HBRP PUBLICATION

Journal of Advances in Civil Engineering and Management
Volume 4 Issue 3

Optimization of Flat Slab Using Genetic Algorithm

Mohanasundari R.[1]*, Subramanian C.[2]
[1]PG Student, ACGCET, Karaikudi, Tamil Nadu, India.
[2]Professor, ACGCET, Karaikudi, Tamil Nadu, India.
****Corresponding Author***
****E-Mail Id:** ravimohanasundari@gmail.com*

ABSTRACT

In this study optimization of reinforced concrete flat slab with drop and column head according to the Indian code (IS 456-2000) is presented. The optimum design of reinforced concrete flat slab could reduce its construction cost because it is usually employed in large floor area without any structural framing beams. Flat slabs are highly versatile elements widely used in construction. The objective function is the total cost of the flat slab, which consists of cost of concrete cost of steel and cost of formwork. The structure is designed by using Direct Design Method. Cost of flat slab is optimized by using Genetic Algorithm as a solver, which is an inbuilt optimization tool of MATLAB software. Trial and Error method is carried out to determine the suitable decision variables for optimization of flat slab. Results of optimum and conventional designs were compared.

***Keywords:** Optimum design, flat slab, cost, genetic algorithm, MATLAB, decision variables.*

INTRODUCTION

Optimization of structures has been considered as an area of interest for structural engineers in recent years, to develop a most optimum design of structure. An optimization process helps to build a most economic structure without affecting the functional purposes of the structure to be achieved.

The optimum design of reinforced concrete flat slab could reduce its construction cost because it is usually employed in large floor area without any structural framing beams. A reinforced concrete (RC) flat slab building is a kind of building in which floors are directly supported by columns without the use of intermediary beams.

In order to increase the punching shear resistance, flat slabs are designed with column head and drop panels. Flat slabs are used in office and residential buildings, hospitals, schools and hotels. Construction of flat slab and formwork is easy.

Due to absence of beams overall height of structure get reduced. Design of flat slab has been done by using direct design method (DDM).[3]

The objective of the optimization in the present work is to find a design that minimizes the cost of the flat slab. The algorithm used for the optimization of flat slab is Genetic algorithm (GA).[2]

METHODOLOGY

The methodology followed in this study is shown in figure 1. In this study, optimization of flat slab is done by using the steps denoted in the flowchart.

Firstly, literatures related to the study were collected and reviewed. Secondly, MATLAB program for the design of flat slab has been developed, which is used for trial-and-error method. Then optimization problem is formulated and the algorithm suitable for the optimization has selected.

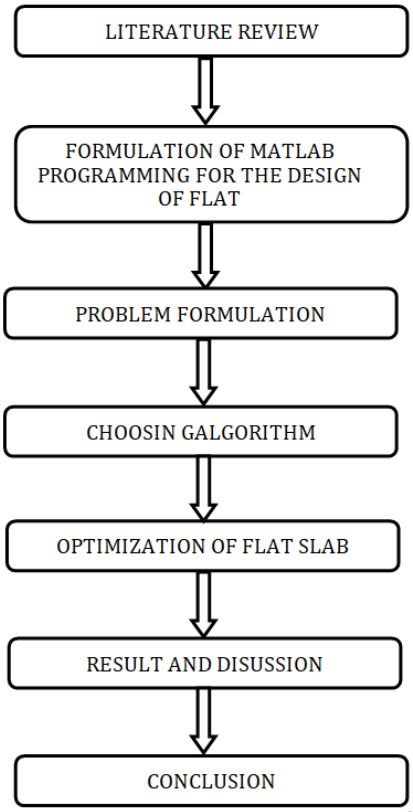

Fig.1:*Flow Chart for Methodology*

After that optimization process is carried out in MATLAB software by inserting the proper decision variables, objective function and constraints function as an input. Then results observed from optimization has been discussed and compared. Finally, the study concluded by explaining the results observed and knowledge gained from the study.

DESIGN OF FLATSLAB

The structural design of flat slab system can be carried out using the direct design method and adopted by Indian code (IS 456-2000). In this method (DDM), a building having rectangular column layout is classified into a series of longitudinal and transverse plane. It is assumed that the width of beam is divided into two strips, namely column and middle strips, shown in Figure 2. Each frame consists of column strip and middle strips which are structurally analyzed to obtain the total bending moments and shear forces at different sections of slabs. These slab panels are subjected to gravity, dead and imposed loads over the width of panels. The average bending moment over each strip is obtained as percentage of the total bending moment at each section. The reinforcement required in each slab section is determined with respect to the design bending moment obtained in each section of column and middle strips. The current design method is adopted to rectangular plan form buildings. The direct design method cannot be used for an irregular plan in such case finite element method should be applied instead.

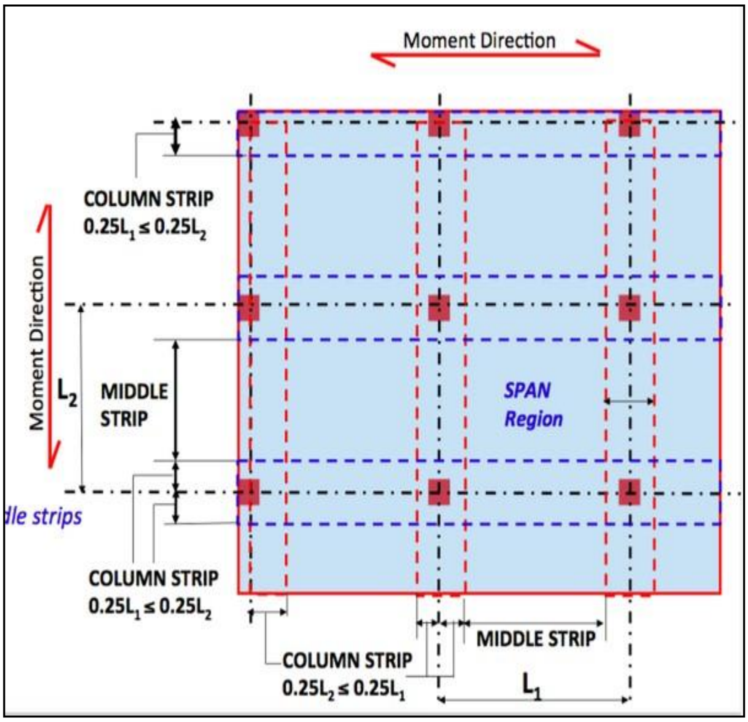

Fig.2:*Division of Flat Slab Panel into Strips*

DESIGN METHODS

- Direct design method
- Equivalent frame method

Direct Design Method

It is the simple and approximate method for analysis of flat slab. The direct design method (DDM) gives rules for the determination of the total static design moment and its distribution between negative and positive moment sections.

Limitations of DDM

- There shall be minimum of three continuous spans in each direction.
- The panels shall be rectangular and the ratio of the longer span to the shorter span within a panel shall not be greater than 2.
- The successive span length in each direction shall not differ by more than 1/3 of longer span.
- The design live load shall not exceed 3 times the design dead load.
- The end span must be shorter but not greater than the interior span.
- It shall be permissible to offset columns a maximum of 10% of the span in the direction of the offset.

Elements Considered in the Design of Flat Slab

Panel

The portion of flat slab that is bound on each of its four sides by center lines of adjacent columns is called a panel. The panel has size L1×L2. A panel may be divided into column strips and middle strips in Figure 2.

Column Strip

Column strip means a design strip having a width of 0.25L 1 or 0.25 L 2 whichever is less. Shown in Figure 2.

Middle Strip

Middle strip means a design strip bounded on each of its opposite sides by the column strip. Shown in Figure 2.

Thickness of Flat Slab

The thickness of flat slab is derived from the consideration of deflection control

IS4562000 specifies minimum thickness in terms of span to effective depth ratio.

Drops

To resist the punching shear which is predominant at the contact of slab and column Support, the drop dimension should not be less than one -third of panel length in that Direction. Shown in Figure 3.

Column Heads

To resist this negative moment the area at the support needs to be increased. This is facilitated by providing column capital/heads shown in Figure 3.

Optimization

The objective of the optimization in the present work is to find a design that minimizes the cost of the flat slab. Steps followed in optimizing the flat slab with drop and column head is given in Figure 4.

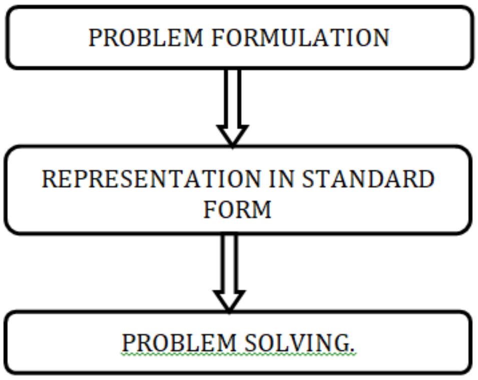

Fig.3:*Steps Involved in Optimization of Flat Slab*

Problem Formulation

Formulation of an optimization problem involves taking statements, defining general goals and requirements of a given activity, and transcribing them into a series of well-defined mathematical statements. Elements involved in problem formulation are,

- Decision variables
- Objective function
- Constraint function

Selection of Decision Variables

These are the variables whose values can change to find an optimal solution. A solution is a set of values assigned to these decision variables. Design variables can be continuous (such as the length of a cantilever beam), or discrete (such as the number of reinforcement bars used in a beam). Design problems with continuous variables are normally solved more easily.

In this study selection of decision variables can be done by trial-and-error method (Parametric optimization). They are,

X1=Effective depth of slab;
X2 = overall depth of drop from top of slab;
X3=diameter of column head;
X4 = Length of longer direction;
X5=Length of shorter direction;

OBJECTIVE FUNCTION

The real valued function whose value is to be either minimized or maximized over the set off feasible alternatives. For example, a designer may wish to maximize profit or minimize weight, cost.

The objective of this study is cost of flat slab. Cost of flat slab is the summation of cost of concrete, cost of reinforcement and cost of formwork.

COST=cost of concrete (C_c)+cost of reinforcement(C_r)+cost of formwork(C_f)

Cost of concrete (Cc)= volume* cost per m^3; = [Length of longer direction * Length of shorter direction * Effective depth of slab + length of drop*breadth of drop*overall depth of drop from top of slab]*cost perm^3;

Cost of reinforcement (Cr) =unit weight* volume* cost per Kg
Cr = W_S*cost per Kg*{[(area of reinforcement in middle strip * length) + (area of reinforcement in column strip * length)] along longer span+ [(area of reinforcement in middle strip*length)+(area of reinforcement in column strip*length)] a long shorter span}

Cost of formwork (Cf) = cost per m^2 *(Length of longer direction * Length of shorter direction)

COST=[X4*X5*X1+l*b*X2]*costperm^3+Ws*cost perKg*{[(A_{stms}*(L_{st}+L_b))+(A_{stcs}*(L_{st}+L_b))]$_{\text{along longer span}}$+[($A_{stms}$*($L_{st}$+$L_b$))+($A_{stcs}$*($L_{st}$+$L_b$))]along$_{\text{shorter span}}$}+cost per m^2*(X4 *X5)

CONSTRAINT FUNCTION

A constraint is a limitation for the objective function or design that must be satisfied to get the feasible solution for the problem. The restrictions for the design of flat slab as per codal provision must be satisfied to produce an acceptable design are called design constraints. The conditions which are considered as constraints in this study are,

Moment Constraints

i. $M_{alonglongerspan}$=(W*Lnx)/8
ii. $M_{alongshorterspan}$=(W*Lny)/8

Lnx=Lx–sqrt((pi/4)*diameter of column head),Lny=Ly–sqrt((pi/4)*diameter of column head)

Depth Constraints

iii. Length in longer span/depth of slab x1 <26;
iv. depth of column head = (Lx +Ly)/10; Lx = length in longer direction Ly=length in shorter direction
v. depth of drop =1.25 *depth of slab;

Shear Constraints

vi. shear constraints for slab 0.215=48.3/ effective depth of slab;
vii. shear constraint for drop0.534 =157.4/depth of drop;

TRIAL AND ERROR METHOD (PARAMETRI C OPTIMIZATION)

To optimize the flat slab, observing the behavior of parameters influences the cost are essential. For that purpose, trial and error method is adopted to study the parameter involved in the cost. Trial and error method is carried out by using MATLAB. The design of flat slab is converted into mathematical programming as shown in Annexure I and the parameters were analyzed by varying the numerical values of them. The results observed from trail and method were tabulated and plotted respectively. Which parameters affect the cost to the most are considered as a decision variable for optimization done by Genetic Algorithm. The parametric optimization carried out by changing the following parameters,

- By varying the depth of slab
- By varying the depth of drop
- By varying both depth of slab and depth of drop
- By varying length along longer direction
- By varying length along shorter direction

By Varying the Depth of Slab

The variation cost of flat slab observed by making change in depth of slab (X1) are noted in Table1

Table1: *By Varying the Depth of SLAB*

X1(mm)	Cost(Rs)
225	75958
220	74819
210	72547
200	70286
190	68038
180	65805
170	63591
160	61400
150	59240
140	57120
130	55054
125	57120

The observed values are plotted by considering total cost in Y axis and depth of slab in X axis which is shown in figure 4

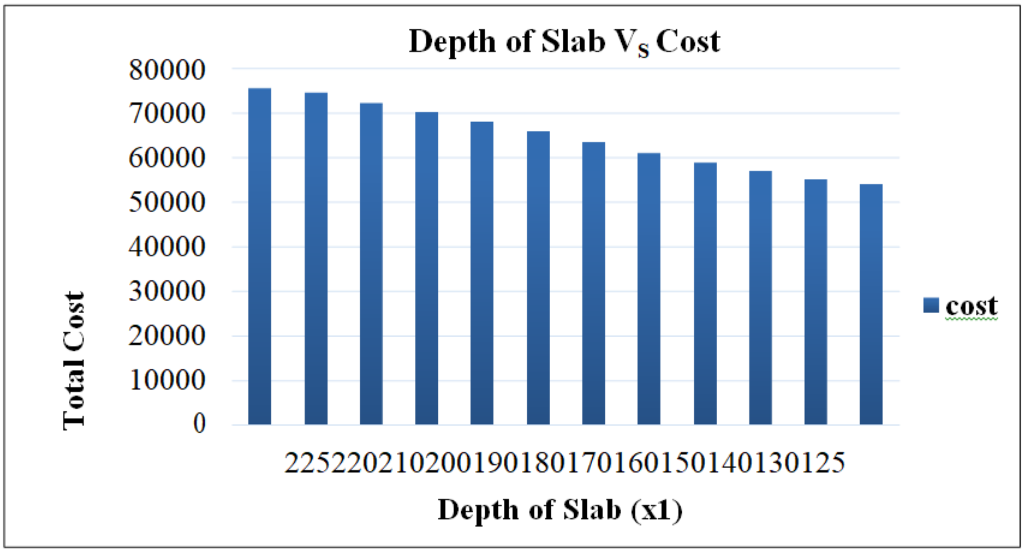

Fig.4: *Variation in total cost with respect to X1*

From the graph (figure 4) it is found that the total cost of flat slab is directly proportional to depth of slab. Cost is **decreased linearly** by means of reducing the depth of slab. The rate of decrease in cost is 2**%** with respect to X1.

The variations occurred in cost of steel and cost of concrete for the changing depth of slab (X1) is also observed and tabulated. (Table2)

Table 2: *Variations in Cost of Steel and Concrete for Changing X1.*

X1(mm)	Cost of Steel(Cs)	Cost of Concrete(Cc)
250	3945	73938
245	3981	72755
235	4057	70390
225	4140	68024
215	4232	65659
205	4334	63293
195	4449	60928
185	4578	58563
175	4725	56197
165	4893	53832
155	5089	51466
145	5322	49101
135	5603	46735
125	5952	44370

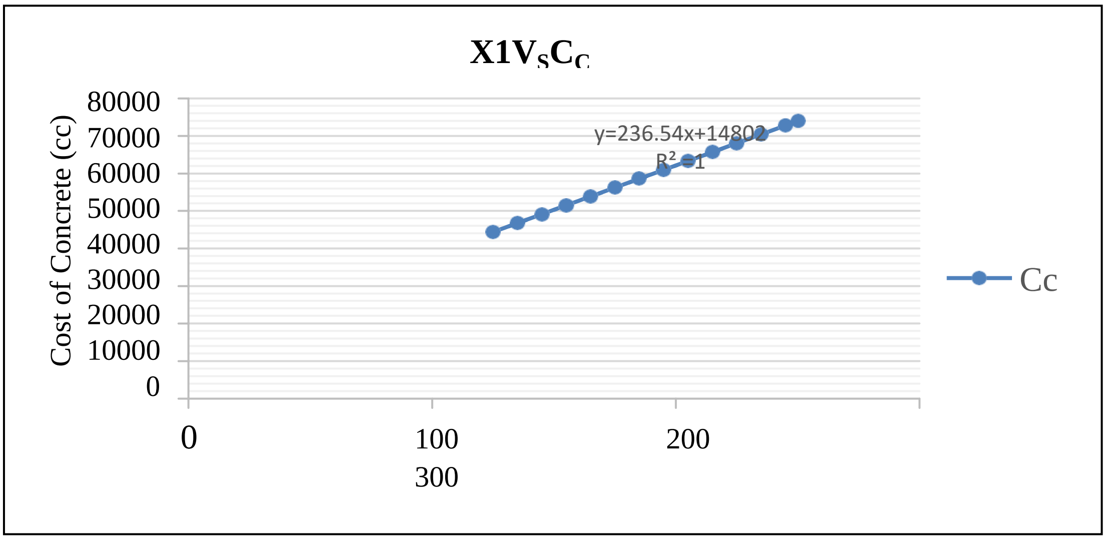

Fig. 5: *Variation in Cost of Concrete with respect to X1*

Cost of concrete is directly proportional to depth of slab, so that the decrease in depth of slab causes decrease in cost of concrete shown in figure 5. But cost of steel is indirectly proportional to depth of slab, hence, cost of steel increases by decreasing the depth of slab shown in figure 6. Total cost of flat slab is consisting of cost of concrete and cost of steel, here the increase in cost of steel doesn't affect the total cost because the cost of concrete is very high compared to steel.

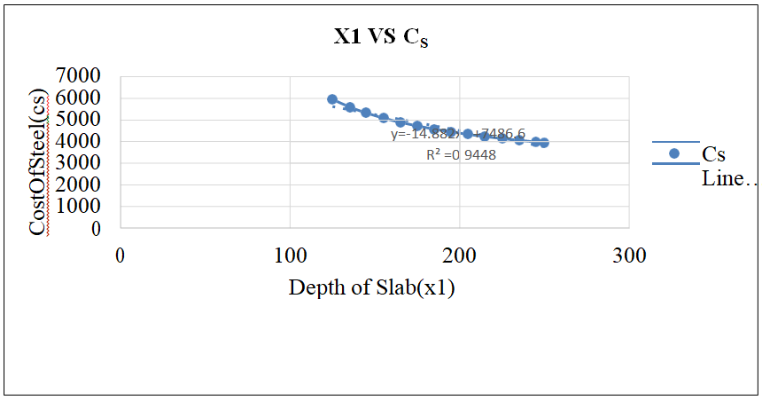

Fig.6: *Variation in Cost of Steel with respecttoX1*

So, the depth of slab(X1) can be decreased in order to get the considerable reduction in total cost as shown in figure 4 and make flat slab more economical.

By Varying Depth of Drop (X2)

In parametric optimization depth of drop (X2) has differed linearly, the variation observed in total cost of flat slab have been represented in Table. 3

Table3: *Varying Depth of Drop (X2).*

X2(mm)	Cost(Rs)
295	75958
280	75352
265	74767
250	74206
235	73676
220	73186
205	72749
190	72386
175	72133

From the Table.3 it is analysed that the total cost is directly proportional to Depth of drop (X2). So, that cost of flat slab being reduced by decreasing X2.Cost is decreasing linearly at the rate of **0.8%** by decreasing X2 observed in figure 7.

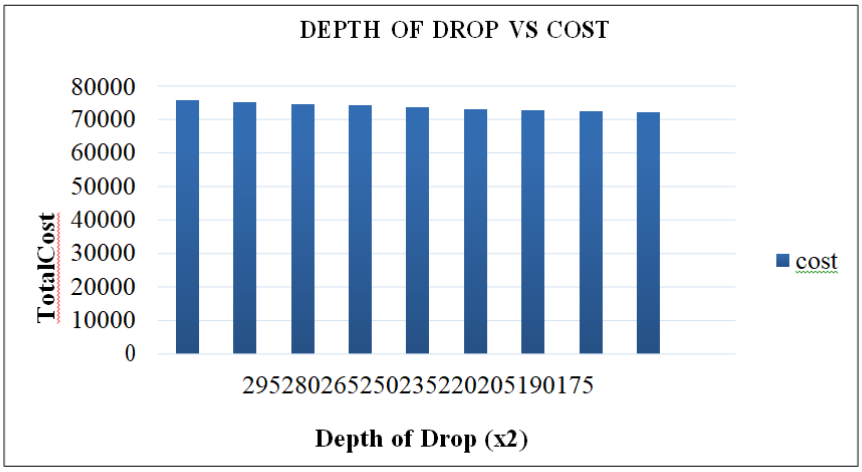

Fig. 7: *Variation in Total cost with respect to X2*

By Varying X1 and X2 Simultaneously

Varying both depth of slab and depth of drop simultaneously causes considerable reduction in cost of flat slab. Reduced cost of flat slab corresponding to the depths are noted and given in Table 4.

Table 4: *Varying both X1, X2 Simultaneously.*

X1(mm)	X2(mm)	COST(Rs)
225	295	75958
210	290	72343
200	275	69483
190	260	66656
180	245	63872
170	230	61140
160	215	58476
150	200	58080
140	185	53449
130	170	51180
125	155	50191

It is found that cost of flat slab is **decreases** at the rate of **4.3%** by reducing the depth of slab (X1) and depth of drop (X2) simultaneously with in limit as per IS 456:2000 provisions. The reduction in cost of flat slab is represented in figure 8.

By Varying Length of Panel

The length of the interior panel along longer and shorter direction has been varied considerably which induces reduction in cost.

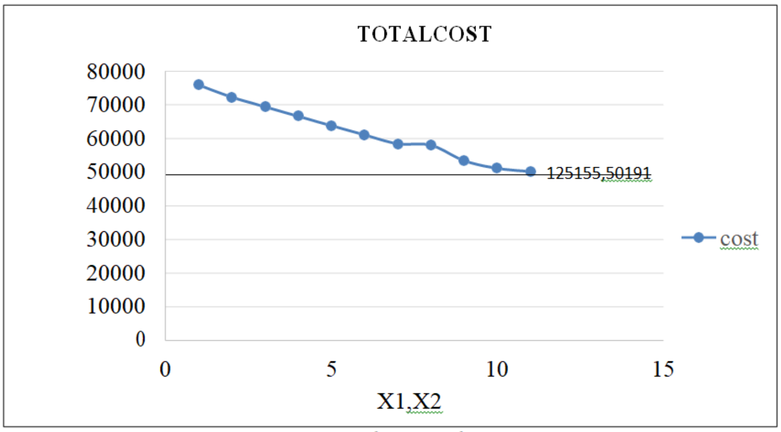

Fig.8: *Variation in Total Cost with Respect to X1, X2*

Table 5: *Variation in cost according to the length of panel.*

Length in Longer direction (X4) (mm)	Length in Shorter direction (X5)(mm)	Cost of Concrete(Cc)	Cost of steel (Cs)	Total cost (Rs)
6.6	6.6	77528	4458	87227
5.6	5.6	59960	3699	66317
5.5	5.5	58362	3620	64434
5.4	5.4	56792	3542	62589
5.3	5.3	55252	3463	60781
5.2	5.2	53740	3384	59010
5.1	5.1	52256	3306	57276

From the Table 5 it is observed that the decrease in length of span along both direction causes reduction in the cost of flat slab. Cost of flat slab decreased at a rate of **2.6%** by reducing the length of span within the considerable limit which is shown in figure 9.

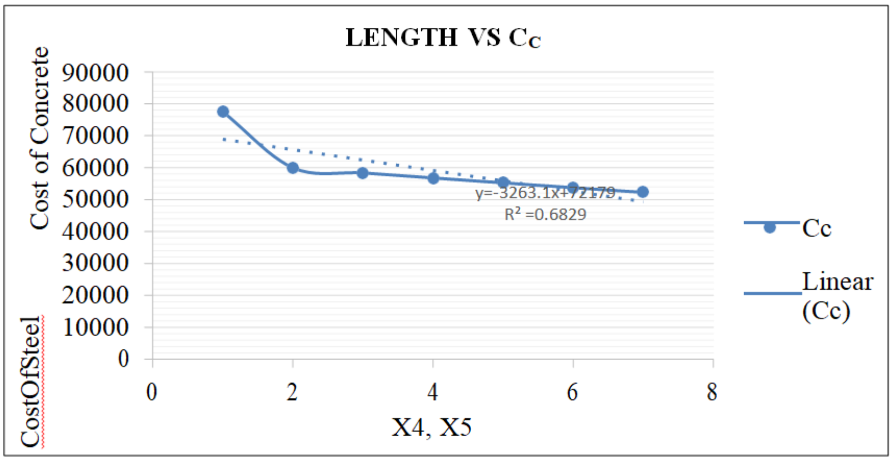

Fig.9: *Variation in Total Cost with Respect to X4, X5*

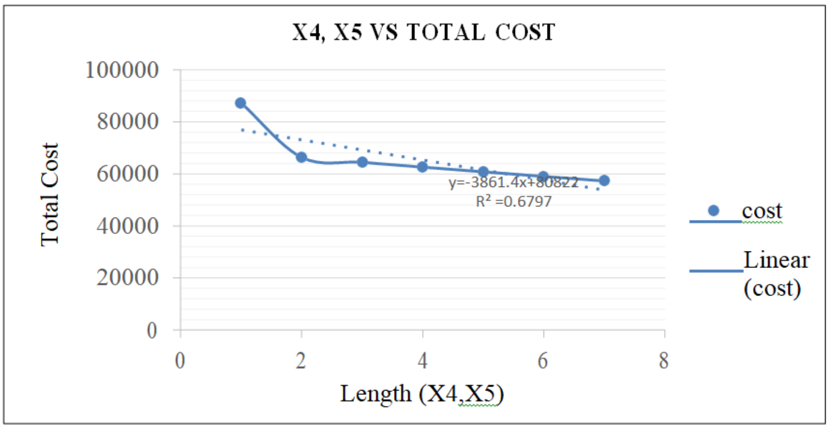

Fig.10:*Decrease in Cost of Concrete with Respect to Length*

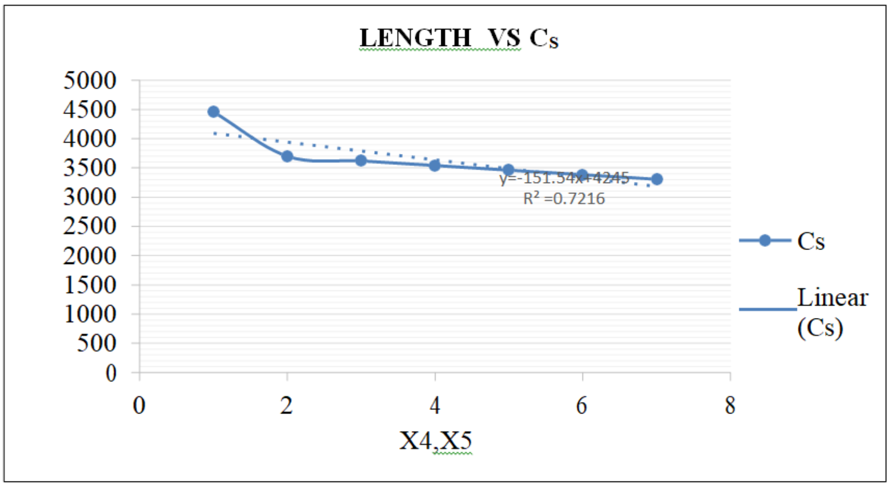

Fig.11: *Decrease in Cost of Steel with Respect to Length*

While analyzing the nature of cost of concrete and cost of steel corresponding to the changing length, it is understanding that the cost of both steel and concrete gets reduced with respect to the decrease in length as shown in figure 10, figure 11.And the observed values are given in Table 5.

DISCUSSION

The cost of flat slab is decrease by changing the depth of slab and drop. By comparing all the graphs decreasing X1 and both X1, X2 causes **more decrease** in cost of flat slab. Length of panel (Lx, Ly) also causes considerable decrease in total cost of flat slab. From the trial-and-error method (parametric optimization) parameters which are influencing the total cost of flat slab were found. The parameters which have been observed in detail were used as a decision variable in optimization using genetic algorithm.

Optimization by Genetic Algorithm

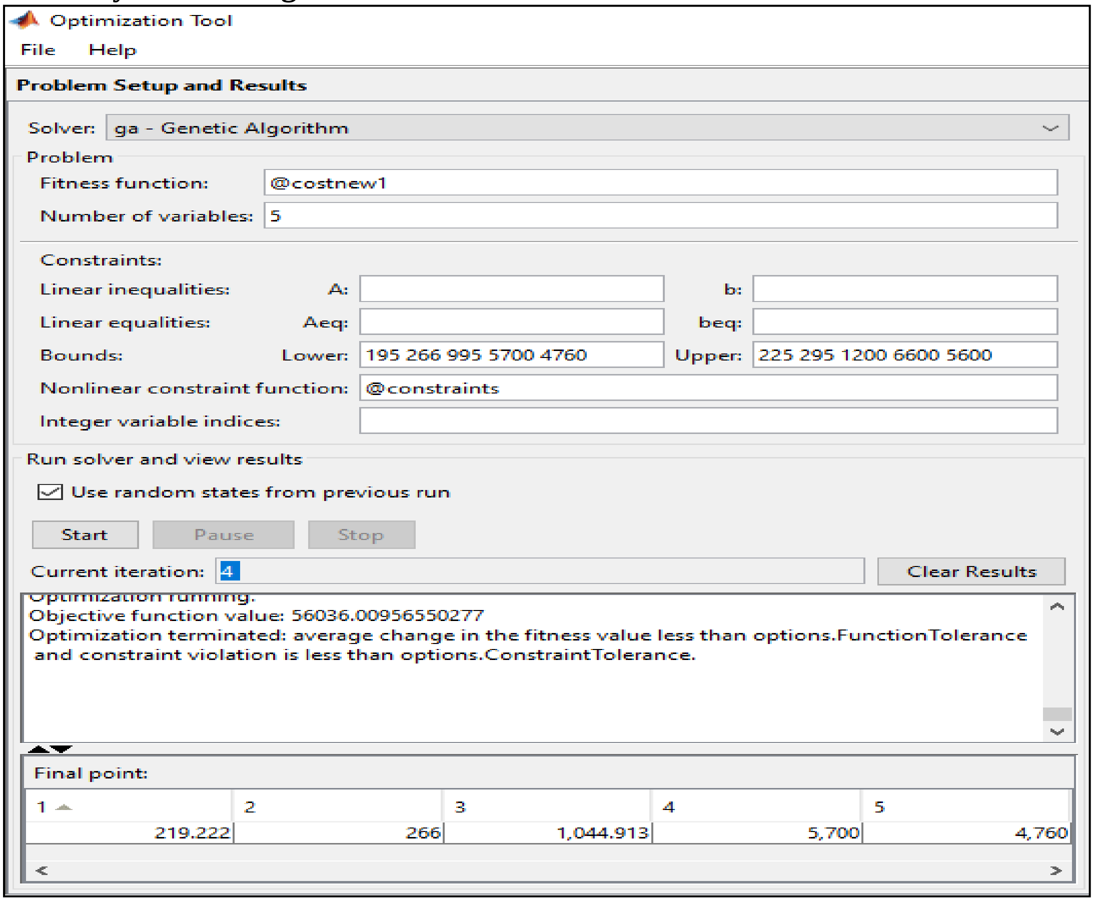

Fig. 12: *Output Obtained by GA*

After formulating an optimization problem that has been represented as a mathematical statement, then it is inserted into the optimization tool and the genetic algorithm is chosen as the solving algorithm optimization tool also a bound values were given to the tool. Finally optimization had been started, after number of generations has run the optimal solution has obtained from the solver by using GA as shown in figure 9.

And also, the plots representing number of generations, current best individual corresponding to the optimization were obtained from the solver as in figure 10.

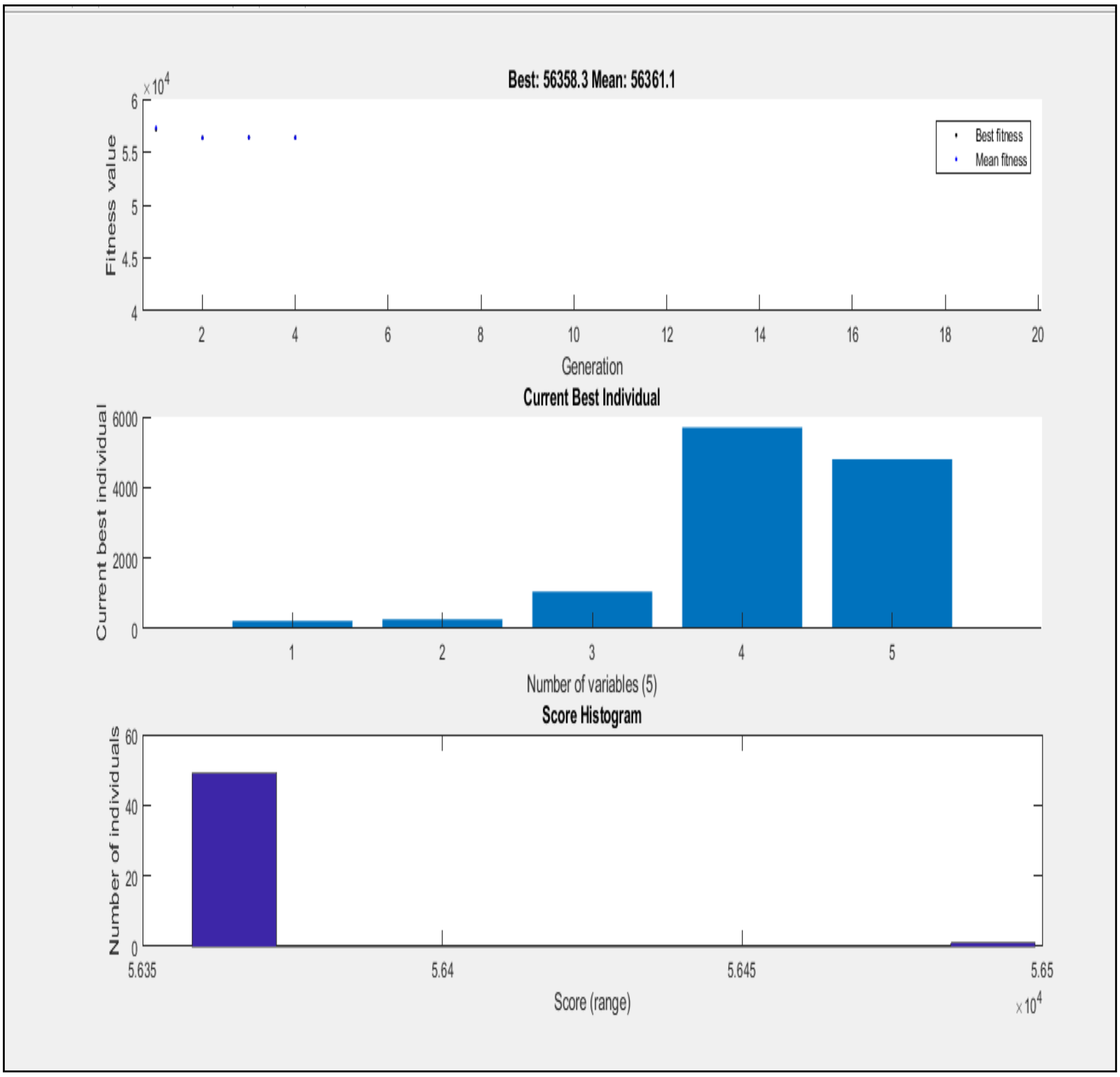

Fig.13:*Plots Obtained as a Result of Optimization by GA*

Optimized Result Obtained From GA

Depth of slab (X1) = 219.22mm, Depth of drop (X2) =266mm, Diameter of column head(X3) = 1044.913mm, Length of longer direction(X4) =5700 mm, Length of shorter direction (X5) = 4760mm

Total Cost of flat slab=Rs.56036

Table 6: *Comparison of Optimized Cost with Conventional Cost.*

Decision variables	**X1(mm)**	**X2(mm)**	**X3(mm)**	**X4(mm)**	**X5(mm)**	**Cost(Rs)**
Conventional design	225	295	1200	6600	5600	**75958**
Optimized design	219	266	1044	5700	4760	**56036**

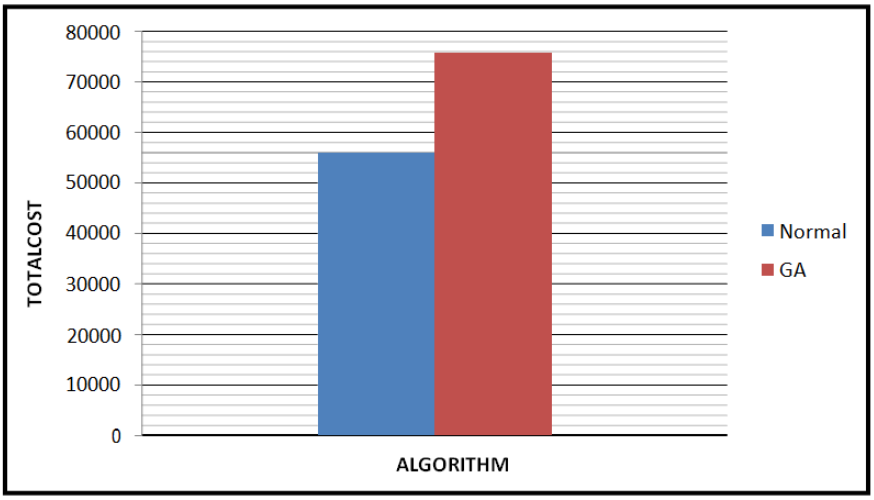

Fig. 6: *Cost Comparison*

From Table 6 it is observed that the cost obtained by optimization using GA is comparatively lesser than cost of flat slab obtained from conventional design. Cost of flat slab is reduced by 26%compared to conventional design results. Hence, the GA provides best optimal solution.

CONCLUSION

This study presents cost optimization of flat slab with drop and column head using Genetic Algorithm (GA) as a solver in optimization tool with the help of MATLAB. Cost of flat slab is reduced in optimized results by varying the value of depth of slab, depth of drop, diameter of column head and length along both directions.

By means of comparing the results obtained from optimization with conventional design, it is understood that the Genetic algorithm provide best result within the boundary condition. And the cost of flat slab is **reduced** and it is economical compared to conventional design results. Hence, the cost of flat slab is optimized with in boundary condition and economical value found.

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