OPTIMIZATION OF REINFORCED CONCRETE STRUCTURES DESIGN

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ABSTRACT

Millions of reinforced concrete structures are being constructed every year throughout the world. Almost all the designers are not able to adopt economical aspects related to the design that may result in lots of saving in materials and cost because, at present, factors to be considered for economical solutions are not available. Hence, in this theoretical investigation an attempt has been made to study the influence of the important parameters in the economical design, of some of the RC members and structures. At first, influence of grades of concrete and steel on the economical design of axially loaded RC tension and compression members has been studied. In addition to the influence of grades of the constituent materials, the percentage of steel has also been considered to arrive at the economical design of RC short columns subjected to axial load and biaxial bending moments.

Keyword: *Reinforced concrete structure, Bending moment, Design consideration*

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1. INTRODUCTION

Research works pertaining to concrete technology, design of concrete elements and execution of concrete structures have been carried out for the past over one hundred and fifty years. Research workers in the past have concentrated on the properties such as strength and durability of concrete. Very little information is available on the economical design of reinforced cement concrete structural members and structures made of it. A small saving effected in the design of a RC structural member will result in the huge saving when numbers of such elements are adopted in the whole structure. Almost all of the structural concrete designers simply follow the codal provisions and do not explore the possibility of reducing the cost within the limitations of the codal provisions. Hence, at present, a huge amount of money is being wasted in the uneconomical design of RC elements and their structures. Considering all these factors, in this theoretical investigation, an attempt has been made to arrive at economical designs for the following RC structural components/ structures.

1.1 OBJECTIVES OF THE INVESTIGATION

i)To study the influence of grades of concrete on the cost of RC tension members.
ii)To study the influence of the grades of steel and concrete on the economical design of an axially loaded compression member.
iii)To study the influence of grades of steel and concrete and that of percentage of longitudinal steel on the lowest cost of a RC compression member subjected to axial load and bi- axial bending.
iv)To find out the effect of the relative moment capacities about the x and y axes of simply supported RC slabs on the minimum cost of these slabs
v)To investigate the effect of grades of concrete and steel, spacing of T-Beams and span on the lowest cost per unit area covered by simply supported T-beam and slab structure and by continuous T-Beam and slab structure.

1.2 Optimization Techniques adopted in this Investigation

i)Artificial Neural Network for tension members
ii)Genetic Algorithm for Axially loaded compression members

iii)Bacterial Foraging optimization for members subjected to axial load and bi axial moments, simply supported slabs, simply supported T beams, bunkers, silos, RC frames, and Multibay Multistorey RC frames

2. LITERATURE REVIEW

Rafael de Paula Garcia et al. (2017) have given a detailed presentation of different types of algorithm techniques for constrained and unconstrained optimization problems using genetic algorithm and have concluded this technique to be easier when compared to the classical methods.

Yintao Wei et al. (2017) proposed a new technique for shape optimization or geometrical optimization for nonlinear analysis of structures which is reliable and useful for the latest trend in the building construction. This method was found to be the latest trend than the classical optimization methods.

Nikos D. Lagaros (2014) explained in a detailed manner, known eight optimization techniques for the real world problems which were analyzed and designed by using SCADE Pro, SAP 2000 and also by a metaheurstic optimization technique and finally concluded that, these methods prove to be very useful if they are transferred from computer lab to the practical site work.

Kamal C. Sarma & HoijatAdeli(1998) have gone through a majority of papers published in that period for cost optimization of RC structural elements such as beams, columns, slabs, pipes, frames, bridges, water tanks and shear walls. They finally concluded that using optimization technique for cost minimization for large structures which have many structural elements involved, leads to a reduction in the cost.

Hector A. Jensen et al. (2013) considered the high dimensional stochastic problem that has higher degrees of freedom for static as well as dynamic model, in which optimization technique, namely, Quasi Newton iteration method was used and proved that this method is found to be economical from various numerical examples.

KavehAIlchi&Ghazaan (2015) introduced a new method of minimizing the cost of the skeletal structure by using two different techniques such as Colliding bodies optimization and enhanced Colliding bodies optimization which are developed from the basics of Physics. The result obtained from Colliding bodies optimization was much accurate than the enhanced Colliding bodies optimization and had an efficiently proposed algorithm.

Matej Leps& Michal Sejnoha (2003) used Genetic Algorithm for the optimal cost estimation of RC continuous beams subjected to uniformly distributed load. The design took into account serviceability and strength considerations. Considering the cost of concrete and steel as variables, they finally concluded that GA gave the most optimal solution.

Ashhad Imam et al. (2015) studied the residual strength of corroded steel by using experimental and theoretical methods. In the theoretical methods they used ANN model to predict the optimal value which was found to be within acceptable limits and finally the model gave good results and it was experimentally verified by tests on four specimens.

Sharafi et al. (2014) presented the application of Ant Colony optimization technique for continuous beams considering the dynamic effects also. With the help of framing the Eigen frequencies, Eigen modal shapes, static and dynamic equations, constraints with spans varying from three to ten metres, with point load and then considering uniformly distributed load, they finally concluded that the method was very effective in giving an optimal solution.

Babita Saini et al. (2007) explained the optimal design of singly and doubly reinforced beams subjected to point load and udl for different grades of concrete and steel, with various b/d ratios, spans, loading conditions using Levenberg - Marquart and Quasi-Newton back propagation technique with the help of Matlab and found it to be accurate and easy for working and finding the optimal solution.

Ricardo Perera& Javier Vique(2009) used the genetic algorithm technique with various constraints for the formation of optimal strut and tie model for the determination of shear strength value and finally they concluded that this technique was found to give the most economical solution.
Hakan Arslan (2010)considered the variables which affect the torsional strength, namely, the dimensions of the beam, area of steel reinforcement, bar diameter, bar spacing, grades of concrete and steel and gave these as the input variables after experimentally testing 78 beams. These were given as input in artificial neural network with different eleven propagations and finally they concluded that a results obtained from this technique was quite satisfactory.

Ammar N. Hanoon et al. (2017), in their paper, gave a detailed description about the use of Particle Swarm Optimization for optimizing the design resultsofultimate shear strength model of a deep beam using Strut and Tie Model, whose final solution was analytically verified using ABACUS software and after experimental verification they concluded that PSO resulted in a most optimal solution.

Ricardo Pereraet al(2014) used Fibre Reinforced Polymer reinforcement to predict the behavior and shear strength of RC beams using ACI 318 Code nine input parameters such as the geometry of the beam cross section, percentage of steel, ratio of FRP, spacing of bars, area of shear reinforcement, grades of steel and concrete, length, height and width of the beam and the output was taken as a single one, that was the design shear strength with one hidden layer and 11 hidden neurons. Artificial Neural Network was used for getting the best optimal solution.

Wang (2013) attempted on the optimal design of an intermediate additional support which is to be added in a beam in order to demonstrate the effect of compressive load. For this he designed three sample beams with different end conditions and concluded that, with the help of the optimization technique used, the additional intermediate support increases the fundamental frequency of the beam due to increased structural stiffness and its dynamic properties.

Sinan Melih Nigdeli & Gebrail Bekdas (2017), used the recommendations of ACI-318 code for the design of RC continuous beams, the width and depth of the beam having been already determined using preliminary design and then the cross sections were optimized with the amount of the steel reinforcement to be provided, by using random search technique for cost minimization and was found to be effective and useful for site.

Sharafi P Hadiet al.(2014)used the Ant Colony algorithm for the design of Continuous beams in which the variables chosen were the dynamic responses and cost minimization. The constraints in this problem were chosen to be the Eigen values, modal shape of the continuous beam during static and dynamic conditions and they found that when the technique was used, they were able to derive the optimal value easily and it was found to be very simpler than that by the classical method.

Fedelinski & Górski (2015) studied the arrangement of reinforcements in an optimal way to increase the stiffness value of the beam by considering suitable modulus of elasticity. Finite element method was used to analyze and design the reinforcement in a composite beam. An evolutionary optimization technique was used to solve this optimal problem. This proved to be a very accurate method.

MM et al (2013)fine-tuned Artificial Bee Colony optimization techniques for determining the cost minimization of RC continuous beams considering the steel reinforcement and cross section area of the continuous beam. They found that the value of changing percentage of steel, if used as a variable in the Artificial Bee Colony Optimization technique, the performance of the algorithm has been improved. Four different sets of beams have been tested and found to be optimized.

Sankhadeep Chatterjee et al. (2017)based on the requirements of IS456:2000 and adopting Staad Pro v8i software, analyzed 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.

3. TENSION MEMBERS

Reinforced concrete develops tensile stresses either due to direct tensile force or combined with bending. Tie members of trusses and tied arches, walls of rectangular tanks and bunkers, suspended roofs, cylindrical pipes, walls of liquid retaining structures are some of the examples where tensile stresses develop. Traditional elastic approach (working stress method) and the limit state method can be applied for the design of such structures. Based on the elastic theory, the working stress method is simpler in concept and applications, while the limit state method, based on cracking behavior of concrete, is not fully developed yet. IS 456:2000 gives due considerations for compression either direct or associated with bending and shear when limit state method is employed. However, it is silent on tension members, and IS 3370:2009 dealing with liquid retaining structures, is still adopting working stress method.

3.1 Design Procedure

The total tensile force is considered to be resisted by the reinforcement only.

The tensile stress in the reinforcement must be less than or equal to the allowable stress given in Annexure B of IS456:2000 (Table 3.1). The allowable stress in concrete of the transformed section must be less than or equal to than the allowable tensile stress to prevent excessive cracking as given in Clause B-2.1.1 of Annexure B of IS456:2000 code

These criteria may be expressed as follows

$$\frac{T}{Ast} \leq fast$$

Further,

$$T / A_c + A_{st}(m-1) \leq fa$$

Where T - axial tensile face
Ast - area of steel reinforcement
Ac - area of concrete

fast - allowable tensile stress in steel

fact - allowable direct tensile stress in concrete

3.2 APPLICATION OF ARTIFICIAL NEURAL NETWORK

The objective function is taken as the cost per unit length of the tension member and is given by the following relationship: -

Total Cost per metre length = Cost of Concrete + Cost of Steel + Cost of Formwork

= Cc Ac + CsAast+ Cf*Af

= Cc (Ag – Ast) + Cs Ast + 4 Cfb (3.1) Ag and Ast are expressed in m2 units and b in metre units
Where, Cc - Cost of concrete per unit volume (Rs/m3)
Cs -Cost of steel per unit volume (Rs/m3)
Cf -Cost of formwork per unit contact area (Rs/m2)
Af -Area of formwork in m2
B - Size of square cross section in m

The optimization problem is to determine Ag and Ast to minimize Equation (3.1). The problem is solved for different values of fy, fck, and T to build a database using which the neural network is trained, validated and tested in the following phase of the work.

3.3 APPLICATION OF ARTIFICIAL NEURAL NETWORK

Two hundred and fifty RC tension members were designed by working stress method for working axial load in the range of 50kN to 200kN for grades of concrete varying from M25 to M50 and grades of steel varying from Fe250 to Fe550.The total cost including the cost of formwork per unit length of members has been estimated using the costs of locally available materials given The first neural network is arbitrarily constructed with an input layer of four nodes, one hidden layer of ten nodes and an output layer of two nodes as shown in Figure.3.1.The second network is chosen with eight nodes in the hidden layer, while the third network is chosen with six nodes in the hidden layer. The other network parameters were kept constant and are as stated below:

Number of training samples = 100 Learning rate = 0.001

Training Style : Batch training

Type of back propagation : Levenberg - Marquardt Number of epochs = 100

Performance function : Mean Square Error (mse)

Performance goal = 0.001

Activation function for the hidden layer nodes:tansig Activation function for the output layer nodes: purlin

The inputs to the network are:

Characteristic Compressive Strength of Concrete, fck Characteristic Strength of the tension reinforcement, fy Axial working load acting on the tension member, T Modular ratio between steel and concrete, m

The outputs are:

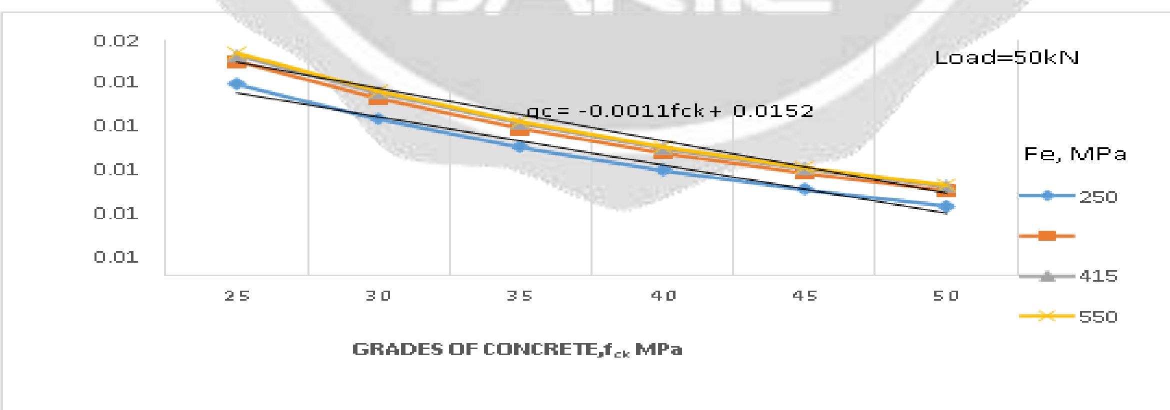
Optimum size of square tension member, Ag optimum

Optimum amount of steel, Asc optimum

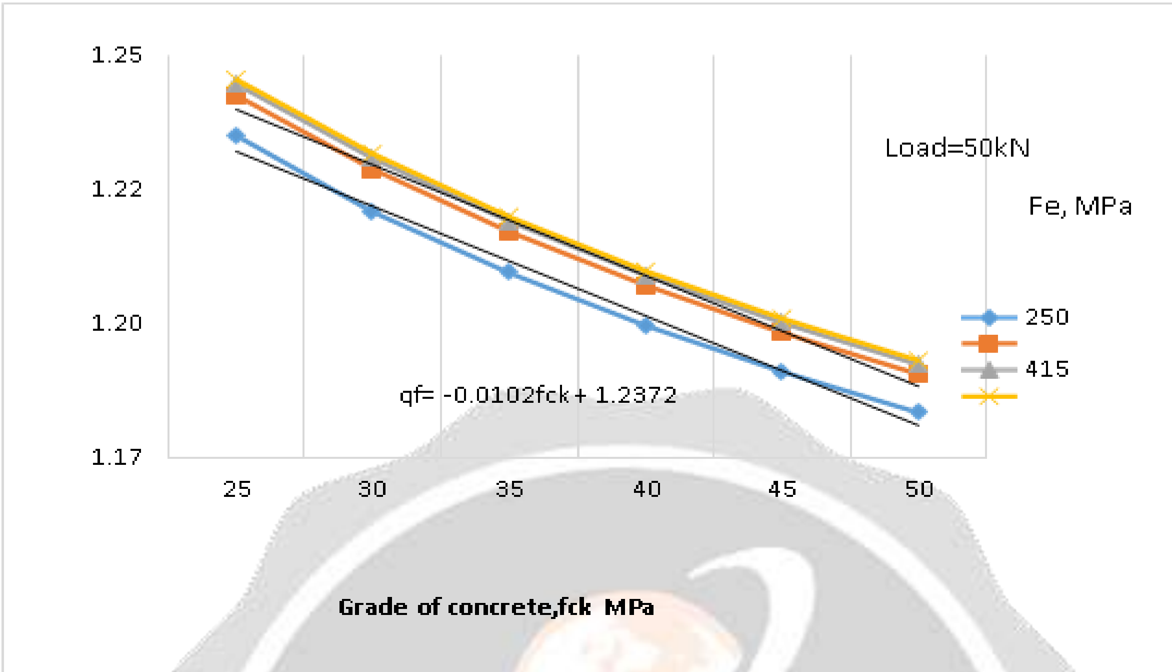
which results in the lowest cost per unit length of the tension member.

For the formation of the training data set, six values of fck were used viz, 25 N/ mm2, 30 N/ mm2, 35 N/ mm2, 40 N/ mm2, 45 N/ mm2 and50 N/ mm2, four values of fy, namely, 250 N/ mm2, 415 N/ mm2 and 500 N/ mm2 550 N/ mm2, were used and the magnitude of axial load was varied from 50kN to 200kN

4. COMPARISON OF RESULTS



Variation of concrete volume with grades of steel and concrete



Variation of Area of Formwork with Grades of Steel andConcrete

5. CONCLUSIONS

The application of Genetic Algorithm for the design axially loaded RC compression members has been demonstrated. Based on the design of two thousand and ninety two RC short columns using Indian Standard code IS456:2000, the effects of grade of concrete and grade of steel on the total cost per unit length have been studied. As the grades of concrete and steel increase, the total quantities of constituent materials including the formwork required are reduced. Hence the total cost is reduced as the grades of concrete and steel are increased.

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