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OPTIMIZATION OF REINFORCED CONCRETE ONE WAY SLAB & CANTILEVER SLAB USING GENETIC ALGORITHM

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Abstract:

For structural optimization algorithms to find wide spread usage among structural design for economy as well as safety considerations. A designer's goal is to develop an optimal solution for the structural design under consideration. An optimal solution normally implies the most economic structure without impairing the functional purposes the structure is supposed to serve. The total cost of reinforced concrete (RC) structure is the sum of the total cost of its constituent materials; these constituent materials are at least concrete,steel and formwork. As there are an infinite number of possible slab dimensions and reinforcement ratios that yield the same moment of resistance it becomes difficult to achieve the least cost design by conventional iterative methods.The formulated problem contains three optimization variables,the thickness of the slab, steel bar diameter and bar spacing while objective involves the minimization of overall cost of structure which includes the cost of concrete, cost of reinforcement and cost of formwork.In present work the using the genetic algorithms(GA) design optimization of RC simply supported one way slab and cantilever slabs according to IS 456:2000.

Key words:RC slab design optimization, formwork , structure cost reduction, GA

1 Introduction

1.1 General

Traditional design, even with the aid of computers, is based on postulating, appraising, and modifying potential solutions to achieve an acceptable form. By contrast, design by optimization employs numerical models of decision-making processes to generate direct prescriptive information on the nature of good solutions for the satisfaction of specified objectives. This design method reverses the design process to a certain extent. The procedures involved in this design process provide the potential for better designs by encompassing a much wider range of possibilities, and offering the designer an opportunity to examine the implications of the subjective decisions on the specified objectives. The optimization theory, coupled with cheap computational power, serves as a practical option to improve the design process without the need for impractical and more complex analysis. Material cost is an important issue in designing and constructing reinforced concrete (RC) structures. The main factors affecting cost is the amount of concrete and steel reinforcement required. Therefore, light RC structures that can fulfill the serviceability and strength requirements i.e., it must be a practicable design, for an effective design of structures. A great amount of workable or practicable designs are possible, it must be able to select the finest design from the several design that have been given. Design would be called best only when it is economical as well as safe as per IS codes. When the total amount and weight of building is minimum and adequate or else collection of all the above conditions. Various optimization processes provide local minimum value or local maxima value. In fact the majority of such processes provide local minimum value. It mostly depends on the numerical character of the goal function and the specific constraints.

Optimization processes act as a vital part in design of structure; the main aim of optimization is to find the best design so that a designer can figure the maximum gain from existing resources**.** Optimum structural design methods provide economical and safety corresponding to the design belief involved. Even today, the majority of the civil structures were designed based on allowable stress criteria as per code requirements. A specific factor of safety beside ultimate collapse of the structure is used by various new process.

The objective of this research is to minimize the total cost of the RC simply supported one way slab and cantilever slab.

1.2 Objective

1. To carry out a survey on the previous relevant researches
2. Develop the GA optimization programs to perform the design optimization process.
3. Validate the developed optimization programs using two numerical examples, one for RC simply supported one way slab and the other for cantilever slab and compare the design results obtained from MATLAB with the previous work

The Objective Function:

The principal work involved in the optimization technique by considering all the requirements of the IS code which including the safety and serviceability, providing the least optimum cost design. The objective function in this RC one way slab are defined as follows in which the total cost includes the cost of concrete, the cost of reinforcement steel and the cost of formwork.

$$f(x) = C_c[width*(x(1)+d^{'})*breadth - \{(x(2)*0.01*width*x(1)*x(3)*(\frac{width}{x(2)}+1)*breadth) + (0.0012*width*(x(1)+d^{'}))\}] + C_s[(x(2)*0.01*width*x(1)*x(3)*(\frac{width}{x(2)}+1)*breadth) + (0.0012*width*(x(1)+d^{'}))] + C_f[breadth*(x(1)+d^{'})]$$

Where,

- x(1) = effective depth of the slab, d
- x(2) = percentage reinforcement ratio of steel, p_t
- $p_t = \frac{100 f_{ck}}{2 f_y} * \left(1 - \sqrt{(1 - \frac{4.598 * w_u * l^2}{bd^2 * f_{ck} * 8})}\right)$
- x(3) = spacing of reinforcement,
- $s_v = \frac{78.5398 * \varnothing^2}{b \times d \times p_t}$
- C_c = cost of concrete including labour charges(Rs./m^3)
- C_s = cost of steel including bending of bars (Rs./m^3)
- C_f= cost of formwork(Rs./m^2)
- $d^{'}$ = effective nominal cover to the reinforcement (mm)
- f_{ck} = characteristic compressive strength of the concrete in N/mm^2
- f_y = characteristic yield strength of the steel in N/mm^2
- l = effective span of the slab in metre.
- M_u = bending moment due to super imposed load and self-weight in kN-m
- w_u = design load in kN/m^2 = 1.5(dead load +live load)
- b = width of the slab = 1000 mm
- Ø = diameter of the reinforcing bar (mm)

Values of Cost

The value of C_c, C_s, C_f as per USSR (Unified schedule of rates and specifications) are given below:

Cost of concrete:

For M20 grade, cost of concrete, C_c = 6854.7(Rs. /m^3)

For M25 grade, cost of concrete, C_c = 7091.05(Rs. /m^3)

Cost of steel:

For Fe415 grade, cost of steel, C_s = 353250(Rs. /m^3)

For Fe500 grade, cost of steel, C_s = 392500(Rs. /m^3)

Cost of formwork, C_f = 401.65(Rs. /m^2)

Result and discussion

Illustrated problems and study of the results

Both the reinforced concrete simply supported one way and cantilever slab are studied by making validity of the generated GA programs, illustrated problems was implemented and the value of the obtained results are analysed and compared with the previous work.

Reinforced concrete one way slab problem:

An illustrated problem of the reinforced concrete one way slab is analysed in this section. The following figure describing this one way slab along with constant variables.

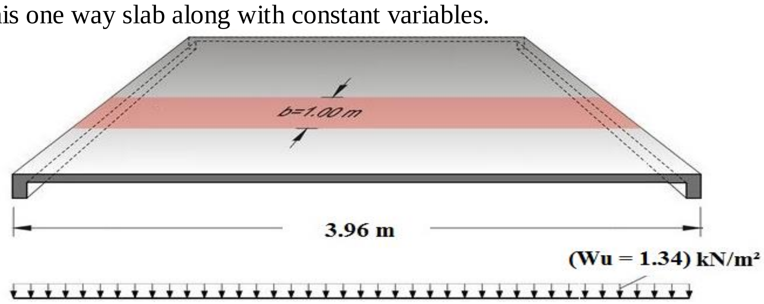


Figure- RC one way slab numerical example

The Fixed Parameters:

- Span of the slab is 3.96 m,
- Uniformly distributed load of 1.34kN/m^2,
- Characteristic cube strength of the concrete f_{ck}= 20.68 MPa,
- Characteristic strength for the steel f_y= 275.8 MPa,
- Cost of concrete, C_c= 610 (Rs. /m^3),
- Cost of steel bars, C_s=95.2809 (Rs. /kg).

Solution:

The above problem is solved using Genetic algorithm coding and the results obtained are as follows:

Cost = 1650.34Rs. /m

d = 167.80 mm

p_t = 0.3738%

s_v= 262.9mm

This study is compared with one of the previous works

Cost = 1770.36 Rs. /m

d = 158.75 mm

p_t = 0.42%

s_v= 220 mm

The optimal cost obtained by genetic algorithm coding is compared with the optimal cost obtained by one of the previous works and it is observed that former showed a reduction of 6.78% in total cost.

Figure (4.2) showing graphs plotted for best fitness vs. generation and average distance vs. generation for one way slab For 100 generation, 100 population size, and 0.01mutation.

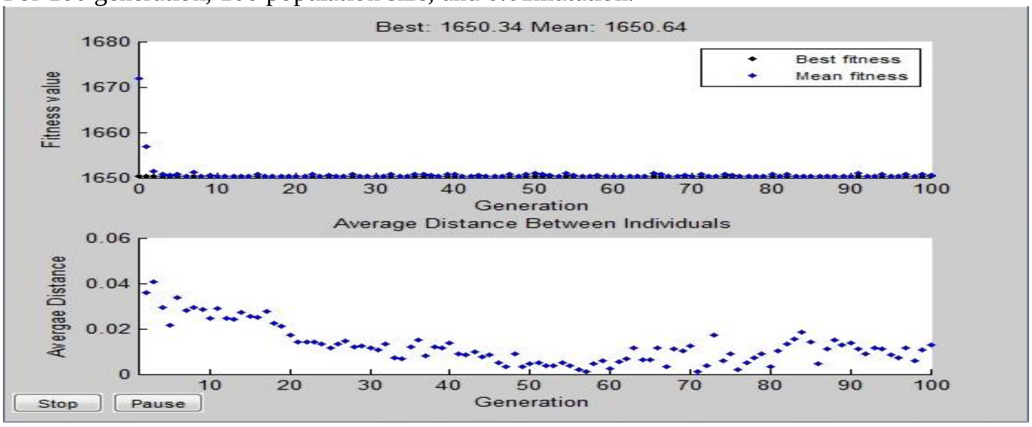


Figure 4.2 showing the optimum cost value for one way slab

The graph on the top plots the function's best and mean values versus generation. As the algorithm creates fitter individuals in subsequent generations, the mean value converges towards the best fitness value. And the graph below indicates the mean distance for every set of individuals. This gives us an idea about the population diversity in a generation

Discussion:

From the above graph it was observed that the optimum solution value of 1650.34 (Rs. /m) is obtained by giving 100 generations, 100 number of population size and 0.01 mutation rate and by changing these values doesn't cause any further reduction in optimal cost with the change in operator values.

Reinforced concrete cantilever slab problem:

An illustrated problem of the reinforced concrete cantilever is analysed in this section. The following figure (4.3) describing this cantilever slab along with constant variables.

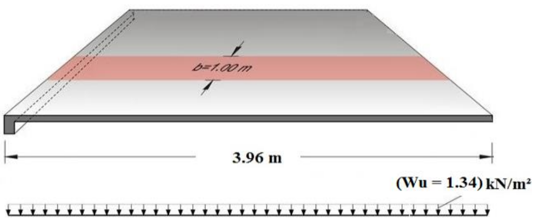


Figure 4.3: The RC cantilever slab numerical example

The Fixed Parameters:

- Span of the slab is 3.96 m,
- Uniformly distributed load of 1.34kN/m^2,
- Characteristic cube strength of the concrete f_{ck}= 20.68 MPa,
- Characteristic strength for the steel f_y= 275.8 MPa,
- Cost of concrete, C_c= 610 (Rs. /m^3),
- Cost of steel bars, C_s=95.2809 (Rs. /kg).

Solution:

The above problem is solved using Genetic algorithm coding and the results obtained are as follows:

Cost = 3204.05Rs. /m

d = 343.90 mm

p_t = 0.3907%

s_v= 191.8 mm

This study is compared with one of the previous works

Cost = 3951.83 Rs. /m

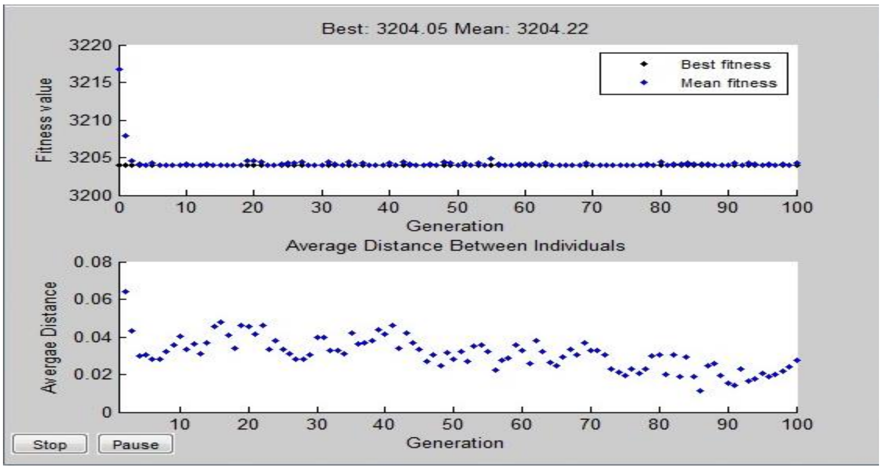
d = 317.50 mm

p_t = 0.54%

s_v= 127.0 mm

The optimal cost obtained by genetic algorithm coding is compared with the optimal cost obtained by one of the previous works and it is observed that former showed a reduction of 18.92% in total cost.

Figure (4.4) showing graphs plotted for best fitness vs. generation and average distance vs. generation for cantilever slab.



.**Figure 4.4 showing the optimum cost value for cantilever slab**

Discussion:

From the above graph it was observed that the optimum solution value of 3204.05(Rs. /m) is obtained by giving 100 generations, 100 number of population size and 0.01 mutation rate and by changing these values doesn't cause any further reduction in optimal cost with the change in operator values

4.2.4 Effect on optimum cost by changing the constant parameters:

The effect on the optimum cost value by changing the constant parameters is studied in this region. Some illustrated problems of both the RC one way and the cantilever slab is studied.

4.2.4.1 Effect of variation in grade of concrete and steel:

By changing the value of the compressive cube strength of the concrete and for the steel, there will be correspondingly change in the unit cost of the concrete and steel. In this region genetic algorithm programs are applied for different values of the compressive cube strength of the concrete and for the steel and the respective obtained optimum values of the solution is studied. The changing values of concrete are 20 and 25 MPa and for steel the changing values are 415 and 500 MPa for the RC one way slab and cantilever examples.

The results of the illustrated problems shown in figures (4.13) and (4.15) subsequently for a particular load is studied and by changing loading values the effect of variation in grade of concrete and steel is studied in figures (4.14) and (4.16) respectively for both the simply supported RC one way and cantilever slabs.

Input data for design problem

- Span of the slab is 4 m,
- Uniformly distributed live load of 3,5 and 7 kN/m^2,
- The characteristic cube strength for concrete f_{ck}= 20 and 25 MPa,
- The characteristic yield strength of steel f_y= 415 and 500 MPa.

Table 4.7: Effect of variation of grade of concrete and steel (RC one way slab)

Grade of concrete (N/mm^2)	M20		M25	
Grade of steel (N/mm^2)	**Fe415**	**Fe500**	**Fe415**	**Fe500**
Minimum cost (Rs./m)	6319.93	6238.82	6370.27	6306.34
Optimum depth(mm)	163.1	165.0	159.0	160.8
Optimum p_t	0.2764	0.2252	0.2835	0.2313
Optimum spacing(mm)	250.8	135.3	251.0	135.1

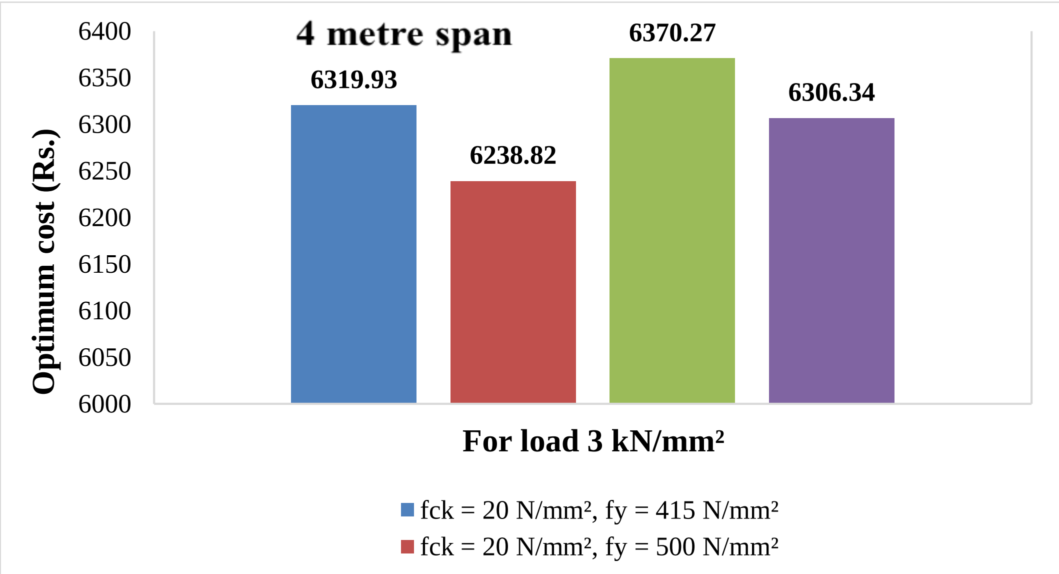


Figure 4.13: Effect of variation of grade of concrete and steel (RC one way slab)

Table 4.8: Effect of variation of grade of concrete and steel for different loading values (RC one way slab)

Grade of concrete (N/mm^2)		M20		M25	
Grade of steel (N/mm^2)		**Fe415**	**Fe500**	**Fe415**	**Fe500**
Minimum cos (Rs./m)	**Load 3 (kN/m^2)**	6319.93	6238.82	6370.27	6306.34
	Load 5 (kN/m^2)	6603.09	6509.26	6647.10	6570.30
	Load 7 (kN/m^2)	6878.52	6771.95	6916.33	6826.75

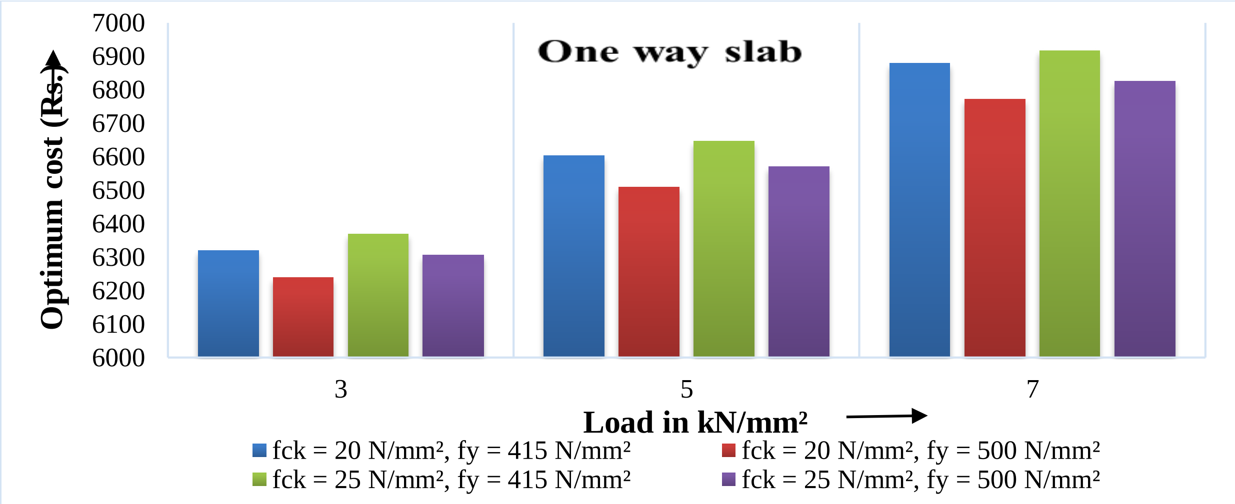


Figure 4.14: Effect of variation of grade of concrete and steel for different loading values (RC one way slab)

Table 4.9: Effect of variation of concrete and steel (RC cantilever slab)

Grade of concrete (N/mm^2)	**M20**		**M25**	
Grade of steel (N/mm^2)	**Fe415**	**Fe500**	**Fe415**	**Fe500**
Minimum cost (Rs./m)	10513.52	10416.87	10687.46	10593.85
Optimum depth(mm)	374.9	379.3	370.6	374.9
Optimum p_t	0.2626	0.2144	0.2637	0.2153
Optimum spacing(mm)	204.2	139.1	205.8	140.1

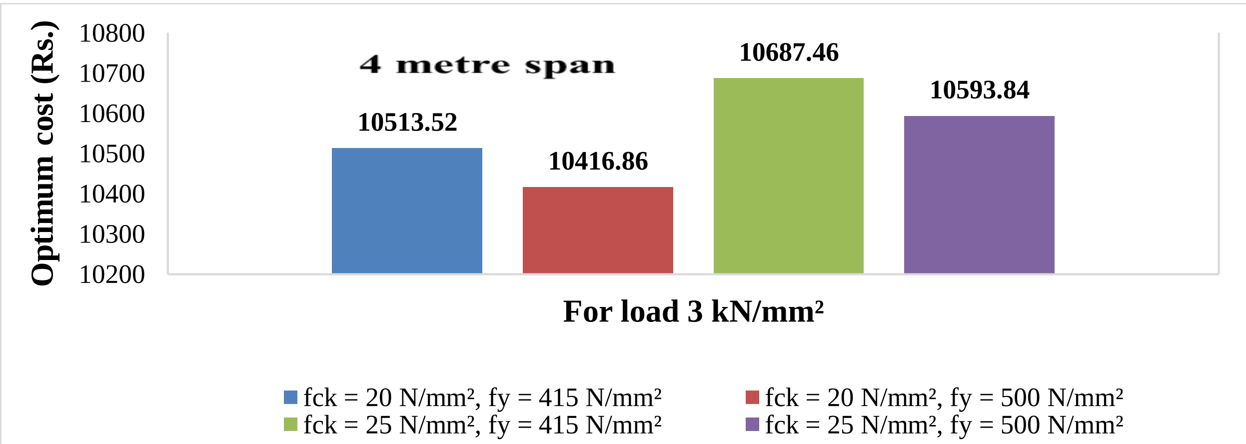


Figure 4.15: Effect of variation of grade of concrete and steel (RC cantilever slab)

Table 4.10: Effect of variation of grade of concrete and steel for different loading values (RC cantilever slab)

Grade of concrete (N/mm^2)		**M20**		**M25**	
Grade of steel (N/mm^2)		**Fe415**	**Fe500**	**Fe415**	**Fe500**
Minimum cost (Rs./m)	**Load 3 (kN/mm^2)**	10513.52	10416.87	10687.46	10593.85
	Load 5 (kN/mm^2)	10950.77	10833.45	11111.75	10997.63
	Load 7 (kN/mm^2)	11375.61	11237.87	11524.42	11390.09

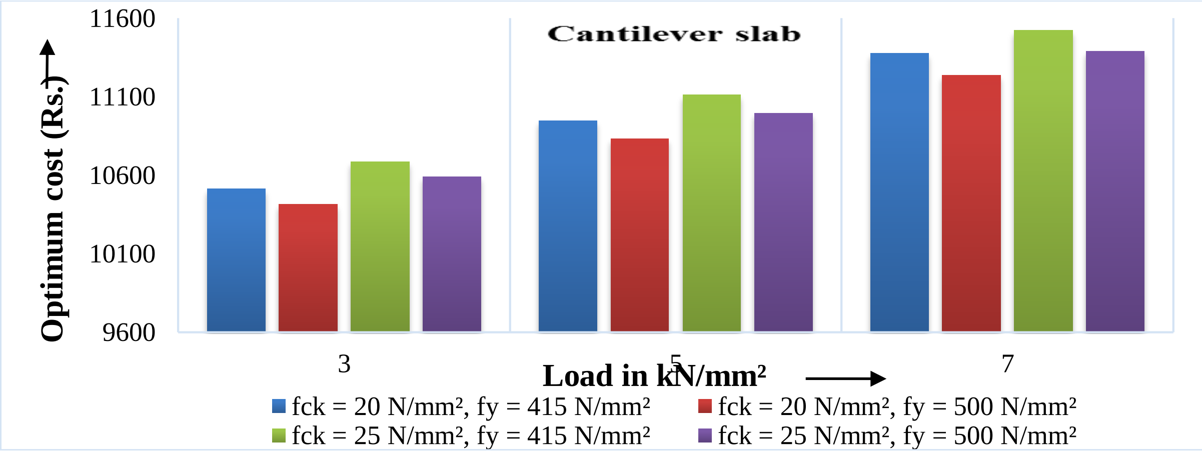


Figure 5.16: Effect of variation of grade of concrete and steel for different loading values (RC cantilever slab)

From the above results, the conclusions is listed as follows:

- From above it was showed that the total cost of slab increases when there is increase in characteristic strength of concrete, while fixing the applied load and grade of steel.
- It was showed that when there is increase in grade of steel the amount of the total optimum cost decreases, while fixing the applied load and compressive strength of concrete. The Genetic Algorithm optimizes the final cost by changing the dimensions of section in order to find the optimal cost.
- The optimum cost for the slab is achieved in M20 grade of concrete and Fe500 grade of steel.
- By increasing loading values for a particular problem will give the corresponding same pattern of values which was given for a fixed loading value, it gives the optimal solution values only and it doesn't show any variation by increasing the loading values.
- Cantilever slab (problem 2) has the maximum total cost among the two examples. It should be noted that cantilever slabs are rarely used in high span lengths and for most practical span lengths (3-4 m).
- As expected in all examples the optimum value of the cost at higher span lengths increases predominantly.
- The percent reduction in optimum reinforcement ratio for the slab is directly proportion to number of span length increases.
- The percent reduction in optimum reinforcement ratio for the slab is directly proportion to number of span length increases.
- On comparison with an earlier literature related to cost optimization of reinforced concrete slabs, it was concluded that there was cost reduction of 6.78% and 18.92% for the RC one way and cantilever slab respectively.

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