

Estimate and Design of Compression Member Using G.A.

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Abstract— As for the optimal structural design, due to both the complexity of cross sections of beams and columns and the discreteness of design variables, it is difficult to obtain satisfactory results by traditional optimization. Furthermore, material cost is an important issue in designing and constructing reinforced concrete structures. The main factors affecting cost are the amount of concrete and steel reinforcement required. It is, therefore, desirable to make reinforced concrete structures lighter, while still fulfilling serviceability and strength requirements. In addition to material costs, labor and formwork costs are significant. The formwork cost is usually expressed in cost per unit area, but the labor can be difficult to estimate. Therefore, the labour and the formwork cost are generally combined to obtain a reasonable estimate of the total construction cost of the structure. Optimization techniques play an important role in structural design, the very purpose of which is to find the best ways so that a designer or a decision maker can derive a maximum benefit from the available resources.

In this study we present a use of genetic algorithm applications and lay a special emphasis on use of the same as one of the most important optimization tool. Finally, some examples illustrates the effectiveness and efficiency of the genetic-algorithm-based optimal design. This study proposes a new genetic algorithm for long and short column design. A genetic algorithm (GA) optimization program for long and short column, written in MATLAB code, was proposed in this paper. This optimization problem is then solved by a genetic algorithm specially tailored to the problem. In the objective function, the total cost of the structure is minimized. The objective function is the total cost of the building including the cost of concrete, cost of steel and cost of formwork. Cost optimization for long and short column is illustrated and plotting of various cases are shown. The optimal cost obtained from this study was compared with optimal cost, in one of literatures and it was found that the previous one showed a considerable fall in total optimal cost and also demonstrates instances where design assumptions of this study resulted in efficient structures when compared to the literature considered for comparison.

I. INTRODUCTION

The design of reinforced concrete structures has a vital importance in today's day to day life due to its panoptic use by

structural engineers or the designers. They are generally found to have significant compressive strength in comparison to most other construction materials. When compared to steel structures, reinforced concrete structures are more durable, versatile, and incur relatively low maintenance costs. They provide good resistance for damage caused by fire and water, and have splendid potential for a better serviceability.

The traditional structural design method of reinforced cement concrete commonly known as RCC structures is an iterative process which is always carried out as per the limitations and regulations of IS 456:2000. The code presents a particular solution which is later substantiated or affirmed by mathematical logic to check if all the conditions defined for the particular problem are satisfactorily met. In case the conditions are not met, then a fairly new design is projected by the engineer, which is purely based on his hunch and heuristics gained or deduced from his preceding experience (Figure 1.1). Apparently the whole process becomes tedious in the sense that it requires lots of time and indeed human effort as well. Therefore, considering the time constraint in this real design process, a fairly logical solution that satisfactorily meets all the limitations posed by the code, is normally adopted but cost optimization is never even considered. Although the various prospects of structural design process are monitored by several codes and practices, the designer has to take caution along with the calculations, in the rendition of the several provisions of the relevant specifications in order to obtain an effective and an economical design.

Hence the drawbacks of traditional design methods compel the researchers to pull out a better alternative which not only minimizes time required for design process but also reduces total cost of construction. Therefore it was later found that optimization of the design process which consists of altering the design as per a certain "optimality condition" (Figure 1.2), could be the best alternative to the traditional design process.

GENETIC ALGORITHM

Genetic Algorithms are search algorithms grounded in the mechanics of natural selection and natural genetics. It integrates the strategy of "survival of the fittest" among string structures with some of the advanced endowment of human search. Genetic Algorithm is an example of search technique that employs random selection as a tool to lead an extremely exploitive search with the help of a coding of a parameter space.

Genetic algorithm was developed by John Holland, his co-workers and his scholars at the University of Michigan. The main aim of their research was:

- To conceptualize and to explain thoroughly the accommodative process of natural systems.
- To design software on artificial systems that holds the main performance of the natural organization or the system.

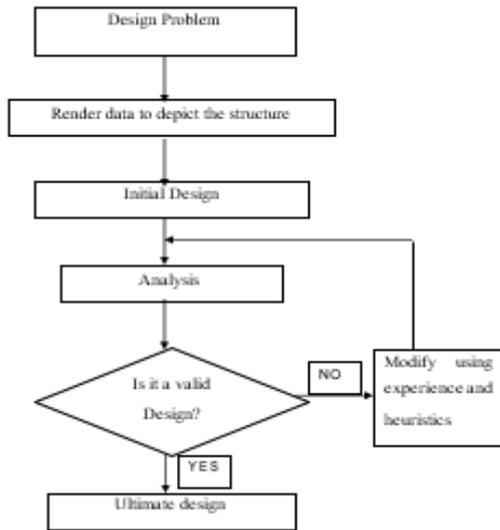


Figure 1.1 Traditional design process

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Working Principle of Genetic algorithm (GA)

The GA works on following main steps:

- Produce a population of solutions.
- Determining the objective function. Fitness function and the application of genetic operators.

GENETIC ALGORITHM IMPLEMENTATION USING MATLAB

MATLAB stands for MATrix LABoratory, is a very effective technical language for mathematical programming. It was first developed by Cleve Moler as an interfacing software for easy access to FORTRAN subroutines libraries called LINPACK and EISPACK for solving linear equation problem and Eigen value problems. MATLAB is a scientific software package structured to provide intense numeric calculation and graphics visualization in high-level programming language.

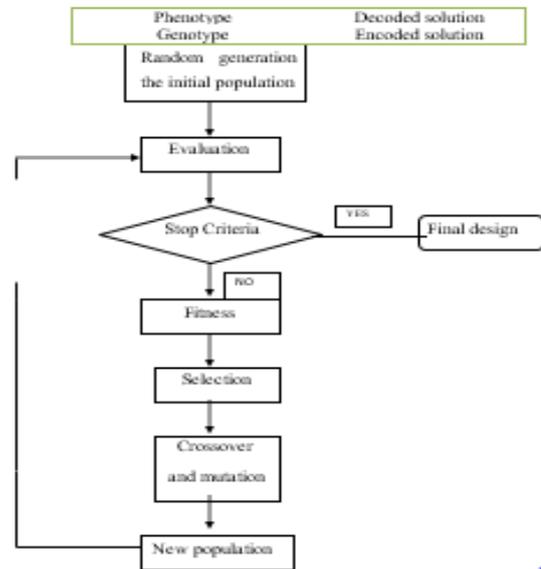


Figure 2. Principal Function of a Simple Genetic Algorithm

MATLAB consists of functions that are advantageous to the Genetic Algorithm learner. It is due to the versatility of MATLAB’s high-level language, that problems can be easily coded in m-files in relatively less time than that of coding in C or FORTRAN programs for the same function. Coupled with MATLAB’s advanced data analysis, especial function application field toolboxes and visualization tools, and then the practitioner is brought in with logical surroundings with which to explore the prospective of GA. [26] Among various optimization tools, MATLAB offers GA Toolbox, which employs MATLAB matrix functions furnish a couple of tools in order to enforce a broad extent of manipulation of GA methods. The GA Toolbox is an assembly of functions, penned generally in m-files that carry out the most important functions in Genetic Algorithms (GA).

MATLAB essentially permits or take into account only one data type: a rectangular matrix of real or complex numerical constituents. The chief data structures in the Genetic Algorithm (GA) toolbox are:

- Chromosomes
- Objective function
- Fitness values

TOOL BOX FUNCTION

The GA toolbox and the Direct Search Toolbox is an assembly of functions that holds the capabilities of the Optimization Toolbox and the surroundings of MATLAB numeric calculation. The GA and the Direct Search Toolbox comprises of the process for working out optimization problems using the following:

- Genetic algorithm
- Directsearch

These algorithms can be employed to work out various kinds of optimization problems including ones that lay beyond the capability of the Optimization Toolbox.

The genetic algorithm employs three major concepts at each step to produce the next generation from the current population, they are:

Selection rules- consists of selecting the best individuals commonly called as “parents” that contribute to the population for the next generation.

Crossover rules- consist of uniting two parents to make or to create “offspring” for the succeeding generation.

Mutation rules- impart random modifications to individual parents to create children.

MODEL FORMULATION

Column, a compression member, can be defined as a structural element used majorly to support compressive loads. It supports vertical loads from the floor and roof slabs and transfers these loads to the footings. Columns ordinarily support compressive loads with or without bending. The behavior of column generally varies from pure beam action to pure column action depending upon the magnitude of the bending moment and the axial force. Columns are commonly classified as short or long column depending on their slenderness ratios. Short columns failure have been commonly reported when their materials are overstressed whereas long columns failure occurs due to buckling which in return produces secondary moments resulting from the P . There are various types of columns: circular and square spiral columns with steel reinforcement, circular and square columns with steel tubing on the outside and rectangular tied columns with steel reinforcement.

To begin with working out an optimization problem, it is generally desirable to formulate the problem beforehand commonly known as “formulating model”. Optimization models, called as mathematical programming as well, comprises of problem selections as decision variables or design variables and searches for values that minimize or maximize the objective functions of the design variables. The main fundamental statement in any structural optimization problems is the “objective function”. It can be broadly defined as the mathematical statement or function one desire to maximize or minimize while also fulfill a certain constraints. The typical optimization procedure is depicted through a flow chart in Figure 4.1.

In order to use any type of simulating or analytical formulation for solving an optimization problem, there are five main tracks:

- Figuring out the realproblem.
- Developing a design model for theproblem.
- Collecting and producing the input data for the designmodel.
- Solving or working out the functioningmodel.
- Application of the solution in the actualpractice.

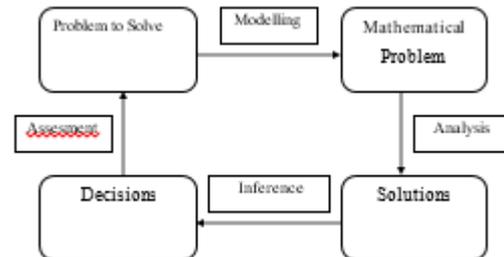


Figure 3. Model Based Optimization Procedure.

✓ **Objective function-** symbolizes the primary purpose of the model which is either minimization or maximization of the problem under study. For instance, in a production process, the objective may be to maximize the profit or minimize the cost. On comparing the data dictated by the user-defined model with the observed data, the objective is to minimize the total deviation of the predictions based on the model from the observed data.

✓ **Unknowns or variables-** control the measure of the objective function. In a production process, the variables may be the amount of various resources utilized or the time consumed by eachoperation.

✓ **Constraints-** allow the variables to choose certain values while bounce back other ones. In any production process, one cannot afford to deplete a desired amount of time on any particular activity, so one constraint is that the "time" variable has to be non-negative. The optimization problem is therefore all about to find the values of the variables that has to be minimized or maximized.

II. RESULTS AND DISCUSSION

In this study, long column and short column (rectangular and square) under biaxial bending is considered. The column is assumed to be bent in double curvature with the moment at bottom end equal to 50% of the corresponding moments at top. Ratio of lateral dimension is taken as 0.5, and 1. The grade of concrete and steel is assumed to be varied between M25, M30, M35 and Fe415, Fe500respectively.

Input for design problem:

Grade of concrete =M25, M30, M35 Grade of steel = Fe415, Fe500

Cost of concrete sas per USSR: (Unified Schedule of Rates and Specifications)^[34]:

Cost of concrete:

For M25, cost of concrete, $C_c = 2888.42(\text{Rs}/\text{m}^3)$ For M30, cost of concrete, $C_c = 3032.84(\text{Rs}/\text{m}^3)$ For M35, cost of concrete, $C_c = 3184.48(\text{Rs}/\text{m}^3)$

Cost of steel as per USSR:

For Fe415, cost of steel, $C_s = 52.65$ (Rs/kg) For Fe500, cost of steel, $C_s = 65.58$ (Rs/kg)

Cost of formwork as per USSR = 212.14 (Rs/m²)

Ratio of lateral dimensions= $D_x/D_y=0.5$ Nominal clear cover=0.04m

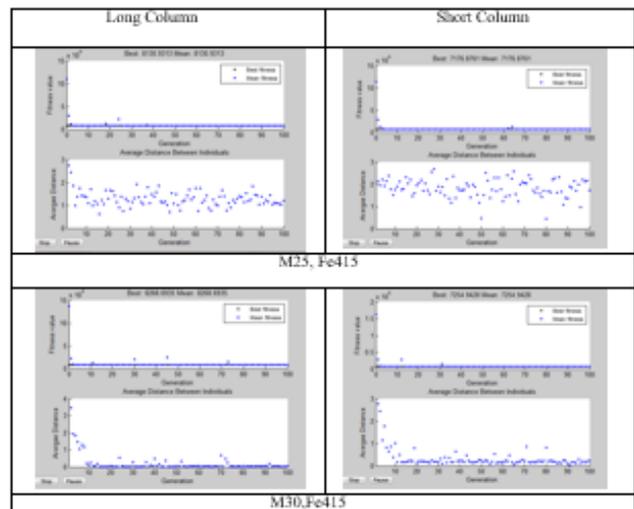
Axial load = $P_u=2500$ kN

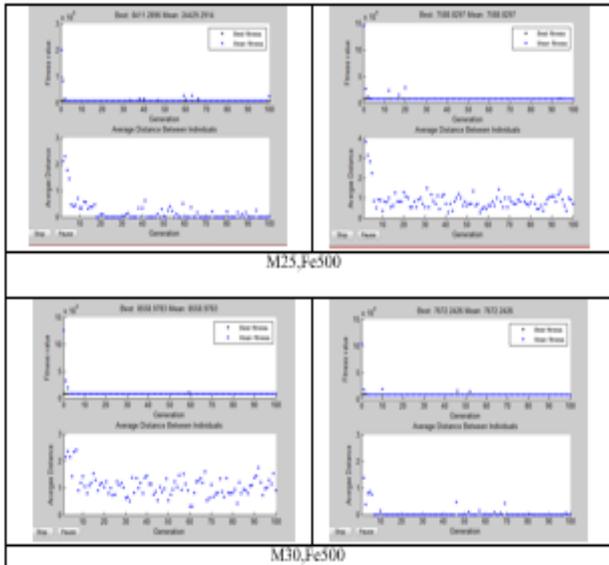
Moment in major axis= $M_{ux}=300$ kNm Moment in minor axis= $M_{uy}=180$ kNm

Population size-20, Crossover fraction-0.8, Mutation-0.01, Generation-100						
When Effective length $l=7$ m, $D_x/D_y=0.5$ (Long Column)						
Grade of steel	Fe415			Fe500		
Grade of concrete	M25	M30	M35	M25	M30	M35
Optimum width(D_x) (mm)	437	442	448	434	432	436
Optimum depth(D_y) (mm)	874	884	896	868	865	872
Area of steel(A_{sc})mm ²	7120	7135	7135	7006	7082	7086
Total optimized cost(Rs./m)	8130.9	8268.6	8314.8	8411.2	8558.9	8631.3
When effective length $l=5$ m, $D_x/D_y=0.5$ (Short column)						
Grade of steel	Fe415			Fe500		
Grade of concrete	M25	M30	M35	M25	M30	M35
Optimum width(D_x) (mm)	526	526	524	526	515	530
Optimum depth(D_y) (mm)	1052	1052	1048	1052	1030	1060
Area of steel(A_{sc})mm ²	5999	5990	5880	5818	5286	5522
Total optimized cost(Rs./m)	7176.8	7254.9	7308.6	7588.8	7672.2	7770.12

III. DISCUSSION

Optimal value for both rectangular and square column is calculated and tabulated as shown in table 5.1. It is evident that the optimal costs are higher in case of long column and as the grade of steel goes higher the optimal values too varies proportionally for both, long column and short column. The graphs obtained for the ratio of $D_x/D_y=0.5$ and for each combination of steel and concrete for long and short column are plotted below.





IV. CONCLUSIONS

This approach studies the cost optimization of long and short column under biaxial bending using Genetic Algorithm. It also integrates realistic materials (i.e. steel and concrete), formwork and labor costs that are based on member dimensions, and implements a structural model with distinct design variables for the design problem considered for the study. The model formulation includes the member sizing and the cost evaluation, which is programmed in MATLAB coding and is solved to obtain the optimized (minimum) cost design using Genetic Algorithm. A number of design examples are solved to demonstrate the use of the method to achieve optimal designs as well as an optimized cost. Different design examples are considered for the long and short column and their result is tabulated along with the various graphs obtained in each case.

Following conclusions are withdrawn from this study:

- As per the traditional design methods of long and short columns, the choice of lateral dimensions and structural pattern must fulfill the specifications of applicable building code that governs the scope of certain parameters, like strength requirements, stiffness and stability. These parameters, to a larger extent, affect the total structural cost. Thus, an inappropriate allocation might be a big or a considerable waste. Consequently, the optimal design method of column is of great practical significance.
- It is also concluded that as the grade of concrete goes higher, the cost varies proportionally in both the cases i.e. long column and short column.
- Also, the variation due to change in mutation rate, generation and population are shown using graph and it is observed that it did not show any considerable change in the total optimal cost, which implies that the change in these GA operators does not have considerable impact on the total optimized values.
- The optimal cost obtained from this study using GA is compared with optimal cost obtained by Neural Network, in one of the literatures [28] and it was found that the previous

one showed a cost savings of up to 3.05% in total optimal cost and also demonstrates instances where design assumptions of this study resulted in efficient structures when compared to the literature considered for comparison.

- Apart from considerable savings in building material and reduction in cost, there is an immense saving of time and human effort while carrying out whole design process. The present study can be extended for future such as:
- This study can be further extended to carry cost optimization for other types of columns like circular columns.
- The programming can also be done as per the guidelines and specifications of some other code apart from the IS456:2000.
- The optimization process can be studied by using Neural Network.
- This work can be further extended for the cost optimization of the structure like multistory building, steel frames etc.

REFERENCES

1. Adeli.H and Sarma.K.C. "Cost Optimization of Structures: Fuzzy Logic, Genetic Algorithms, and Parallel Computing" John Wiley & Sons, Ltd, 2006.
2. Ahmed B. Senouci, Mohammed S.Al-Ansari, "Cost optimization of composite beams using genetic algorithms" Advances in Engineering Software 40 1112–1118, journal homepage: www.elsevier.com/locate/advengsoft, 2009.
3. Anan Nimtawat, Pruettha Nanakorn, "A genetic algorithm for beam-slab layout design of rectilinear floors", Engineering Structures 32 3488–350, 2010.
4. Andres Guerra and Panos D. Kioussis; "Design optimization of reinforced concrete structures Computers and Concrete" Vol. 3, No. 5313-334, 2006.
5. Belen Prendes Gero, Francisco Ortega Fernandez, Antonio Bello García and Joaquín Villanueva Balsera; "Optimization Of The Design Of 3d Building Steel Structures Using Genetic Algorithms", 2003.
6. Carlos Coello Coello Alan D. Christiansen, Filiberto Santos Hernandez; "A simple genetic algorithm design of reinforced concrete beams"; Indian Institute of Technology Bombay, 1997.
7. Chachuat.B. ChE 4G03, "Optimization in Chemical Engineering- Formulation An Optimization Problem", 2005.
8. Chakrabarty, B.K, "A model for optimal design of reinforced concrete beam", Journal of Structural Engineering, 118(11):3238-3242, 1992.
9. Chakrabarty, B.K, "Model for optimal design of reinforced concrete beam", Computers Structures, 42(3):447-451, 1992.
10. Charles V. Camp, Shahram Pezeshk and Hakan Hansson; "Flexural Design Of Reinforced Concrete Frames Using A Genetic Algorithm", 2003.
11. Devdas Menon, Unnikrishna Pillai S.; "Reinforced

concrete design”, 2nd edition, 2004.

12. Goldberg D.E., Genetic algorithm in search, optimization and machine learning, Addison-Wesley, 1989.

13. Hooke R, Jeeves T.A. “Direct search solution of numerical and statistical problems”. Journal of the Association for Computing Machinery, 212-29, 1961..

14. IS: 456 - “Code of Practice for Plain and Reinforced Concrete”, 2000.

15. Iyengar. N.G.R. “Optimization in Structural design”.

16. Jaehong lee, Sun-Myung Kim, Hyo Seon Park, “Optimum Design Of Cold- Formed Steel Columns By Using Micro Genetic Algorithms”; science direct thin-walled structures 44952–960, 2006.

17. Mamoun Alqedra, Mohammed Arafa and Mohammed Ismail, ”Optimum cost of Prestressed concrete beams using genetic algorithms”. Journal of artificial intelligence 4(1):76-88, 2011, ISSN1994-5450/DOI:10.3923/jai.2011.76.88, 2011 Asian network for scientific information, 2011.