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Optimisation of RCC Beam

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Abstract: In the present research work the optimisation of reinforced cement concrete doubly reinforced beam subjected to imposed load has been done. In this research work the principle design objective is to minimise the total cost of beam after full filling all the requirements according to IS 456:2000 and in other case of ductile detailing, additional requirements according to IS 13920:1993 are used. To optimise the overall cost of beam, objective function is used and the codal requirements are used as design constraints. All the design variable are taken as discrete variables. The cost comparison between with ductile detailing results and without ductile detailing results have been done. In the present research work Genetic Algorithm is used with the help of MATLAB software.

Keywords: Optimisation, Genetic Algorithm, Matlab, Doubly reinforced beam.

I. INTRODUCTION

Optimum design of Reinforced Cement Concrete (RCC) elements plays an important role in economic design of RCC structures. Structural design requires judgement, intuition and experience, besides the ability to design structures to be safe, serviceable and economical. The design codes do not directly give a design satisfying all of the above conditions. Thus, a designer has to execute a number of design analyse cycles before converging on the best solution. The optimisation involves choosing of the design variables in such a way that the overall cost of the beam is minimum, subject to the satisfaction of behavioural and geometrical constraints as per recommended method of design codes. A designer's goal is to develop an "optimal solution" for the structural design under consideration.

Material cost is an important issue in designing and constructing reinforced concrete structures. The main factors affecting cost are the amount of concrete and steel reinforcement required. It is therefore, desirable to make reinforced concrete structures lighter, while still fulfilling serviceability and strength requirements.

The optimization of reinforced concrete structural elements is more challenging than the optimization of members made of isotropic material e.g. steel. The main difference comes from the fact that more combinatorial characteristics exist in determining the sectional dimensions and the number of reinforcing bars for reinforced concrete members than steel members, which are usually prefabricated with a finite number of sections. In addition to the discrete and combinatorial nature of the sectional dimensions and the number of reinforcing bars, topological reinforcement details specified in the design code make optimization of reinforced structures even more complicated.

Even then Optimization algorithms are becoming increasingly popular in engineering design activities, primarily because of the availability and affordability of high speed computers. They are extensively used in these engineering design problems where the emphasis is on maximizing or minimizing a certain goal. Civil engineers are involved in designing buildings bridges, dams and other structures in order to achieve a minimum overall cost or maximum safety or both. Practical application of these solutions, however, requires additional modifications to fit the discrete nature of the structural design variables.

Structural optimization is the selection of design variables to achieve its goal of optimality defined by the objective function for specified loading or environmental conditions, within the limits (Constraints) placed on the structural behavior, geometry or other factors. In this research work optimization technique based on Genetic algorithm method has been modeled in MATLAB.

II. OPTIMISATION TECHNIQUE

The genetic algorithm (GA) is a heuristic search technique based on the mechanics of natural selection developed by John Holland. Koza provides a good definition of a GA:

The genetic algorithm is a highly parallel mathematical algorithm that transforms a set (population) of individual mathematical objects (typically fixed-length character strings patterned after chromosome strings), each with an associated fitness value, into a new population (i.e. the next generation) using operations patterned after the Darwinian principle of reproduction and survival of the fittest and after naturally occurring genetic operations.

- Genetic algorithms use a population of points at a time in contrast to the single-point approach by the traditional optimization methods. That means, at a given time, Genetic algorithms process a number of designs.
- Genetic algorithms do not require problem-specific knowledge to carry out a search. For instance, calculus-based search algorithms use derivative information to carry out a search. In contrast to this, Genetic algorithm are in different to problem-specific information.
- Genetic algorithms work on coded design variables, which are finite length strings. These strings represent artificial chromosomes. Every character in the string is an artificial gene. Genetic algorithms process successive populations of these artificial chromosomes in successive generations.
- Genetic algorithms use randomized operators in place of the usual deterministic ones.

a) 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. Optimisation 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 optimisation may not be practically feasible even though they are mathematically feasible. This issue is of great importance in solving practical problems of design optimisation.

III. 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 IS456: 2000, and additional requirements according to IS13920: 1993 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 doubly reinforced beam subjected to imposed load is taken in this present research work, the cost optimisation 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 doubly 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 main reinforcement in compression side
- Number of bars in compression side
- Diameter for shear reinforcement
- Spacing for shear reinforcement

Design variables for doubly 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 main reinforcement in compression side
- Number of bars in compression side
- Diameter for shear reinforcement
- Spacing at end span (special confining reinforcement)
- Spacing at centre span

a) Objectives

1. Cost optimisation of doubly reinforced beam in case of with ductile detailing and without ductile detailing.
2. Cost comparison of doubly reinforced beam results between with ductile detailing and without ductile detailing.

b) Optimisation of Doubly Reinforced Beam

The general form of an optimisation problem is as follows

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

Constant Parameters

Cost of concrete per m³ for M20 = C = Rs 4400/m³
 Cost of concrete per m³ for M25 = C = Rs 4550/m³
 Cost of concrete per m³ for M30 = C = Rs 4750/m³
 Cost of concrete per m³ for M35 = C = Rs 5000/m³
 Cost of steel per kg for Fe 415 = S = Rs 45/-
 Cost of steel per kg for Fe 500 = S = Rs 50/-
 Cost of steel per kg for Fe 550 = S = Rs 55/-
 Cost of Formwork per m² = F = Rs 100/m²
 Span of Beam = L = 3m, 5m, 7m, 9m
 Live Load = 25kN/m, 35kN/m, 45kN/m, 50kN/m, 60kN/m
 Effective Cover = dc = 50mm
 Characteristics strength of steel = $f_y = 415 \text{ N/mm}^2, 500 \text{ N/mm}^2, 550 \text{ N/mm}^2$
 Characteristics strength of concrete = $f_{ck} = 20 \text{ N/mm}^2, 25 \text{ N/mm}^2, 30 \text{ N/mm}^2, 35 \text{ N/mm}^2$

Design Variables

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

- Design variables for Doubly Reinforced Beam without ductile detailing

Width of Beam = $b = x_1$

Depth of beam = $d = x_2$

Diameter of bars for steel in tension zone = $\text{dia}_1 = x_3$

No of bars for steel in tension zone = bars no (1) = x_4

Diameter of bars for steel in compression zone = $\text{dia}_2 = x_5$

No of bars for steel in compression zone = bars no (2) = x_6

Diameter of bars for shear reinforcement = $\text{dia}_3 = x_7$

Spacing for shear reinforcement = $sv = x_8$

Set of discrete values for design variables:

$b = (225-700)$ step size- 25

$d = (225-1000)$ step size- 25

$\text{dia}_1 = (16, 20, 25)$

bars no (1) = (2, 3, 4, 5, 6)

$\text{dia}_2 = (16, 20, 25)$

bars no (2) = (2, 3, 4, 5, 6)

$\text{dia}_3 = (8, 10)$

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

- Design variables for Doubly Reinforced Beam with ductile detailing

Width of Beam = $b = x_1$

Depth of beam = $d = x_2$

Diameter of bars for steel in tension zone = $\text{dia}_1 = x_3$

No of bars for steel in tension zone = bars no (1) = x_4

Diameter of bars for steel in compression zone = $\text{dia}_2 = x_5$

No of bars for steel in compression zone = bars no (2) = x_6

Diameter of bars for shear reinforcement = $\text{dia}_3 = x_7$

Spacing at end span (special confining reinforcement) = $sv_1 = x_8$

Spacing at centre span = $sv_2 = x_9$

Set of discrete values for design variables:

$b = (225-700)$ step size- 25

$d = (225-1000)$ step size- 25

$\text{dia}_1 = (16, 20, 25)$

bars no (1) = (2, 3, 4, 5, 6, 7, 8)

$\text{dia}_2 = (16, 20, 25)$

bars no (2) = (2, 3, 4, 5, 6, 7, 8)

$\text{dia}_3 = (8, 10)$

$sv_1 = (100, 110, 120, 130, 140, 150, 160, 170)$

$sv_2 = (180, 190, 200, 210, 220, 230, 240, 250, 260, 270)$

Objective Function

The objective function to be minimized for the cost of doubly reinforced beam without ductile detailing:

$F(x) =$

$$C [(b * d * L) - (((\pi/4 * d^2 * \text{no of bars tension side}) * L) + ((\pi/4 * d^2 * \text{no of bars compression side}) * L))] + S [((\pi/4 * d^2 * \text{no of bars tension side}) * L) + ((\pi/4 * d^2 * \text{no of bars compression side}) * L)) + (\pi/4 * d^2 * ((L/sv) + 1) * ((b + d) * 2))] + F [(b * L) + (b * d * 2) + (d * 2 * L)]$$

$$F(x) = C [(x1 * x2 * L) - (((\pi/4 * x3^2 * x4) * L) + ((\pi/4 * x5^2 * x6) * L))] + S [((\pi/4 * x3^2 * x4) * L) + ((\pi/4 * x5^2 * x6) * L)) + (\pi/4 * x7^2 * ((L/x8) + 1) * ((x1 + x2) * 2))] + F [(x1 * L) + (x1 * x2 * 2) + (x2 * 2 * L)]$$

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

$$F(x) = C [(b * d * L) - (((\pi/4 * d^2 * \text{no of bars tension side}) * L) + ((\pi/4 * d^2 * \text{no of bars compression side}) * L))] + S [((\pi/4 * d^2 * \text{no of bars tension side}) * L) + ((\pi/4 * d^2 * \text{no of bars compression side}) * L)) + (\pi/4 * d^2 * (\text{no of bars at end span} + \text{no of bars at centre span}) * ((b + d) * 2))] + F [(b * L) + (b * d * 2) + (d * 2 * L)]$$

Design Constraints

1. Constraint on Flexural Strength

When $M_u > M_{ulim}$, Doubly Reinforced beam is to be designed.

$$Mu > Mulim$$

$$g1 = Mulim - Mu \leq 0$$

2. Constraint for minimum area of tension reinforcement

As per clause 26.5.1.1a of IS 456-2000, tension reinforcement shall not be less than that given by the equation

$$\frac{Ast}{bd} = \frac{0.85}{fy}$$

$$Ast > \frac{0.85bd}{fy}$$

This can be written as constraint

$$g2 = \frac{0.85bd}{fy} - Ast \leq 0$$

$$g2 = \frac{0.85 * X1 * x2}{fy} - \left(\frac{\pi}{4} * x3^2 * x4\right) \leq 0$$

For doubly reinforced beam design the area of tension reinforcement should not be less than

$$Ast1 = \frac{0.36 * fck * b * xulim}{0.87 * fy}$$

$$Ast2 = \frac{Asc * fsc}{0.87 * fy}$$

$$Ast = Ast1 + Ast2$$

$$g3 = Ast - \left(\frac{\pi}{4} * x3^2 * x4\right) \leq 0$$

3. Constraint for maximum area of tension reinforcement

As per clause 26.5.1.1b of IS 456-2000, the maximum area of tension reinforcement shall not exceed 0.04bD.

$$Ast \leq 0.04 b (d + dc)$$

$$Ast - 0.04 b (d + dc) \leq 0$$

$$g4 = \left(\frac{\pi}{4} * x3^2 * x4\right) - 0.04 * x1 * (x2 + dc) \leq 0$$

4. Constraint for area of compression reinforcement

As per clause 26.5.1.2 of IS 456-2000, the maximum area of compression reinforcement shall not exceed 0.04bD, which results in the constraint equation as,

$$Asc \leq 0.04 b (d + dc)$$

$$Asc - 0.04 b (d + dc) \leq 0$$

$$g5 = \left(\frac{\pi}{4} * x5^2 * x6\right) - 0.04 * x1 * (x2 + dc) \leq 0$$

The area of compression reinforcement for doubly reinforced beam should not be less than

$$Asc = \frac{Mu - Mulim}{fsc * (d - dc)}$$

$$g6 = Asc - \left(\frac{\pi}{4} * x5^2 * x6\right) \leq 0$$

5. Constraint for shear strength

As per clause 40.1, 40.4 IS 456-2000 the design of shear reinforcement in the form of constraint equation written below,

$$\tau v = \frac{vu}{bd}$$

Where,

V_u = shear force due to design loads

b = breadth of the member

d = effective depth

$$p_t = \frac{100A_{st}}{bd}$$

The value of τ_c and design shear strength of concrete are taken from Table 19 and Table 20 IS 456-2000, But, table 19 is difficult to use when design parameter has to be computerized. For this purpose it is better to express the values by a formula. The semi-empirical formula used to derive table 19 is as follows,

$$\tau_{uc} = \frac{0.85(\sqrt{0.8f_{ck}})(\sqrt{1+5\beta}-1)}{6\beta}$$

Where,

$$\beta = \frac{0.8f_{ck}}{6.89p_t}$$

For $f_{ck} = 20 \text{ N/mm}^2$ the value reduced to

$$V_{uc} = 8.314 \sqrt{\frac{A_{st}}{bd}}$$

Shear reinforcement shall be provided to carry a shear equal to,

$$V_{ud} \leq V_{uc} + V_{us}$$

$$V_{us} = V_u - \tau_c b d$$

$$V_{us} = \frac{0.87 * f_y * A_{sv} * d}{sv}$$

$$g7 = V_{uc} - \tau_v \leq 0$$

$$g8 = 8.314 \sqrt{\frac{\pi}{4} * x_3^2 * x_4} - \frac{V_u}{x_1 * x_2} \leq 0$$

6. Constraint for spacing of shear reinforcement

As per the clause 26.5.1.5 of IS 456-2000 the maximum spacing of shear reinforcement measured along the axis of the member shall not be exceed $0.75d$, Where, d is the effective depth of beam and in no case shall the spacing exceed 300 mm which can be stated as,

$$sv = 0.75d, 300\text{mm}$$

$$g9 = X8 - 0.75 * x_2 \leq 0$$

$$g10 = X8 - 300 \leq 0$$

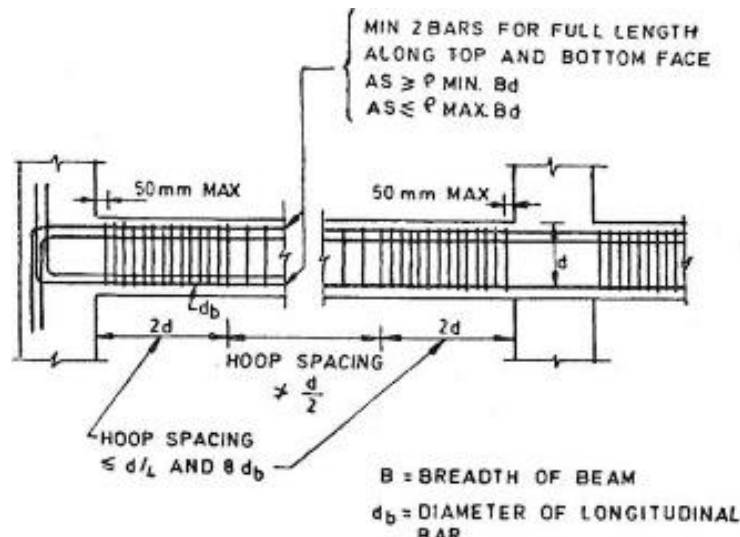


Figure 1: Beam Reinforcement (Special confining reinforcement)

Ductile detailing requirements for doubly reinforced beam according to IS 13920:1993.

- The member shall have preferably had a width-to-depth ratio of more than 0.3.
- The width of the member shall not be less than 200 mm.
- The depth of the member shall preferably be not less than $\frac{1}{4}$ of the clear span.
- The spacing of hoops over a length of $2d$ at either end of a beam shall not exceed

- $d/4$
 - 8 times the diameter of the smallest longitudinal bar (it must not less than 100 mm).
 - The first hoop shall be at a distance not exceeding 50 mm from the joint face.
- e) Vertical hoops at the same spacing shall also be provided over a length equal to $2d$ on either side of a section where flexural yielding may occur under the effect of earthquake forces.
- f) Elsewhere, the beam shall have vertical hoops at a spacing not exceeding $d/2$.

IV. RESULTS

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

I take four cases for optimisation of doubly reinforced beam.

Case-1. In this case span, f_{ck} and f_y are constant, Load vary.

Sr.No	Parameters	x(1)	x(2)	x(3)	x(4)	x(5)	x(6)	x(7)	x(8)	cost
1	span=4m	225	375	16	4	16	2	8	280	3950
	fck=25 N/mm ²									
	fy=415N/mm ²									
	w=25kN/m									
2	span=4m	225	400	25	2	16	2	8	300	4314
	fck=25 N/mm ²									
	fy=415N/mm ²									
	w=35kN/m									
3	span=4m	225	400	20	4	16	2	8	300	4697
	fck=25 N/mm ²									
	fy=415N/mm ²									
	w=45kN/m									
4	span=4m	225	375	25	3	16	2	8	280	4882
	fck=25 N/mm ²									
	fy=415N/mm ²									
	w=50kN/m									
5	span=4m	225	425	20	5	16	2	8	300	5271
	fck=25 N/mm ²									
	fy=415N/mm ²									
	w=60kN/m									
6	span=5m	225	375	16	5	16	2	8	280	5537
	fck=20 N/mm ²									
	fy=500N/mm ²									
	w= 25kN/m									
7	span=5m	225	450	16	6	16	2	8	300	6401
	fck=20 N/mm ²									
	fy=500N/mm ²									
	w= 35kN/m									
8	span=5m	225	525	20	4	16	2	8	300	7001
	fck=20 N/mm ²									
	fy=500N/mm ²									
	w= 45kN/m									
9	span=5m	225	575	20	4	16	2	8	300	7335
	fck=20 N/mm ²									
	fy=500N/mm ²									
	w= 50kN/m									
10	span=5m	225	600	20	5	16	2	8	300	8112

	$f_{ck}=20 \text{ N/mm}^2$									
	$f_y=500\text{N/mm}^2$									
	$w= 60\text{kN/m}$									

Case-2. In this case load, f_{ck} and f_y are constant, span vary.

Sr.No	Parameters	x(1)	x(2)	x(3)	x(4)	x(5)	x(6)	x(7)	x(8)	cost
1	$w=40\text{kN/m}$	225	350	16	4	16	2	8	260	2886
	$f_{ck}=25\text{N/mm}^2$									
	$f_y=415\text{N/mm}^2$									
	span=3m									
2	$w=40\text{kN/m}$	225	450	20	5	16	2	8	300	6748
	$f_{ck}=25\text{N/mm}^2$									
	$f_y=415\text{N/mm}^2$									
	span=5m									
3	$w=40\text{kN/m}$	225	650	25	5	16	2	8	300	13482
	$f_{ck}=25\text{N/mm}^2$									
	$f_y=415\text{N/mm}^2$									
	span=7m									
4	$w=40\text{kN/m}$	275	800	25	6	16	2	8	300	22427
	$f_{ck}=25\text{N/mm}^2$									
	$f_y=415\text{N/mm}^2$									
	span=9m									
5	$w=50\text{kN/m}$	225	350	16	4	16	2	8	260	3021
	$f_{ck}=20\text{N/mm}^2$									
	$f_y=500\text{N/mm}^2$									
	span=3m									
6	$w=50\text{kN/m}$	225	575	20	4	16	2	8	300	7335
	$f_{ck}=20\text{N/mm}^2$									
	$f_y=500\text{N/mm}^2$									
	span=5m									
7	$w=50\text{kN/m}$	250	725	25	4	16	3	8	300	14716
	$f_{ck}=20\text{N/mm}^2$									
	$f_y=500\text{N/mm}^2$									
	span=7m									
8	$w=50\text{kN/m}$	275	800	25	6	16	6	8	300	26257
	$f_{ck}=20\text{N/mm}^2$									
	$f_y=500\text{N/mm}^2$									
	span=9m									

Case-3. In this case span, load and f_y are constant, f_{ck} vary.

Sr.No	Parameters	x(1)	x(2)	x(3)	x(4)	x(5)	x(6)	x(7)	x(8)	cost
1	span=4m	225	375	16	6	16	2	8	280	4461
	$w=40\text{kN/m}$									
	$f_y=415\text{N/mm}^2$									
	$f_{ck}=20\text{N/mm}^2$									
2	span=4m	225	350	20	4	16	2	8	260	4466
	$w=40\text{kN/m}$									
	$f_y=415\text{N/mm}^2$									
	$f_{ck}=25\text{N/mm}^2$									
3	span=4m	225	350	20	4	16	2	8	260	4528
	$w=40\text{kN/m}$									
	$f_y=415\text{N/mm}^2$									
	$f_{ck}=30\text{N/mm}^2$									
4	span=4m	225	350	20	4	16	2	8	260	4605
	$w=40\text{kN/m}$									
	$f_y=415\text{N/mm}^2$									

	$f_{ck}=35\text{N/mm}^2$									
5	span=6m	225	625	20	5	16	2	8	300	9923
	w=45kN/m									
	$f_y=500\text{N/mm}^2$									
	$f_{ck}=20\text{N/mm}^2$									
6	span=6m	225	575	20	6	16	2	8	300	10368
	w=45kN/m									
	$f_y=500\text{N/mm}^2$									
	$f_{ck}=25\text{N/mm}^2$									
7	span=6m	225	525	20	6	16	2	8	300	10096
	w=45kN/m									
	$f_y=500\text{N/mm}^2$									
	$f_{ck}=30\text{N/mm}^2$									
8	span=6m	225	500	25	4	16	2	8	300	10232
	w=45kN/m									
	$f_y=500\text{N/mm}^2$									
	$f_{ck}=35\text{N/mm}^2$									

Case-4. In this case span, load and f_{ck} are constant, f_y vary.

Sr.No	Parameters	x(1)	x(2)	x(3)	x(4)	x(5)	x(6)	x(7)	x(8)	cost
1	span=4m	225	375	16	6	16	2	8	280	4511
	w=40kN/m									
	$f_{ck}=25\text{N/mm}^2$									
	$f_y=415\text{N/mm}^2$									
2	span=4m	225	375	16	5	16	2	8	280	4488
	w=40kN/m									
	$f_{ck}=25\text{N/mm}^2$									
	$f_y=500\text{N/mm}^2$									
3	span=4m	225	350	25	2	16	2	8	260	4592
	w=40kN/m									
	$f_{ck}=25\text{N/mm}^2$									
	$f_y=550\text{N/mm}^2$									
4	span=6m	225	650	25	5	16	4	8	300	12277
	w=60kN/m									
	$f_{ck}=20\text{N/mm}^2$									
	$f_y=415\text{N/mm}^2$									
5	span=6m	225	675	20	6	16	3	8	300	11523
	w=60kN/m									
	$f_{ck}=20\text{N/mm}^2$									
	$f_y=500\text{N/mm}^2$									
6	span=6m	225	650	20	6	20	2	8	300	12046
	w=60kN/m									
	$f_{ck}=20\text{N/mm}^2$									
	$f_y=550\text{N/mm}^2$									

Results of optimal design of doubly reinforced beam in case of with ductile detailing.**Case-1. In this case span, f_{ck} and f_y are constant, Load vary.**

Sr.No	Parameters	x(1)	x(2)	x(3)	x(4)	x(5)	x(6)	x(7)	x(8)	x(9)	Cost
1	span=4m	225	400	16	4	16	2	8	100	200	4392
	$f_{ck}=25\text{ N/mm}^2$										
	$f_y=415\text{N/mm}^2$										
	w=25kN/m										
2	span=4m	225	400	16	5	16	2	8	100	200	4672
	$f_{ck}=25\text{ N/mm}^2$										
	$f_y=415\text{N/mm}^2$										
	w=35kN/m										
3	span=4m	225	400	20	4	16	2	8	100	200	5022

	$f_{ck}=25 \text{ N/mm}^2$										
	$f_y=415\text{N/mm}^2$										
	$w=45\text{kN/m}$										
4	span=4m	225	450	20	4	16	2	8	110	220	5282
	$f_{ck}=25 \text{ N/mm}^2$										
	$f_y=415\text{N/mm}^2$										
	$w=50\text{kN/m}$										
5	span=4m	225	450	25	3	16	2	8	110	220	5583
	$f_{ck}=25 \text{ N/mm}^2$										
	$f_y=415\text{N/mm}^2$										
	$w=60\text{kN/m}$										
6	span=5m	225	400	16	5	16	2	8	100	200	6079
	$f_{ck}=20 \text{ N/mm}^2$										
	$f_y=500\text{N/mm}^2$										
	$w= 25\text{kN/m}$										
7	span=5m	225	450	16	6	16	2	8	110	210	6799
	$f_{ck}=20 \text{ N/mm}^2$										
	$f_y=500\text{N/mm}^2$										
	$w= 35\text{kN/m}$										
8	span=5m	225	525	20	4	16	2	8	130	260	7315
	$f_{ck}=20 \text{ N/mm}^2$										
	$f_y=500\text{N/mm}^2$										
	$w= 45\text{kN/m}$										
9	span=5m	225	575	20	4	16	2	8	140	270	7643
	$f_{ck}=20 \text{ N/mm}^2$										
	$f_y=500\text{N/mm}^2$										
	$w= 50\text{kN/m}$										
10	span=5m	225	600	20	5	16	2	8	150	270	8404
	$f_{ck}=20 \text{ N/mm}^2$										
	$f_y=500\text{N/mm}^2$										
	$w= 60\text{kN/m}$										

Case-2. In this case load, f_{ck} and f_y are constant, span vary.

Sr.No	Parameters	x(1)	x(2)	x(3)	x(4)	x(5)	x(6)	x(7)	x(8)	x(9)	Cost
1	$w=40\text{kN/m}$	225	400	16	4	16	2	8	100	200	3348
	$f_{ck}=25\text{N/mm}^2$										
	$f_y=415\text{N/mm}^2$										
	span=3m										
2	$w=40\text{kN/m}$	225	450	16	8	16	2	8	110	220	7156
	$f_{ck}=25\text{N/mm}^2$										
	$f_y=415\text{N/mm}^2$										
	span=5m										
3	$w=40\text{kN/m}$	225	650	25	5	16	2	8	160	270	13768
	$f_{ck}=25\text{N/mm}^2$										
	$f_y=415\text{N/mm}^2$										
	span=7m										
4	$w=40\text{kN/m}$	250	750	25	7	16	4	8	170	270	24047
	$f_{ck}=25\text{N/mm}^2$										
	$f_y=415\text{N/mm}^2$										
	span=9m										

5	w=50kN/m	225	475	16	3	16	2	8	110	230	3591
	$f_{ck}=20\text{N/mm}^2$										
	$f_y=500\text{N/mm}^2$										
	span=3m										
6	w=50kN/m	225	575	20	4	16	2	8	140	270	7643
	$f_{ck}=20\text{N/mm}^2$										
	$f_y=500\text{N/mm}^2$										
	span=5m										
7	w=50kN/m	250	725	25	4	16	3	8	170	270	15059
	$f_{ck}=20\text{N/mm}^2$										
	$f_y=500\text{N/mm}^2$										
	span=7m										
8	w=50kN/m	275	800	25	6	16	6	8	170	270	26694
	$f_{ck}=20\text{N/mm}^2$										
	$f_y=500\text{N/mm}^2$										
	span=9m										

Case-3. In this case span, load and f_y are constant, f_{ck} vary.

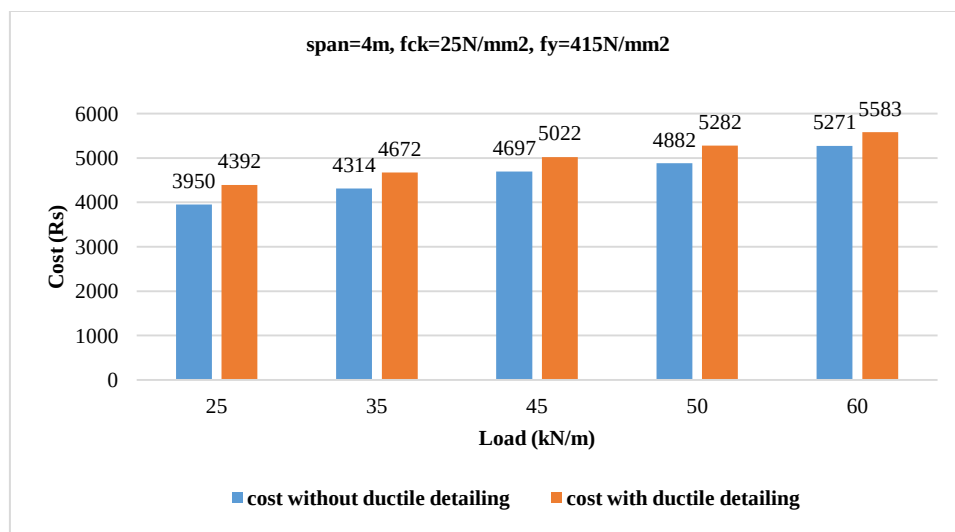
Sr.No	Parameters	x(1)	x(2)	x(3)	x(4)	x(5)	x(6)	x(7)	x(8)	x(9)	Cost
1	span=4m	225	500	20	3	16	2	8	120	250	5029
	w=40kN/m										
	$f_y=415\text{N/mm}^2$										
	$f_{ck}=20\text{N/mm}^2$										
2	span=4m	225	400	16	6	16	2	8	100	200	4952
	w=40kN/m										
	$f_y=415\text{N/mm}^2$										
	$f_{ck}=25\text{N/mm}^2$										
3	span=4m	225	475	16	5	16	2	8	110	230	5164
	w=40kN/m										
	$f_y=415\text{N/mm}^2$										
	$f_{ck}=30\text{N/mm}^2$										
4	span=4m	225	400	16	6	16	2	8	100	200	5111
	w=40kN/m										
	$f_y=415\text{N/mm}^2$										
	$f_{ck}=35\text{N/mm}^2$										
5	span=6m	225	625	20	5	16	2	8	150	270	10246
	w=45kN/m										
	$f_y=500\text{N/mm}^2$										
	$f_{ck}=20\text{N/mm}^2$										
6	span=6m	225	625	20	5	16	2	8	150	270	10371
	w=45kN/m										
	$f_y=500\text{N/mm}^2$										
	$f_{ck}=25\text{N/mm}^2$										
7	span=6m	225	525	20	6	16	2	8	130	260	10426
	w=45kN/m										
	$f_y=500\text{N/mm}^2$										
	$f_{ck}=30\text{N/mm}^2$										
8	span=6m	225	500	20	6	16	2	8	120	250	10412
	w=45kN/m										
	$f_y=500\text{N/mm}^2$										
	$f_{ck}=35\text{N/mm}^2$										

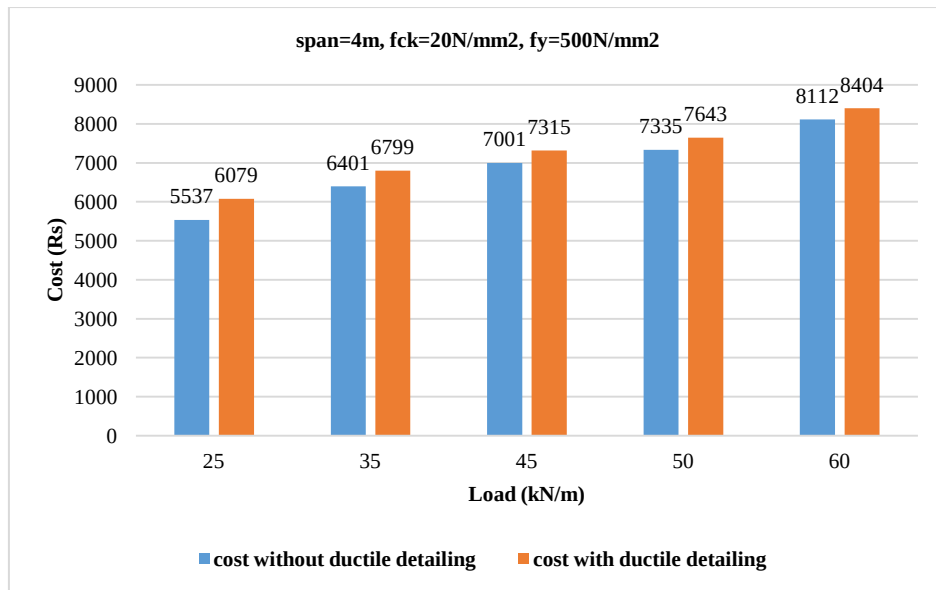
Case-4. In this case span, load and f_{ck} are constant, f_y vary.

Sr.No	Parameters	x(1)	x(2)	x(3)	x(4)	x(5)	x(6)	x(7)	x(8)	x(9)	Cost
1	span=4m	225	475	25	2	16	2	8	110	230	5047
	w=40kN/m										
	$f_{ck}=25\text{N/mm}^2$										
	$f_y=415\text{N/mm}^2$										
2	span=4m	225	400	20	3	16	2	8	100	200	4867
	w=40kN/m										
	$f_{ck}=25\text{N/mm}^2$										
	$f_y=500\text{N/mm}^2$										
3	span=4m	225	425	16	4	16	2	8	100	210	5067
	w=40kN/m										
	$f_{ck}=25\text{N/mm}^2$										
	$f_y=550\text{N/mm}^2$										
4	span=6m	225	625	25	5	20	3	8	150	270	12659
	w=60kN/m										
	$f_{ck}=20\text{N/mm}^2$										
	$f_y=415\text{N/mm}^2$										
5	span=6m	225	675	20	6	16	3	8	160	270	11846
	w=60kN/m										
	$f_{ck}=20\text{N/mm}^2$										
	$f_y=500\text{N/mm}^2$										
6	span=6m	225	675	20	6	16	3	8	160	270	12539
	w=60kN/m										
	$f_{ck}=20\text{N/mm}^2$										
	$f_y=550\text{N/mm}^2$										

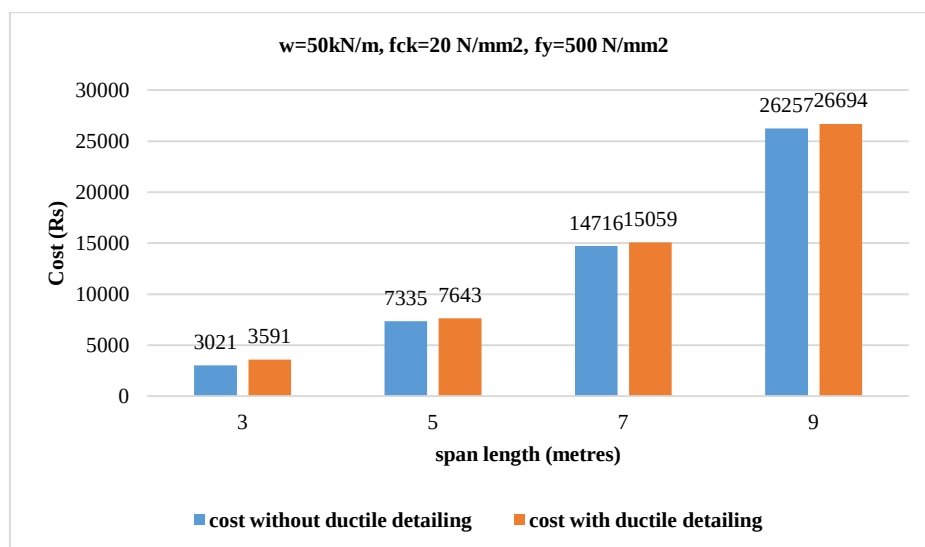
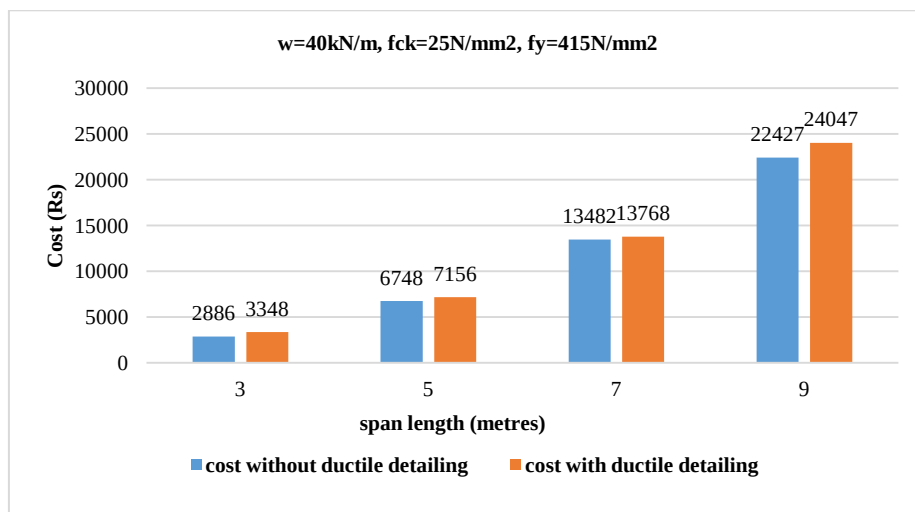
Cost comparison of doubly reinforced beam results with and without ductile detailing

Case-1.

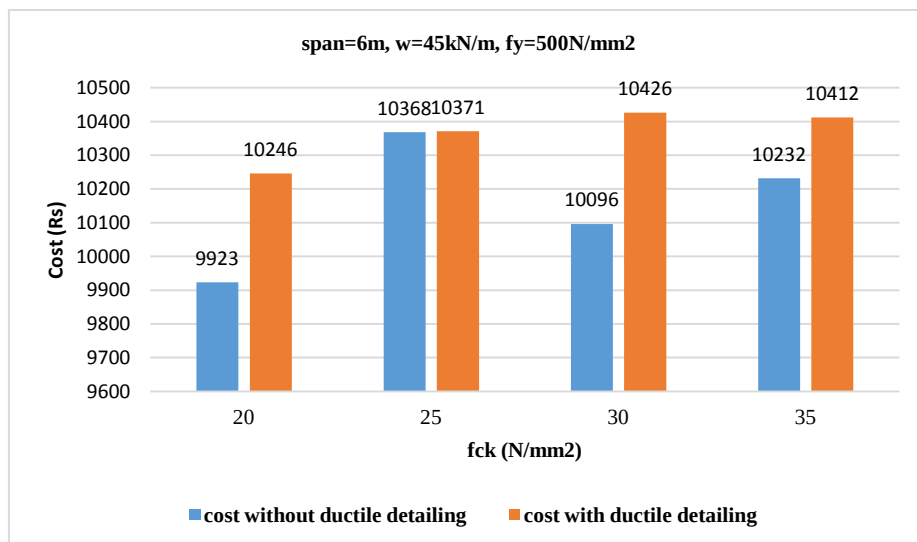
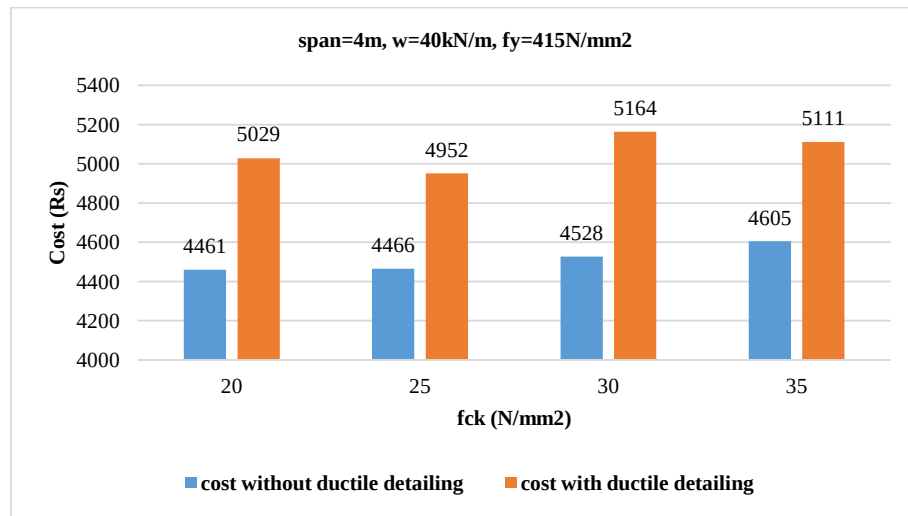




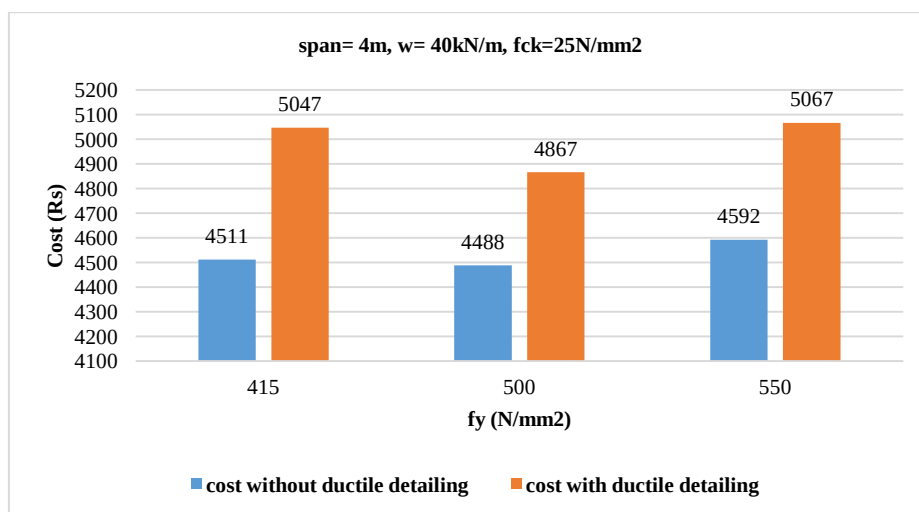
Case-2.

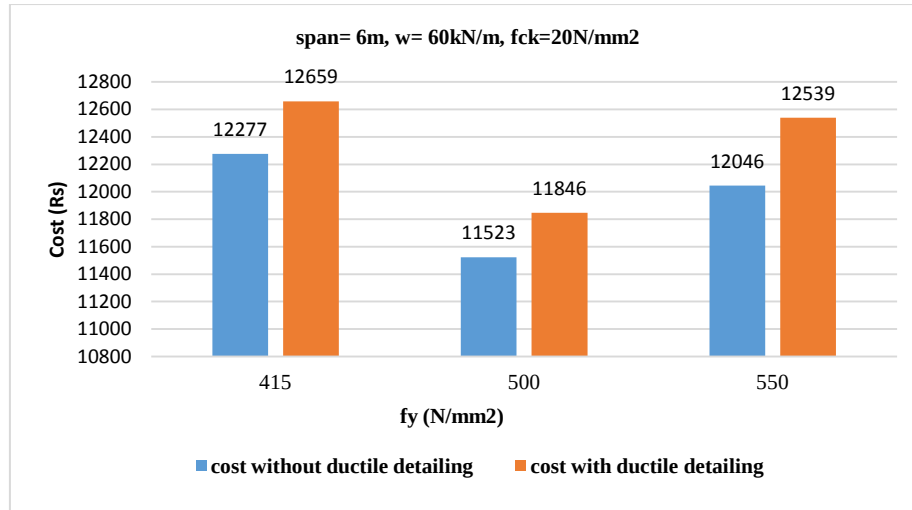


Case-3.



Case-4.





V. CONCLUSIONS

- The GA gives near about optimum results, in case of finding the optimal solution for given parameters. The GA optimizer does a good effort to minimize the overall cost in the objective function. This effort is used to reduce the amount of material since it has the higher percentage of the total cost.
- The GA is the good technique of discrete optimisation.
- In case of doubly reinforced beam design, it is 3-6% difference in cost between without ductile detailing case and with ductile detailing case.

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