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COMPARISON OF OPTIMAL COSTS OF AXIALLY LOADED RC TENSION MEMBERS USING INDIAN AND EURO STANDARDS

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Abstract: The aim of this study is to find the cost design of RC tension with varying conditions using the Artificial Neural Network. Design constraints were used to cover all reliable design parameters, such as limiting cross sectional dimensions and; their reinforcement ratio and even the beahviour of optimally designed sections. The design of the RC tension members were made using Indian and European standard specifications which were discussed. The designed tension members according to both codes satisfy the strength and serviceability criteria. While no literature is available on the optimal design of RC tension members, the cross-sectional dimensions of the tension membersfor different grades of concrete and steel, and area of formwork are considered as the variables in the present optimum design model. A design example is explained and the results are presented. It is concluded that the proposed optimum design model yields rational, reliable, and practical designs.

Key Words: RC tension members, optimal design, optimization, loadings, neural networks, design model, Indian standards, Euro standards.

1. INTRODUCTION

Reinforced concrete structures are ones made of two or more different materials:-, minimum weight has no meaning with respect to optimization. Optimization has been formulated as minimum cost. Large number of papers have been published on optimization of structures. However, only a small fraction of these deal with cost optimization of structures. For concrete structures, the objective function to be minimized should be cost, since they are made of more than one material. Tie members of trusses and tied arches, walls of rectangular tanks and bunkers, suspended roofs, cylindrical pipes, and walls of liquid retaining structures are some of the sample problems where tensile stresses develop. Traditional elastic approach and the limit state method can be useful for the design of such structures. Based on the elastic theory, the classical method is straight - forward in concept and application, while the limit state method, based on cracking behaviors of concrete, is not yet fully developed. IS 456:2000 and Euro codal specifications give due considerations for compression either direct or connected with bending and shear when the limit state method is working. However, it is silent on tension members. Therefore the working stress method is employed in this paper to explain the design of such members.

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2. TENSION MEMBERS

Vertical suspenders in a bowstring girder and the-, ring beam of a dome are some of the members subjected to direct tensile forces. Many RC structural components such as walls of water tanks, bunkers, silos, and counter forts of retaining walls are subjected to tensile force, in addition to bending moments.

3. PREVIOUS LITERATURE

Abobakr A.A.Aga, Fathelrahman M.Adam[1] (2015) in their paper explain the formation of objective function for a frame in a detailed manner with the various constraints for each and every element in a frame, and optimization is done with the help of ANN.-, The cost compared is the actual manually calculated one with that of ANN, the difference between them is discussed and it is found that ANN gives a better result than the manual design.

Anand Prakash. S.K. Agarwala..K.K. Singh[2] (1988) explain the optimal design considerably in a simplified manner, handling the cost ratio of steel-to-concrete as a variable. The authors have adopted this approach using modern computers, software and relatively simple optimization techniques to obtain optimum design results for singly and doubly--reinforced beams, T-beams, and columns, which are eccentrically loaded and the results and conclusions are then described in a detailed manner.

ArunlfoLuevanos-Rojas (2016)[3], in their paper demonstrated the optimal design of the Singly Reinforced Beam by creating a model and an analytic approach using ACI-318, considering two criteria, with four different cases for minimum weight (Case 3,4) and minimum cost (Case1,2) and it is concluded that for Case 1 the optimum section is very economical compared to other sections that may be obtained using the standard design method. The optimum steel ratio is usually smaller than the maximum ratio, ρmax, and greater than minimum ratio, ρmin. Cases 2, 3 and 4: The optimum steel ratio is equal to the maximum ratio ρmax.If we analyze the mathematical results of the standard design method and the optimal design method, they are equal.

S.A.Bhalchandra, P.K.Adsul[4], (2012) in their paper explained the design of simply supported doubly reinforced beam with two types of loadings and the optimal cost solution is determined, in addition to the serviceability conditions, with the help of the GRG approach and MATLAB.

Luisa Maria Gil Martin and Enrique Hernandez[1](2010) in their research work explain the optimal positioning of the reinforcement area with the help of the latest computing tools, considering the effect of the constraints with a suitable example which has bars on both sides, it saves the cost of construction and improves the durability of structural construction.

Chakrabarty-(1992) [5] in his paper made use of geometric programming and found the optimal design of singly-reinforced rectangular concrete beams. The design variables considered are the cross-section of the beam and the area of steel reinforcement. The main objective function was the total cost of construction of the beam. He included the strength aspects in the design process for bating optimal or minimal values but discounted the ductility and side constrains.

G Preethi and Prince G Arulraj[7]in their paper regarding different grades of concrete and steel, determined the optimal total cost of the RC column by the use of MATLAB programming using the fmincon SQL algorithm and found it to be a very effective approach for determining optimal design.

N.S.Hadi[8](2002) in his paper gives a brief description about the application of ANN and the different kinds of methods we can use and implement in structural engineering problems.

H.Sudarshana Rao and B. Ramesh Babu, (2006)[9], in their paper demonstrate the design of short columns under biaxial bending with use of optimization techniques. In this paper, they used ANN and GA. The results of biaxial columns are optimized by modified GA, the outputs are compared and it is observed that the maximum difference between both methods is only 1.6%. The conclusion is then made that a developed neural network model can provide a safe and economical outline for the design of short columns under biaxial bending.

ImaRahmanian,YvesLucet, and Solomon Tesfamariam (2014)[10] in their paper describe the review of optimal design of a RC beam by using various optimization techniques and a nonlinear approach is determined which gives suitable, appropriate results.-, It is then checked against the manual design in Excel, which gives a contribution of various design parameters to the overall cost of RC beams.

Luisa Maria Gil Martin – Enrique Hernandez[11] (2010) in their research work explain about the optimal positioning of the reinforcement area with the help of latest computing tools, considering the effect of the constraints with a suitable example which has bars on both sides:-, it saves on the cost of construction and improves the durability of structural construction.

GebrailBekdas, SinanMelihNigdeli (2012)[12] in their paper decsribe the optimization ofbeams using HS and BA approaches respectively, and it is finally concluded that if the flexural moment is 300 kNm or more, doubly reinforced design is needed. The HS approach is not effective for 400 kNm and 450 kNm flexural moments, because reinforcements are placed in two lines at the compressive section of the beam. Optimum reinforcements placed in a single line were found for the BA and TLBO approaches. Population based methods such as BA and TLBO are effective on the optimum solution of the problem. As a conclusion, TLBO is a competitive algorithm for the optimum design of RC beams. Comparing to BA, TLBO is more on finding an optimum solution, and it is easy to apply.

Sinan Melih Nigdeli, Gebrail Bekdaş (2016)[13] in their paper demonstrate the preliminary design of RC continuous beams using ACI-318, from which the optimal cross--sections of beams are acheived by using a random search technique, which in turn minimizes the cost of materials used in the construction of continuous beams. It has been explained that the random search technique gives an effective solution when compared with the other available techniques.

R. Deepan. et.al, March (2016)[14], state in their paper that the optimal design of RC beams is carried out with two loading conditions, for central pointed load and for udl. The designs of the beams and the constraints for optimal design have been carried out using the recommendation of IS456:2000. Manually, the design has been done using MS Excel and verified using Non-traditional Optimization techniques, and it is concluded that use of optimization techniques gives 98% optimal results (over classical methods).

4. DESIGN OF A RC MEMBER SUBJECTED TO AXIAL TENSION ONLY

The following criteria are :

1. The total tension force is considered to be resisted by the reinforcement only.
2. The tensile stress in the reinforcement must be less than or equal to the allowable stress The allowable stress in concrete of the transformed section must be less than or equal to the allowable tensile stress to prevent excessive cracking as given in Clause B-2.1.1 of Annexure B of IS456:2000

These criteria may be expressed as follows

$$\text{(4.1)} \longrightarrow \frac{T}{A_{st}} \leq f_{ast}$$

Further,

$$\text{(4.2)} \longrightarrow \frac{T}{A_c + A_{st}(m-1)} \leq f_a$$

where

T-axial tension face

A_{st}-area of steel reinforcement

A_c-area of concrete

f_{ast}- allowable tensile stress in steel

f_a- allowable direct tensile stress in concrete

4.1 DESIGN VARIABLES:

The design example illustrated below gives the step by step procedure for the RC design of a tension member with respect to the working stress method as per codal provisions of IS456:2000.The grades of concrete used for the design are M25, M30, M35, M40, M45, M50 and steel of grades Fe_{250}, Fe415, Fe_{500}, Fe_{550} resp in the case of IS code. In the case of Euro code, the grades of concrete used for the design are M25, M30, M35, M40, M45, M50 and steel of grades Fe_{235}, Fe_{275}, Fe_{355}, Fe_{420},Fe_{460} resp. In both the cases the live loads used are 50kN, 100kN, 150kN and 200kN.

4.2 WORKING STRESS METHOD:

Design a tie member of a RCC structure subjected to a tensile force of 100kN including dead and imposed loads. Assume M_{35} grade concrete and Fe_{250} steel.

f_{ast}-140MPa

f_{act}-4MPa (as per IS 456:2000)

(4.3) ⟶ Modular ratio=m=$\frac{280}{3\sigma_{cbc}}$ =6.76

STEP1: Calculation of A_{st} required:

The required area of tension reinforcement

(4.4) ⟶ $$A_{st} = \frac{T}{f_{ast}} = \frac{100 * 1000}{140} = 714.28mm^2$$

STEP 2: Calculation of gross area of concrete section:

(4.5) ⟶ $$\frac{T}{A_g + (m-1)A_{st}} \leq f_{act}$$

$$\frac{T}{f_{act}} - (m-1)A_{st} = A_g$$

(4.6) ⟶ $$Ag = \frac{100 * 1000}{4} - (6.76 - 1) * 714.28) = 20884.83mm^2$$

Required theoretical section is of size 144.5mm by 144.5mm.

5. ARTIFICIAL NEURAL NETWORK

The objective function is to minimize the cost per unit length of the tension which is determined as

Total Cost = Cost of Concrete + Cost of Steel + Cost of Formwork

$$\text{Total Cost} = C_c A_c + C_s A_{ast} + C_f * A_f$$

$$\text{Total Cost} = C_c (A_g - A_{st}) + C_s A_{st} + 4 C_f b \quad (5.1)$$

A_g and A_{st} are expressed in m^2 units and b in meter 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_{st} to minimize equation (5.1). The problem is solved for different values of f_y, f_{ck}, and T to build a database through which the neural network is trained, validated and tested in the following phase of the work.

6. NEURAL NETWORK MODELS FOR OPTIMUM DESIGN OF RC TENSION MEMBERS

Five Hundred RC tension members were designed using the two codal provisions, and the total cost (including the cost of formwork per unit length) of members has been estimated. The design has been carried out with three different numbers of hidden layers, the results tabulated, and finally concluded in the discussion is the best optimal solution.

NEURAL NETWORK MODEL I

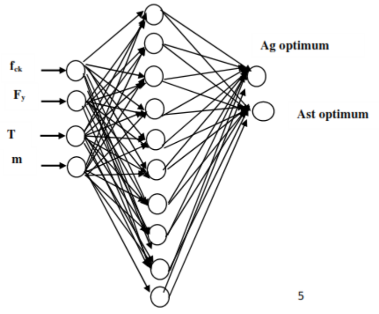

Fig. 1. Neural network model with ten nodes

NEURAL NETWORK MODEL –II

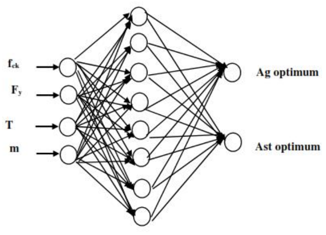

Fig. 2. Neural network model with 8 nodes

NEURAL NETWORK III

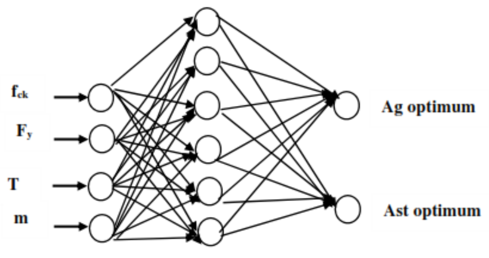

Fig. 3. Network model with six nodes

6.1 TEST PROBLEMS

The test result problems obtained from the different hidden layers are tabulated in the table with some samples, and they are compared with the actual results of the tension member design by using the Indian standards and the Euro Code Standards.

Table1: Results obtained from actual and neural network model

SI. No.	**Inputs**	**Theoretical Result**	**Network Output IS Code**			**Inputs**	**Theoretical Result**	**Network Output Euro Code**		
			6 nodes	**8 nodes**	**10 nodes**			**6 nodes**	**8 node**	**10 nodes**
1	f_{ck}=25, f_y= 250	b =162	162.6	162.1	161.53	f_{ck}=25, f_y= 235	b=166.8	166.1	164.0	163.9
	P_u=100, m=8	Ast = 714.28	714.6	714.1	713.81	P_u=100, m=8	Ast=489.3	489.1	488.6	487.2
2	f_{ck}=30, f_y= 415	b = 158	158.8	158.1	157.81	f_{ck}=30, f_y= 275	b=158.56	158.3	157.8	156.5
	P_u=100, m=6	Asc =434.7	434.6	432.0	433.51	P_u=100, m=6	Ast=418.1	417.9	417.5	416.4
3	f_{ck}=35, f_y= 500	b = 151.3	151.1	150.6	149.26	f_{ck}=35, f_y= 355	B=152.0	151.9	151.4	150.0
	P_u=, m=7	Asc= 363.	363.4	362.9	361.6	P_u= 100, m=7	Ast=323.9	323.71	323.23	321.8
4	f_{ck}=40, f_y= 550	b= 138.	138.2	137.3	135.69	f_{ck}=40, f_y= 420	B=13.55	139.361	138.88	136.8
	P_u=, m=6	Asc = 333.33	333.1	332.6	331.26	P_u= 100, m=6	Ast=273.80	237.61	237.13	271.7

6.2 Theoretical results:

The influence of grades of steel and concrete on the required quantities of these two materials and on the total cost, including the cost of the formwork of the RC tension members is given in Figures 4-11

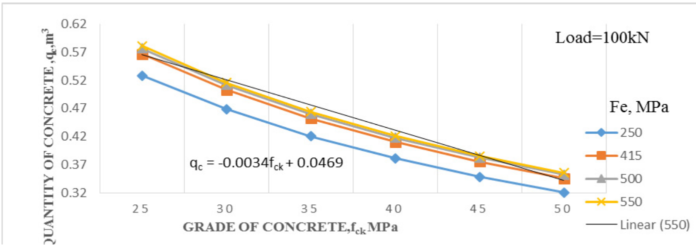

Fig. 4. Variation of Concrete volume with grades of Steel and Concrete.

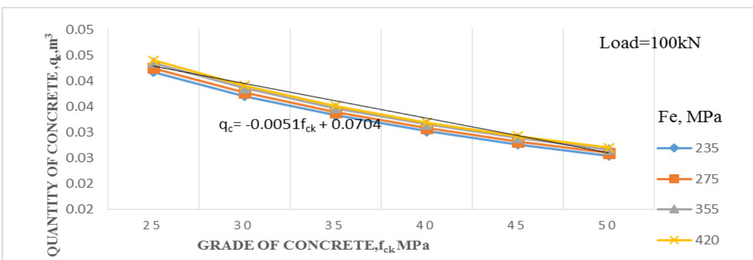

Fig. 5. Variation of Concrete volume with grades of Steel and Concrete.

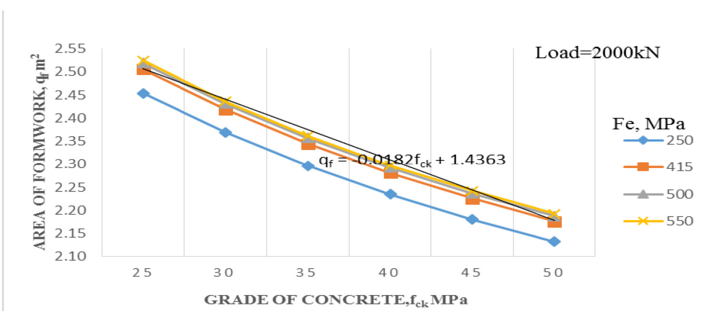

Fig. 6. Variation of area of formwork with grades of Steel and Concrete.

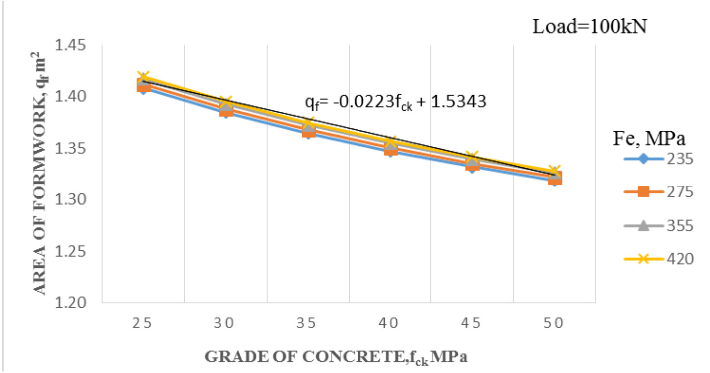

Fig. 7. Variation of area of formwork with grades of Steel and Concrete.

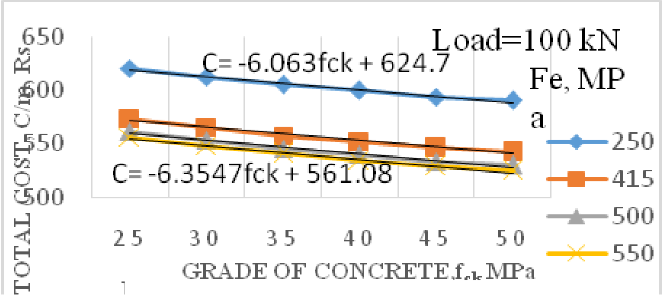

Fig. 8. Variation of Total Cost with grades of Steel and Concrete.

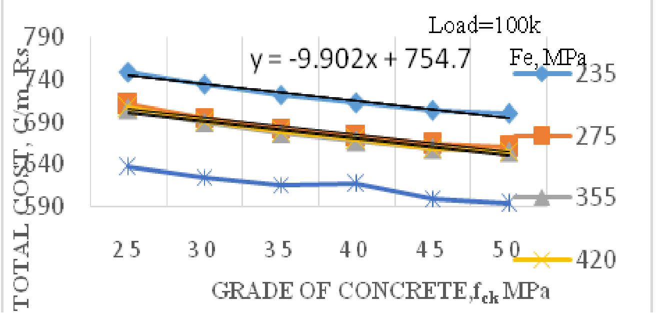

Fig. 9. Variation of Total Cost with grades of Steel and Concrete.

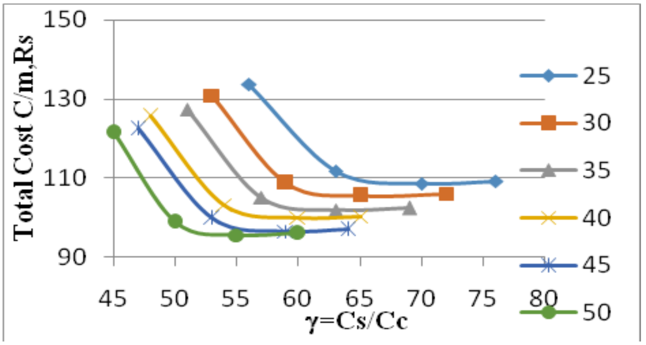

Fig. 10. Variation of Total Cost with γ.

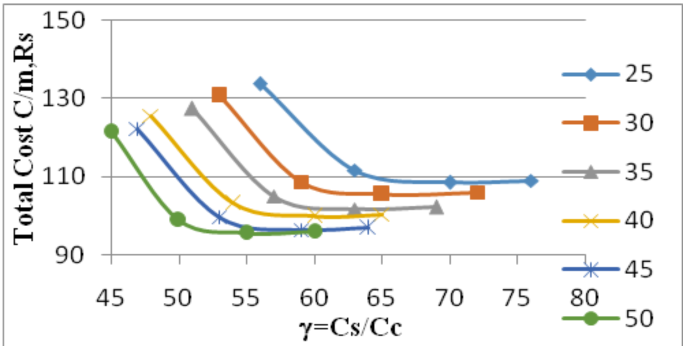

Fig. 11. Variation of Total Cost with γ.

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PORÓWNANIE OPTYMALNYCH KOSZTÓW OSIOWO OBCIĄŻONYCH ZBROJONYCH CIĘGIEN Z WYKORZYSTANIEM STANDARDÓW EUROPEJSKICH I INDYJSKICH

Słowa kluczowe – zbrojone cięgna, optymalna konstrukcja, optymalizacja, obciążenia, sieci neuronowe, model projektowy, standardy indyjskie, standardy europejskie.

Niniejsza praca została poświęcona optymalnemu projektowi zbrojonych cięgien. Zaprojektowano blisko pięćset zbrojonych cięgien zgodnie ze standardem indyjskim IS 456:2000 i standardem europejskim EN1992, ręcznie przy użyciu arkuszy kalkulacyjnych Microsoft Excel. Uwzględnione zmienne stanowią charakterystyczną wytrzymałość betonu, wahającą się od 25 do 50N/mm^2 dla obu specyfikacji kodału? (codal?). Wytrzymałość plastyczna stali waha się pomiędzy 250, 415, 500 i 550 N/mm^2 w przypadku IS 456:2000 i pomiędzy 235, 275, 355, 420 i 460 N/mm^2 w przypadku standardu europejskiego. Obciążenie osiowe wahało się od 500kN do 3000 kN. Teoretyczne wyniki uzyskane na podstawie ręcznego projektu zostały wyjaśnione poniżej.

Na podstawie Rysunku 4 i 5 można stwierdzić, że wraz ze wzrostem klasy betonu, wymagana objętość betonu maleje, a wariacja staje się nieliniowa. W przypadku stali Fe 250, wariacja może być przybliżona za pomocą linii prostej o następującym równaniu: $q_c = -0.0034f_{ck} + 0.0469$ w oparciu o IS 456:2000, natomiast dla standardu europejskiego, równanie jest następujące: $q_c=-0.002f_{ck}+0.027$. Oczywisty jest również fakt, że wymagana objętość betonu dla konkretnej klasy betonu wzrasta wraz ze wzrostem klasy stali.

Na podstawie Rysunku 6 i 7 można stwierdzić, że wraz ze wzrostem klasy betonu, wymagany obszar szalowania się zmniejsza, ponieważ rozmiar cięgien się zmniejsza, a wariacja staje się nieliniowa. Dla klasy stali Fe 415, 500 i 550, wariacja może być przybliżona za pomocą linii prostej o następującym równaniu: $q_f = -0.0182f_{ck} + 1.4363$. W przypadku standardu europejskiego, równanie jest następujące: $q_f=-0.014f_{ck}+1.351$

Na podstawie Rysunku 6 można stwierdzić, że wraz ze wzrostem klasy betonu, koszt konstrukcji cięgna zbrojonego maleje, zgodnie z poniższymi równaniami:

$C = -6.063fck + 624.7$ dla klasy stali Fe250

$C = -6.2773fck + 578.04$ dla klasy stali Fe415

$C = -6.3316fck +566.14$ dla klasy stali Fe500

$C = -6.354fck + 561.08$ dla klasy stali Fe550

Na podstawie Rysunku 7 można stwierdzić, że wraz ze wzrostem stosunku γ kosztów stali do kosztów betonu, koszt konstrukcji cięgna zbrojonego maleje dla różnych klas betonu.

Na podstawie podejścia teoretycznego i podejścia ANN zastosowanych przez autorów, stwierdzono, że:

1. Wraz ze wzrostem klasy betonu, wymagana objętość betonu maleje, wnioski są wyciągane, a wymagany obszar szalowania się zmniejsza.
2. Wraz ze wzrostem klasy betonu, całkowity koszt cięgna zbrojonego maleje.
3. Wraz ze wzrostem wartości γ, koszt konstrukcji cięgna zbrojonego maleje dla wszystkich klas betonu.
4. Wraz ze wzrostem klasy stali, koszt konstrukcji (koszt betonu i stali) cięgna zbrojonego maleje.
5. Wraz ze wzrostem klasy betonu, koszt cięgna zbrojonego maleje.

Sztuczna inteligencja jest dziedziną nauki, która obejmuje badania, projektowanie oraz zastosowanie sztucznej inteligencji w dziedzinie informatyki. Tradycyjne metody modelowania i optymalizacji złożonych systemów strukturalnych wymagają ogromnych zasobów komputerowych, jak również problemów związanych ze sztuczną inteligencją, które często mogą stanowić cenne alternatywy dla skutecznego rozwiązywania problemów inżynierii lądowej. Niniejsza praca zawiera krótki opis ostatniej opracowanej metody i teorii w rozwijającym się kierunku zastosowań sztucznej inteligencji w inżynierii lądowej, takie jak obliczenia ewolucyjne, sieci neuronowe, rozmyte systemy, systemy eksperckie, rozumowanie, klasyfikacja i nauka, jak również inne, takie jak teoria chaosu, algorytm „cuckoo search", algorytm „firefly", inżynieria oparta na wiedzy oraz symulowane wyżarzanie. Praca zawiera przegląd postępów w zakresie sztucznej inteligencji oraz jej zastosowania w inżynierii lądowej.

ANN jest zbiorem systemu opartego na działaniu biologicznych sieci neuronowych. Dane wejściowe są przesyłane do sieci neuronowej i uzyskuje się odpowiednią pożądaną docelową odpowiedź. Błąd składa się z różnicy pomiędzy pożądanym wyjściem i wejściem systemu. W niniejszej pracy, metoda wstecznej propagacji ANN została wykorzystana w celu określenia optymalnej wartości funkcji kosztów.

Projektant konstrukcji ma na celu znalezienie optymalnego rozwiązania dla projektu konstrukcji. Optymalne rozwiązanie dla całkowitego kosztu konstrukcji cięgien zbrojonych jest związane z sumą trzech kosztów, takich jak koszt betonu, koszt stali oraz koszt szalowania. Dzięki zastosowaniu nietradycyjnych technik, takich jak ANN, zmiennych wejściowe, które stanowiły charakterystyczną wytrzymałość betonu i stali, obciążeniu cięgna zbrojonego oraz wartości stosunku modularnego, ukryte warstwy zostały zmienione na trzy typy, takie jak sześć węzłów, osiem węzłów i dziesięć węzłów, odpowiednio. Funkcja wagi jest obliczana i normalizowana. Wartości wejściowe są badane w celu uzyskania optymalnej wartości dla powierzchni przekroju brutto i stali. Wreszcie, na podstawie różnych badań ukrytych węzłów stwierdzono, że wraz ze wzrostem liczby ukrytych węzłów uzyskujemy bardziej optymalną wartość w porównaniu z rzeczywistym projektem w standardzie indyjskim iS456:2000 i standardzie europejskim. Wyniki uzyskane w oparciu o wyjścia generowane przez sztuczne modele sieci neuronowych, w odniesieniu do wyników teoretycznych, okazały się mieścić w zadowalającym zakresie. Zbadano wpływ klasy betonu i stali na całkowity koszt cięgien zbrojonych i wyciągnięto wnioski przydatne dla praktycznych zastosowań.