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GENETIC ALGORITHM BASED DESIGN OF A REINFORCED CONCRETE CANTILEVER BEAM

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Abstract-This paper demonstrates an application of the genetic algorithms to the design of reinforced concrete cantilever beam. Cost optimisation of reinforced concrete cantilever beam is carried out to get the most economical concrete section and the reinforcements at user specified intervals. Genetic algorithm is used to find out the depth, the number and diameter of bars and the diameter and spacing of stirrups. A program is created based on genetic algorithm to carry out the design. The loading conditions considered are uniformly distributed load in the full span of the beam. Design constraints for the optimization are considered according to the Indian Standard specifications. The program requires the user to input design parameters like the grade of concrete and steel, the design live loads, both uniformly distributed load, the cover required and the number of sections at which the beam has to be analysed. The width of the beam also need to be given as input to the program. The algorithm computes the area of concrete and steel at the sections, by minimising the overall cost of materials involved, concrete and steel. A trial design of beam is carried out using the program and the results obtained are compared with those obtained by manual calculations using limit state method for their feasibility and effectiveness.Genetic algorithm based design method gives results reasonable results satisfying the design code guidelines and other requirements of design.Genetic algorithm sometimes gave infeasible results due to the random nature of search carried out by genetic algorithms.

Key words: *R.C.C cantilever beam, Genetic algorithms, Design.*

1. Introduction

The wide spread use of concrete materials in engineering in recent decades has led to many design methods for improving the performance of structures. An optimal solution means the most economical solution and that which satisfies the functional aspects of the structure. Feasible designs are obtained by optimization using numerical models of decision-making processes and satisfaction of specified objectives. The optimization theory, with the availability of many megahertz of processing speed serves to improve design processes.

In this paper a method using genetic algorithms have been proposed for the design of an RCC cantilever beam. The program analyses the moments and forces at as many points as specified by the user and generates the sections and the reinforcements required. The program is based on the IS: 456-2000 design guide lines.

1.1 Genetic Algorithm in Structural Optimization

Genetic algorithms belong to stochastic heuristic optimization techniques. GA is inspired by Darwin's theory of evolution, where the best individuals have the greatest chance of survival and to become parents of new offspring [1]. GA also uses mutation. Mutation is a small but random change. Mutation allows individuals to adapt to the changing environment. The GA provides a number of feasible solutions to a given problem.

GA is iterativein nature. GA works with a whole population of solutions. The population contains many individuals. GA starts with an initial population and thereafter generates successive populations using three operations: reproduction, crossover, and mutation. Reproduction is the process of copying individual strings to an objective function value. Copying of strings according to their fitness value means that strings which are having a higher value, has a greater possibility of creating the next generation. This is similar to natural selection.Optimization studies using GA were initially focussed on steel structures. The weight and the cost were considered as the objective functions and were minimised. David Shaw et al. demonstrated the application of Genetic programming to civil engineering design problems[2]. They described and demonstrated how by using a suitable form of representation, genetic algorithms can be applied to structural design problems to produce improved solutions.Charles Camp et al.

studied the optimisation of a steel frame using GA. The objective function was weight, which was minimised while satisfying the serviceability and strength requirements. A program was developed based on GA. This program included features like multiple loading conditions, nodal displacements, element stresses etc. checked using AISC-ASD specifications[3].

P Sivakumaer et al., performed study on design improvements on lattice towers using GA. Each bay was considered as an object & treated as a member. Being treated as a member reduced the search space needed and enhanced the convergence of the solution [4].M.P Sakadesigned a GA for the optimization of steel framed pitched roofs with haunches for the rafters and eves. The GA correlated cost of the haunch to the size and length in order to develop an ideal design. The buckling and torsion of columns and rafters were also analysed [5].

JiapingYang used tournament selection scheme to find the optimization of a structure's design. A comparative study between the differences of using Roulette wheel selection and Tournament selection process was also carried out. Tournament selection technique was found to be more efficient, and the program had greater potential for solving optimization problems [6].

Matˇej Lepˇset al.studied the application of genetic algorithms to minimize the cost of a steel reinforced concrete beam. They searched for a design characterized by a minimum price, while all strength and serviceability requirements are satisfied for a given applied load [7].Yousif S.T &NajemR.M used genetic algorithms for the optimum design of reinforced concrete continuous beams based on the specifications of the American Concrete Institute. The beam dimensions and the area of reinforcing steel in this research were introduced as the design variables, considering the flexural and shear, effects on the beam [8].

S. A. Bhalchandra and P.K.Adsul, studiedoptimum design of simply supported doubly reinforced beams with uniformly distributed and concentrated loads. The design objective was to minimize the total cost of a structure. The resulting structure not only was lower in cost but also satisfied all strength and serviceability requirements as per IS: 456-2000. A comparative study between the classical optimization techniques, the Generalized Reduced Gradient Method, Interior point algorithm optimization technique and the Genetic Algorithm was carried out [9]. The results obtained from the Genetic Algorithm optimization technique showed a lower cost.

2. Optimum design of reinforced concrete cantilever beam

In this study, the basic design criterion is the cost of the cantilever RC beams. The objective is to design an RCC cantilever beam while minimising the cost without violating the constraints. The cost of the beams includes the costs of the concrete and the reinforcing steel. The total cost of the RC cantilever beam is

$$F = V_c C_c + W_s C_s, \quad (1)$$

where V_c is the concrete volume, Ws is the reinforcement weight including the tension steel and also the stirrups, and Cc and Cs are the unit costs of concrete and reinforcement, respectively.

2.1 Design variables and design parameters

The design variables were the section thickness, and the number of barsof the reinforcement, the diameter of the bars, the diameter of stirrups and their spacing. The number and size of stirrups, as well as the spacing to meet shear forces, are obtained optimally for a specified section.

2.2 Design Constraints

The RC beam must have a structural capacity greater than the factored applied loading and should meet the specifications defined in the IS Codes.The IS Codes has restrictions and limitations on the cross-sectional geometry of a beam and the position and quantity of steel reinforcement. These restrictions are introduced into the design in the form of design constraints of the genetic algorithm. These constraints were in terms of the five design variables.These constraints were used to specify the main variables so that the designs are safe and stay within the limits of the used code, making the solution more realistic.

First constraint ensures the deflections are within the permissible limits. IS 456-2000 specifies that,

$$\frac{Span}{Effective\ Depth} \leq 7 \text{ for cantilever beams.} \quad (2)$$

$$\frac{l}{d} \leq 7 \quad (3)$$

$$\frac{l}{d} - 7 \leq 0 \quad (4)$$

To ensure that a doubly reinforced section in not required the design moment,Mu was kept below the limiting value of the moment, Mulim .

$$Mu \leq Mulim \quad (5)$$

$$Mu - Mulim \leq 0 \quad (6)$$

The reinforcements should be within the minimum and the maximum limits .The maximum value of tension steel, A_{st} was limited as per IS 456-200.

$$Ast \leq 0.04bd \quad (7)$$

$$Ast - 0.04bd \leq 0 \quad (8)$$

The minimum area of tension steel is,

$$\frac{Ast}{bd} \leq \frac{0.85}{fy} \quad (9)$$

$$\frac{Ast}{bd} - \frac{0.85}{fy} \leq 0 \quad (10)$$

The difference in design shear strength, τ_c of the RC beam should and the nominal shear stress,$\tau_v$is to be taken care by providing stirrups.The magnitude of design shear strength has been introduced using the empirical formula,

$$\tau c = \frac{0.85 * \sqrt{((0.8fck))}(\sqrt{(1+5\beta)}-1)}{6\beta} \quad (11)$$

where

$$\beta = \frac{0.8fck}{6.89pt} \text{ or } 1, \text{whichever is greater} ,$$

where,

$$pt = \frac{100\,Ast}{bd}$$

so

$$\frac{(\tau c - \tau v) * b * d)}{0.87 * fy * d} = \frac{Asv}{Sv} \quad (12)$$

where Asv is the area of shear reinforcement, Sv is the spacing of stirrups.

The equations 4, 6, 10, and 12 also has been introduced as a constraint of the genetic algorithm in terms of thefive design variables.

Finally the spacing of the stirrups, s were also introduced as a constraint. The spacing of the stirupps were,

$$s \leq 0.75d \text{ or } s \leq 300mm \text{ which ever is smaller} \quad (13)$$

2.3 Mutation and Crossover Functions

The mutation rate was 0.03. Too high and too low rates of mutation will produced infeasible results. The mutation function chosen was Adaptive Feasible and the crossover function was intermediate.Mutation function-Adaptive Feasible, is the function in which when there are constraints, it randomly generates directions that are adaptive with respect to the last successful or unsuccessful generation. The mutation chooses a direction and step length that satisfies bounds and linear constraints. The crossover function-Intermediate, creates children by taking a weighted average of the parents[10].

3. Design Example

This design example demonstrates the use of the program created to design an RCC cantilever beam of span 2500mm and subjected to a factored live load of 30kN/m. The grade of concrete chosen is M25 and the grade of steel is Fe415.The width of the beam is 230mm and cover of 25mm. The number of divisions of the beam to be designed is selected as 5, equal divisions. The cost of concrete is taken as Rs. 6000/- per m^3 and that of steel is Rs. 40/- per kg. The program was run and the results are obtained.

3.1 Results and Discussions

Table-1 gives the depth of the beam at various sections taken along the span of the beam. The depths obtained satisfy the deflection criteria.

Table-1 Depth of beam

Section at 'x" mm from support	Overall Depth in mm
0	381.056
500	307.98
1000	235.84
1500	164.64
2000	100

Table-2 compares the moment of resistance of the section provided and the design moments. The moments are equal, ensuring that design moments are tackled by the section provided and singly reinforced sections will suffice.

Table-2 Moment values

Effective depth in mm	Moment of resistance of the section obtained from GA in kNm	Moment due to the loading in kNm
356.056	100.59	100.59
282.98	63.54	63.54
210.84	35.27	35.27
139.64	15.47	15.47
75	4.46	4.46

Table-3 compares the area of steel required from manual calculation to those obtained from the GA program. The area obtained from GA program is very slightly lower than that from manual calculations.

Table-3 Area of steel

Section at 'x" mm from support	Area of steel A_{st} required mm^2	Area of steel A_{st} obtained from GA		
		No. of bars	Diameter mm	Area mm^2
0	975.36	4.16	17.27	974.46
500	775.18	3.49	16.80	773.63
1000	577.56	6.54	10.60	577.13
1500	382.52	3.22	12.28	381.36
2000	205.45	2.36	10.50	204.35

Table-4 gives the spacing of 8mm diameter 2 legged stirrups for the beam as per manual calculation. Spacing obtained is greater than the maximum spacing. The GA program as per the constraint gave a spacing of 300mm.

Table-4 Spacing of stirrups

Section at 'x" mm from support	Shear stress τ_v	Shear stress τ_c	Spacing required mm
0	0.98	0.685	561.13
500	0.97	0.685	561.13
1000	0.96	0.685	561.13
1500	0.96	0.685	561.13
2000	0.88	0.685	561.13

The Genetic algorithm based design gave design results which are comparable to that from manual calculations. GA gave an almost equal but slightly lower area of steel, while all other results were at par with the manual designs. The difference in area of steel, even though is very feeble, can be of significance in the design of large structures.

4. Conclusions

Genetic algorithm based design of cantilever beam gave reasonable results, satisfying all constraints. This method has the advantage that the cost of concrete and steel can be incorporated into the design. This will help in obtaining reasonable sections and steel based on the cost. Other constraints can also be easily applied into the design, making the design to suit various requirements. The values obtained from the GA program are representative values only. The choice of practical values are left to the decision of the design engineers.

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