Design and Optimization of Reinforced Concrete Slabs by using Non-Traditional Optimization Techniques

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Abstract. This research paper gives a detailed summary of the optimal design of reinforced concrete slabs using different codal provisions namely ACI, Indian, Euro codes which are presently available and also predicts the failure pattern by using finite element analysis simply supported, reinforced concrete slabs under uniformly distributed loading. In order to check the result obtained, a model of the slab is done in concrete and the tests on five slabs have been performed of values which was optimized using the non-traditional optimization techniques by writing a separate code in Matlab. The results obtained after the optimization technique produces a reasonable and acceptable solution. One hundred and forty five simply supported RC slabs have been designed adopting M 25 grade concrete and Fe 500 grade steel and using yield line theory and Bacterial Foraging Optimization Technique. A live load of 2.5kN per square metre was considered. The ratio of Ultimate moment of resistance of slab with respect to x and y axis, μ, was varied from 0 to 1. The length of the slab was varied from 3m to 6m and L/b ratio from 1 to 2.0. The value of μ that results in the most economical solution has been found out.

1. Introduction

The most widely used structural element is slab. It is an element which is used to resist loads which are always applied normal to the plan of action. The slab becomes the most important part of the structure in a frame element in order to resist the lateral load. The finite element method is chosen as this is more powerful and versatile compared to other numerical methods. A slab element is developed on the basis of conventional slab theory expressed in terms of rectangular co-ordinates and displacement. The element incorporates 20 degree of freedom, namely, normal displacement with its first derivatives along longitudinal and transverse direction respectively and two tangential displacements.
To determine the optimal cost of construction for the design of slabs, a Matlab coding has been developed using Bacterial Foraging Optimization technique. The results obtained from the experimental work and the analytical works have been compared and the results are discussed in detail.

2. Literature Survey

[1] based on the requirements of IS456:2000 and adopting Staad Pro v8i software analysed and designed High rise buildings. The ANN tool gave accurate results even if a small amount of data was given, and Particle Swarm Optimization gave accurate solution for global problems. Thus by combining Neural Network -Particle Swarm Optimization technique it is possible to get good results with respect to accuracy. [2] studied four optimal positions of shear walls for a ten storey building, analysed and designed with the help of ETABS software according to Indian and European standard codal provisions and they concluded that box type shear wall at top of the building give the most optimal solution. [3-5] in their paper, explained the different optimization techniques used such as Genetic Algorithm, Ant Colony Optimization, Particle Swarm Optimization, Big Bang-Big Crunch, Colliding Bodies Optimization and Enhanced Colliding Bodies Optimization for determining the size and topology optimization of 3 storey, 5storey, and 10storey frames, whose height at each floor was 3 m, the width of the frame was 5m, live load was taken as 1.96kN/m² and dead load of 6.3kN/m². The joints were considered as rigid, and finally, after analysis and design by ACI code, they concluded that when a new technique known as dolphin monitoring was included in each of the algorithm it gave the most optimal solution of all the three frames. [6-9] presented the optimal design of steel frames assuming semi rigid connections and adopting non-linear analysis. They considered the size, displacement and stress constraints for the design of beams and columns with respect to the Load and Resistance Factor Design and Allowable Stress Design specifications for a seven storey frame with three bays, nine storey frames with one bay and ten storey frame with four bays. They finally concluded that the most optimal solution of the frame can be obtained when the stiffness of the connections in the frame are adjusted as the deflection caused are reduced when larger sections are used.[11] in his article, deals with the use of multi objective optimization technique for determining the least cost design of a three storey RC frame inclusive of seismic retrofitted columns only, and the retrofitted columns and beams by using Fiber Reinforced polymer materials. The designs were based on ACI standards and genetic algorithm optimization technique and he finally concluded that if minimization of cost is considered, then, the column members alone should be retrofitted and if seismic criteria are considered, the retrofitted beams as well as the columns give optimal strength value. [13-17] give a detailed shape optimization and design of axis symmetric shell using fracture mechanics and genetic algorithm technique for a sample of 12 different types and conclude that Genetic Algorithm is very effective. It is a type of nature inspired optimization algorithm found by Passino, based on the group activity of E-coli bacteria, for solving multi-objective optimization problems. It mainly deals with the movement of bacteria for the search of nutrients to maximize the energy of it inside a defined medium. [18-19] The bacteria also gives definite results while the searching process is carried out which is found to be efficient than classical optimization techniques. The process in which a bacteria moves in search of its food is known as chemotaxis. This process has been found to be applied to various real life problems in multi-dimensional fields of engineering in the past few decades. In this present research work, this technique is used for finding the optimal solution (lowest cost) for reinforced concrete elements and structures and is found to give a solution which paves way for the easy design of these elements for the future designers. [20-23] Optimal design of various structural elements such as tension members, compression members, slabs and beams with various optimization techniques have been carries out and was found to produce accurate results using genetic algorithm, artificial neural network, bacterial foraging optimization technique.
3. Optimization Procedure

In this work, the design of One hundred and forty five simply supported RC slabs have been designed adopting M 25 grade concrete and Fe 500 grade steel and using yield line theory and Bacterial Foraging Optimization Technique. A live load of 2.5kN per square metre was considered. The ratio of Ultimate moment of resistance of slab with respect to x and y axis, \( \mu \), was varied from 0 to 1. The length of the slab was varied from 3m to 6m and L/b ratio from 1 to 2.0. The value of \( \mu \) that results in the most economical solution has been found out.

This algorithm is briefly explained in the following steps:

3.1 Chemotaxis

The initial step in this algorithm deals with the movement of the E.coli cell with the flagella, this bacteria has the possibility of moving in two directions. The movement of the chemotaxis of the bacteria mat is represented by

\[
\theta(i+1,j,k,l) = \theta(i,j,k,l) + C(i) \frac{\Delta(i)}{\sqrt{\Delta(i)\Delta(i)}}
\]

where \( \Delta \) is the random direction whose elements lie between \([-1,1]\).

3.2 Swarming

The E. coli cells arrange themselves in a ring shape by moving up the nutrient gradient when placed in a semisolid matrix with a nutrient chemo-effector. When these cells are stimulated at to a very high level, they release an aspirate which helps them to move together and move as concentric circles patterns with a high density level of bacteria.

3.3 Reproduction

The bacteria which has the least value dies at the end of this process while the bacteria with the highest value clears and moves to the next process when placed in the same location. This helps to maintain the swarm size in a constant manner.

3.4 Elimination – Dispersal

The final process in this step has the effect of possibly destroying the chemotactic progress which has the effect of assisting it, which are a part of population level long distant mobile behaviour.

4. Optimization Formation

The objective function \( C \) is to minimize the cost in the slab

\[
\text{Total Cost} = \text{Cost of Concrete} + \text{Cost of Steel} + \text{Cost of Formwork}
\]
Total Cost = \( C_c (V_c) + C_s V_s + C_f [L*b] + 2(L+b)*D \)  \( \quad (1) \)

5. Results

Bacterial Foraging Optimization results: Results obtained for some of the slabs by using Bacterial Foraging optimization technique are given in Table 1 for a simply supported two way slab for a span of 3m, live load of 2.5kN/m², \( \mu = 0 \) to 1, \( \alpha = 0.7 \) for different grades of steel and concrete.

| Length of slab, m | \( \alpha \) | \( \mu \) | D in mm | \( A_{st} \) in shorter direction in mm²/m | \( A_{st} \) in longer direction in mm²/m | Cost in Rs |
|-------------------|---------|--------|--------|---------------------------------|---------------------------------|-----------|
| 3                 | 0.5     | 0      | 67.86  | 199.1817                       | 51.42857                       | 3266.049  |
|                   |         | 0.2    | 67.86  | 152.2164                       | 51.42857                       | 3196.958  |
|                   |         | 0.4    | 67.86  | 136.4324                       | 53.25361                       | 3204.959  |
|                   |         | 0.6    | 67.86  | 125.5613                       | 73.93517                       | 3214.797  |
|                   |         | 0.8    | 67.86  | 117.1574                       | 92.42261                       | 3224.907  |
|                   |         | 1      | 67.86  | 110.2862                       | 109.2057                       | 3234.846  |
| 3                 | 0.6     | 0      | 76.43  | 251.8841                       | 61.71429                       | 4181.187  |
|                   |         | 0.2    | 76.43  | 182.4097                       | 61.71429                       | 4065.869  |
|                   |         | 0.4    | 76.43  | 160.0722                       | 62.54785                       | 4071.717  |
|                   |         | 0.6    | 76.43  | 145.03                          | 85.521                         | 4081.259  |
|                   |         | 0.8    | 76.43  | 133.6075                       | 105.5673                       | 4091.636  |
|                   |         | 1      | 76.43  | 124.4093                       | 123.3919                       | 4102.016  |
| 3                 | 0.7     | 0      | 85     | 308.9588                       | 72                             | 5193.272  |
|                   |         | 0.2    | 85     | 212.0417                       | 72                             | 5057.219  |
|                   |         | 0.4    | 85     | 182.2518                       | 72                             | 5015.401  |
|                   |         | 0.6    | 85     | 162.6374                       | 96.02207                       | 5021.588  |
|                   |         | 0.8    | 85     | 148.0051                       | 117.0964                       | 5030.631  |
|                   |         | 1      | 85     | 136.3977                       | 135.4555                       | 5040.109  |

Note: like this two hundred and fifty six slabs have been designed using Bacterial Foraging Optimization technique.

6 Analysis of Design Results

Economical \( \mu \) for various spans

The various values of \( \mu \) that result in the least cost of simply supported slabs for different L/b ratios are graphically given in Figures 1.2, 1.3, 1.4, 1.5 and 1.6.
Figure 1 Variation of economical $\mu$ for various L/b ratios

Figure 2 Variation of economical $\mu$ for various L/b ratios

Figure 3 Variation of economical $\mu$ for various L/b ratios

0 0.2 0.4 0.6 0.8 1 1.2
0 0.2 0.4 0.6 0.8 1 1.2
0 0.2 0.4 0.6 0.8 1 1.2

L=3 m
Concrete = M25
Steel = Fe 500

L=3 m
Concrete = M25
Steel = Fe 500

L=3 m
Concrete = M25
Steel = Fe 500

Economical $\mu$
Economical $\mu$
Economical $\mu$

L/b ratio
L/b ratio
L/b ratio

3 m
4
5
When the L/b ratio is 1 the economical value of $\mu$ is one. Now when L/b ratio is 2, i.e., when the slab becomes one way slab the economical value of $\mu$ is not zero because a minimum reinforcement of 0.12% of bD is provided and this gives rise to certain value of moment of resistance.

**Figure 4** Variation of economical $\mu$ for various L/b ratios

**Figure 5** Variation of Total cost with $\mu$ and grade of steel

**Figure 6** Variation of Total cost with $\mu$ and grade of steel
The variation of Cost with grade of steel is graphically shown in Figure 1.6 and 1.7 for slabs having \(L=3\)m and \(L=6\)m respectively. From these figures it is clear that, as the grade of steel is increased, the total cost of the slab gets reduced. The variation between higher grades of steel (Fe 415- Fe 500) is very small.

It is also clear that, as the value of ratio, \(\mu\), increases the cost decreases for different grades of steel except for Fe 250.

7. Conclusions

When the \(L/b\) ratio is 1 the economical value of \(\mu\) is one. Now when \(L/b\) ratio is 2, i.e., when the slab becomes one way slab the economical value of \(\mu\) is not zero because a minimum reinforcement of 0.12% of \(bD\) is provided and this gives rise to certain value of moment of resistance.

The variation of Cost with grade of steel is graphically shown in Figure 1.6 and 1.7 for slabs having \(L=3\)m and \(L=6\)m respectively. From these figures it is clear that as the grade of steel is increased, the total cost of the slab gets reduced.

The variations of cost with \(\mu\) are shown in Figures 1.6 and 1.7. It is clear that, as the value of ratio, \(\mu\), increases the cost decreases for different grades of steel except for Fe 250.

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