8. GA Based Optimization of Composite Elements

8.1 General Remarks

The goal of the design engineer is to arrive at structures which are safe, functionally efficient and economical. There is no totally risk-free environment and hence the structural engineer should make the best use of available resources to balance between safety and economy. Thus, when designing structures, engineers have to consider not only the load carrying capacity of the structures but also the cost to construct them. To achieve this goal optimization techniques have been employed in structural design.

Genetic Algorithms (GAs) are naturally suitable for solving optimization problems. In general, fitness function F(x) is first derived from the objective function O(x) and used in successive genetic operators. Fitness in biological sense is a quality value, which is a measure of the reproductive efficiency of the chromosomes. In GA, fitness is used to allocate reproductive traits to the individuals in the population and thus act as some measure of goodness to be maximized. This means that individuals with higher fitness value will have higher probability of being selected as candidate for further examination.

In the present chapter, for the optimum design of composite beam and columns, GA based procedure is used with the objective function considered as the total cost of the structure. Two different composite beam and columns examples are included.

The structural system of a composite beam is essentially a series of parallel T-beams with thin wide flanges. The concrete flange is in compression and the steel beam is largely in tension. The benefits of composite action in terms of strength and serviceability are considerable, leading to economy in the sizing of the steel beams. The bending capacity of the section is evaluated on "plastic" analysis principles, whereas the serviceability performance is evaluated on elastic section analysis principles.

The columns are optimized using various load condition like axial load, axial load with uni-axial bending and axial load with bi-axial bending.

Here a program is developed for optimization of composite beams and columns in VB.NET environment. The simplicity of VB in creating menus, tool boxes, forms and MDI forms is exploited extensively to make the software as user friendly as possible. A number of subroutines and functions are developed to facilitate the optimum design of composite beams and columns.

8.2 Optimum Design Parameters for Composite Beam

8.2.1 Design Variables and Coding

The design variables for optimum design of steel-concrete composite beam are the center to center distance between beams (Spacing), size of intermediate beams (I-sec1), size of end beams (I-sec2), type of shear connectors (Type_Stud) and thickness of RCC slab (Thickness_slab). The idea is to arrive at such a combination of these variable components that the overall cost is minimum and at the same time, the composite beam and slab is safe from structural design point of view.

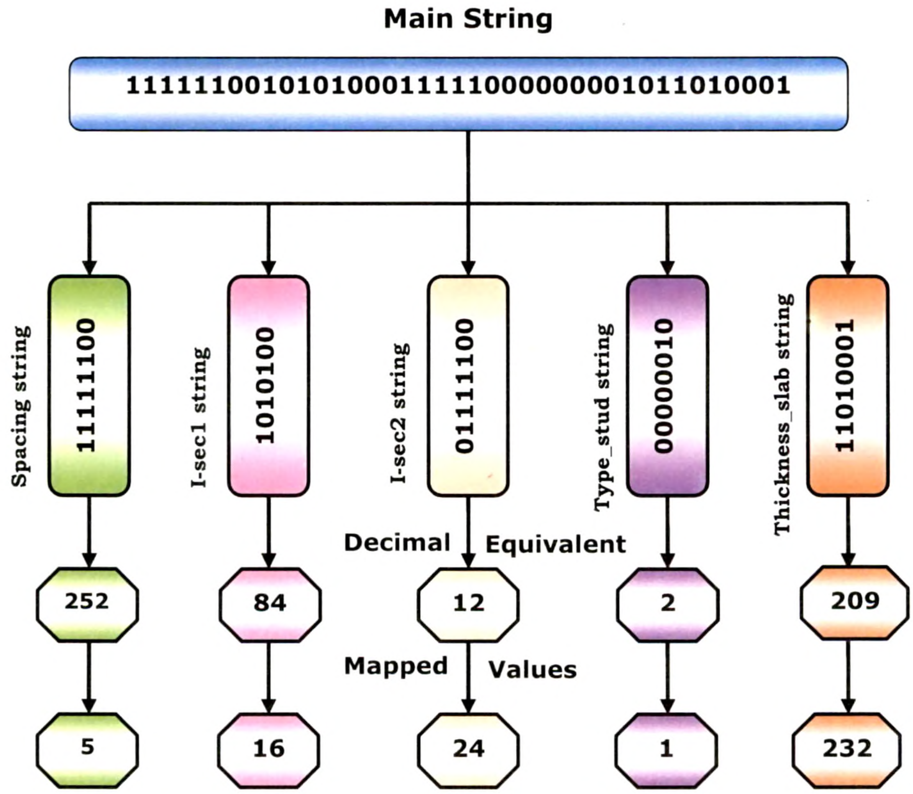

Fig. 8.1 Binary Representation of the Variables

Each potential solution is represented by a single binary string called the "Main String", which is then divided into five smaller strings each representing a design variable i.e. "spacing string", "I-sec1 string", "I-sec2 string", Type_stud string" and "Thickness_slab string". The binary strings are then converted into their decimal equivalents and are mapped between upper and lower bounds to obtain the values of the variables. The procedure is illustrated in **Fig. 8.1**.

8.2.2 CONSTRAINTS

Safety is of prime importance in any structural design. Thus, while optimizing any structural component there should be no compromise with safety. This requires fulfilment of certain condition and constraints, violation of which would make the structure unsafe. In the present case, a penalty approach is used for solutions that violate constraints. The objective function of these solutions is penalized suitably to prevent occurrence of this solution string in the further generations.

Plastic Moment

As discussed earlier the bending capacity of the section is evaluated based on "plastic" analysis principles in composite construction. For the safety of the structure, the design moment which is calculated from the design load should be less than the plastic moment of the section.

Reinforced concrete slab connected to rolled steel section through shear connectors is considered for the optimization. The ultimate strength of the composite beam is determined from its collapse load capacity. The moment capacity of such beams can be found by the method given in IS:11384-1985 [1]. In this code a parabolic stress distribution is assumed in the concrete slab. The equations used were explained in detail in the Chapter 5 and are presented here in **Table 8.1**. Reference can be made to **Fig. 8.2** for the notations used in IS: 11384-1985 [1].

Constraint:

$$M \leq Mp$$

$$\text{Penalty} : g1 = \max\,(M/M_p - 1,0)$$

where,

M = Design moment, and

M_p = Plastic moment.

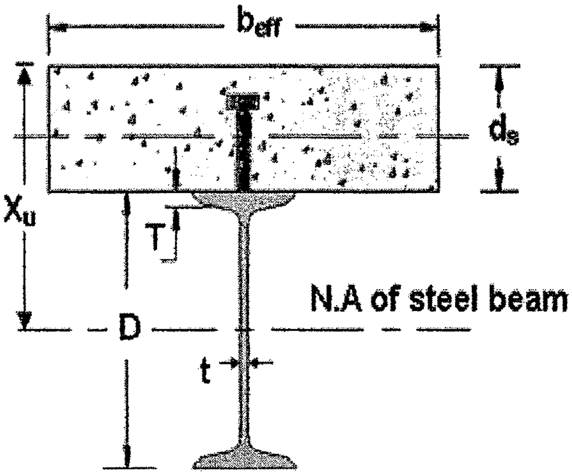

Fig. 8.2 Notation as per IS: 11384-1985

Table 8.1 Moment Capacity of Composite Section

Position of Plastic Neutral Axis	Value of x_u	Moment Capacity M_p
In Slab	$x_u = aA_f/b_{eff}$	$M_p = 0.87A_a f_y(d_c + 0.5d_s - 0.42x_u)$
In Steel Flange	$x_u = d_s + \frac{(aA_a - b_{eff}d_s)}{2Ba}$	$M_p = 0.87f_y[A_s(d_c + 0.08d_s) - bfxu - dsxu + 0.16ds$
In Web	$x_u = d_s + T + \frac{a(A_a - 2A_f) - b_{eff}d_s}{2at}$	$M_u = 0.87f_y A_s(d_c + 0.08d_s)$ $-2A_f(0.5t_f + 0.58d_s)$ $-2t_w(x_u - d_s - t_f)$ $(0.5x_u + 0.08d_s + 0.5t_f)$

A_f = Area of top flange of steel beam, A_s = Cross sectional area of steel beam, b_{eff} = Effective width of concrete slab, b_f = Width of top flange of steel section, d_c = Distance between centroids of concrete slabs and steel beam in a composite section, t_f = Thickness of the top flange of the steel section, x_u = Depth of neutral axis at ultimate limit state of flexure, M_u = Ultimate bending moment.

Permissible Deflection

The serviceability performance of composite beam is evaluated based on elastic section analysis principles. For the safety of the structure, actual deflection should be less than the permissible deflection.

Constraint: $\delta_d \leq \delta$

Penalty : $g2 = \max\,(\delta_d/\delta - 1{,}0)$

where, δ_d = Actual Deflection, and δ = Permissible Deflection (L/325).

Stress in Steel Flange

Assuming that full interaction exists between steel beam and concrete slab, the beam is checked for stresses in steel flange and concrete due to dead load and live load both.

Constraint:

For the stress in steel flange,

Constraint: $\sigma_{act,s} \leq \sigma_{per,s}$

Penalty : $g3 = \max\,(\frac{\sigma_{act,s}}{\sigma_{per,s}} - 1{,}0)$

For the stress in concrete,

Constraint: $\sigma_{act,s} \leq \sigma_{per,s}$

Penalty : $g4 = \max\,(\frac{\sigma_{act,c}}{\sigma_{per,c}} - 1{,}0)$

Where $\sigma_{per,c} = \frac{(f_{ck})_{cu}}{3}$.

Flexure Check for Concrete Slab

The slab is designed as one-way continuous slab. The coefficients given in IS: 456-2000 [96] are used in the analysis of the slab. Using these coefficients, moments at supports and spans are calculated. Required depth of slab is calculated from the maximum moment among all. The depth selected for the slab must satisfy the flexure check i.e. depth obtained from the solution string should be greater than the required depth.

$$d_{req} = \sqrt{(M_{max}/Q.b)} \quad \text{... (8.1)}$$

Constraint:

$d_{req.} \leq d_{pro.}$

Penalty : $g5 = \max\,(\frac{d_{req.}}{d_{Pro.}} - 1{,}0)$

Where, M_{max} = Maximum moment from span moments and support moments, Q = Material Constant, B = Unit width of slab, d_{req} = Depth required for safety in flexure, and d_{prov} = Provided depth of the slab.

8.2.3 OBJECTIVE FUNCTION AND FITNESS FUNCTION

In steel-concrete composite beam "cost" can be considered as the objective function that is to be minimized, as it is common parameter for both steel and concrete. The objective function for the composite beam can be formulated as

$$CS = (Cs_l * Wt_1) + (Cs_l * Wt_2) + (C_{st} * N) + C_{sl} \quad \text{... (8.2)}$$

where, CS = Total cost of beam and slab, Cs_l = Cost of steel in ₹/Kg, Wt_1 = Weight of intermediate beam in Kg, Wt_2= Weight of end beam in Kg, C_{st} = Cost of stud (shear connector) per number, N = No. of shear connectors, and C_{sl} = Cost of slab which include cost of concrete and cost of steel in slab.

<u>Fitness function</u>

$$F = \frac{1}{1 + P_c} \quad \text{... (8.3)}$$

where, F = Fitness function and P_c = Penalized cost.

8.3 GA BASED PROGRAM DEVELOPED FOR COMPOSITE BEAMS

As discussed earlier, Visual Basic is used for the development of GA based program for optimum design of composite beam. For the design purpose the limit state method is employed as per Indian standard [100]. Some of the design criteria where Indian code is silent, EC4 code is used. The GA based inbuilt functions like "Rnd function", "Mid, Left and Right function" etc. are used in the program. In addition, a number of subroutine and functions are developed. In the composite beam program, the channel sections given in the design tables of SP 6 [101] are also used along with Indian Standard I-sections. Here various screen shots of steps to use the program are depicted in **Figs. 8.3** to **8.8**.

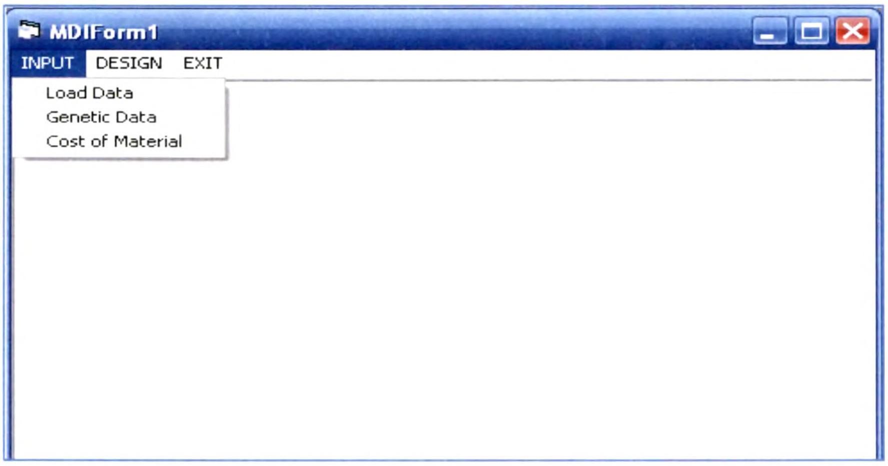

Fig. 8.3 Invoke the Start-up Screen

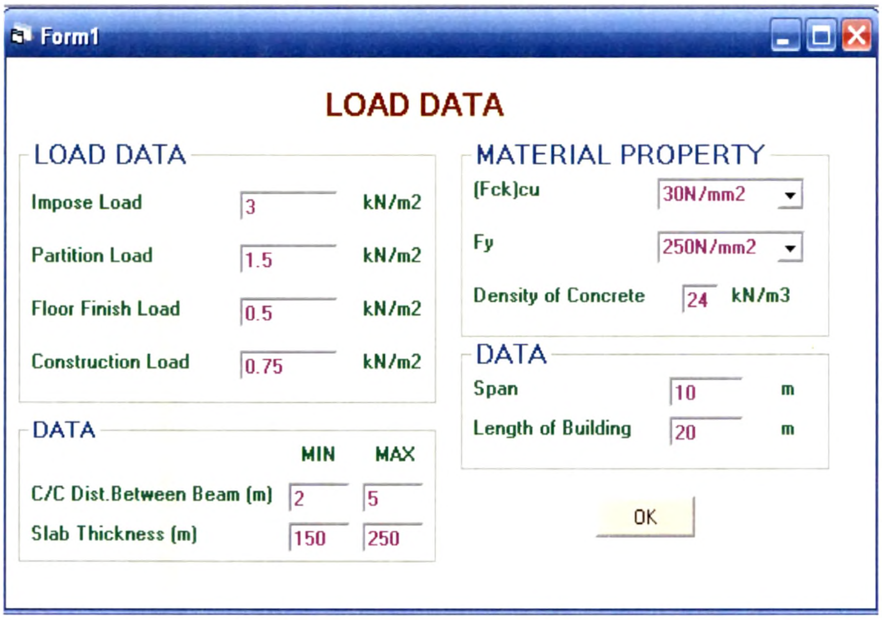

Fig. 8.4 Supply the Load Data

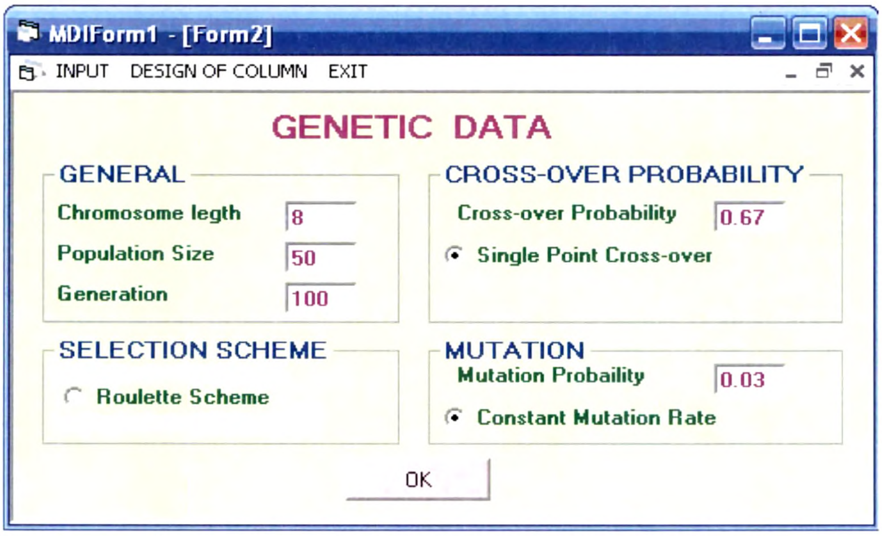

Fig. 8.5 Supply the Genetic Data

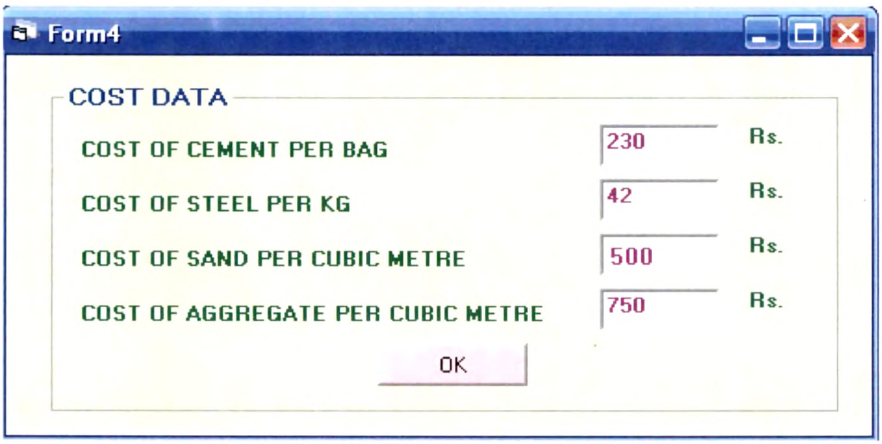

Fig. 8.6 Supply the Cost Data

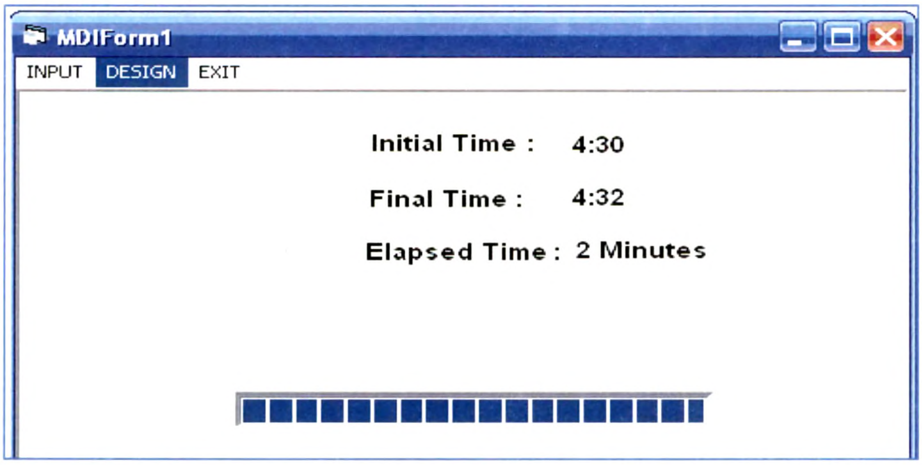

Fig. 8.7 Run the Program

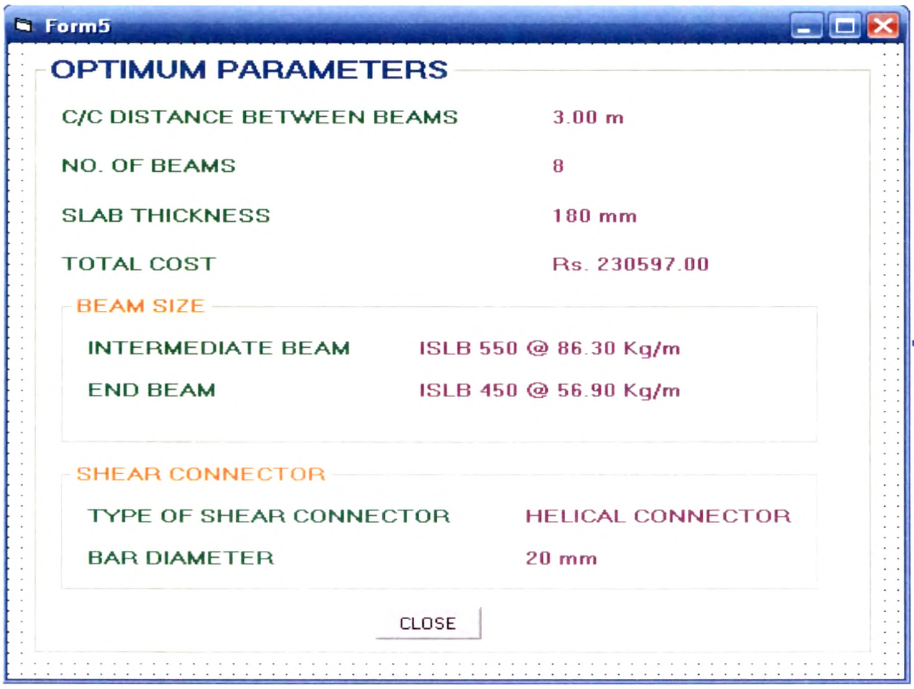

Fig. 8.8 View the Results

8.4 Design Example with Fixed Beam Spacing

Design of a simply supported steel-concrete composite beam with beam spacing of 3 m is considered here. The thickness of slab is 125 mm. The floor is to carry an imposed load of 3.0 kN/m^2, partition load of 1.5 kN/m^2 and a floor finish load of 0.5 kN/m^2.

8.4.1 Input

Load Data

i. Impose Load – 3 kN/m^2
ii. Partition Load – 1.5 kN/m^2
iii. Floor Finish Load – 0.5 kN/m^2

iv. Constructional Load – 0.75 kN/m^2
v. Beam Span – 10 m
vi. C/C Distance between Beam – 3 m
vii. Thickness of Slab – 125 mm
viii. Density of Concrete – 24 kN/m^3
ix. Yield Strength of Steel – 250 N/mm^2
x. Characteristic Compressive Strength of Concrete ($(F_{ck})_{cu}$) – 30 N/mm^2.

Genetic Data

i. Population Size – 20
ii. Generation – 50
iii. Chromosome Length – 8
iv. Type of Crossover – Single Point Crossover
v. Crossover Probability – 0.67
vi. Selection Scheme – Roulette Wheel Scheme
vii. Mutation Probability – 0.03.

Design Constraints

i. Plastic Moment (M_p) $=0.87A_a f_y(d_c + 0.5d_s - 0.42x_u)$
ii. Maximum Permissible Deflection (δ) $= L/325$
iii. Maximum Permissible Stress in Steel = f_y
iv. Maximum Permissible Stress in Concrete $=(f_{ck})_{cu}/3$

Objective Function

Cost of Beam + Cost of Shear Connector

8.4.2 OUTPUT

i. Size of I-Section – ISLB 450 @ 65.30 Kg/m
ii. Type of Shear Connector – Headed Stud of 12 mm x 62 mm.

The final solution is obtained after three GA runs. Graph of generations v/s fitness **(Fig. 8.9)** indicates that the final solution is obtained in 33rd generation after which no further improvement is observed.

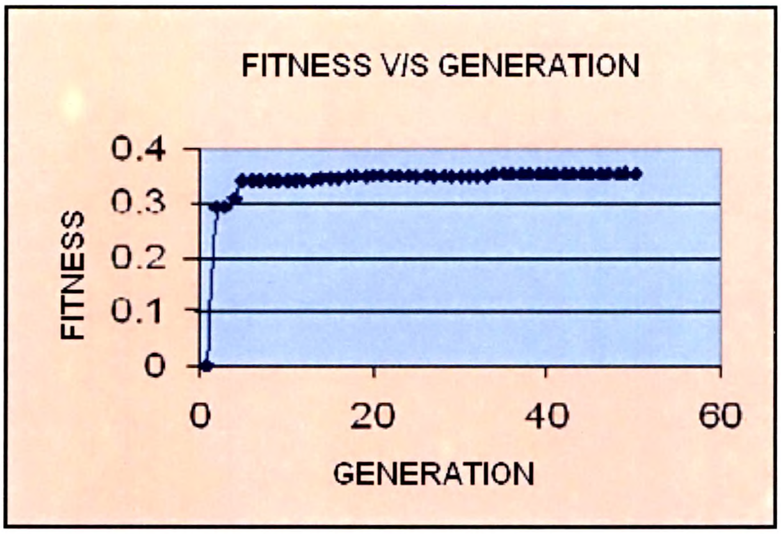

Fig. 8.9 Generation History (Fixed Beam Spacing)

8.5 Variable Beam Spacing Without RCC Slab Example

Design of a simply supported steel-concrete composite beams for a building with plan area of 10 m x 20 m (**Fig.8.10**) is taken up here. The floor has to carry an imposed load of 3.0 kN/m^2, partition load of 1.5 kN/m^2 and a floor finish load of 0.5 kN/m^2.

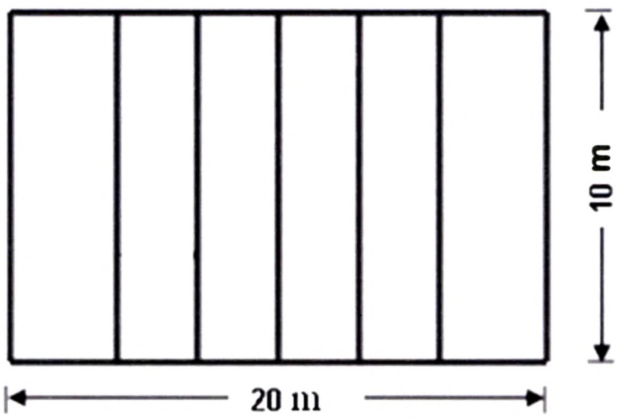

Fig. 8.10 Plan Area of Building

8.5.1 Input

Load Data

i. Impose Load – 3 kN/m^2
ii. Partition Load – 1.5 kN/m^2
iii. Floor Finish Load – 0.5 kN/m^2
iv. Constructional Load – 0.75 kN/m^2
v. Plan area of Building – 20 m x 10 m

vi. Thickness of Slab – 125 mm

vii. Density of Concrete – 24 kN/m^3

viii. Yield Strength of Steel – 250 N/mm^2

ix. Characteristic Compressive Strength of Concrete $((F_{ck})_{cu})$ – 30 N/mm^2

x. Minimum and Maximum Value of Beam Spacing – (2 m - 5 m)

Genetic Data

i. Population Size – 20

ii. Generation – 50

iii. Chromosome Length – 8

iv. Type of Crossover – Single Point Crossover

v. Crossover Probability – 0.67

vi. Selection Scheme – Roulette Wheel Scheme

vii. Mutation Probability – 0.03

Design Constraints

i. Plastic Moment (M_p) = $0.87A_a f_y(d_c + 0.5d_s = 0.42x_u)$

ii. Maximum Permissible Deflection (δ) = $L/325$

iii. Maximum Permissible Stress in Steel = f_y

iv. Maximum Permissible Stress in Concrete = $(f_{ck})_{cu}/3$

Objective Function

Cost of Beam + Cost of Shear Connector

8.5.2 OUTPUT

i. C/C Distance between Beams – 5 m

ii. Size of Intermediate Beams – ISLB 500 @ 75.00 Kg/m

iii. Size of End Beams – ISLB 500 @ 75.00 Kg/m

iv. Type of Shear Connector – Channel of size 100 mm x 50 mm x 9.2 kg x 150 mm

The final solution is obtained after three GA runs. Graph of generation v/s fitness is shown in **(Fig. 8.11)**. No further improvement in solution is observed after 41 generations.

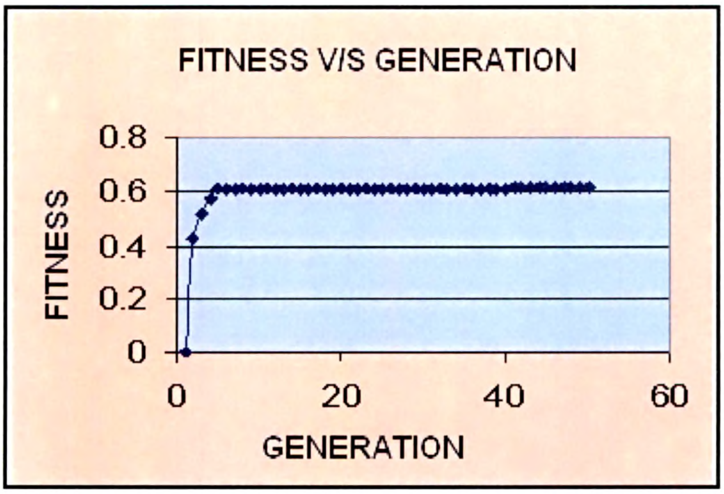

Fig. 8.11 Generation History (Without RCC Slab)

Comparison between the optimum solutions for both cases (fixed and variable beam spacings) is presented in **Table 8.2.**

Table 8.2 Comparison between Solutions

Items For 10 x 20 m Plan Area	With Fixed Beam Spacing	With Variable Beam Spacing
C/C Distance between beams	3 m	5 m
No. of Beams	8 Nos.	5 Nos.
Beam Size	ISLB 450 @ 65.3 kg/m	ISLB 500 @ 75 kg/m
Total Weight of Beams	522.4 kg/m	375 kg/m

8.6 Variable Beam Spacing With RCC Slab Example

Next, design of a simply supported steel-concrete composite beam with plan area of 10 m x 20 m is considered. The floor has to carry an imposed load of 3.0 kN/m^2, partition load of 1.5 kN/m^2 and a floor finish load of 0.5 kN/m^2.

8.6.1 Input

Load Data

i. Impose Load – 3 kN/m^2
ii. Partition Load – 1.5 kN/m^2

iii. Floor Finish Load – 0.5 kN/m^2
iv. Constructional Load – 0.75 kN/m^2
v. Plan area of Building – 20 m x 10 m
vi. Thickness of Slab – 125 mm
vii. Density of Concrete – 24 kN/m^3
viii. Yield Strength of Steel – 250 N/mm^2
ix. Characteristic Compressive Strength of Concrete ($(f_{ck})_{cu}$) – 30 N/mm^2
x. Minimum and Maximum Value of Beam Spacing – (2 m - 5 m)

Genetic Data

i. Population Size – 20
ii. Generation – 50
iii. Chromosome Length – 8
iv. Type of Crossover – Single Point Crossover
v. Crossover Probability – 0.67
vi. Selection Scheme – Roulette Wheel Scheme
vii. Mutation Probability – 0.03

Design Constraints

i. Plastic Moment (M_p) = $0.87A_a f_y(d_c + 0.5d_s = 0.42x_u)$
ii. Maximum Permissible Deflection (δ) = $L/325$
iii. Maximum Permissible Stress in Steel = f_y
iv. Maximum Permissible Stress in Concrete = $(f_{ck})_{cu}/3$

Objective Function

Cost of Beam + Cost of Shear Connector + Cost of Slab

8.6.2 Output

i. C/C distance between beams – 3m
ii. Intermediate beam – ISWB 300 @ 48.10 Kg/m
iii. End beam - ISWB 250 @ 40.9 Kg/m
iv. Type of stud – Headed stud of size 16 mm x 75 mm
v. Slab thickness – 185 mm
vi. Total cost – ₹ 22,49,470

In this case the final solution is obtained after five GA runs. Graph of generation v/s fitness (**Fig. 8.12**) indicates that the maximum fitness is 0.51. The cost is minimum at 45th generation after which no further improvement is observed.

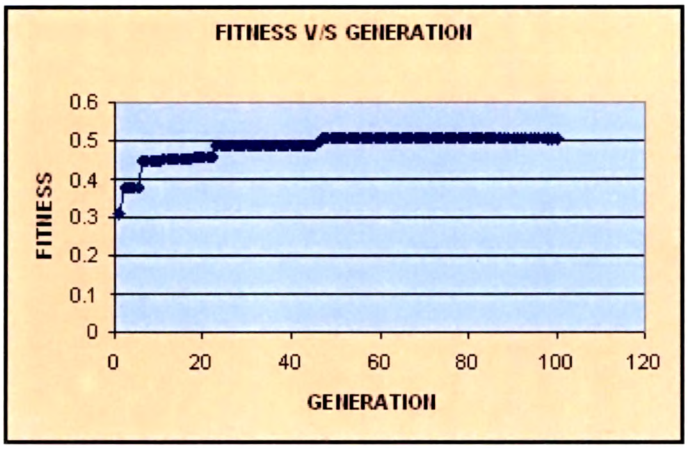

Fig. 8.12 Generation versus Fitness Considering RCC Slab

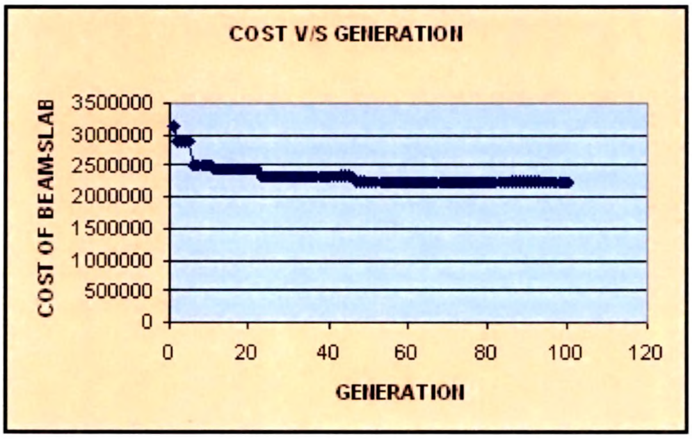

Fig. 8.13 Generation versus Cost Considering RCC Slab

8.7 Optimum Design Parameters for Composite Column

8.7.1 Design Variables and Coding

For the optimum design of the steel-concrete composite column, the first variable is the type of column. As discussed earlier, there are mainly following two types of composite columns:

(i) Concrete encased steel columns (rolled steel section)

(ii) Concrete filled inside steel tubes (square, rectangular or circular hollow section)

The other variables based on the selection of the first variables are shown in the **Fig. 8.14**. The idea is to arrive at such a combination of these variable components that the overall cost is minimum and at the same time, the composite column is safe from structural design point of view.

The binary string representation scheme is used for all the variables. The user can select any string length depending on the accuracy required. Each solution is represented by a single binary string called the "Main String", which is then divided into smaller strings each representing a design variable.

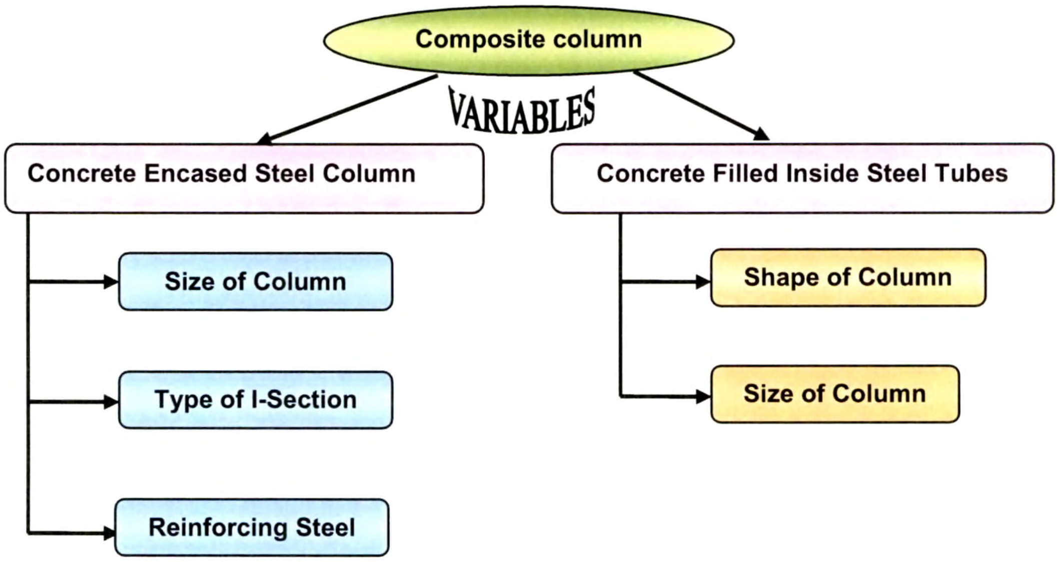

Fig. 8.14 Composite Column Variables

8.7.2 CONSTRAINTS

These are special conditions which should not be violated for a safe and economical design. In the present case, a penalty approach is used for solutions that violate constraints. The objective function of these solutions is penalized suitably to prevent occurrence of this solution string in the further generations. Following are the constraints for the composite column optimization that are imposed on the string before evaluating the fitness function.

Resistance of member to axial compression

$$P < \chi P_p \qquad \text{... (8.4)}$$

where, P_p = Plastic resistance to compression of the section, and χ = Reduction factor due to column buckling which is a function of the non-dimensional slenderness of the composite column.

The χ value mainly depends on the type of the steel sections and the axis of bending, and can be calculated by,

$$\chi = \frac{1}{\emptyset + \sqrt{\emptyset^2 - \bar{\lambda}^2}} \; but \; \chi \leq 1.0 \quad \text{... (8.5)}$$

$$where \; \emptyset = 0.5\left[1 + \alpha\left(\bar{\lambda} - 0.2\right) + \bar{\lambda}^2\right]$$

The factor α allows for different levels of imperfections, residual stresses in the columns and an eccentricity of load application. No further provision is necessary for composite column.

Resistance of member to uni-axial bending

Composite column is checked with the relevant non-dimensional slenderness, in the plane of the applied moment. The design is adequate when,

$$M \leq 0.9\mu M_p \quad \text{... (8.6)}$$

where, M is Design bending moment, μ is Moment resistance ratio obtained from the interaction curve and M_p is Plastic moment resistance of the composite cross-section.

Reduction factor of 0.9 is applied to allow for the simplification in this approach. μ can be obtained from the interaction curve or may be evaluated from the Eqs. 6.33 and 6.34 given in article 6.5.5.

Resistance of member to bi-axial bending [7]

After checking the axial resistance of the column, the moment resistance of composite column is checked in the presence of applied moment about each axis with the relevant non-dimensional slenderness of the composite column.

The design is adequate when

$$\frac{M_x}{\mu_x M_{px}} + \frac{M_y}{\mu_y M_{py}} \leq 1.0 \quad \text{... (8.7)}$$

8.7.3 OBJECTIVE FUNCTION AND FITNESS FUNCTION

Objective function

In steel-concrete composite column, "cost" can be considered as the objective function that is to be minimized as it is common parameter for both steel and concrete.

The total cost in case of concrete encased steel column,

$$CS = (CS_1) + (CS_2 \times Wt_1) + (CS_2 \times Wt_2) + (CS_3) \quad \text{... (8.8)}$$

Where, CS is total cost of composite column, CS_1 is cost of concrete, CS_2 is unit cost of steel, Wt_1 is Weight of Bar, Wt_2 is Weight of I-section/m, and CS_3 is Cost of Formwork.

Fitness function

$$F = \frac{1}{1 + P_c} \qquad \text{... (8.9)}$$

$$P_c = (1 + KC) \times CS \qquad \text{... (8.10)}$$

where, F is Fitness Function, P_c = Penalized Cost, K = Penalty Perameter, and C = Total Constraint Violation.

8.8 GA Based Program Developed For Composite Columns

The program of optimum design of composite column is developed in Visual Basic. In this program, one has to select first the type of column. Depending on the type of column the solution string is developed. For concrete filled tubular column the total length of string is 8. In this case, the string returns an integer value which represents the section number from a list of discrete column sections stored in a data base. Here, the design tables given in EC 4 [7] are used for the design of concrete filled tubular sections. For concrete encased steel column, the length of the solution string is 24. Here size of RCC column is treated as continuous and type of steel section is considered as discrete variable. The optimization problem involving discrete as well as continuous design variables is very efficiently handled in the program wherein following three main subroutines/functions are developed:

(i) **Sub Genetic ( )** to generate the initial set of population randomly and to transfer it to the subroutine *analysis* for fitness calculation.

(ii) **Sub Breeding ( )** develops new generations by applying GA operators on previous generations. For this, it calls various other subroutines to carry out analysis and calculate penalty parameters, objective function and fitness function.

(iii) **Sub Analysis ( )** calculates the plastic resistance of the section and evaluates the penalty parameters to find out the fitness function.

Steps to solve a problem are given here (**Figs. 8.15** to **8.20**) in the form of screen shots.

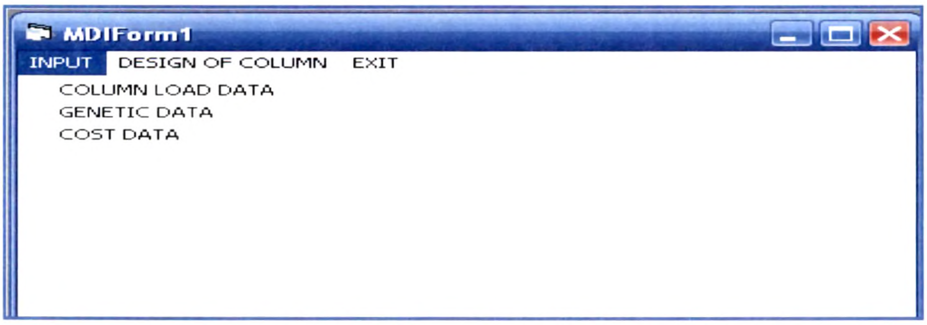

Fig. 8.15 Invoke the Start-up Screen

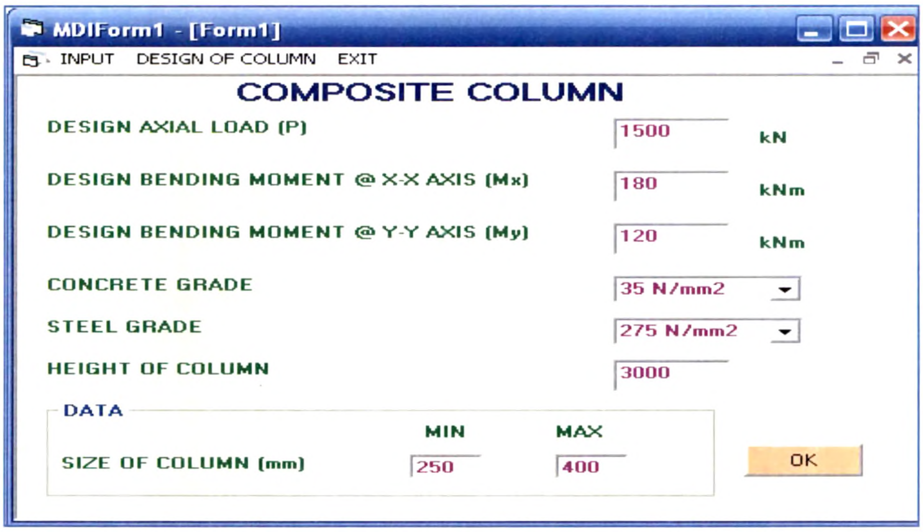

Fig. 8.16 Supply Load Data and Material Data

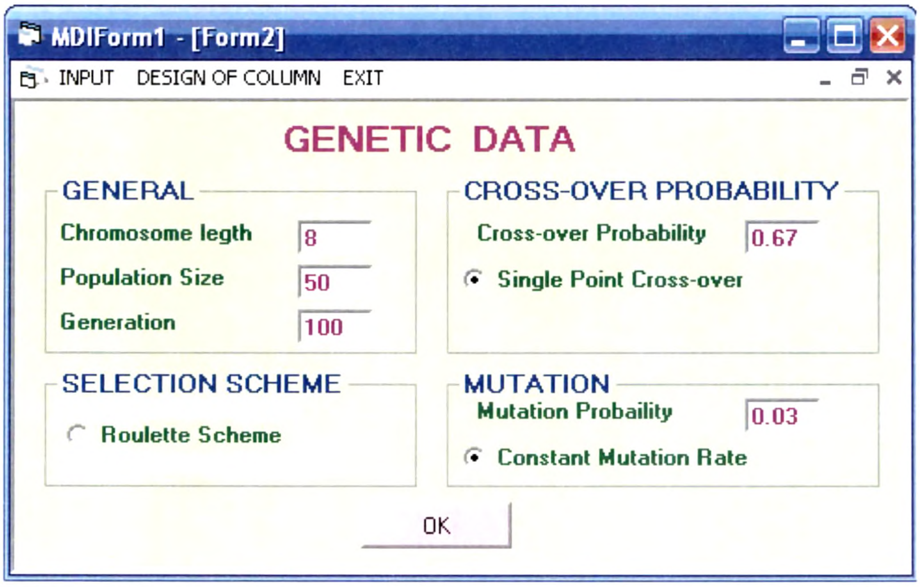

Fig. 8.17 Enter Genetic Data

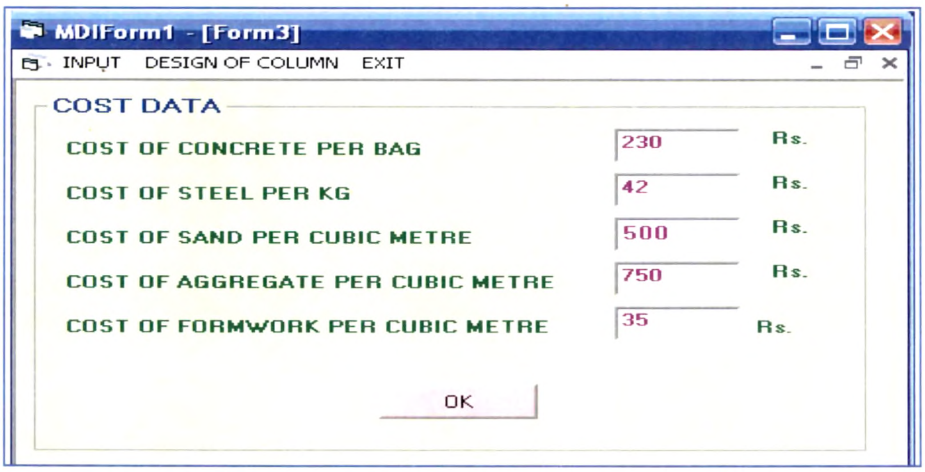

Fig. 8.18 Input Unit Costs of Materials

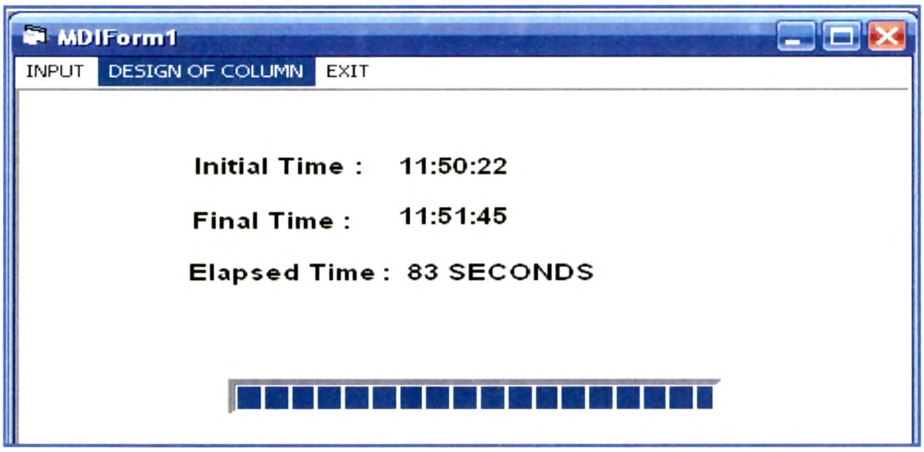

Fig. 8.19 Run the Program

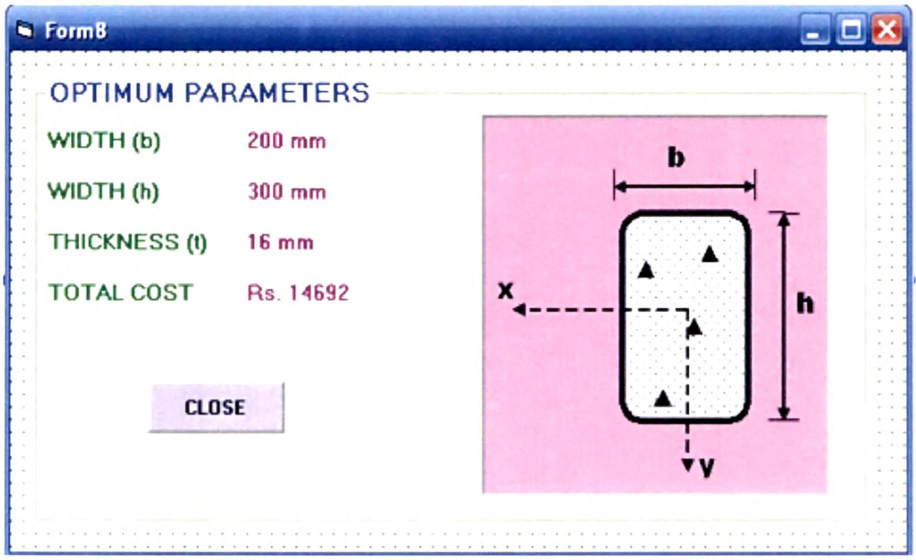

Fig. 8.20 View the Output

8.9 Composite Column Design Examples

8.9.1 Axially Loaded Column Example

Load Data

i. Axial Load – 4000 kN

ii. Concrete Grade – C35

iii. Steel Grade- S275

iv. Height of Column – 3 m

v. Minimum and Maximum Range of Size of Column – (250 mm - 400 mm)

Genetic Data

i. Population Size – 50

ii. Maximum No. of Generations – 100

iii. Chromosome Length – 8

iv. Type of Crossover – Single Point Crossover

v. Crossover Probability – 0.67

vi. Selection Scheme – Roulette Wheel Scheme

vii. Mutation Probability – 0.03

Cost Data

i. Unit Cost of Cement – ₹ 230 /Bag

ii. Unit Cost of Steel – ₹ 42 /Kg

iii. Unit Cost of Sand – ₹ 500 /m^3

iv. Unit Cost of Aggregate – ₹ 750 /m^3

v. Unit Cost of Formwork – ₹ 35 /m^2

Design Constraints

i. Resistance of members to axial compression, $P < \chi\ P_p$

ii. Minimum area reinforcement = 0.5 % of gross area

Objective Function

i. Concrete filled tubular column,

Total Cost = Cost of Concrete + Cost of Casting

ii. Concrete encased steel column,

Total Cost = Cost of Concrete + Cost of Bars + Cost of I-sec + Cost of Formwork

Output

Type of Composite Column – Circular tubular filled column

Diameter of Composite Column –244.5 mm

Thickness of Tube – 10 mm

Total Cost of Column – ₹ 7282

The final solution is obtained after second GA run. Graph of generation versus cost of column (**Fig. 8.21**) indicates that the final solution is obtained in 53^{rd} generation after which no further improvement is observed.

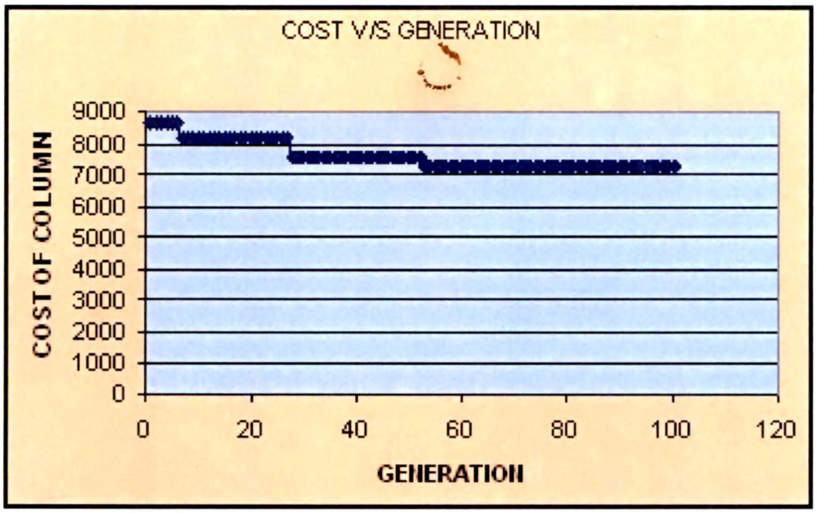

Fig. 8.21 Generation History (Axially Loaded Column)

8.9.2 Uni-axially Loaded Column Example

Load Data

i. Axial Load – 1500 kN
ii. Bending Moment About X-axis – 150 kNm
iii. Concrete Grade – C35
iv. Steel Grade- S275
v. Height of Column – 3 m
vi. Minimum and Maximum Range of Size of Column – (250 mm - 400 mm)

Genetic Data

i. Population Size – 50
ii. Maximum No. of Generations – 100
iii. Chromosome Length – 8
iv. Type of Crossover – Single Point Crossover
v. Crossover Probability – 0.69
vi. Selection Scheme – Roulette Wheel Scheme
vii. Mutation Probability – 0.03

Cost Data

i. Unit Cost of Cement – ₹ 230 /Bag
ii. Unit Cost of Steel – ₹ 42 /Kg
iii. Unit Cost of Sand – ₹ 850 /m^3
iv. Unit Cost of Aggregate – ₹ 750 /m^3
v. Unit Cost of Formwork– ₹ 35 /m^2

Design Constraints

i. Resistance of members to axial compression, $P < \chi\ P_p$

ii. Resistance of member under uni-axial bending, $M \leq 0.9\, \mu\, M_p$

iii. Minimum area reinforcement = 0.5 % of gross area

Objective Function

i. Concrete filled tubular column,

Total Cost = Cost of concrete + Cost of Casing

ii. Concrete encased steel column,

Total Cost = Cost of Concrete + Cost of Bars + Cost of I-sec + Cost of Formwork

Output

i. Type of Composite Column – Rectangular tubular filled column

ii. Size of Composite Column – 300 mm X 250 mm

iii. Thickness of Tube – 6.3 mm

iv. Total Cost of Column – ₹ 6678

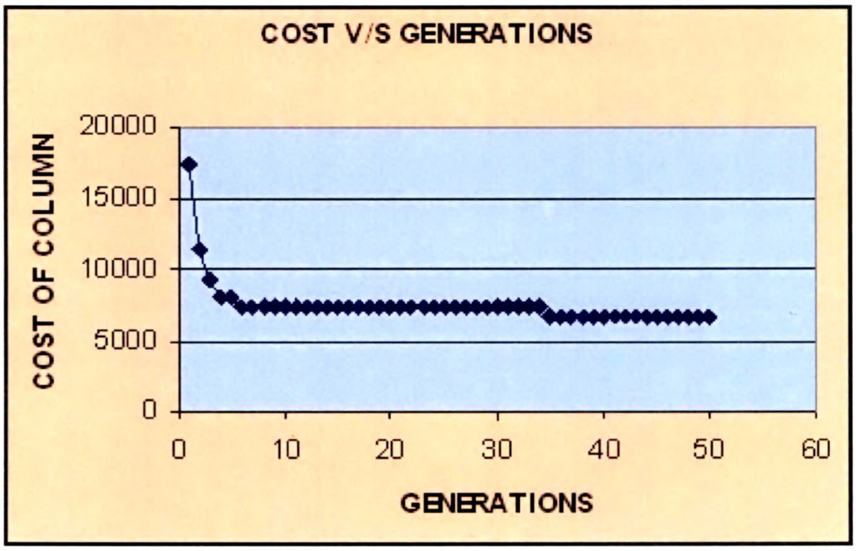

Fig. 8.22 Generation History (Uni-Axially Loaded Column)

The final solution is obtained after 3 GA runs. Graph of generation versus cost of column shown in **Fig. 8.22** indicates that the final solution is obtained in 34th generation after which no improvement could be seen.

8.9.3 Bi-Axially Loaded Column Example

Load data

i. Axial Load – 2000 kN
ii. Bending Moment About X-axis – 180 kNm
iii. Bending Moment About Y-axis – 120 kNm
iv. Concrete Grade – C45
v. Steel Grade- S275
vi. Height of Column – 3 m
vii. Minimum and Maximum Range of Size of Column – (250 mm - 400 mm)

Genetic Data

i. Population Size – 50
ii. Maximum No. of Generations – 70
iii. Chromosome Length – 8
iv. Type of Crossover – Single Point Crossover
v. Crossover Probability – 0.70
vi. Selection Scheme – Roulette Wheel Scheme
vii. Mutation Probability – 0.03

Cost Data

i. Unit Cost of Cement - 230 ₹/Bag
ii. Unit Cost of Steel - 42 ₹/Kg
iii. Unit Cost of Sand - 850 ₹/m^3
iv. Unit Cost of Aggregate - 750 ₹/ m^3
v. Unit Cost of Formwork- 35 ₹/m^2

Design Constraints

i. Resistance of members to axial compression, $P < \chi P_p$
ii. Resistance of member under uni-axial bending, $M \leq 0.9\mu M_p$
iii. Resistance of member under bi-axial bending, $M_x/\mu_x M_{px} + M_y/\mu_y M_{py}$
iv. Minimum area of reinforcement = 0.5 % of gross area

Objective Function

i. Concrete filled tubular column,

   Total Cost = Cost of Concrete + Cost of Casting

ii. Concrete encased steel column,

Total Cost = Cost of Concrete + Cost of Bars + Cost of I-sec + Cost of Formwork

Output

i. Type of composite column – Rectangular tubular filled column
ii. Diameter of composite column – $350\,\text{mm} \times 250\,\text{mm}$
iii. Thickness of tube - $8\,\text{mm}$
iv. Total cost of column – ₹ 9210

In this case the final solution is obtained after two GA runs. Graph of generation versus cost of column depicted in **Fig. 8.23** indicates that the cost is minimum at 44^{th} generation after which no further improvement is observed.

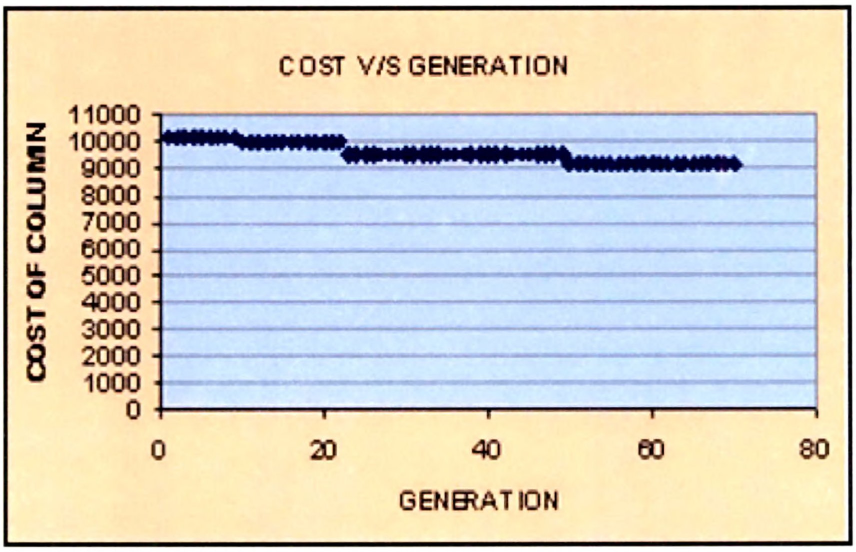

Fig. 8.23 Generation History (Bi-Axially Loaded Column)

From the results obtained for the above three cases it is clear that the optimum section of column is concrete filled tubular section. The presence of concrete inside steel tube increases the bearing capacity of column.