Design Optimization of Reinforced Concrete Beams by Genetically Optimized Neural Network Technique

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Abstract. An approach to find the accurate optimal solution for structural elements such as beams, columns, footings etc. has been studied by huge researches in the current situation. As an addition in this research paper optimal design of two different types of reinforced concrete beams with different loading conditions one with concentrated load and another with UDL has been considered in addition to its self-weight, live load, equilibrium and serviceability constraints. Manual design of beams has been done in order to verify with the optimization technique limit state approach with accordance to the Indian standard codal provisions, classical and non-traditional optimization technique are done and the results are tabulated

1. Introduction

Optimal design of reinforced concrete slabs are done by using traditional and non-traditional methods by satisfying the limit state of serviceability and collapse. The codal provision does not give a design satisfying the requirements directly with an optimal solution for the design of slab. The intuition of a design engineer is to give an accurate design solution with affordable cost with trial and error process at the same time should be safe to live in. The techniques of optimization involve the choice of design variables, constraints in a way to find the optimal single solution satisfying the constraints with respect to geometry and behaviour. The steel provided in a slab increases the ductility of the slabs whereas reduces the long term deflection.

[1-4] choice of constraints and design variables during the design as well as the optimization process requires the execution of various trial and error process. If artificial neural network is used to do the optimization process it can find a solution in a faster way than the process done manually. [6-7] researchers have used non-traditional methods satisfying the ultimate load method by satisfying moment...
capacity behaviour constraint. [8] paper Artificial Neural Network in which the user defined parameters where the learning rate and error goal were optimized by genetic algorithm for the problem concerned to learn the optimal design for the following.

1. One way slab
2. Two way slab with various end conditions

The optimization of the slab is done by satisfying the moment carrying capacity, durability, as recommended by the IS code provisions.

2. Objective Function

Formulation of objective function play a vital role and it is of much importance as how we create it depends on the final output of our problem also. It main aim in the current problem is to minimize the total cost of structure, with accordance to IS456: 2000. The optimized structure, should not only have a reduced cost but also it satisfies the serviceability and strength requirements. Some of the variables considered for the design are as given below.

- Dimension of slab
- Diameter for short span reinforcement
- Diameter for long span reinforcement
- Diameter for torsional reinforcement
- Spacing for torsional reinforcement
- Diameter for edge strip reinforcement
- Spacing for edge strip reinforcement

a) Objectives
1. Cost optimization of reinforced concrete slabs

b) Optimization of slabs
The following are the parameters that should be defined as below
- Constant Parameters - are given as input
- Design Variables - are the ones that should be examined or found out
- Objective function - the parameter that should be minimized or maximized
- Design Constraint - conditions that are to be incorporated in the function

The optimization process is to select the values of variables in a way that satisfies the provisions of the code regarding safety and serviceability within the least cost possible, the function below defines the total cost of the RC simple slab model in terms of the cost of the concrete and reinforcement and form work used.

\[ TC = C_c + C_s + C_f \]  (1)

\[ C_c = C_{vc} * V_c \]
\[ C_s = C_{ws} * W_s \]
\[ C_f = C_{sf} * S_f \]

Where,
TC= total cost in Rs
Cc = cost of concrete in Rs
Cs =cost of steel in Rs
Cf=cost of formwork in Rs
Cvc=cost per unit volume of concrete Rs/m3
Cws = cost per unit weight of steel Rs/kg
Cs = cost per unit area of formwork Rs/m²
Vc = volume of concrete in m³
Ws = weight of steel in kg
Sf = sectional area of formwork in m²

\[ V_c = LL * LS * X_1 - \left[ \left( \frac{\pi}{4} \right) X_2 * X_3 * L_s + \left( \frac{\pi}{4} \right) X_4 * X_5 * LL + 0.75 \left( \frac{\pi}{4} \right) X_2 * X_3 * L_s + \left( \frac{\pi}{4} \right) X_6^2 * 0.1 * LERL + \left( \frac{\pi}{4} \right) X_2 * 0.1 * LERS \right] \]  

\[ C_c = C_{vc} * V_c \]
\[ C_s = C_{ws} * W_s \]
\[ W_S = \frac{X_2}{162} (L_{SR}) \times N_{SR} + \frac{X_4}{162} (L_{LR}) \times N_{LR} + \frac{X_2}{162} (L_{S/5}) \times N_{TR} + \frac{X_2}{162} (L_{ERS}) \times N_{ERS} + \frac{X_2}{162} (L_{LERL}) \times N_{LERL} \]

Where,
LS is the short span length in m.
LL is the long span length in m.

\[ 7850 = \text{density of steel in kg/m³} \]

\[ C_f = C_{sf} * S_f \]
\[ S_f = (2 * L_{S} * X_1) + (2 * L_{L} * X_1) + (L_{L} * L_{S}) \]

Therefore
\[ T_C = C_{vc} * \left[ LL * LS * X_1 - \left[ \left( \frac{\pi}{4} \right) X_2 * X_3 * L_s + \left( \frac{\pi}{4} \right) X_4 * X_5 * LL + 0.75 \left( \frac{\pi}{4} \right) X_2 * X_3 * L_s + \left( \frac{\pi}{4} \right) X_6^2 * 0.1 * LERL + \left( \frac{\pi}{4} \right) X_2 * 0.1 * LERS \right] \right] + C_{WS} \times \frac{X_2}{162} (L_{SR}) \times N_{SR} + \frac{X_4}{162} (L_{LR}) \times N_{LR} + \frac{X_2}{162} (L_{S/5}) \times N_{TR} + \frac{X_2}{162} (L_{ERS}) \times N_{ERS} + \frac{X_6}{162} (L_{LERL}) \times N_{LERL} + C_{sf} \times (2 * L_{S} * X_1) + (2 * L_{L} * X_1) + (L_{L} * L_{S}) \]

Where,
X_1 = overall of the beam in m
X_2 = diameter of reinforcement bar in short span in m
X_3 = number of reinforcement bar in short span in m
X_4 = diameter of reinforcement bar in long span in m
X_5 = number of reinforcement bar in long span in m
X_6 = diameter of reinforcement in edge strip in m
LERL = length of edge strip reinforcement in short span in m
LERS = length of edge strip reinforcement in long span in m
NERS = number of edge strip reinforcement in short span
NERL = number of edge strip reinforcement in long span

CONSTRAINTS:
1.) Flexural Strength:
Factored moment < Permissible moment
\[ Mu \left[ \frac{0.87 \times f_{y} \times \phi^2 \times (width/S_v + 1)}{d} \right] \times (1 - 0.75 \times f_{y} \times (width/S_v + 1) / f_{ck} \times d) \leq 0 \]

2.) Shear Strength:
\[ \text{Shear} / (width \times d \times 0.5 \times \tau_{\text{max}}) - 1 \leq 0 \]

3.) Reinforcement Constraint:
Spacing of main reinforcement:
\[ S_v / 300 - 1 \leq 0 \]
\[ S_v / 3 \times d - 1 \leq 0 \]
Minimum Reinforcement:
\[ 0.0012 \times width \times d / (ast \times \phi^2 \times (width/S_v + 1)) - 1 \leq 0 \]

S_v = spacing , \phi = dia of main bar , d = depth of slab , ast = area of dia bar used.
3. Genetically Optimized ANN algorithm

The flow chart as shown in Figure 1 below explains on how the general algorithm for any optimization problem works with in. Identifying the initial population or random population and the number of iterations needed is a very tough job as it mainly affects the results at the end.

Genetic Algorithm generally is used as it deals with multiple solutions in a problem and it develops the results with a greater number of iterations. Each solution deals with all parameters that helps in enhancing the results. While using Artificial Neural Networks the weights used in all the layers help in achieving high accuracy results. In order to make the work and easier and simple, a single solution in GA is made to contain all weights in the ANN. In the particular problem the ANN has 4 layers (3 inputs, 4 hidden, and 1 output). Any weight in any layer will be part of the same solution.

![Image of the flow chart](image_url)

**Figure 1:** Genetically Optimized ANN algorithm

4. Results

In this section, the model of the RC slab is described, showing the fixed parameters, the design variables, the design variables’ bounds, the design constraints and the objective function. A typical simply supported rectangular RC slab has a dimension of Lx X Ly m and may be carrying a Moment kN-m. The grades of concrete considered are M20, M30, M40, M50. The grades of steel adopted Fe250, Fe415, Fe500, Fe550. It is intended to optimize the design of the beam according to the provisions of the IS-456:2000 Code.
Figure 2: Variation of grade of concrete with total cost

Figure 3: Variation of Steel with Total Cost

4.1 MINITAB:
Using Minitab software, the factors that affects the cost of the slab. The factors are grade according to their influential order.
a) Dimension 1 (3*4) yields least price while Dimension 4 (3.5*4.5) yields maximum price.
b) In regards with fck, 20 gives the least price while 30 gives the maximum price.
c) In case of grade of steel as the grade increases cost decreases concluding that fy 550 is preferable.
d) As for load case min load yields minimum cost and maximum load yields maximum cost.

5. 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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