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Least cost design of RC singly reinforced beams using bacterial foraging optimization technique

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ABSTRACT

In this paper the optimal design of singly reinforced beam has been done by using Artificial neural network and the results are compared with the manual design and the results are compared.

Keywords: Optimal, Beam, Singly, Neural

INTRODUCTION

Optimization means making things the best. Thus, structural optimization is the subject of making an assemblage of materials that sustains loads in the best way. To fix ideas, think of a situation where a load is to be transmitted from a region in space to a fixed support .We want to find the structure that performs this task in the best possible way. However, to make any sense out of that objective we need to specify the term “best.” The first such specification that comes to mind may be to make the structure as light as possible, i.e., to minimize weight. Another idea of “best” could be to make the structure as stiff as possible, and yet another one could be to make it as insensitive to buckling or in stability as possible. Another idea best to get satisfactory structure with least cost. Clearly such maximizations or minimizations cannot be performed without any constraints. For instance, if there is no limitation on the amount of material that can be used, the structure can be made stiff without limit and we have an optimization problem without a well defined solution. Quantities that are usually constrained in structural optimization problems are stresses, displacements and/or the geometry. Note that most quantities that one can think of as constraints could also be used as measures of “best,” i.e., as objective functions. Thus, one can put down a number of measures on structural performance—weight, stiffness, critical load, stress, displacement and geometry—and a structural optimization problem is formulated by picking one of these as an objective function that should be maximized or minimized and using some of the other measures as constraints.

APPLICATIONS OF OPTIMIZATION

- Design of civil engineering structures such as frames, foundations, bridges, towers, chimneys and dams for minimum cost.
- Minimum weight design of structures for earthquake, wind and other types of random loading.
- Design of water resources systems for maximum benefit
- Optimal plastic design of structures
- Optimum design of linkages, cams, gears, machine tools and other mechanical components
- Selection of machining conditions in metal-cutting processes for minimum production cost
- Design of material handling equipment such as conveyors, trucks and cranes for minimum cost

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- Design of pumps, turbines and heat transfer equipment for maximum efficiency
- Optimal production planning, controlling and scheduling
- Optimum design of chemical processing equipment and plants selection of a site for an industry**.**

METHOD OF OPTIMIZATION

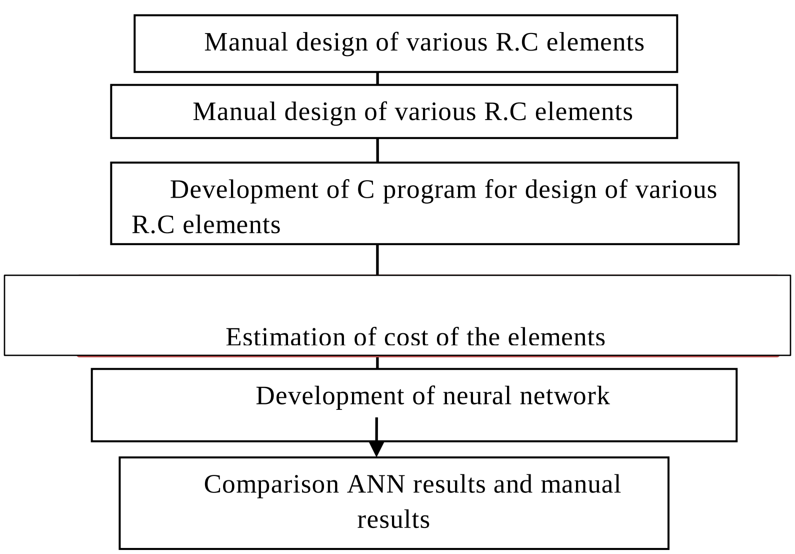
Experimental Method

- Oldest method
- In this method a finite number of models/prototypes with different parameters are made and tested.
- With the help of charts and tables prepared from the experimental studies, the designer selects the best design parameters.
- In this method the area of search for optimum is limited
- It is very expensive and
- It is time consuming method

OPTIMIZATION ALGORITHMS

The classical optimization techniques are useful in finding the optimum solution or unconstrained maxima or minima of continuous and differentiable functions.

METHODOLOGY



- These are analytical methods and make use of differential calculus in locating the optimum solution.
- The classical methods have limited scope in practical applications as some of them involve objective functions which are not continuous and/or differentiable.
- Yet, the study of these classical techniques of optimization form a basis for developing most of the numerical techniques that have evolved into advanced techniques more suitable to today's practical problems

These methods assume that the function is differentiable twice with respect to the design variables and the derivatives are continuous.

Three main types of problems can be handled by the classical optimization techniques:

- Single variable functions
- Multivariable functions with no constraints,
- Multivariable functions with both equality and inequality constraints.

In problems with equality constraints the Lagrange multiplier method can be used. If the problem has inequality constraints, the Kuhn-Tucker conditions can be used to identify the optimum solution.

OPTIMIZATION FORMULATION

The design variables which are considered in this RC beam model are listed below:

INDEPENDENT DECISION VARIABLES

Discr. Beam width (mm)

(ex-200, 250, 300, 400 ..mm etc)
(bLL< = b < = bUL, i.e b- Lower and Upper Bound Value)
D : Discr. Beam Overall Depth (mm)
(ex-300, 450, 600, 750 ..mm etc)
(DLL< = D < = DUL, i.e D- Lower and Upper Bound Value)
Fck : Grade of Concrete (N/mm2).
(ex- Fck 20, 25, 30,35,40.N/mm2 etc)
Fy : Grade of Reinforcement Steel (N/mm2).
(ex- Fy 250, 415, 500,550 N/mm2 etc).

INDEPENDENT PREASSIGNED DESIGN DECISION PARAMETERS

Lclr :Clear Length of the beam between support
Mu: Fact.Bending Moment (KN.M).
Vu : Factored Shear force (KN)
pAsmax : 4% or Even lesser User Defined (Max. Percentage Steel)

DEPENDENT PREASSIGNED DESIGN DECISION PARAMETERS

CC, CS, CF : Unitary Rate of Concrete, Formwork, Reinforcement Steel respectively – with Material supply, Labour, Fixing and placement all inclusive.
Xumax/deff : Neutral Axis ratio as per steel grade.
Q : Limiting Moment of resistance Factor.=0.36* (Xumax /deff)*(1-0.42*Xumax/deff)*Fck pAsmin : 0.85/ Fy *100 (Min. Percentage Steel)

CONCRETE COST

Cost of M20 concrete = Rs 4550 /m^3
Cost of M30 concrete = Rs 4950 /m^3
Cost of M40 concrete = Rs 5500 /m^3
Cost of M50 concrete = Rs 6250 /m^3

STEEL COST

Cost of steel =Rs 48 /kg.

FORMWORK COST

Cost of Formwork = Rs 185 /m^2
Labour cost of formwork = Rs 70 / m^2

DEPENDENT DESIGN DECISION VARIABLES

Asmin : pAstmin * b *deff /100 (Min. Area of Steel)
Asmax : pAsmax * b *D /100 (Max. Area of Steel)
Mulim : Q * b * $deff^2$ (Limiting Moment)

Singly reinforced design

MuMax <= Mulim , Then Tension Steel Area reqd
Astreqd = 0.5 *Fck/Fy*[1 – Sqrt (1-4.6*MuMax / (Fck*b*deff2))] *b*deff

Shear Design

v = Vu / b * deff (Nominal shear Stress)
Pt=100Ast/ b*d
c = Depending upon Astprov (Area of Steel Tension provided) and Grade of Concrete Fck.
C > v (hence safe)
Vus = Vu –(c * b *deff)-Transverse Steel Shear resistance Required.
Vus_pr = 0.87 *Fy * Asv_pr *deff / Sv_pr

DESIGN CONSTRAINTS

A)Bending Strength Related Constraints :

1) MuMax < = MOR_pr

B) Steel Constraints :

2) Astreqd < = Astprov

3) Astprov < = Asmax

4) Asmin < = Astprov

5) deff< = deff_pr

C) Side Face Steel Constraints :

7) AS_SF_reqd < = AS_SF_prov

8) SFRdistprov < = SFRdistmax

D) Upper and Lower Bound Constr. on Beam Sizes:

9) b< = bUL

10) bLL< = b

11) D < = DUL

12) DLL < = D

OBJECTIVE FUNCTION

The chief task of 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 beam model in terms of the cost of the concrete and reinforcement and form work used.

$TC=C_c +C_s +C_f$

$C_c = C_{vc} * V_c$

$C_s = C_{ws} * W_s$

$C_f = C_{Pf} * P_f$

Where,

TC= total cost in Rs

C_c =cost of concrete in Rs

C_s =cost of steel in Rs

C_f=cost of formwork in Rs

C_{vc}=cost per unit volume of concrete Rs/m^3

C_{ws}=cost per unit weight of steel Rs/kg

C_{Pf}=cost per unit area of formwork Rs/m^2

V_c=volume of concrete in m^3

W_s=weight of steel in kg

P_f=perimeter of formwork in m^2

$V_c=L*X_1*X_2-[((\pi/4)*X_3^2*X_4*L)+((\pi/4)*X_5^2*X_6*L)+((\pi/4)*X_7^2*X_8*L*2)]$

$= L*X_1*X_2-[(\pi/4)*L)*((X_3^2*X_4)+(X_5^2*X_6)+(2*X_7^2*X_8)]$

$C_c = C_{vc} * V_c$

$= C_{vc}*L*\{X_1*X_2-[(\pi/4)*((X_3^2*X_4)+(X_5^2*X_6)+(2*X_7^2*X_8)]\}$

$C_s = C_{ws} * W_s$

$W_S=((\pi/4)*L)*((X_3^2*X_4)+(X_5^2*X_6)+(2*X_7^2*X_8))*7850$

Where,

L is the span length in m.

7850=density of steel in kg/m^3

$C_S=C_{WS}*(\pi/4)*L*\{(X_3^2*X_4)+(X_5^2*X_6)+(2*X_7^2*X_8)\}*7850$

$C_f = C_{Pf} * P_f$

$P_f=(2*X_1* X_2)+(2*L* X_2)+(L* X_1)$

$C_F= C_{Pf}*[(2*X_1* X_2)+(2*L* X_2)+(L* X_1)]$

Therefore

$TC= C_{vc}*L*\{X_1*X_2-[(\pi/4)*((X_3^2*X_4)+(X_5^2*X_6)+(2*X_7^2*X_8))]\} +$

$C_{WS}*((\pi/4)*L)*\{(X_3^2*X_4)+(X_5^2*X_6)+(2*X_7^2*X_8)\}*7850 +$

$C_{Pf}*[(2*X_1* X_2)+(2*L* X_2)+(L* X_1)]$

Where,

X_1=breadth of the beam in m

X_2=overall depth of beam in m

X_3=diameter of reinforcement bar in tension zone in m

X_4=number of reinforcement bar in tension zone

X_5= diameter of reinforcement bar in compression zone in m

X_6= number of reinforcement bar in compression zone

X_7=diameter of stirrup reinforcement in m

X_8=(length of stirrup/spacing of stirrup)=L_s/S_v

X_9=effective cover in m

L_s=length of stirrup in m=[2*{(b-(2*25)-6)+(D-(2*25)-6)+90}]

S_v=spacing of stirrup in m.

CONSTRAINTS

Reinforcement constraint:

$(0.85* X_1 *(X_2-X_9))/f_y<Astp<0.04* X_1 *X_2$

$Astp=0.5*Fck/Fy*[1 – (1-4.6*Mulim / (Fck*X_1*(X_2-X_9)^2))^{0.5}] *X_1*(X_2-X_9)$

Strength constraint:

$Pu*L^2/8<Q * X_1*(X_2-X_9)^2$

Where,

$Q=0.36* (Xumax /(X_2-X_9))*(1-0.42*Xumax/(X_2-X_9))*Fck$

Q is the bending moment factor

Deflection constraint:

$\delta_{max}<\delta_{perm}$

$\delta_{max} =PL^3/48EI=(P*L^3)/(4*E*X_1*(X_2-X_9)^3)$

$\delta_{perm}=L/360$

f_y	X_{umax}/d
250	0.53
415	0.48
500	0.46

$Pu*L^2/8<0.36*(Xumax/(X_2-X_9))*(1-0.42*Xumax/(X_2-X_9))*Fck*X_1*(X_2-X_9)^2$

1) $Pu*L^2/8<0.36*(Xumax/(X_2-X_9))*(1-0.42*Xumax/(X_2-X_9))*Fck*X_1*(X_2-X_9)^2$

2) $(P_u*L^3)/(4*E*10^3*X_1*(X_2-X_9)^3)<(L*1000)/360$

3) $(0.85*X_1*(X_2-X_9))/f_y<0.5*Fck/Fy*[1-(1-(4.6*Mulim/(Fck*X_1*(X_2-X_9)^2)))^{0.5}]*X_1*(X_2-X_9)<0.04*X_1*X_2$

RESULTS DISCUSSIONS

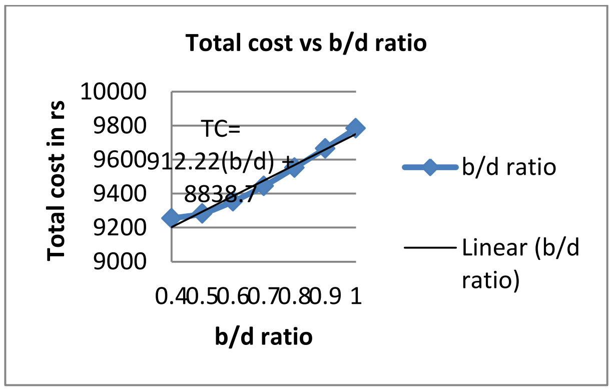


Fig .1 Total cost vs b/d ratio

From Fig 1 we can conclude that as the b/d ratio increases, the total cost of construction of beam increases so lesser the ratio of breadth to depth lesser the cost of construction.

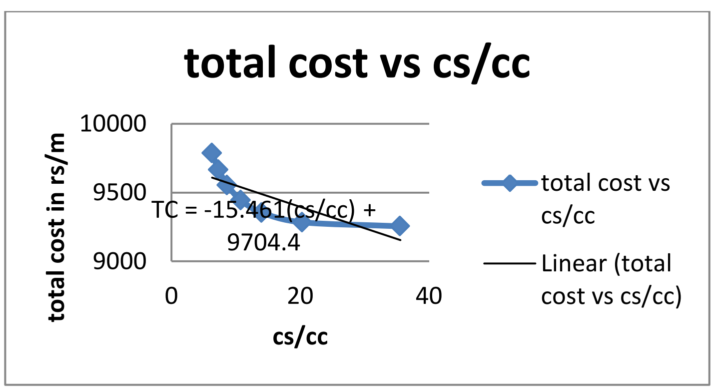


Fig 3) Totals cost in rs/m vs c_s/c_c

From 3 we conclude that as the c_s/c_c ratio increases the total cost of beam also increases, i.e., Total cost is directly proportional to the c_s/c_c ratio.

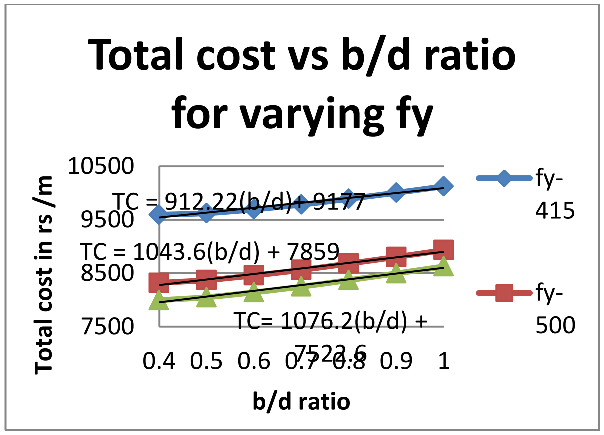


Fig 2 Total cost vs b/d ratio for varying f_y

From fig 2 we can conclude that as the grade of steel increases, the total cost decreases.

CONCLUSION

- Grade of concrete is directly proportional to total cost.
- Grade of steel is inversely proportional to total cost
- b/d ratio is directly proportional to total cost until the point where $M_u < M_{u,lim}$
- Hence for singly reinforced beams for all spans for varying loads, the optimal solution obtained is for the least b/d ratio i.e., 0.4 for spans from 4 to 10 and fck-20 and fy-550 should be used as the grade of concrete and grade of steel respectively.

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