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Optimum Cost Design of Reinforced Concrete Beams Using Artificial Bee Colony Algorithm

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ABSTRACT

The objective of this study is to obtain the optimum design for reinforced concrete beams in terms of cross section dimensions and reinforcement details using a fine tuned Artificial Bee Colony (ABC) Algorithm while still satisfying the constraints of the ACI Code (2008) (ACI Committee 318, 2008). The ABC algorithm used in this paper has been slightly modified to include a Variable Changing Percentage (VCP) that further improves its performance when dealing with members consisted of multiple variables. The objective function is the total cost of the beam which includes the cost of concrete, formwork and reinforcing steel bars. The design variables used are beam width, beam height, number and diameter of reinforcing bars and top cutoff reinforcing bars as well as the diameter of stirrups , and design constraints can include strain, stress and sizing constraints. The optimal design is performed by using the Sequential Quadratic Programming algorithm. All computational implementation was made in MATLAB® computational environment. The emphasis is particularly placed on the practical applicability of the optimization technique in engineering practice. Graphical results are shown for optimal sizing of a reinforced concrete beam of rectangular cross section for different bending moments. For validating of the proposed model the results are compared with those found in literature and usual practice of beam construction.

Keywords: optimization, Cost optimization, ACI1318, RC.Beams, Artificial Bee Colony Algorithm

INTRODUCTION

Actually the industry of the civil construction is developing quickly and becomes a very competitive market where the reduction in the cost of individual beam through pre-casting represents an important issue considering that these are produced in industrial processes in great amounts and then carried until the construction site. In elapsing of the time several studies have been published to optimize reinforced and pre-stressed concrete structures for building purpose dealing mainly with beams of rectangular sections and rarely about T cross sections (Barros M. H. F. M., 2005). A large number of cross section dimensions combinations, as well as useful height, effective depth, beam width and steel reinforcement areas can yield equal nominal moment capacity of reinforced concrete beam. In the conventional procedure, a designer often assumes the beam section dimensions, and then the design is improved accordingly to previous experiences. The procedure can be repeated many times aiming at reducing costs and the enhancement of the mechanical performance of the beam. Using techniques of mathematical programming the solution of the problem consists, basically, in finding the best solution that identifies a point of maximum or minimum of an objective function, subjected to some restrictions. In this way, the optimal solution for the adopted model does not ask for previous experiences. Optimization leads to a better structural solution, the lightest and most economical one, guaranteeing architectural, safety, and constructive conditions. In the description of a problem of optimization the variables and parameters are defined to explain the physical problem, the restrictions to which the variables are subjected to and the objective function that has to quantify the quality of the project being studied. Optimization techniques can be divided into three categories: mathematical programming, optimization criteria method and heuristic search methods (B.K.CHAKRABARTY, 1992). In the linear programming, the objective function and the restrictions are linear functions of the project variables while nonlinear programming was developed for the optimization problems where the restrictions are nonlinear functions of the project variables. In the literature about this subject, it can be found several methodologies that provide solutions utilizing nonlinear programming techniques and also heuristic methods, like genetic algorithms (Park H. S., 2006). Concerning structural reinforced concrete elements most of published articles are studies on optimization of the dimensions of rectangular cross-section beams, aiming at the minimum cost of fabrication (Arafa M, 2011). In the last decades a few studies dealing with optimization of reinforced and pre-stressed concrete for building purpose have been released, being still rare the works that deal with T section beams. A number of analytical solutions can be found in the literature, in particular those resulting from the application of the Augmented Lagrangean Method (Barros AFM, 2012). In these works optimality conditions established by Karush-Kuhn-Tucker are used to identify the points where an optimal solution should be expected. Then, applying second-order conditions the optimal solutions of the problem are verified. One likes to remark, that these methodologies are academically attractive, but are very limited for practical use. Similar works have been carried through with the objective to optimize plane and spatial frames (Camp C, 2003). According to the knowledge of the authors, these researches are open for studies due to the complexity of interaction among the elements of the structure (Dr. Punmia B. C., 2007). In this work beams of rectangular section have been optimized by using nonlinear programming technique and the implementation of computational codes in MATLAB environment. For this, a mathematical modeling with the purpose of minimizing the cost manufacture of beams has been developed. The emphasis is particularly placed on the practical applicability of the optimization technique in engineering practice. Results of this model have been compared with those of similar works.

THE ARTIFICIAL BEE COLONY (ABC) ALGORITHM

The Artificial Bee Colony (ABC) Algorithm is a newly developed meta-heuristic optimization algorithm. The common factor in meta-heuristic algorithms is that they combine rules and randomness to imitate natural phenomena in solving complex optimization problems (Lee K, 2005), (Ozturk, 2013). The ABC algorithm is based on the foraging behavior of a honey bee swarm in its search for the best food source (Karaboga D, 2005); (Karaboga D B. B., 2008); (Hadidi A, 2010). Further details about the ABC algorithm can be found in (Joubari, 213), (Jahjouh, 2013), (Karaboga D B. B., 2008) and (Hadidi A, 2010).

Steps of ABC algorithm

1: Parameters: *sn*, limit

2: Initialize the food sources x_i randomly

3: Evaluate fitness (x_i) of the population

4: cycle = 1

5: **repeat**

6: **for** *i* = 1 to s*n* / 2 **do** {*Employed phase*}

7: **for** *j* = 1 to *D* **do**

8: Produce a new food source v_i in the neighborhood of the food source x_i for the employed bee by using $v_i = x_{ij} + \phi_{ij}\left(x_{ij} - x_{kj}\right)$

9: Select *k* at random such that $k \in \{1, 2, \ldots, sn\}$, $k \neq i$, $\phi \in [-1, 1]$

10: **end for**

```
        Evaluate solutions v_i and x_i
        if (v_i) is better than (x_i) then
            Greedy selection
        else
            count_i = count_i + 1
        end if
    end for
    for i = sn / 2 + 1 to n do                      {Onlooker phase}
        Calculate selection probability
        P(x_k) = f(x_k) / \sum_{k-1}^{sn} f(x_k)
        Select a bee using the selection probability
        Produce a new solution v_i from the selected bee
        Evaluate solutions v_i and x_i
        if (v_i) is better than (x_i) then
            Greedy selection
        else
            counti = counti + 1
        end if
    end for
    for i = 1 to sn do                              {Scout phase}
        if counti >limit then
            x_i =random
        end if
    end for
    Memorize the best solution achieved so far
cycle=cycle+1
until cycle=Maximum Cycle Number (MCN)
Post process results and visualization
```

DISCRETE OPTIMISATION

In most practical problems in engineering design, the design variables are discrete. This is due to the availability of components in standard sizes and constraints due to construction and manufacturing practices. A few algorithms have been developed to handle the discrete nature of design variables. Optimization procedures that use discrete variables are more rational ones, as every candidate design evaluated is a practically feasible one .This is not so where design variables are continuous, where all the designs evaluated during the process of optimization may not be practically feasible even though they are mathematically feasible. This issue is of great importance in solving practical problems of design optimization.

PROBLEM FORMULATION

The optimization techniques in general enable designers to find the best design for the structure under consideration. In this particular case, the principal design objective is to minimize the total cost of structure, after full filling all the requirements according to ACI 318 – 2008, in other case. The resulting structure, should not only be marked with a low price but also comply with all strength and serviceability requirements for a given level of applied load. The reinforced cement concrete reinforced beam subjected to imposed load is taken in this present research work, the cost optimization and comparison between with ductile detailing and without ductile detailing is made for both the structural elements. All the design variables are taken as discrete variables.

- ➢ Design variables for reinforced beam in case of without ductile detailing are:
  - Width of beam
  - Depth of beam
  - Diameter for main reinforcement in tension side
  - Number of bars in tension side
  - Diameter for shear reinforcement
  - Spacing for shear reinforcement
- ➢ Design variables for reinforced beam in case of with ductile detailing are:
  - Width of beam
  - Depth of beam
  - Diameter for main reinforcement in tension side
  - Number of bars in tension side
  - Diameter for shear reinforcement
  - Spacing at end span (special confining reinforcement)
  - Spacing at center span

a) Objectives

1. Cost optimization of reinforced beam in case of with ductile detailing and without ductile detailing.

2. Cost comparison of reinforced beam results between with ductile detailing and without ductile detailing.

b) Optimization of Reinforced Beam

The general form of an optimization problem is as follows

- Given - Constant Parameters
- Find - Design Variables
- Minimize - Objective function
- Satisfy - Design Constraint

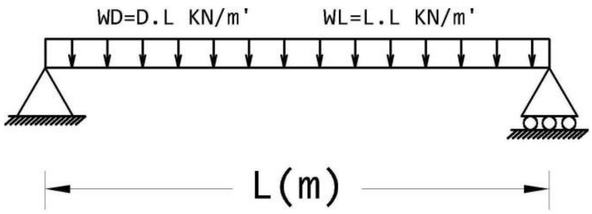

Figure (1): Typical simple RC beam with distributed loads

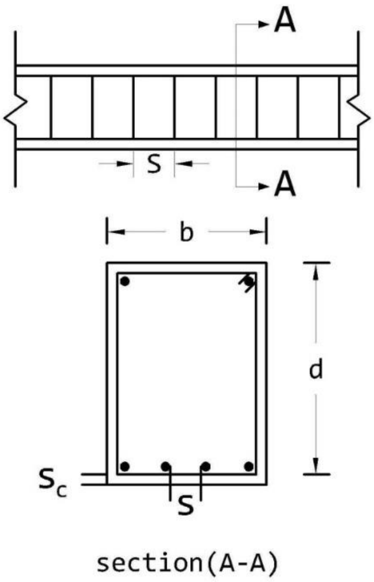

Figure (2): Geometry of a RC simple beam

Constant Parameters

Cost of concrete per m^3 for M20 = C = \$ 60/m^3

Cost of concrete per m^3 for M25 = C = \$ 70/m^3

Cost of concrete per m^3 for M30 = C = \$ 80/m^3

Cost of concrete per m^3 for M35 = C = \$ 90/m^3

Cost of steel per ton for Fe 415 = S = \$ 450/ton

Cost of steel per kg for Fe 500 = S = \$ 500/ton

Cost of steel per kg for Fe 550 = S = \$ 500/ton

Cost of Formwork per m^2 = F = \$ 30/m^2

Span of Beam = L = 3m, 5m, 7m, 9m

Live Load = 15kN/m, 20kN/m, 22.5kN/m, 25.0kN/m

Effective Cover = dc= 25mm γ_s = Specific gravity of steel = 7.86 t/m^3

Characteristics strength of steel = f_y = 240 N/mm^2, 280 N/mm^2, 360 N/mm^2, 410 N/mm^2

Characteristics strength of concrete = f_c = 20 N/mm^2, 25 N/mm^2, 30 N/mm^2, 35 N/mm^2

Design Variables

In my problem all the variables are taken as Discrete Variables:

- **Design variables for Reinforced Beam without ductile detailing**

Width of Beam = b = x1

Depth of beam = d = x2

Diameter of flexural bars = dia1= x3

No of flexural bars = bars no (1) = x4

Diameter of bars for shear reinforcement = dia2 = x5

Spacing for shear reinforcement = sv= x6

Set of discrete values for design variables:

b = (25-50) step size- 5 = x1

d = (50-100) step size- 10 = x2

dia1= (12, 16, 20, 24) = x3

bars no (1) = (4, 5, 6, 7, 8, 9, 10, 11, 12) = x4

dia2 = (6, 8) = x5

sv = (180, 200, 220, 240, 260, 280, 300) = x6

- **Design variables for Reinforced Beam with ductile detailing**

Width of Beam = b = x1

Depth of beam = d = x2

Diameter of bars for steel in tension zone = dia1= x3

No of bars for steel in tension zone = bars no (1) = x4

Diameter of bars for shear reinforcement = dia2= x5

Spacing at end span (special confining reinforcement) = sv1= x6

Spacing at centre span = sv2 = x7

Set of discrete values for design variables:

b = (25-50) step size- 5

d = (50-100) step size- 10

dia1= (12, 16, 20, 24)

bars no (1) = (4, 5, 6, 7, 8, 9, 10, 11, 12)

dia2 = (6, 8)

sv1 = (100, 110, 120, 130, 140, 150, 160, 170)

sv2 = (180, 190, 200, 210, 220, 230, 240, 250, 260, 270)

Objective Function

The objective function to be minimized for the cost of reinforced beam without ductile detailing (S., Y.H., & H, 2006):

$$F(x) = C\begin{bmatrix} (b*d*L) - ((\frac{\pi}{4}*d_1^{\ 2}*no\ of\ \ bars\ tension\ side)*L) \\ -(\frac{\pi}{4}*d_2^{\ 2}*((\frac{L}{sv})+1)*((b+d)*2)) \end{bmatrix} +$$

$$S*\gamma_s*\left[((\frac{\pi}{4}*d_1^{\ 2}*no\ of\ \ bars\ tension\ side)*L)+(\frac{\pi}{4}*d_2^{\ 2}*((\frac{L}{sv})+1)*((b+d)*2))\right]+$$

$$F\left[(b*L)+(b*d*2)+(d*L*2)\right] \qquad (5)$$

$$F(x) = C\left[(x_1*x_2*L)-((\frac{\pi}{4}*x_3^{\ 2}*x_4)*L)-(\frac{\pi}{4}*x_5^{\ 2}*(\frac{L}{x_6}+1)*((x_1+x_2)*2))\right]+$$

$$S*\gamma_s*\left[((\frac{\pi}{4}*x_3^{\ 2}*x_4)*L)+(\frac{\pi}{4}*x_5^{\ 2}*(\frac{L}{x_6}+1)*((x_1+x_2)*2))\right]+$$

$$F\left[(x_1*L)+(x_1*x_2*2)+(x_2*L*2)\right] \qquad (6)$$

The objective function to be minimized for the cost of reinforced beam in case of with ductile detailing:

$$F(x) = C\left[(x_1*x_2*L)-((\frac{\pi}{4}*x_3^{\ 2}*x_4)*L)-(\frac{\pi}{4}*x_5^{\ 2}*(x_6+x_7)*((x_1+x_2)*2))\right]+$$

$$S*\gamma_s*\left[((\frac{\pi}{4}*x_3^{\ 2}*x_4)*L)+(\frac{\pi}{4}*x_5^{\ 2}*(x_6+x_7)*((x_1+x_2)*2))\right]+$$

$$F\left[(x_1*L)+(x_1*x_2*2)+(x_2*L*2)\right] \qquad (7)$$

Design variables bounds

As it is stated earlier, some or all of the variables have bounds, these bounds results from different issues such as the provisions of the code under consideration, the aesthetic of the structural elements in the building, the practical issues and the availability of some sizes of the material at the local market, listed below are the bounds considered at this research project.

$$d_{\min} = h_{\min} - \frac{d_b}{2} + S_c - d_s \quad , \qquad d_{\max} = h_{\max} - \frac{d_b}{2} + S_c - d_s \qquad (8)$$

$$b \geq b_{\min} \quad , \; b \geq b_{\max} \qquad (9)$$

Where $b_{\min}$ and $b_{\max}$ are chosen according to architectural and practical considerations

$$d_b \geq d_{b\min} \quad , \; d_b \leq d_{b\max} \qquad (10)$$

Where $d_{b\min}$ and $d_{b\max}$ are chosen according to range of reinforcement available at market

Where:

- $h_{\min} = \frac{L}{16}$ (Table 9.5a of the ACI - code)
- $h_{\max}$ is chosen according to architectural considerations
- *Sc* = Concrete cover
- *ds* = diameter of stirrups

Design Constraints

1. Constraint on Flexural Strength

$$M_u \leq \phi M_n \tag{12}$$

Where

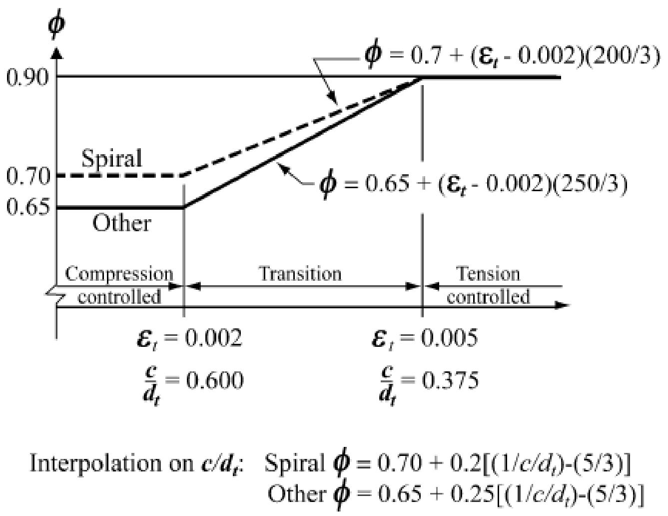

Figure (3) Strength reduction factor for bending moment and shear (ACI 318-08)

- ϕ = strength reduction factor

$$M_u = \frac{W_u \times L^2}{8} (KN.\text{m}) \tag{a}$$

- M_u = factored bending moment
- W_u = factored total distributed load = $1.2 \times (W_d + W_{sd}) + 1.6 \times W_l$
- *L* = Span of the beam

$$M_n = A_s * f_y * \left[d - \frac{A_s * f_y}{1.7 * f_c' * b} \right] (KN.m) \tag{b}$$

- M_n= nominal moment strength

$$C1 = M_u - \phi M_n \leq 0 \tag{13}$$

2. Maximum and Minimum amounts of bending reinforcement

As per paragraph 10.5.1 of the ACI 318-08 code, the minimum amount of flexural reinforcement is given by the following relationship:

$$A_s, \min = \frac{0.25 \times \sqrt{f_c^{'}}}{f_y} \times b_w \times d \qquad (cm^2) \qquad (14)$$

And not less than $$\frac{1.4 \times b_w \times d}{f_y} \qquad (15)$$

$$C2 = \frac{1.4 * x_1 * x_2}{f_y} - \frac{\Pi}{4} * x_3^2 * x_4 \leq 0 \qquad (16)$$

And according to paragraph 10.3.5 of the Code, the maximum reinforcement ration is:

$$\mu_{\max} = 0.273 \times \frac{f_c^{'}}{f_y} \times \left(\frac{0.003}{0.003 + 0.004 f_y} \right) \qquad (17)$$

$$C3 = \frac{\Pi}{4} * x_3^2 * x_4 - 0.04 * x_1 * x_2 \leq 0 \qquad (18)$$

3. Maximum and Minimum Spacing of Shear Reinforcement

Minimum and maximum spacing between Shear Reinforcement as follows:

$$S_v \geq 2.5(cm) \; , 0.75 d (cm) \qquad (19)$$

$$C4 = x_6 - 2.5 \leq 0 \qquad (20)$$

$$C5 = x_6 - 0.75 x_2 \leq 0 \qquad (21)$$

4. The Factored shear force

The factored shear force is calculated at a distance of d from the face of the support as per paragraph 11.1.3.1 of the ACI 318-08 building Code, assuming that the width of the support is z m, the factored shear force is calculated using the following relationship:

$$V_u = \frac{W_u \times (L - z/2 - d)}{2} (KN) \qquad (22)$$

Where:

- *Wu* = Factored total distributed load
- *L* = Span of the beam
- d = Depth of the beam
- z = Width of the support

5. The design shear force

According to ACI Code 11.1.1, the design of beams for shear is to be based on the relation

$$V_u \leq \phi V_n \qquad (23)$$

Where V_u is the total shear force applied at a given section of the beam due to factored loads, and $V_n = V_c + V_s$ is the nominal shear strength, equal to the sum of the contribution of the concrete and the web steel if present. Thus for vertical stirrups

$$V_u \leq \phi V_c + \phi V_s (KN) \qquad (24)$$

The strength reduction factor ϕ is to be taken equal to 0.75 for shear. For typical support conditions, where the reaction from the support surface or from a monolithic column introduces vertical compression at the end of the beam, sections located less than a distance d form the face of the support may be designed for the same shear V_u as that computed at a distance d (ACI code 11.1.3.1) as shown in the following figure.

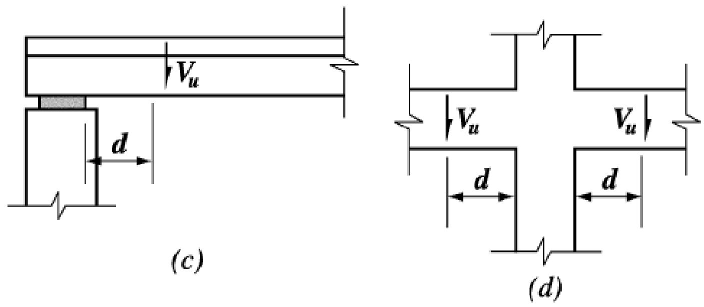

Figure (4) Actual design shear force (ACI 318-08)

According to ACI code, the nominal shear strength contribution of the concrete is

$$V_c = 0.17 \times \sqrt{f_c^{'}} \times b \times d \qquad (25)$$

6. Minimum web reinforcement

If V_u , the shear force at factored loads, is no larger than φV_c , then theoretically no web reinforcement is required. Even in such a case, however, ACI Code 11.5.5 requires provision of at least a minimum area of web reinforcement equal to

$$A_{v,\min} = 0.062 \times \sqrt{f_c^{'}} \times \frac{b \times s}{f_y} \geq 0.35 \times \frac{b \times s}{f_y} (cm^2) \qquad (26)$$

Where:

- S = Longitudinal spacing of web reinforcement
- f_y= Yield strength of web steel

- A_v= Total cross sectional area of web steel within distances

$$C6 = 0.35 * \frac{x_1 * s}{f_y} - 0.062\sqrt{f_c^{'}}\frac{x_1 * s}{f_y} \le 0 \quad (27)$$

7. Design for shear reinforcement

Where V_u exceeds φV_c , shear reinforcement shall be provided, such that shall be computed. The strength of shear reinforcement perpendicular to the axis of the reinforced concrete beam is given by ACI section (11.4.7.2) as,

$$V_s = \frac{A_v \times f_y \times d}{S} \times 10^{-3} \le 0.66 \times \sqrt{f_c^{'}} \times b \times d \quad (KN) \quad (28)$$

$$C7 = \frac{A_v * f_y * x_2}{S} - 0.66 * \sqrt{f_c^{'}} * x_1 * x_2 \le 0 \quad (29)$$

Where

- V_s = nominal strength provided by shear reinforcement (kN)
- S = center to center spacing between shear reinforcement ties (mm)
- A_v = area of transverse reinforcement (mm^2)
- f_y = yield strength of reinforcement (MPa).

8. Deflection control

$$M_d \le 3M_{cr}, \qquad M_s \le 3M_{cr} \quad (30)$$

$(\Delta_i)_l$ ≤ Limit by ACI - code, as mentioned in table (4.1) in section 4.1.16

$2*(\Delta_i)_{d+l} + (\Delta_i)_l$ ≤ Limit by ACI - code, as mentioned in table (4.1) in section 4.1.16

Where:

- M_s = Bending moment under service dead and live loads
- M_{cr} = Cracking bending moment
- M_d = Bending moment under service dead loads only
- $(\Delta_i)_l$ = Immediate deflection due to live load only
- $2*(\Delta_i)_{d+l}$ = Long term deflection due to service dead and live loads

RESULTS

Results of optimal design of reinforced beam in case of without ductile detailing.

Design optimization of RC simple beams using ABC optimization method				
Input Data				
Simply Supported Span, (L)	7	(m)		
Uniforn Dead Load, (W_d)	7.85	(Kn/m)		
Uniforn Live Load, (W_l)	12.5	(Kn/m)		
f_c'	24.5	Mpa		
f_y	410	Mpa		
Max Agg. Size	25	mm		
Cost of Conc/m^3, (C)	60	$		
Cost of Steel/ton, (S)	450	$		
	Design Variables			
	Width (b, cm)	Effective Depth (d, cm)	No. of bars (Nbars)	Diameter of Bars (dbar,mm)
	X1	**X2**	**X3**	**X4**
	25.00	**60.00**	**5.00**	**16.00**
Minimum Values of Design Variables	25	50	4	12
Maximum Values of Design Variables	50	100	12	24
Optimum cost, Z	**91.6052**	$		

Table (1) Part of the ABC optimization for the RC beam without framework's cost

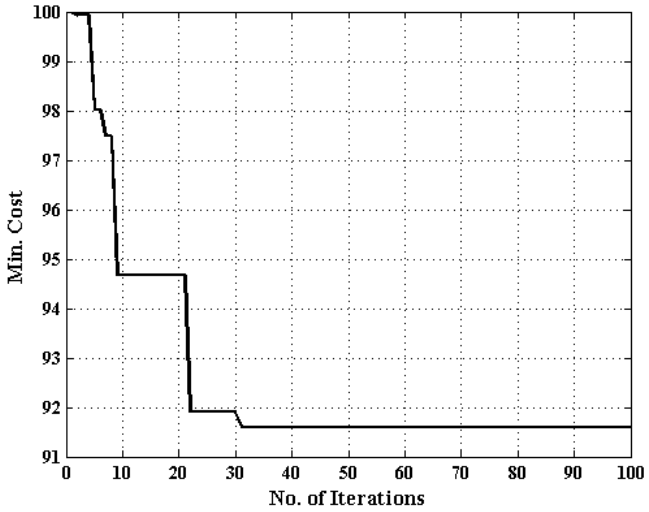

Figure (5) No. of iterations Vs. Min cost for the RC beam without framework's cost

Sr.No	Parameters	x(1)	x(2)	x(3)	x(4)	x(5)	x(6)	Min. Cost
1	Span = 4 m	0.2500	0.5000	0.0120	5.0000	0.0060	0.3000	197.5149
	F_c = 25 N/mm^2							
	F_y = 410 N/mm^2							
	W= 30 Kn/m							
2	Span = 4m	0.2500	0.5000	0.0120	6.0000	0.0060	0.3000	199.0879
	F_c = 25 N/mm^2							
	F_y = 410 N/mm^2							
	W= 35 Kn/m							
3	Span = 4 m	0.3000	0.5000	0.0120	7.0000	0.0060	0.3000	214.3042
	Fc = 25 N/mm^2							
	Fy = 410 N/mm^2							
	W= 40 Kn/m							
4	Span = 4 m	0.3500	0.5000	0.0120	7.0000	0.0060	0.3000	227.9475
	Fc = 25 N/mm^2							
	Fy = 410 N/mm^2							
	W= 45 Kn/m							
5	Span = 4 m	0.3500	0.5000	0.0120	8.0000	0.0060	0.3000	229.5205
	F_c = 25 N/mm^2							
	F_y = 410 N/mm^2							
	W= 50 Kn/m							
6	Span = 5 m	0.3000	0.5000	0.0120	8.0000	0.0060	0.3000	267.5564
	F_c = 25 N/mm^2							
	F_y = 410 N/mm^2							
	W= 30 Kn/m							
7	Span = 5 m	0.3500	0.5000	0.0160	5.0000	0.0060	0.3000	285.9808
	F_c = 25 N/mm^2							
	F_y = 410 N/mm^2							
	W= 35 Kn/m							
8	Span = 5 m	0.4000	0.5000	0.0120	10.0000	0.0060	0.3000	304.8422
	F_c = 25 N/mm^2							
	F_y = 410 N/mm^2							
	W= 40 Kn/m							

9	Span = 5 m	0.4500	0.5000	0.0200	4.0000	0.0060	0.3000	323.7035
	F_c = 25 N/mm^2							
	F_y = 410 N/mm^2							
	W= 45 Kn/m							
10	Span = 5 m	0.4500	0.5000	0.0200	5.0000	0.0060	0.3000	329.1652
	F_c = 25 N/mm^2							
	F_y = 410 N/mm^2							
	W= 50 Kn/m							

Table (2) span, F_c and F_y are constant, Load vary.

Sr.No	Parameters	x(1)	x(2)	x(3)	x(4)	x(5)	x(6)	Min. Cost
1	Span = 3 m	0.2500	0.5000	0.0120	4.0000	0.0060	0.3000	148.8690
	F_c = 25 N/mm^2							
	F_y = 410 N/mm^2							
	W= 40 Kn/m							
2	Span = 5 m	0.4000	0.5000	0.0120	10.0000	0.0060	0.3000	304.8422
	F_c = 25 N/mm^2							
	F_y = 410 N/mm^2							
	W= 40 Kn/m							
3	Span = 7 m	0.4500	0.6000	0.0160	10.0000	0.0060	0.3000	530.1468
	Fc = 25 N/mm^2							
	Fy = 410 N/mm^2							
	W= 40 Kn/m							
4	Span = 9 m	0.5000	0.7000	0.020	10.0000	0.0060	0.3000	828.7503
	Fc = 25 N/mm^2							
	Fy = 410 N/mm^2							
	W= 40 Kn/m							
5	Span = 3 m	0.3000	0.5000	0.0120	5.0000	0.0060	0.3000	160.6587
	F_c = 25 N/mm^2							
	F_y = 410 N/mm^2							
	W= 50 Kn/m							
6	Span = 5 m	0.4500	0.5000	0.0160	7.0000	0.0060	0.3000	326.3251
	F_c = 25 N/mm^2							
	F_y = 410 N/mm^2							

	W= 50Kn/m							
7	Span = 7 m	0.5000	0.7000	0.0200	7.0000	0.0060	0.3000	626.3646
	F_c = 25 N/mm^2							
	F_y = 410 N/mm^2							
	W= 50 Kn/m							
8	Span = 9 m	0.5000	0.9000	0.0240	6.0000	0.0060	0.3000	984.6203
	F_c = 25 N/mm^2							
	F_y = 410 N/mm^2							
	W= 50 Kn/m							

Table (3) load, F_c and F_y are constant, span vary.

Sr.No	**Parameters**	**x(1)**	**x(2)**	**x(3)**	**x(4)**	**x(5)**	**x(6)**	**Min. Cost**
1	Span = 4 m	0.3500	0.5000	0.0120	7.0000	0.0060	0.3000	227.9475
	F_c = 20 N/mm^2							
	F_y = 410 N/mm^2							
	W= 40 Kn/m							
2	Span = 4 m	0.3000	0.5000	0.0120	7.0000	0.0060	0.3000	214.3042
	F_c = 25 N/mm^2							
	F_y = 410 N/mm^2							
	W= 40 Kn/m							
3	Span = 4 m	0.4500	0.6000	0.0160	10.0000	0.0060	0.3000	208.3042
	Fc = 30 N/mm^2							
	Fy = 410 N/mm^2							
	W= 40 Kn/m							
4	Span = 4 m	0.2500	0.5000	0.120	6.0000	0.0060	0.3000	199.0879
	Fc = 35 N/mm^2							
	Fy = 410 N/mm^2							
	W= 40 Kn/m							
5	Span = 6 m	0.4500	0.7000	0.0200	5.0000	0.0060	0.3000	502.9003
	F_c = 20 N/mm^2							
	F_y = 410 N/mm^2							
	W= 50 Kn/m							
6	Span = 6 m	0.4500	0.6000	0.0240	4.0000	0.0060	0.3000	452.5613
	F_c = 25 N/mm^2							

	F_y = 410 N/mm^2							
	W= 50Kn/m							
7	Span = 6 m	0.5000	0.5000	0.0160	11.0000	0.0060	0.3000	425.6261
	F_c = 30 N/mm^2							
	F_y = 410 N/mm^2							
	W= 50 Kn/m							
8	Span = 6 m	0.4500	0.5000	0.0160	10.0000	0.0060	0.3000	401.4358
	F_c = 35 N/mm^2							
	F_y = 410 N/mm^2							
	W= 50 Kn/m							

Table (4) load, span and F_y are constant, F_c vary.

Sr.No	Parameters	x(1)	x(2)	x(3)	x(4)	x(5)	x(6)	Min. Cost
1	Span = 4 m	0.3000	0.5000	0.0160	6.0000	0.0060	0.3000	220.0717
	F_c = 25 N/mm^2							
	F_y = 240 N/mm^2							
	W= 40 Kn/m							
2	Span = 4 m	0.3000	0.5000	0.0160	5.0000	0.0060	0.3000	217.2753
	F_c = 25 N/mm^2							
	F_y = 280 N/mm^2							
	W= 40 Kn/m							
3	Span = 4 m	0.3000	0.5000	0.0120	7.0000	0.0060	0.3000	214.3042
	Fc = 25 N/mm^2							
	Fy = 360 N/mm^2							
	W= 40 Kn/m							
4	Span = 4 m	0.3000	0.5000	0.120	7.0000	0.0060	0.3000	214.3042
	Fc = 25 N/mm^2							
	Fy = 410 N/mm^2							
	W= 40 Kn/m							
5	Span = 6 m	0.4500	0.5000	0.0200	9.0000	0.0060	0.3000	418.4762
	F_c = 25 N/mm^2							
	F_y = 240 N/mm^2							
	W= 40 Kn/m							
6	Span = 6 m	0.4500	0.5000	0.0200	8.0000	0.0060	0.3000	411.9222

	F_c = 25 N/mm^2							
	F_y = 280 N/mm^2							
	W= 40Kn/m							
7	Span = 6 m	0.4500	0.5000	0.0200	6.0000	0.0060	0.3000	398.8142
	F_c = 25 N/mm^2							
	F_y = 360 N/mm^2							
	W= 40 Kn/m							
8	Span = 6 m	0.4500	0.5000	0.0240	4.0000	0.0060	0.3000	397.2412
	F_c = 35 N/mm^2							
	F_y = 410 N/mm^2							
	W= 50 Kn/m							

Table (5) load, span and F_c are constant, F_y vary. Cost comparison of reinforced beam results with and without ductile detailing

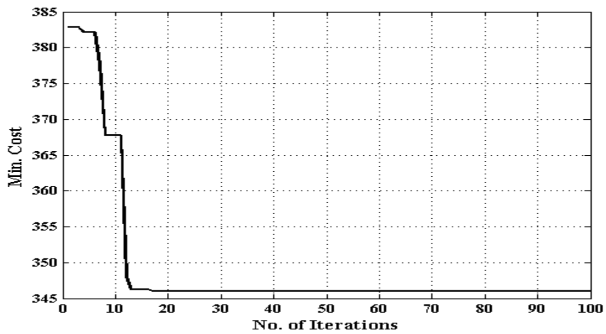

Figure (6) No. of iterations Vs. Min cost for the RC beam with ductile detailing.

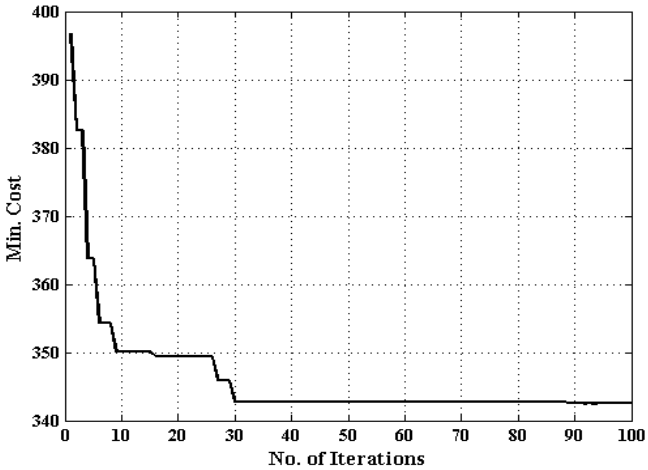

Figure (6) No. of iterations Vs. Min cost for the RC beam without ductile detailing.

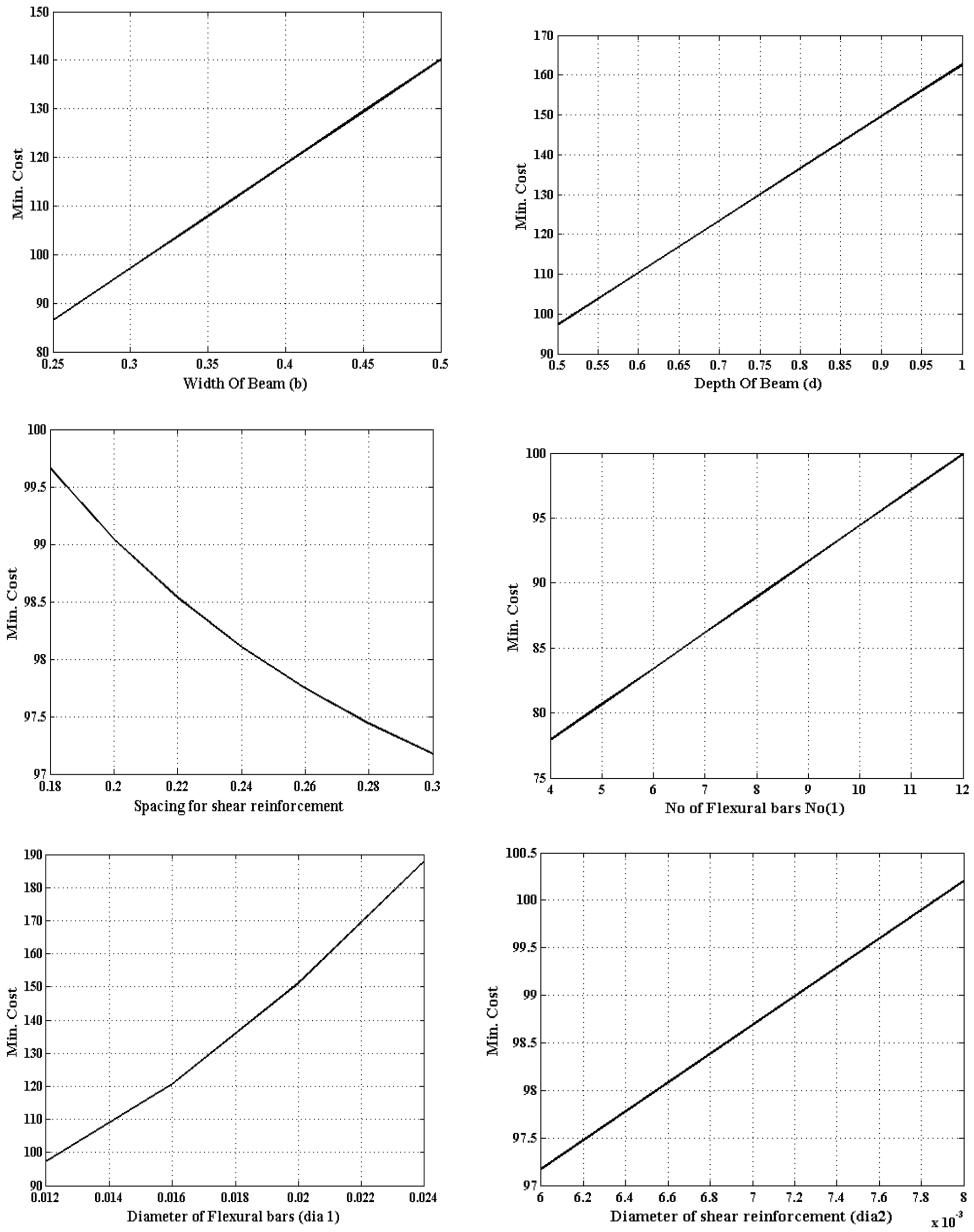

Figure (7) effect of depth, width, no and dia. of flexural and shear bars on Min cost for the RC beam without ductile detailing.

CONCLUSIONS

- This work proposes a friendly methodology for optimum designing of reinforced concrete beams. All the computational implementation was carried out in the MATLAB® computational environment.

- The actual program is very easy to use and its results are easily comprehensible without the need of abacus or tables.
- The actual results strongly depend on the relative costs between concrete, steel and the formwork material and these costs vary from one region to another and also along the time.
- This modeling achieves local minimum which fully satisfies the equality and inequality constraints.
- The actual results are very sensitive to the initial configuration and the material costs adopted.
- This model achieved a lower cost than the bibliographic reference and it was used for validation of the present methodology.

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