of the random search methods, are based on Darwin's principles of natural selection and Fisher's genetic theory of the natural selection. They were developed by Holland and described in more detail by Goldberg. Genetic algorithms use random selection to optimize an objective function with respect to variables in the presence of constraints on those variables and have been proven successful for robust searches in complex spaces.

4.1 Genetic Algorithms

Genetic algorithm is the process of resolving constrained and unconstrained problems. In GA the concept of survival of fittest is applied. The best fit sorts are continues and the unfit sorts are being rejected. In this process many number of solutions are generated but only the best fit solution is survived on other hand the other solution is thrown. The best fit solutions are taken for the process of crossover. The mutation operative is employed to continue the variability the population. The more fit solutions replaces the less fit solutions and the process continues till the optimum solution is achieves based on the requirements. The main advantage of Gas is we can easily see the progress of each cycle. Using GAs we can solve both constrained and unconstrained problems.

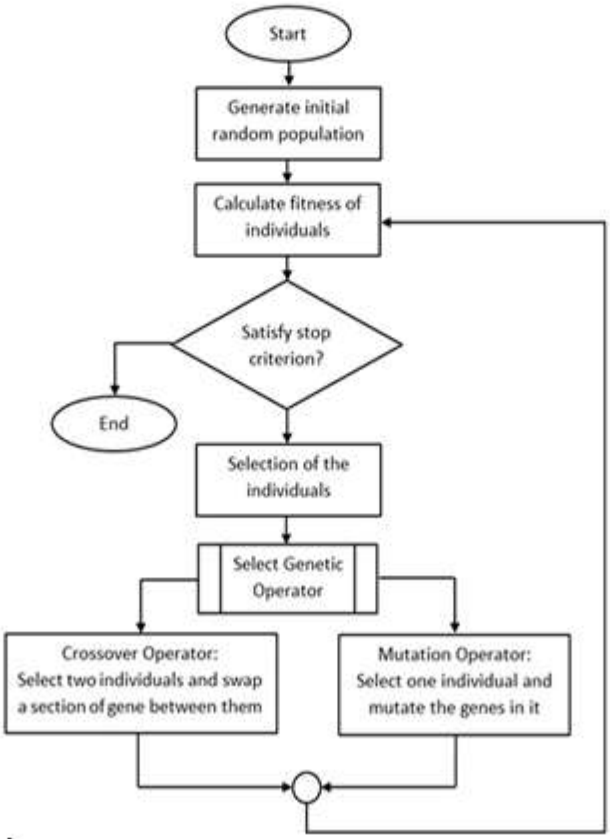


Fig 3.1: Flow chart of genetic algorithm.

4.2 PROBLEM FORMULATION

The general form of an optimization problem is as follows,

- Given - Constant Parameters
- Find - Design variables
- Minimize - Objective function
- Satisfy - Design Constraint

A. CONSTANT PARAMETERS FOR RC COLUMN

1. Axial load (P_u)
2. Moment along X and Y directions (M_{ux} &M_{uy})
3. Length of column (L)
4. Effective cover (d')
5. Grade of concrete (f_{ck})
6. Grade of steel (f_y)
7. Diameter of the bars

B. DESIGN VARIABLES FOR COLUMN DESIGN

1. Breadth of column (b)
2. Depth of column (D)
3. Percentage of reinforcement (pt)

C. OBJECTIVE FUNCTION OF COLUMN

Minimization of total cost of concrete and steel is taken as objective function.

D. DESIGN CONSTRAINTS OF COLUMN

1. Minimum percentage of steel in a column section should not be less than 0.8%.
2. Maximum percentage of steel in a column section should not be greater than 4%
3. Maximum clear spacing of main bars measured along the periphery of a column section should not exceed 300 mm.
4. Minimum width of column section should not be less than 230mm
5. Minimum depth of column section should not be less than 230mm
6. Maximum depth of column is restricted to 1000mm
7. Maximum width of column is restricted to its depth.
8. Minimum number of bars 4.
9. For the columns with biaxial bending interaction check should be satisfied.

E. CONSTANT PARAMETERS FOR ISOLATED FOOTING

1. Axial load (P)
2. Column size (b & D)
3. Safe bearing capacity of soil
4. Grade of concrete (f_{ck})
5. Grade of steel (f_y)
6. Cover (d')
7. Footing size (L & B)

F. OBJECTIVE FUNCTION OF COLUMN

Minimization of total cost of concrete and steel is taken as objective function.

G. DESIGN VARIABLES FOR FOOTING DESIGN.

1. Depth of footing (D)

H. DESIGN CONSTRAINTS OF FOOTING

1. Minimum depth of footing 300 mm
2. Minimum area of reinforcement 0.12%BD

5. RESULTS

The optimum values are being validate by comparing the results with reference of text book results.

5.1 Column Results

Example I

results	Breadth	Depth	Ast Pt	Dia of bar	No of bars	Cost
	mm	mm	%	mm		Rupees
Book	400.0	400.0	3.68	20	12	7388
Optimized	486.7	435.3	1.23	20	8	6359

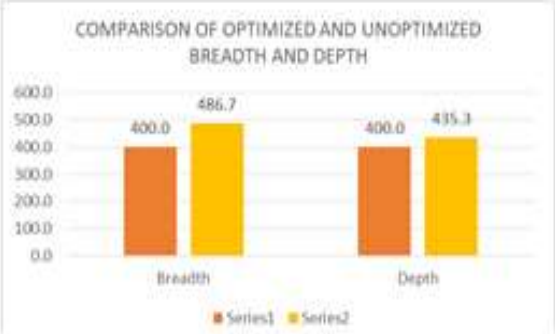


Chart No 7.1.1 Comparison of optimized and book results (Breadth & Depth)

Chart No 7.1.2 Comparison of optimized and book results (Reinforcement)

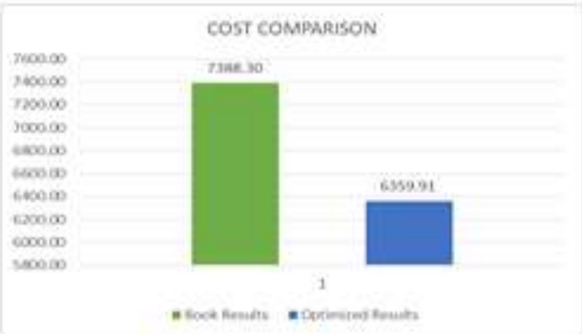


Chart No 7.1.3 Comparison of cost

- From the above results it can be seen that there is increase in cross section of column and decrease in reinforcement quantity, the overall cost of the column is reduced by optimization technique is 1029 rupees.

Example II

Results	Breadth	Depth	Ast Pt	Dia of bar	No of bars	Cost
	mm	mm	%	mm		Rupees
BOOK	300	600	2.20	2#-28mm, 4#-22mm		7174
OPTIMIZED	332.67	692	0.8	25	4	4941

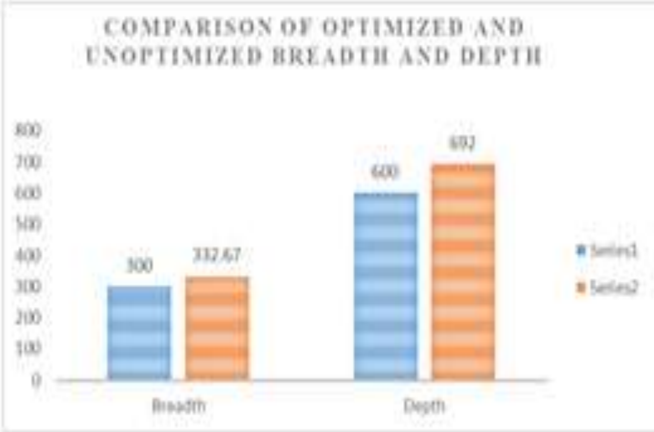


Chart No 7.1.4 Comparison of optimized and book results (Breadth & Depth)

Chart No 7.1.5 Comparison of optimized and book results (Reinforcement)

Chart No 7.1.6 Comparison of cost

- From the above results it can be seen that there is increase in cross section of column and decrease in reinforcement quantity, the overall cost of the column is reduced by optimization technique is 2233 rupees.

5.2 Footing Results

Example I

Results	Axial Load (kN)	Footing size (L) m	Footing size (B) m	Depth (d) mm	Atea of steel (Ast) mm²	Total cost Rupees
BOOK	2300	3	3	675	5026	35117
OPTIMIZED	2300	3	3	659	5280	34296

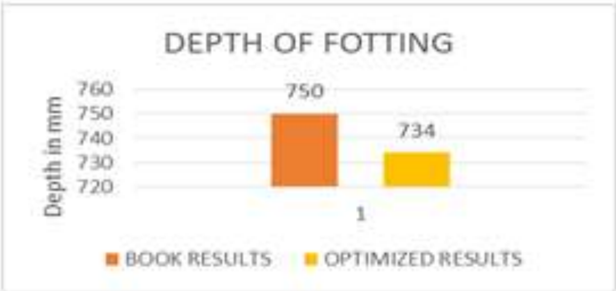
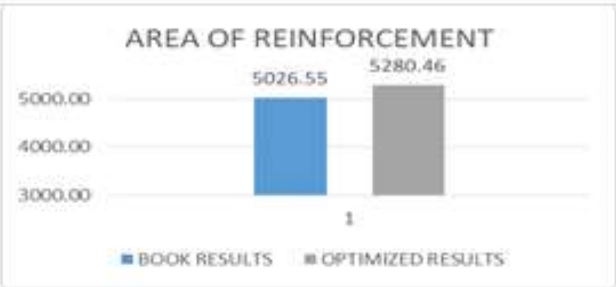


Chart No 7.2.1 Comparison of optimized and un optimized depth of footing



C hart No 7.2.2 Comparison of optimized and un optimized reinforcement of footing

Chart No 7.2.3 Comparison of optimized and un optimized cost of footing

- From the above results it can be seen that after optimization depth of footing is decreased and area of reinforcement is increased. The overall cost footing reduced by optimization technique is 821 rupees.

Example II

Results	Axial Load (kN)	Footing size (L) m	Footing size (B) m	Depth (d) mm	Area of steel (Ast) mm²	Total cost Rupees
BOOK	910	2	1.7	550	2513	10583
OPTIMIZED	910	2	1.7	414	1894	8268

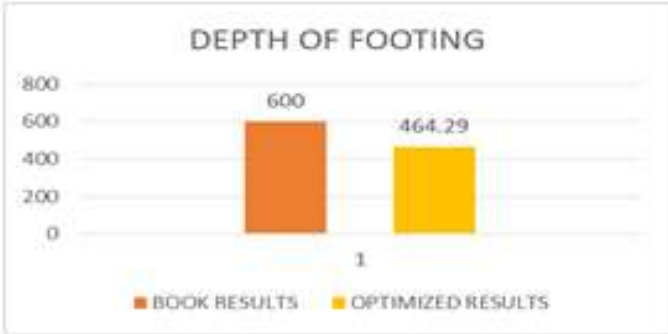


Chart No 7.2.4 Comparison of optimized and un optimized depth of footing

Chart No 7.2.5 Comparison of optimized and un optimized reinforcement of footing

Chart No 7.2.6 Comparison of optimized and un optimized cost of footing

- From the above results it can be seen that after optimization depth of footing and area of reinforcement is decreased. The overall cost footing reduced by optimization technique is 2315 rupees.

6. CONCLUSIONS

a. The computational power can be applied to the optimization, suggested method gives the optimum design results within a reasonable amount of time.
b. The numerical example results are compared with optimum results and it can be concluded that obtained optimum were better.
c. The column results shows that optimization can be done by using different combination of breadth, depth and percentage of reinforcement.
d. The footing results shows that the by increasing the depth of footing reinforcement can be reduced which costs higher.

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