Design Optimization of RC Frames using Particle Swarm Optimization Technique

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Abstract. Design of portal frames were carried out for different grades of steel with a well-defined objective function framed in order to minimize the cost of construction of reinforced concrete portal frames for different spans using direct stiffness method. The design variables that are considered are the volume of steel used for reinforcement, volume of concrete for sectional members that is got from the width, depth of the required section. The constrains for the design of beams were done according to the Indian codal provisions. Separate coding was written in MATLAB to determine the optimal design of beams. The optimal design results obtained had a minimum usage of concrete and steel when compared to the normal one with a variation of 5% for the beam and 3% for the column. The reduction in cost is due to reduction in the cross-section as a result of the optimization technique. Nearly 100 designed samples using different cross-section areas were carried out and the final conclusions were derived and found to provide optimal values to certain extent which would be useful for the design engineers.

1. Introduction

Due to the increase in the population depletion in the forests and lands has become a very major cause as a result of which high raise building plays a very important role in the current situations. This lead to this research work that deals with the aim to contribute to the design engineers the aspect of construction of frames for loadings that least to the most optimal design that is very much important in the current situation. The least cost solution was first started by Michell [1] then it was started by Schmidt [2]. The optimal design of continuous beam was done by Heyman [3]. During the past years there were huge developments in the construction field that leads to the most optimal design of various construction materials such as concrete, steel and formwork. Many researched used the classical and non-traditional techniques Krishnamoorthy and Munro [4] used linear programming methods for finding the least cost of RC frames [5]. Computing methods of design variation in the techniques have been carried out by Moharrami and Grierson [6] subjected to various strength and stiffness parameters. Implementation of Genetic algorithm was carried out by many researchers and least cost solutions were obtained using it
for structural elements such as beams, columns, frames etc., [8-9]. Sara studied the optimal design of placement of reinforcement in simply supported beams and tension members using Artificial Neural networks, particle swarm optimization techniques [10-14].

2. Objective Function

Cost optimization involves with the design variables available in a structural element which needs to be minimized, that was subjected to certain constraints

\[
\text{Cost function} = C = C_{\text{columns}} + C_{\text{beams}} \\
C_{\text{columns}} = \text{Cost of columns for the full frame} \\
C_{\text{beams}} = \text{Cost of all beams in the full frame} \\
C = C_c A_c + C_s A_{\text{st}} + C_f A_f \tag{2}
\]

\[
= C_c (A_g - A_{\text{st}}) + C_s A_{\text{st}} + 4 C_f b \tag{3}
\]

\(A_g\) and \(A_{\text{st}}\) are expressed in m\(^2\) units and \(b\) in metre units

Where,

- \(C_c\) - Cost of concrete per unit volume (Rs/m\(^3\))
- \(C_s\) - Cost of steel per unit volume (Rs/m\(^3\))
- \(C_f\) - Cost of formwork per unit contact area (Rs/m\(^2\))
- \(A_f\) - Area of formwork in m\(^2\)
- \(b\) - Size of square cross section in m

The optimization problem is to determine \(A_g\) and \(A_{\text{st}}\) to minimize. The problem is solved for different values of \(f_y\), \(f_{ck}\), and \(T\) to build a database using which the neural network is trained, validated and tested in the following phase of the work.

Following are some of the constraints that are considered for structural elements such as beam and columns

Columns

a. Geometric constraints for columns which deals with the minimum and maximum width and depth of the column
b. Capacity constraint that is used to define the minimum and maximum load that is used to be applied on the columns
c. Minimum and maximum limit of area of reinforcement that is to be provided in a column

Beams

a. Geometric constraints for beams which deals with the minimum and maximum width and depth of the column
b. Flexural capacity constraint that is used to define the minimum and maximum moment that is used to be considered for design of beams
c. Minimum and maximum limit of area of reinforcement that is to be provided in a column
d. Shear strength capacity of the beam for providing shear reinforcement

3. Analysis and Design of Model
A multistorey frame was analysed using ETABS and the design of the reinforcement with the cross section dimensions are taken as variables. The grade of steel are varied from 250N/mm² to 550 N/mm², and concrete from 25-50 N/mm². The design considerations are done according to the IS codal provisions.

Figure 1: Model of the Frame

Figure 2: 3D Model of the Frame
4. Partial Swarm Optimization Technique

The PSO was invented by James Kennedy and Russell Eberhard that explains about the swarming habits of birds. Few relevant technologies same as this are Genetic Algorithm, Artificial bee colony algorithm, movement of fish in the sea, etc. For every individual present in the define medium it should produce a very good fitness value for it to maintain in the long run selection of proper population is necessary from which its velocity and its own individual best position. The global best value is determined for each and every individual that gets updated that leads to a close minimal solution.

The step of the PSO is classified in three steps:

1. Determination of the fitness of individual particle is initially done.
2. Updation of each and every individual that is having the global best solution is determined.
3. The final velocity of the global beat and the updated velocity for each and every individual is done particle.
4. Final Velocity update in the algorithm
5. Results

The results that are got from the design of the frames with respect to the panel size and from the algorithm are given the Table 1 and 2 below for different grades of concrete and steel.

Table 1: Total Cost with respect to the panel size in frames

| Panel size, m | 25            | 30            | 35            | 40            | 45            |
|---------------|---------------|---------------|---------------|---------------|---------------|
| 4             | 6034.238872   | 17250.28372   | 17422.28115   | 17989.4932    | 18185.58558   |
| 4.5           | 5624.772365   | 15887.13724   | 16227.02947   | 16644.03713   | 16684.29776   |
| 5             | 5274.895527   | 14947.04797   | 15180.8453    | 15597.68209   | 15655.00955   |
| 5.5           | 5278.350536   | 14483.57013   | 14610.3248    | 15112.09666   | 15280.84735   |
| 6             | 4991.839343   | 13959.6128    | 14177.64414   | 14619.87769   | 14778.76152   |

Table 2: Variation of Steel Cost with respect to the panel size in frames

| Grade of steel, MPa | Fe 250         | Fe 415         | Fe 500         |
|---------------------|----------------|----------------|----------------|
| 4                   | 6034.238872    | 6354.954675    | 6715.670478    |
| 4.5                 | 5605.772365    | 5987.221017    | 6253.66967     |
| 5                   | 5294.895527    | 5591.710052    | 5898.524576    |
| 5.5                 | 5278.350536    | 5577.98362     | 5847.616704    |
| 6                   | 4991.839343    | 5291.516211    | 5566.193078    |
Figure 5: (a) Displacement curve of building with and without bracings

Figure 5: (b) Variation of Cost and grade of steel with size of square panels

6. Conclusions

Hundred samples were analyzed and designed both manually and by using the Particle swarm optimization it was compared and found that by using the PSO technique the optimal cost was reduced to about 40%. This method was found to be advantageous with respect to the cost of concrete and steel used in the design calculation. 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.

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