9. GA Based Optimum Design of Composite Frames

9.1 General Remarks

In the present chapter, GA based optimal design of steel-concrete composite plane frame is addressed with the aim of minimizing the overall cost of the frame. In cost optimization of composite plane frames, optimum cross sectional shape and dimensions of composite frame members are calculated to minimize the cost of composite frames subject to various functional and behavioural constraints. The design is carried out using recommendations of IS: 11834 [1], EC4 [7] and BS: 5950 [93] and Indian and UK steel section tables. Stiffness member approach is employed for the analysis of plane frame. Optimum design is based on the limit state design philosophy. Parametric study is also carried out using various types of column section. The database is developed for various composite sections, such that the program automatically finds the suitable section. Provision is made to handle symmetrical and unsymmetrical composite plane frames. The software is developed to minimize the overall cost of the structure while satisfying moment, shear force, lateral torsional buckling and axial compression constraints. For the development of GA based optimization program, Visual Basic.Net environment is selected. An attempt is made to make the program user friendly with pre-processing and post- processing facilities.

9.2 Size Optimization Problem Formulation

Problem of size optimization of steel-concrete composite plane frame can be formulated as:

Find, (x)

To minimize, $C_T(x) = C_S + C_C$

Subject to, $g_i(x) \leq 0$ ... (9.1)

Where $C_T(x)$ is the total cost of composite plane frame, C_S is the cost of steel used in plane frame, C_C is the cost of concrete slab, x is the vector of design variables and $g_i(x)$ is the i^{th} constraint function.

9.2.1 DESIGN VARIABLES

A variable is used for composite beam which contains the details of steel section property such as width of flange, depth of section, c/s area of section etc. Another design variable is used for both the types of composite columns which contains column size and steel section detail. A variable when decoded gives a unique integer number which helps in extracting the section properties from SQL server database.

9.2.2 DESIGN CONSTRAINTS

Constraints are formed by setting relationship between function of design variables with the resource values. Constraints in the optimization process prevent the search to enter the infeasible region.

9.2.2.1 Constraints for Composite Beam

i. **Moment constraint:** In ultimate limit state design the moment capacity of the composite beams should exceed the total factored applied moment. Thus,

$$M_n \leq M_{pn} \qquad \text{... (9.2)}$$

$$M_p \leq M_{pp} \qquad \text{... (9.3)}$$

$$M_{pn} = P_y \times Z_{px} + \frac{A_s f_{sk}}{\gamma_s}\left(\frac{D}{2} + a\right) - \left(\frac{A_s f_{sk}}{\gamma_s}\right)^2 / 4t_w f_y / \gamma_a \qquad \text{... (9.4)}$$

$$M_{pp} = \frac{A_a f_y}{\gamma_a}\left(\frac{D}{2} + h_c - \frac{X_u}{2}\right) \qquad \text{... (9.5)}$$

Where, M_{pn} and M_{pp} are negative and positive plastic moment of resistance of the section of the composite beam respectively. M_n is factored design negative moment and M_p is factored design positive moment. Corresponding functions for the constraint are;

$$g_1(x) = \text{Max}\,(M_n / M_{Pn} - 1, 0) \qquad \text{... (9.6)}$$

$$g_2(x) = \text{Max}\,(M_p / M_{Pp} - 1, 0) \qquad \text{... (9.7)}$$

ii. **Shear force constraint:** This constraint ensures that the shear capacity of the frame member is more than the actual load induced in the member. The constraint is:

$$V \leq V_P \qquad \text{... (9.8)}$$

$$V_p = 0.6 \times D \times t \times \frac{f_y}{\gamma_a} \qquad \text{... (9.9)}$$

where, V is the factored shear force and V_p is the plastic shear capacity of beam. The associated constraint function is:

$g_3(x) = Max\ (V / V_p - 1, 0)$ ... (9.10)

iii. **Lateral torsional buckling constraint:** This constraint ensures that the capacity of frame member is more than the actual moment induced in the member. The constraint for member is:

$M \leq M_b$ ... (9.11)

$$M_b = x_{LT}\beta_W Z_{px}\frac{f_y}{\gamma_m} \quad ...(9.12)$$

where, M is the negative moment at construction stage and M_b is the buckling resistance moment of a unrestrained beam. The associated constraint function is:

$g_4(x) = M_{ax}\ (M / M_b - 1, 0)$. ...(9.13)

9.2.2.2 Constraints for Composite Column

i. **Axial compression constraint:** In ultimate limit state design, the compression capacity of the composite columns should exceed the total factored applied axial compression force. The corresponding constraint function is:

$P < \chi\ P_p$ ... (9.14)

$P_p = A_a{*}f_y / \gamma_a + \alpha_c {*}A_c {*}(f_{ck})_{cy} / \gamma_c + A_s {*} f_{sk} / \gamma_s$ ... (9.15)

where, P is design axial force, χ is a reduction factor for column buckling and P_p is a plastic resistance to compression of the cross section.

The constraint function can be written as;

$g_1(x) = M_{ax}\ (P / (\chi\ P_p) - 1, 0)$ ... (9.16)

ii. **Moment constraint:** In ultimate limit state design the moment capacity of the composite column should exceed the total factored applied moment and thus the constraints is:

$M \leq 0.9\ \mu\ M_p$ ... (9.17)

$M_p = p_y\ (Z_{pa}\text{-}Z_{pan}) + 0.5\ p_{ck}\ (Z_{pc}\text{-}Z_{pcn}) + p_{sk}\ (Z_{ps}\text{-}Z_{psn})$ ... (9.18)

where, μ = moment resistance ratio, M is the design bending moment and M_p is plastic moment resistance of the composite column. The design against combined compression and uni-axial bending is adequate if Eq. 9.17 is satisfied.

The constraint function for GA based search can be written as:

$g_2(x) = M_{ax}\ (M / (0.9\ \mu\ M_p) - 1, 0)$. ... (9.19)

9.3 OPTIMUM DESIGN ALGORITHM FOR COMPOSITE FRAMES

Optimum design algorithm for steel concrete composite frames consists of the following steps:

1. Initial population of trial design solutions is constructed randomly. The solutions are generated in binary coding.
2. The binary codes for the design variables of each individual solution are decoded to find the integer number which is assigned as an index to a composite section in the available design table list. The analysis by member stiffness approach is carried out by extracting the section properties of members of steel concrete composite frame. The analysis results are used for design and to evaluate constraint functions.
3. The fitness value for each individual is calculated using [10],

   $$F(x) = 1/(1+ O_p(x)) \qquad \text{... (9.20)}$$

   where, $O_p(x)$ = penalized objective function which is given by

   $$O_p(x) = (1+K^* C)\, O(x) \qquad \text{... (9.21)}$$

   where, O(x) = objective function which is the total cost of the frame, K = penalty factor, and C = cumulative value of constraint violation. The fitnesses thus obtained are scaled to get scaled fitness.
4. Depending on scaled fitnesses, individuals are copied into the mating pool.
5. The individuals are coupled randomly and the reproduction operator is applied. Using one or two point cross sites, offsprings are generated and the new population is obtained.
6. Mutation is applied to the new population with a probability value between 0.01 to 0.07.
7. The initial population is replaced by the new population and steps 1 to 6 are repeated until a pre-determined number of generations are reached or until the same individual dominates the new population. The fittest design among generations is considered to be the near-optimum design.

To ensure that the best individual of each generation is not destroyed from one design cycle to another, an 'elitist' strategy is followed in the design algorithm. At each generation, among the individuals which satisfy all the design constraints, the one with minimum weight is stored and compared with a similar individual of the next generation. If the new one is heavier than the old one, then there is a loss of good genetic material. This situation is rectified by replacing the individual having the lowest fitness of the current generation with the fittest individual of previous generation. In this way the loss of good individuals during the development of new generations is prevented.

9.4 Design Example of a 1 x 2 Storey Composite Frame

A one bay two storey composite portal frame with fixed supports is undertaken here to illustrate the application of the developed software. The frame is subjected to combined gravity and lateral loads as shown in the **Fig. 9.1.**

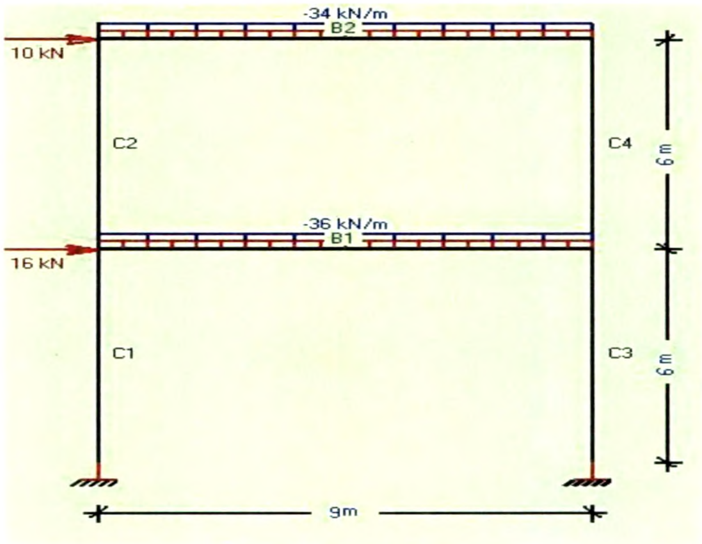


Fig 9.1 Loading and Geometry of Composite Plane Frame

- **Geometry data**
  - Number of bays in horizontal direction = 1
  - Number of storeys = 2
  - Story height = 6 m
  - Span of beam = 9 m
  - Slab thickness = 130 mm
- **Material data**
  - Grade of concrete = M30
  - Grade of steel = Fe 250
  - Grade of reinforcement = Fe 415

- **Unit cost data**
  - Unit cost of steel = 32 ₹ / kg.
  - Unit cost of concrete = 3000 ₹ /m^3.
- **Genetic data**
  - String length = 9
  - Population size = 50
  - Generation = 50
  - Type of crossover = Single point crossover
  - Crossover probability = 0.95
  - Selection scheme = Roulette Wheel Scheme
  - Mutation probability = 0.05 with variable mutation.
- **Design Constraints for beam**
  - Moment constraint: $M_n \leq M_{pn}$; $M_p \leq M_{pp}$
  - Shear force constraint: $V \leq V_P$
  - Lateral torsional buckling constraint: $M \leq M_b$
- **Design constraints for column**
  - Axial compression constraint: $P < \chi\ P_p$
  - Moment constraint: $M \leq 0.9\ \mu\ M_p$
- **Objective function**

  Total cost of composite frame = Cost of beam + Cost of connector + Cost of column.

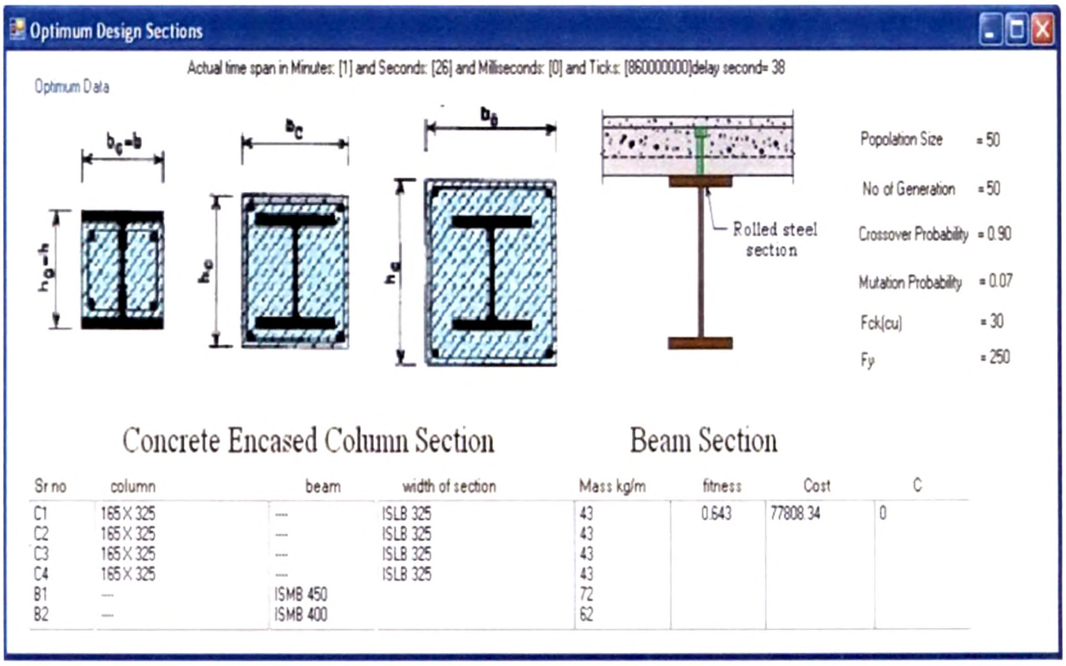


Fig. 9.2 Output of Optimum Design Program

The results obtained through developed program can be summarized as follows **(Fig. 9.2)**:

1. **Type of beam:** Structural steel beam with headed stud shear connector
2. **Size of beam :** (B1) –ISLB 450 @ 72.00 Kg/m
   (B2) –ISLB 400 @ 62.00 Kg/m
3. **Type of shear connector**:– Headed stud of 12 mm dia. x 100 mm height
4. **Type of column:** Partial encased composite column
5. **Size of column:** (C1) – ISLB 325 @ 43.00 Kg/m
   (C2) – ISLB 325 @ 43.00 Kg/m
   (C3) – ISLB 325 @ 43.00 Kg/m
   (C4) – ISLB 325 @ 43.00 Kg/m

The final solution is obtained after 7 GA runs. The problem of minimization of cost is transformed into maximization of fitness. GA is employed to maximize the fitness. Variation of fitness with generation clearly displays convergence towards optimum solution as shown in **Fig 9.3** whereas **Fig. 9.4** depicts reduction in cost with the development of new generation. The final solution is obtained in 40th generation after which no further improvement of fitness is observed.

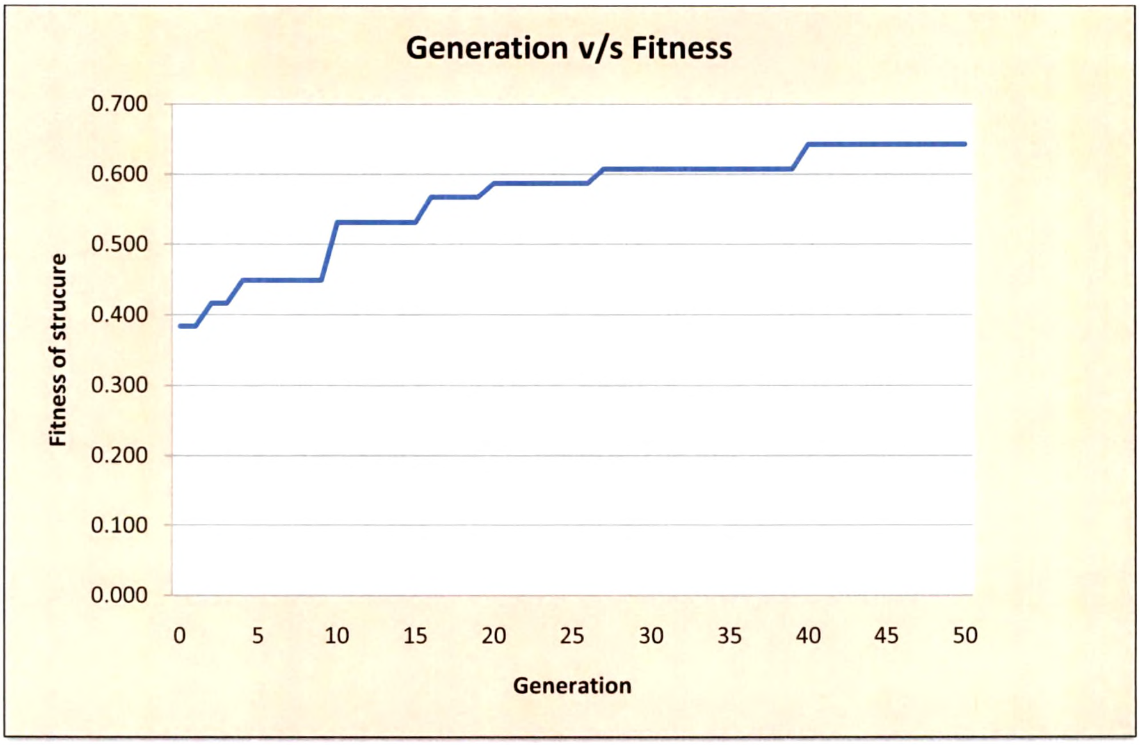


Fig. 9.3 Generation versus Fitness

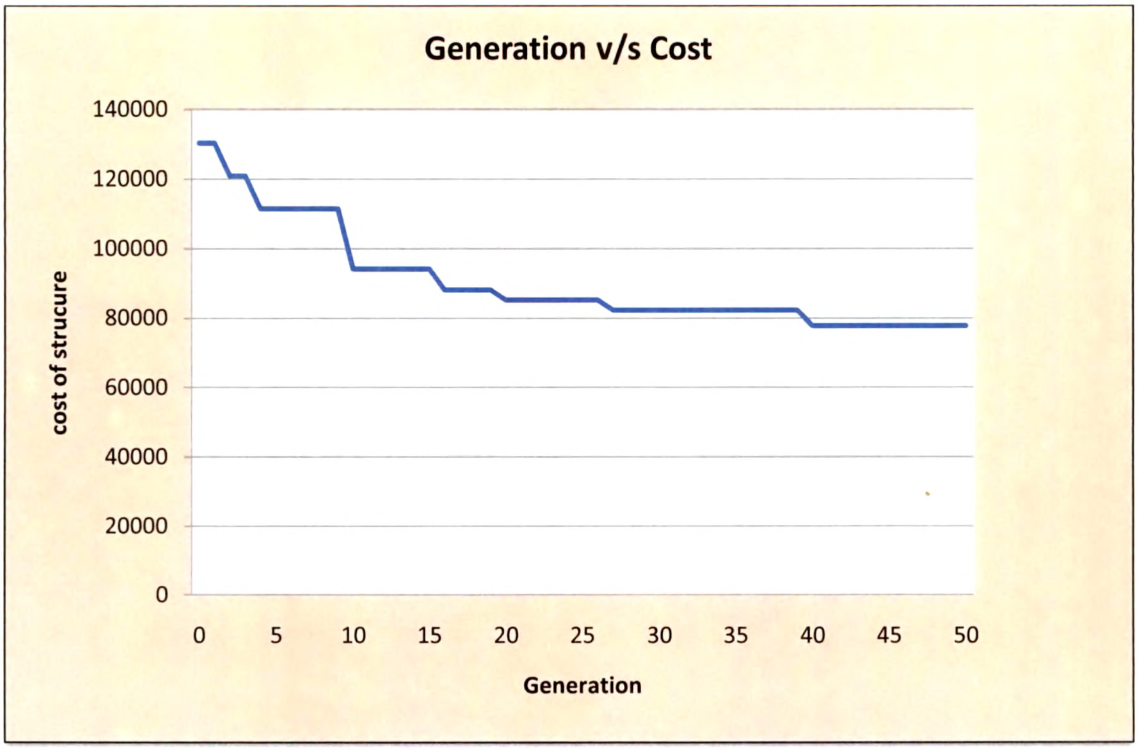


Fig. 9.4 Generation versus Cost

The above example of steel-concrete composite frame having one bay with two storeys is taken up from reference [102], wherein comparison between LRFD and ASD methods is made. In the literature, only structural steel sections are used for design. In the present study, GA based optimization program is employed for optimum design of this plane frame by using composite beam and column sections. The results obtained by GA based program are compared with those available in the literature and tabulated in **Table 9.1**

Table 9.1 Comparison of Results

Storey	Particulars	Structural Steel Frame Using		Composite Frame	% Saving in Weight
		LRFD Method	ASD Method		
2nd	Beam	ISMB 500 @ 86.9 kg/m	ISMB 550 @ 103.7 kg/m	ISLB 400 @ 62.0 kg/m	28.65
	Column	ISLB 500 @ 75.0 kg/m	ISMB 600 @ 122.6 kg/m	ISLB 325 @ 43.0 kg/m	42.66
1st	Beam	ISMB 550 @ 103.7 kg/m	ISMB 600 @ 122.6 kg/m	ISLB 450 @ 72.0 kg/m	30.09
	Column	ISLB 550 @ 86.3 kg/m	ISMB 600 @ 122.6 kg/m	ISLB 325 @ 43.0 kg/m	50.1

From the **Table 9.1**, it can be observed that about 25% to 50% of saving in material weight is achieved which results in considerable reduction in cost.

9.5 Design Example of A 2 x 3 Storey Composite Frame

Next, a problem of two bay three storey composite portal frame with fixed support is under taken. The gravity loads at construction stage and composite stage are as shown in **Fig 9.5** and **Fig 9.6** respectively. The design parameters and GA parameters are written below followed by the output results obtained by GA based optimization program.

- **Geometry data**
  - Number of bays in horizontal direction = 2
  - Number of Storeys = 3
  - Storey height = 3 m
  - Span of beam = 6.6 m
  - Slab thickness = 130 mm
- **Material data**
  - Grade of concrete = M30
  - Grade of steel = Fe 275
  - Grade of reinforcement = Fe 415
- **Load data at serviceability limit state**
  - Dead load on the beam = 35.16 kN/m
  - live load on the beam = 14.84 kN /m
- **Load data at ultimate limit state**
  - Dead load on the beam = 49.224 kN /m
  - live load on the beam = 23.744 kN /m
- **Unit cost data**
  - Unit cost of steel = 32 ₹/ kg.
  - Unit cost of concrete = 3000 ₹/ cum.
- **Genetic data**
  - String Length = 9
  - Population size = 50

- Generation = 50
- Type of crossover = Single Point Crossover
- Crossover probability = 0.90
- Selection scheme = Roulette Wheel Scheme
- Mutation Probability = 0.07 with variable mutation.

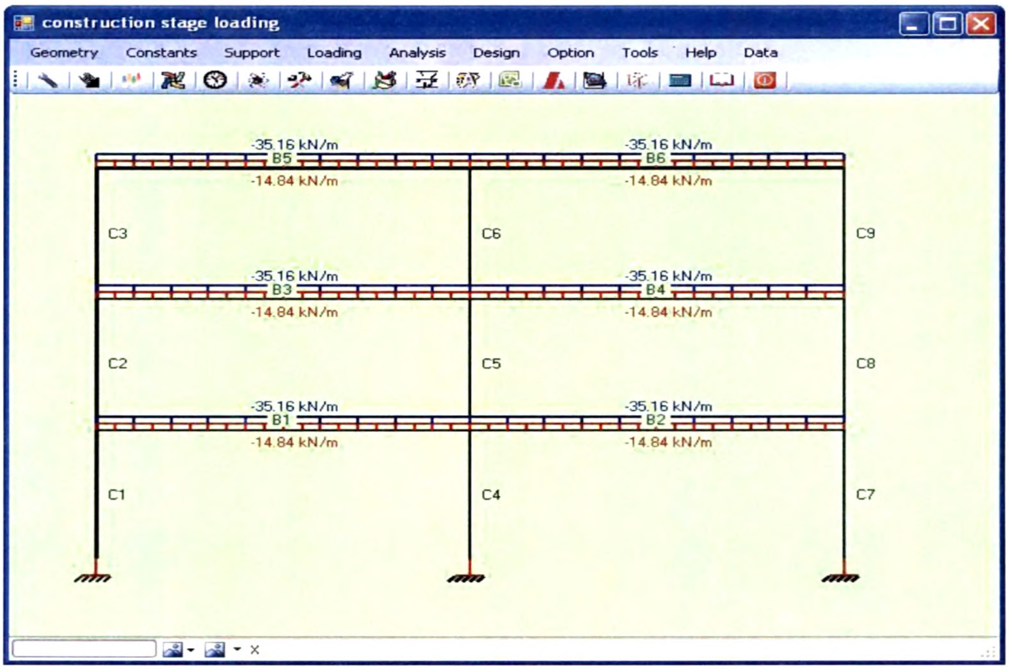


Fig. 9.5 Composite Frame under Loading at Construction Stage

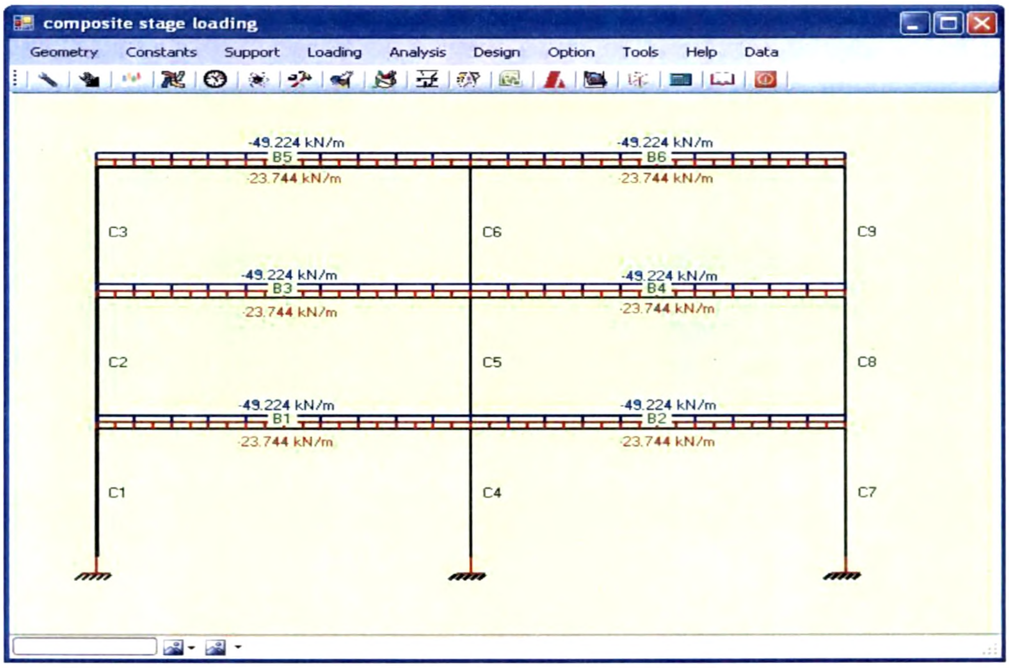


Fig. 9.6 Composite Frame under Loading at Composite Stage

- **Design constraints for beam**
  - Moment constraint: $M_n \leq M_{pn}$ and $M_p \leq M_{pp}$
  - Shear force constraint: $V \leq V_P$
  - Lateral torsional buckling constraint: $M \leq M_b$

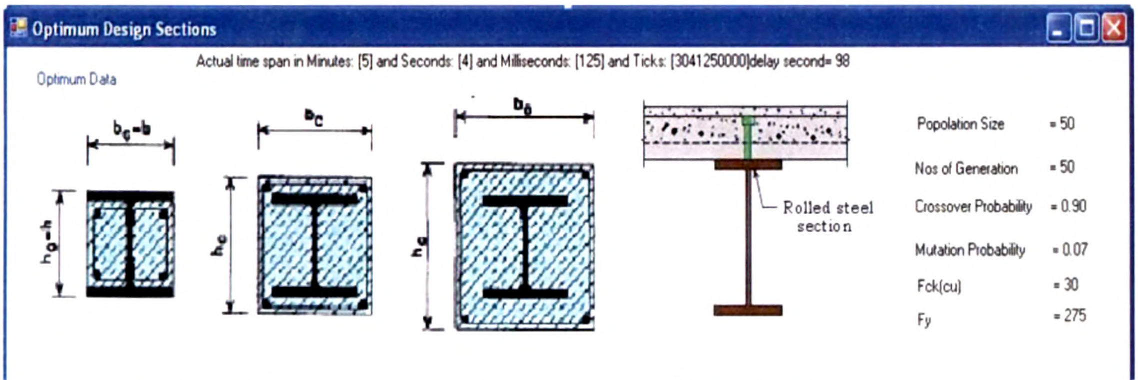
- **Design constraints for column**
  - Axial compression constraint: $P < \chi\, P_p$
  - Moment constraint: $M \leq 0.9\, \mu\, M_p$

- **Objective Function**

  Total cost of composite frame = Cost of beam + Cost of connector + Cost of column.

- **Output**

  Figure 9.7 shows optimum results obtained through genetic algorithm.



Sr no	column	beam	width of section	Mass kg/m	fitness	Cost	C
C1	203 X 204	----	203 X 203	46.1	0.729	137111.563	0
C2	203 X 204	----	203 X 203	46.1			
C3	203 X 204	----	203 X 203	46.1			
C4	203 X 204	----	203 X 203	46.1			
C5	203 X 204	----	203 X 203	46.1			
C6	203 X 204	----	203 X 203	46.1			
C7	203 X 204	----	203 X 203	46.1			
C8	203 X 204	----	203 X 203	46.1			
C9	203 X 204	----	203 X 203	46.1			
B1	----	305x102x33	----	32.8			
B2	----	305x102x33	----	32.8			
B3	----	305x102x33	----	32.8			
B4	----	305x102x33	----	32.8			
B5	----	305x102x33	----	32.8			
B6	----	305x102x33	----	32.8			

Fig. 9.7 Final Results for 2 Bay × 3 Storey Frame

Summary of the results obtained is given below:

1. **Type of beam:** Structural steel beam with headed stud shear connector
2. **Size of beam :** All beam are of size 305 x 102 x 33 mm.
3. **Type of shear connector**– Headed stud of 12 mm dia. x 100 mm height

4. **Type of column:** Partial encased composite column
5. **Size of column:** All columns are of size 203 x 204 mm concrete casing with 203 × 203 × 33 kg/m rolled steel encased section.

The final solution is obtained after 9 GA runs. The convergence of GA towards optimum solution is indicated with the help of graphs of fitness v/s generation and cost v/s generations as shown in **Fig 9.8** and **Fig 9.9** respectively**.** The final solution is obtained in 43rd generation after which no further improvement of fitness is observed.

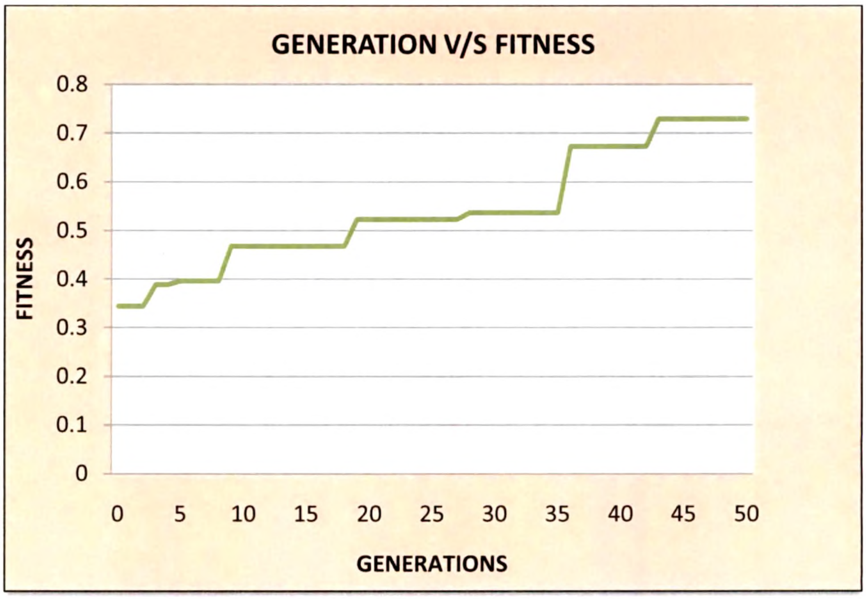


Fig 9.8 Generation versus Fitness

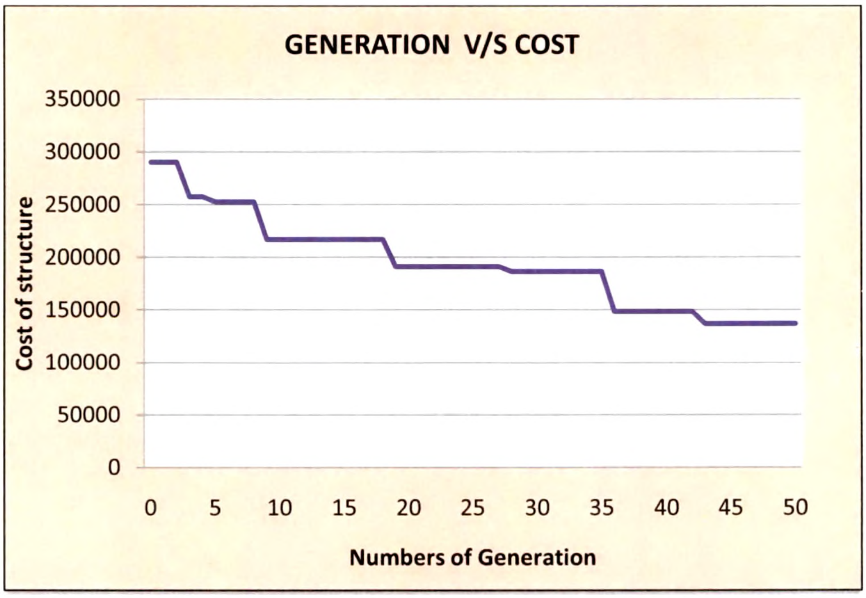


Fig. 9.9 Generation versus Cost

The design results are compared with the results available in the literature [32] in **Table 9.2.**

Table 9.2 Comparison of Results for 2 × 3 Storey Frame

Storey	Particulars	Composite Frame using Composite Beam & Steel Column with Rigid Connection	Composite Frame (Present Work)	% Saving in Weight
3rd	Beam	HN300x150x6.5x9 @ 36 kg/m	302x102 @ 32.8 kg/m	8.89
	Column	HW 250x250x9x14 @70.63 kg/m	203x203 @ 46.1 kg/m	34.73
2nd	Beam	HN300x150x6.5x9 @ 36 kg/m	302x102 @ 32.8 kg/m	8.89
	Column	HW 250x250x9x14 @ 70.63 kg/m	203x203 @ 46.1 kg/m	34.73
1st	Beam	HN300x150x6.5x9 @ 36 kg/m	302x102 @ 32.8 kg/m	8.89
	Column	HW 250x250x9x14 @ 70.63 kg/m	203x203 @ 46.1 kg/m	34.73

9.6 DESIGN EXAMPLE OF A 2 X 5 STOREY COMPOSITE FRAME

A two bay five storeyed fixed footed composite portal frame is selected here. Gravity loads acting on the frame at construction stage and composite stage are as shown in **Fig. 9.10** and **Fig. 9.11** respectively.

The optimum design of this frame is carried out five times by selecting different type of section every time. The following five sections are considered one by one for optimum design:

- Fully encased Indian steel column section.
- Partially encased Indian steel column section.
- Square tubular section filled with concrete.
- Rectangular tubular section filled with concrete.
- Circular tubular section filled with concrete.

➤ **Geometry data**

- Number of bay in horizontal direction = 2
- Number of storey = 5
- Story height = 3 m

- Span of beam = 7 m
- Slab thickness = 130 mm
- c/c distance between beams = 7 m

➢ **Load data**

- Imposed load = 3.5 kN/m^2
- Partition load = 1.0 kN/m^2
- Floor finishing load = 0.5 kN/m^2
- Construction load = 0. 5 kN/m^2

➢ **Unit cost data**

- Unit cost of steel = 32 ₹/kg
- Unit cost of concrete = 3000 ₹/cum

➢ **Genetic data**

- String length = 9
- Population size = 50
- Generation = 50
- Type of crossover = Single point crossover
- Crossover probability = 0.90
- Selection scheme = Roulette Wheel Scheme
- Mutation probability = 0.07 with variable mutation.

➢ **Material data**

- Grade of concrete = M30
- Grade of steel = Fe 250
- Grade of reinforcement = Fe 415

➢ **Design constraints for beam**

- Moment constraint: $M_n \leq M_{pn}$ and $M_p \leq M_{pp}$
- Shear force constraint: $V \leq V_P$
- Lateral torsional buckling constraint: $M \leq M_b$

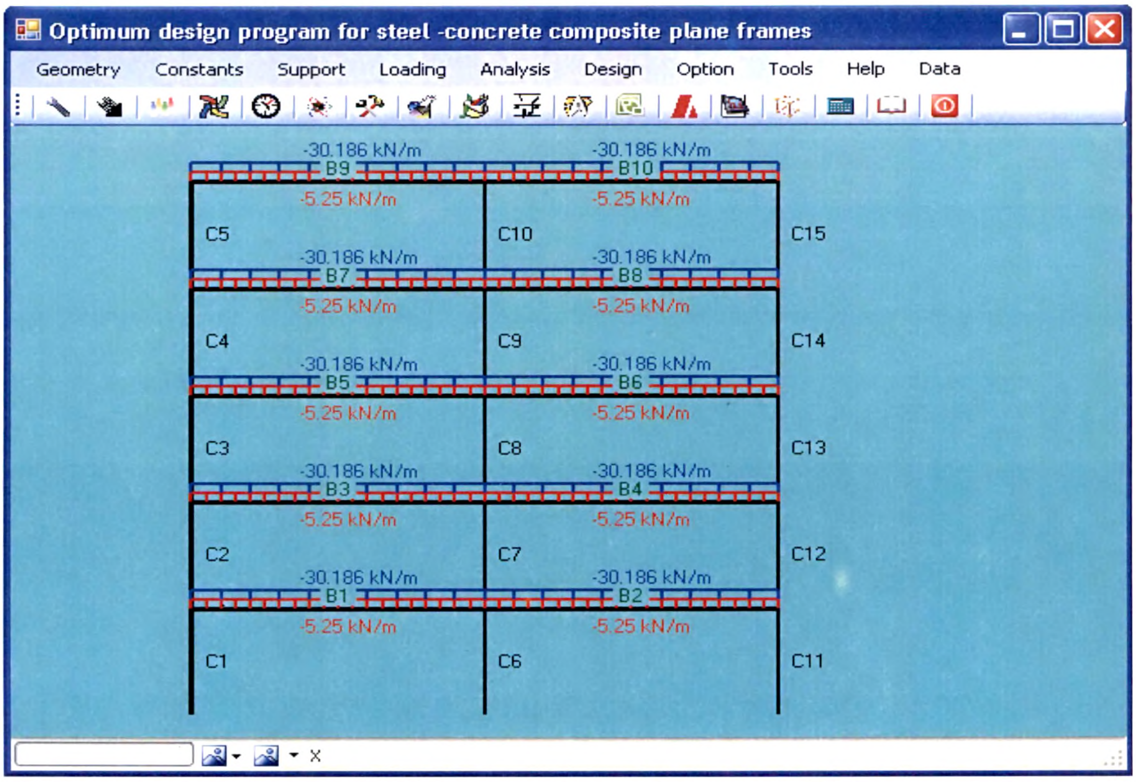


Fig. 9.10 Composite Frame under Loading at Construction Stage

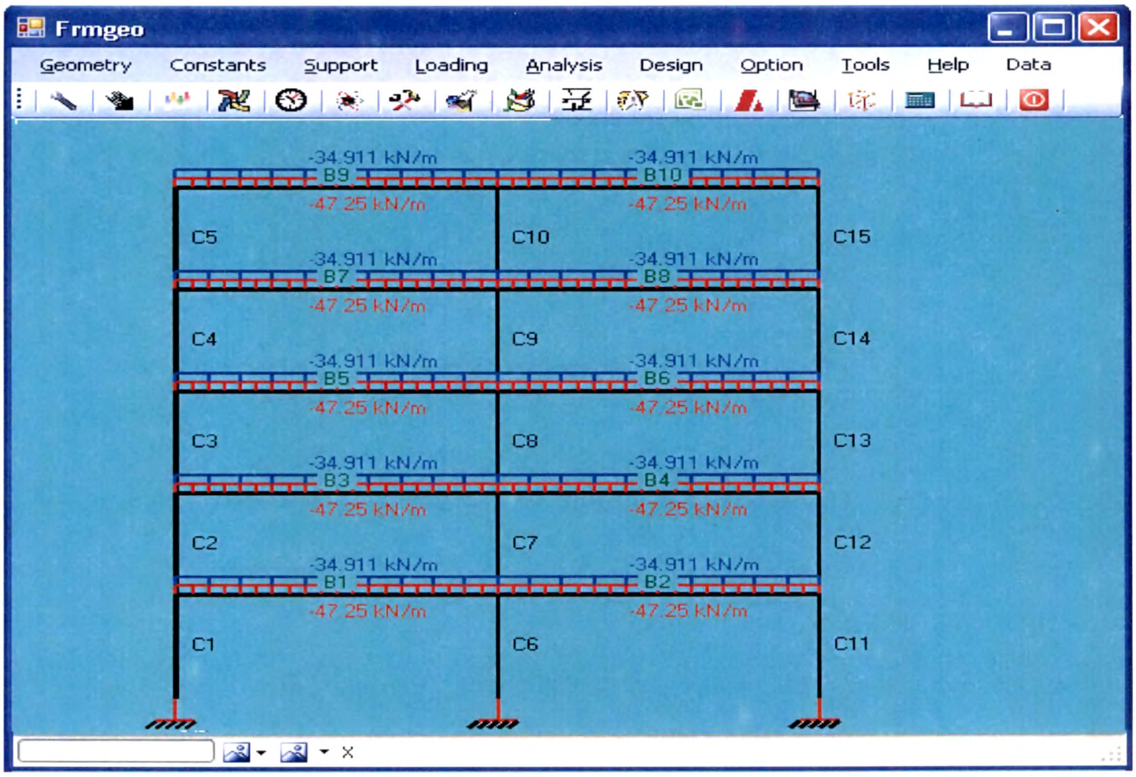


Fig. 9.11 Composite Frame under Loading at Composite Stage

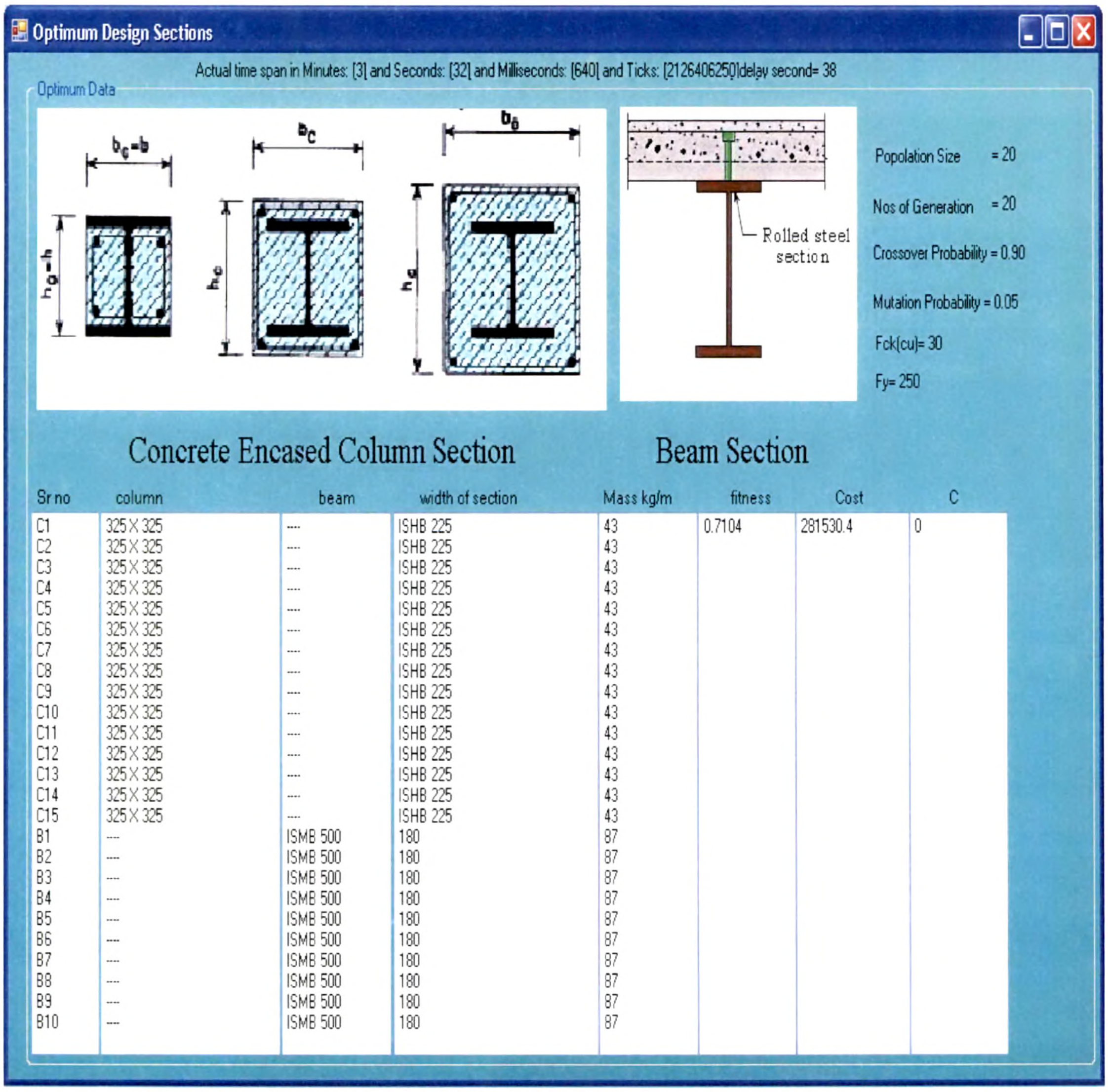
➢ Design Constraints for column

Axial compression constraint $P < \chi \, P_p$

Moment constraint $M \leq 0.9 \, \mu \, M_p$

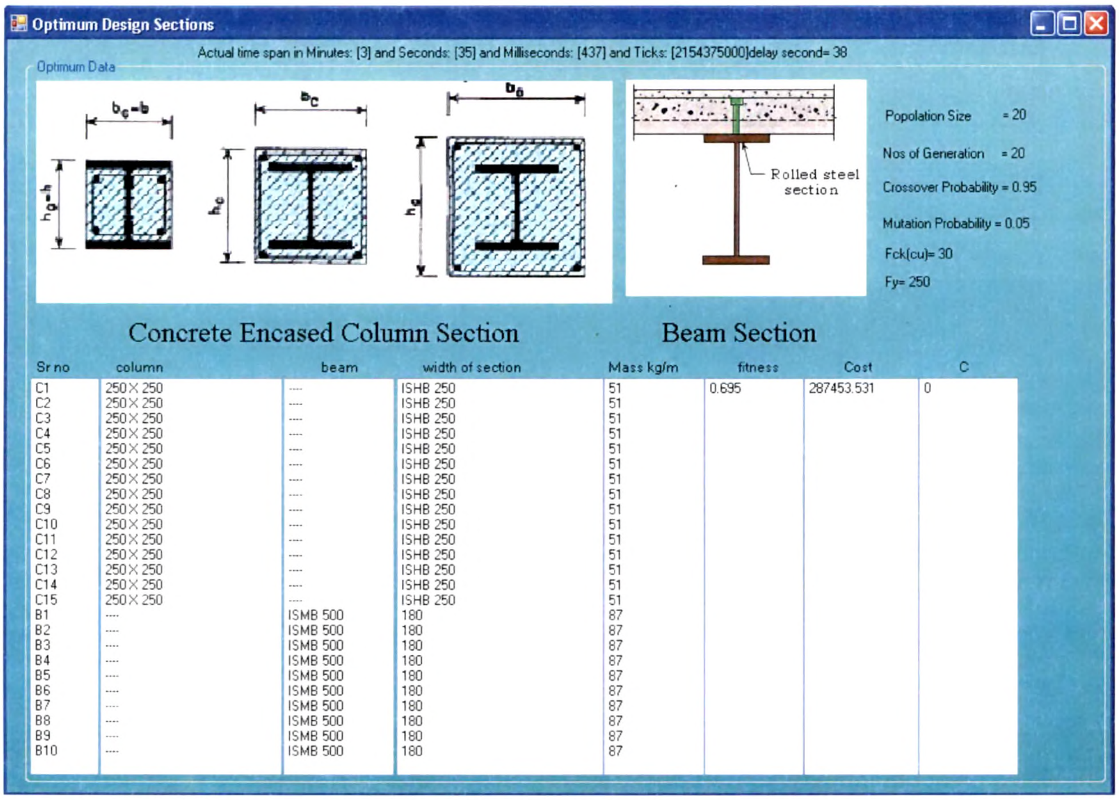
➢ Output

Analysis and design of two bay five storeyed composite frame is carried out by taking different types of column and beam section. **Figure 9.12** shows output obtained by selecting fully encased Indian sections. The results derived from the program by selecting partially encased Indian sections are depicted in **Fig. 9.13**. The optimum concrete infilled hollow square, circular and rectangular sections obtained through the program are displayed in **Figs. 9.14**, **9.15** and **9.16** respectively.



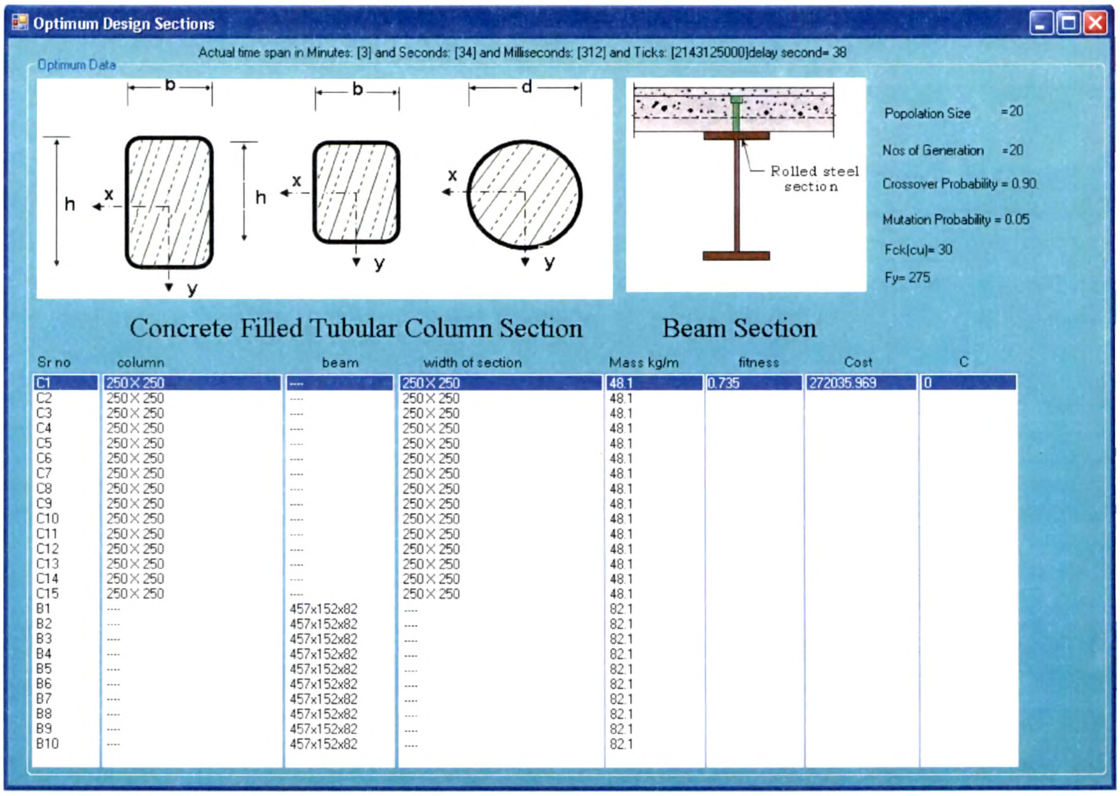
Sr no	column	beam	width of section	Mass kg/m	fitness	Cost	C
C1	325 X 325	----	ISHB 225	43	0.7104	281530.4	0
C2	325 X 325	----	ISHB 225	43			
C3	325 X 325	----	ISHB 225	43			
C4	325 X 325	----	ISHB 225	43			
C5	325 X 325	----	ISHB 225	43			
C6	325 X 325	----	ISHB 225	43			
C7	325 X 325	----	ISHB 225	43			
C8	325 X 325	----	ISHB 225	43			
C9	325 X 325	----	ISHB 225	43			
C10	325 X 325	----	ISHB 225	43			
C11	325 X 325	----	ISHB 225	43			
C12	325 X 325	----	ISHB 225	43			
C13	325 X 325	----	ISHB 225	43			
C14	325 X 325	----	ISHB 225	43			
C15	325 X 325	----	ISHB 225	43			
B1	----	ISMB 500	180	87			
B2	----	ISMB 500	180	87			
B3	----	ISMB 500	180	87			
B4	----	ISMB 500	180	87			
B5	----	ISMB 500	180	87			
B6	----	ISMB 500	180	87			
B7	----	ISMB 500	180	87			
B8	----	ISMB 500	180	87			
B9	----	ISMB 500	180	87			
B10	----	ISMB 500	180	87			

Fig. 9.12 Output for Fully Encased Sections



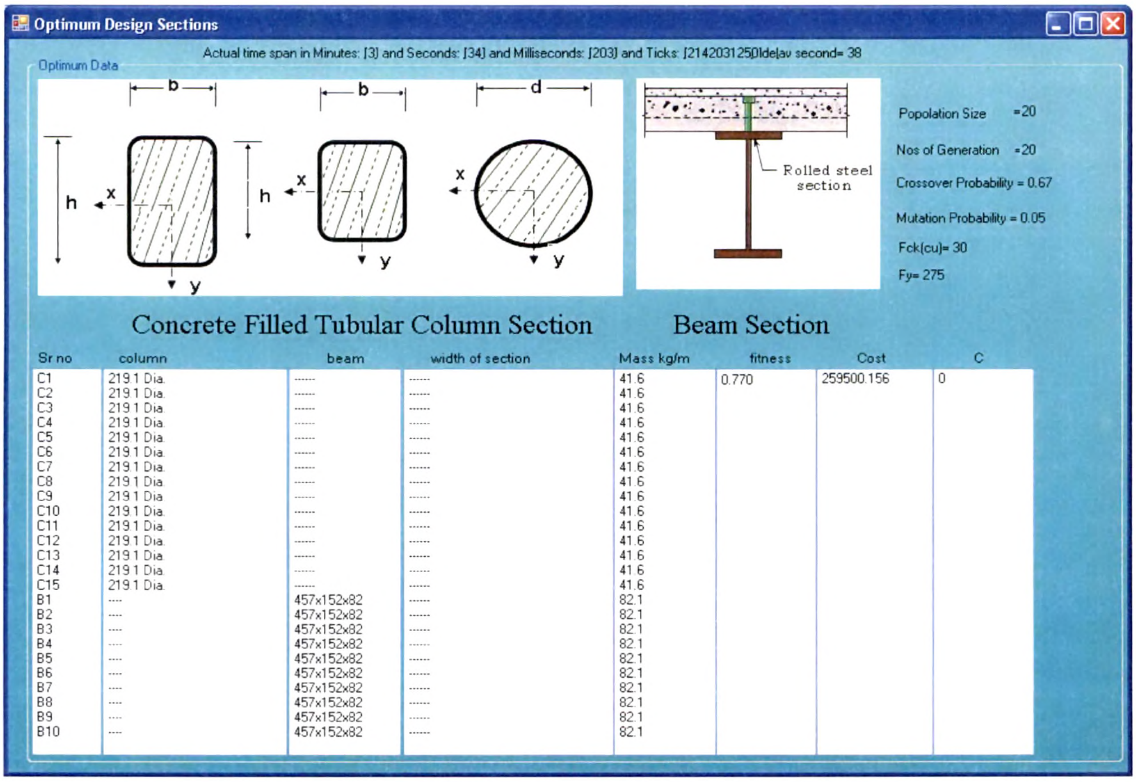
Sr no	column	beam	width of section	Mass kg/m	fitness	Cost	C
C1	250 X 250	----	ISHB 250	51	0.695	287453.531	0
C2	250 X 250	----	ISHB 250	51			
C3	250 X 250	----	ISHB 250	51			
C4	250 X 250	----	ISHB 250	51			
C5	250 X 250	----	ISHB 250	51			
C6	250 X 250	----	ISHB 250	51			
C7	250 X 250	----	ISHB 250	51			
C8	250 X 250	----	ISHB 250	51			
C9	250 X 250	----	ISHB 250	51			
C10	250 X 250	----	ISHB 250	51			
C11	250 X 250	----	ISHB 250	51			
C12	250 X 250	----	ISHB 250	51			
C13	250 X 250	----	ISHB 250	51			
C14	250 X 250	----	ISHB 250	51			
C15	250 X 250	----	ISHB 250	51			
B1	----	ISMB 500	180	87			
B2	----	ISMB 500	180	87			
B3	----	ISMB 500	180	87			
B4	----	ISMB 500	180	87			
B5	----	ISMB 500	180	87			
B6	----	ISMB 500	180	87			
B7	----	ISMB 500	180	87			
B8	----	ISMB 500	180	87			
B9	----	ISMB 500	180	87			
B10	----	ISMB 500	180	87			

Fig. 9.13 Output for Partially Encased Sections



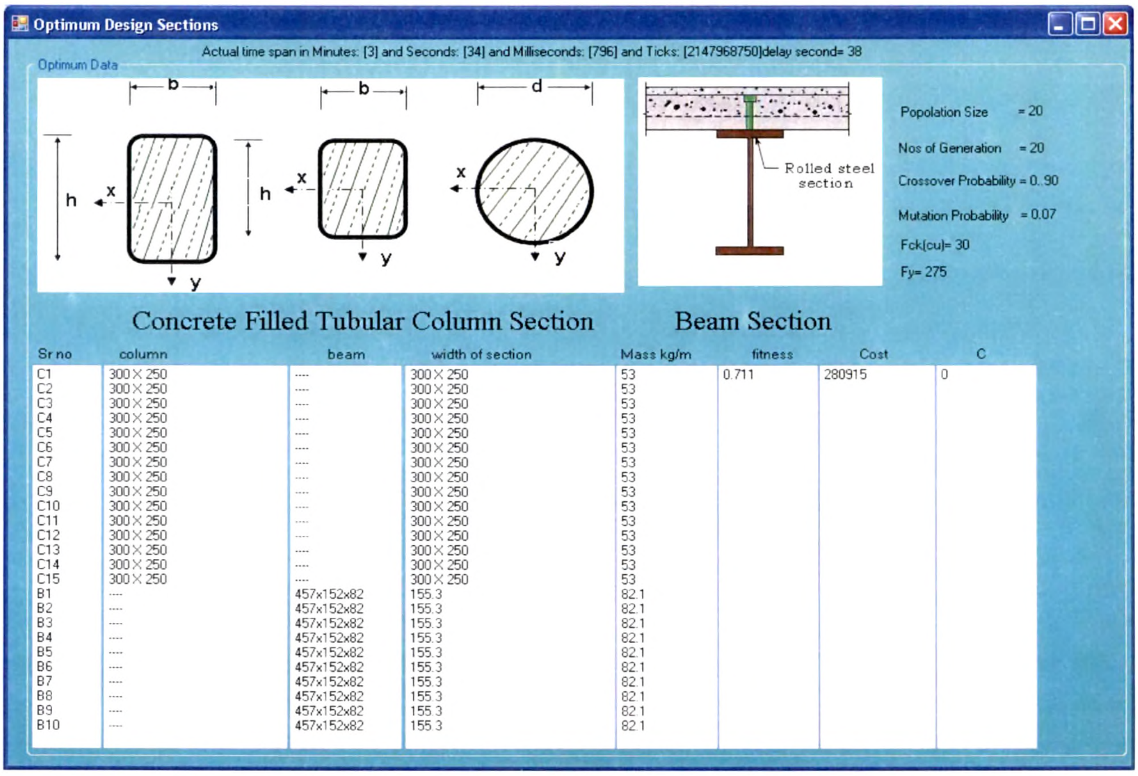
Sr no	column	beam	width of section	Mass kg/m	fitness	Cost	C
C1	250 X 250	----	250 X 250	48.1	0.735	272035.969	0
C2	250 X 250	----	250 X 250	48.1			
C3	250 X 250	----	250 X 250	48.1			
C4	250 X 250	----	250 X 250	48.1			
C5	250 X 250	----	250 X 250	48.1			
C6	250 X 250	----	250 X 250	48.1			
C7	250 X 250	----	250 X 250	48.1			
C8	250 X 250	----	250 X 250	48.1			
C9	250 X 250	----	250 X 250	48.1			
C10	250 X 250	----	250 X 250	48.1			
C11	250 X 250	----	250 X 250	48.1			
C12	250 X 250	----	250 X 250	48.1			
C13	250 X 250	----	250 X 250	48.1			
C14	250 X 250	----	250 X 250	48.1			
C15	250 X 250	----	250 X 250	48.1			
B1	----	457x152x82	----	82.1			
B2	----	457x152x82	----	82.1			
B3	----	457x152x82	----	82.1			
B4	----	457x152x82	----	82.1			
B5	----	457x152x82	----	82.1			
B6	----	457x152x82	----	82.1			
B7	----	457x152x82	----	82.1			
B8	----	457x152x82	----	82.1			
B9	----	457x152x82	----	82.1			
B10	----	457x152x82	----	82.1			

Fig. 9.14 Output for Concrete Filled Hollow Square Sections



Sr no	column	beam	width of section	Mass kg/m	fitness	Cost	C
C1	219.1 Dia	------	------	41.6	0.770	259500.156	0
C2	219.1 Dia	------	------	41.6			
C3	219.1 Dia	------	------	41.6			
C4	219.1 Dia	------	------	41.6			
C5	219.1 Dia	------	------	41.6			
C6	219.1 Dia	------	------	41.6			
C7	219.1 Dia	------	------	41.6			
C8	219.1 Dia	------	------	41.6			
C9	219.1 Dia	------	------	41.6			
C10	219.1 Dia	------	------	41.6			
C11	219.1 Dia	------	------	41.6			
C12	219.1 Dia	------	------	41.6			
C13	219.1 Dia	------	------	41.6			
C14	219.1 Dia	------	------	41.6			
C15	219.1 Dia	------	------	41.6			
B1	----	457x152x82	------	82.1			
B2	----	457x152x82	------	82.1			
B3	----	457x152x82	------	82.1			
B4	----	457x152x82	------	82.1			
B5	----	457x152x82	------	82.1			
B6	----	457x152x82	------	82.1			
B7	----	457x152x82	------	82.1			
B8	----	457x152x82	------	82.1			
B9	----	457x152x82	------	82.1			
B10	----	457x152x82	------	82.1			

Fig. 9.15 Output for Concrete Filled Hollow Circular Sections



Sr no	column	beam	width of section	Mass kg/m	fitness	Cost	C
C1	300 X 250	----	300 X 250	53	0.711	280915	0
C2	300 X 250	----	300 X 250	53			
C3	300 X 250	----	300 X 250	53			
C4	300 X 250	----	300 X 250	53			
C5	300 X 250	----	300 X 250	53			
C6	300 X 250	----	300 X 250	53			
C7	300 X 250	----	300 X 250	53			
C8	300 X 250	----	300 X 250	53			
C9	300 X 250	----	300 X 250	53			
C10	300 X 250	----	300 X 250	53			
C11	300 X 250	----	300 X 250	53			
C12	300 X 250	----	300 X 250	53			
C13	300 X 250	----	300 X 250	53			
C14	300 X 250	----	300 X 250	53			
C15	300 X 250	----	300 X 250	53			
B1	----	457x152x82	155.3	82.1			
B2	----	457x152x82	155.3	82.1			
B3	----	457x152x82	155.3	82.1			
B4	----	457x152x82	155.3	82.1			
B5	----	457x152x82	155.3	82.1			
B6	----	457x152x82	155.3	82.1			
B7	----	457x152x82	155.3	82.1			
B8	----	457x152x82	155.3	82.1			
B9	----	457x152x82	155.3	82.1			
B10	----	457x152x82	155.3	82.1			

Fig. 9.16 Output for Concrete Filled Hollow Rectangular Sections

In optimization process, genetic parameters such as population size, number of generations, crossover probability and mutation probability play an important role. To find out the optimum cross sections for composite plane frame, numbers of trials are required. The final solutions are obtained after 4 to 8 GA runs for various composite sections. The population size and number of members also affect the overall optimization time. The relation between number of generations and time taken in optimization process is depicted in **Fig. 9.17**.

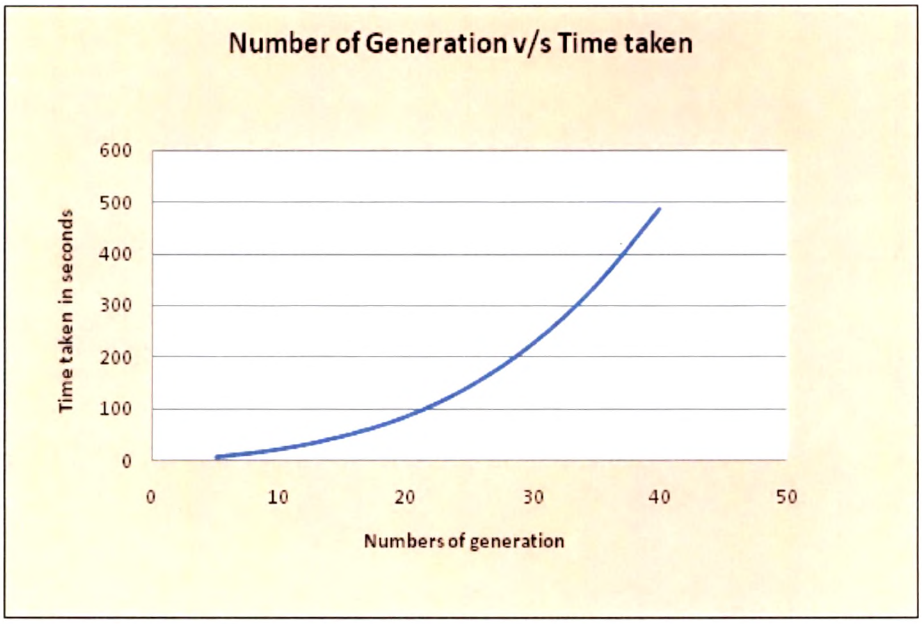


Fig. 9.17 Time Taken in Optimization Process

9.7 A Parametric Study

An example of five storey-two bay frame was solved in the previous section with the aim to find the optimum sectional properties for members of plane frame, from each type of section, among five categories discussed. Results of the parametric study are summarized here in **Table 9.**3 wherein total structural weight and overall cost obtained for each type of section are mentioned. The comparison is also shown in **Fig. 9.18**. It can be observed that the fully encased Indian steel section performs better than the partially encased one. Whereas, in case of concrete filled tubular sections, concrete filled hollow circular section performs the best with structural steel weight of 7619 kg which is the minimum among the five types of sections.

Table 9.3 Weight and Cost Comparison

Case	Type	Total Structural Steel used in Composite Frame (Kg)	Overall Cost by Program For Composite Frame (₹)
Case 1	Square concrete filled tubular column and beam section	7912	272035
Case 2	Circular concrete filled tubular column and beam section	7619	259500
Case 3	Rectangular concrete filled tubular column and beam section	8132	280915
Case 4	Fully encased Indian column and beam section	8025	281530
Case 5	Partially encased Indian column and beam section	8385	287454

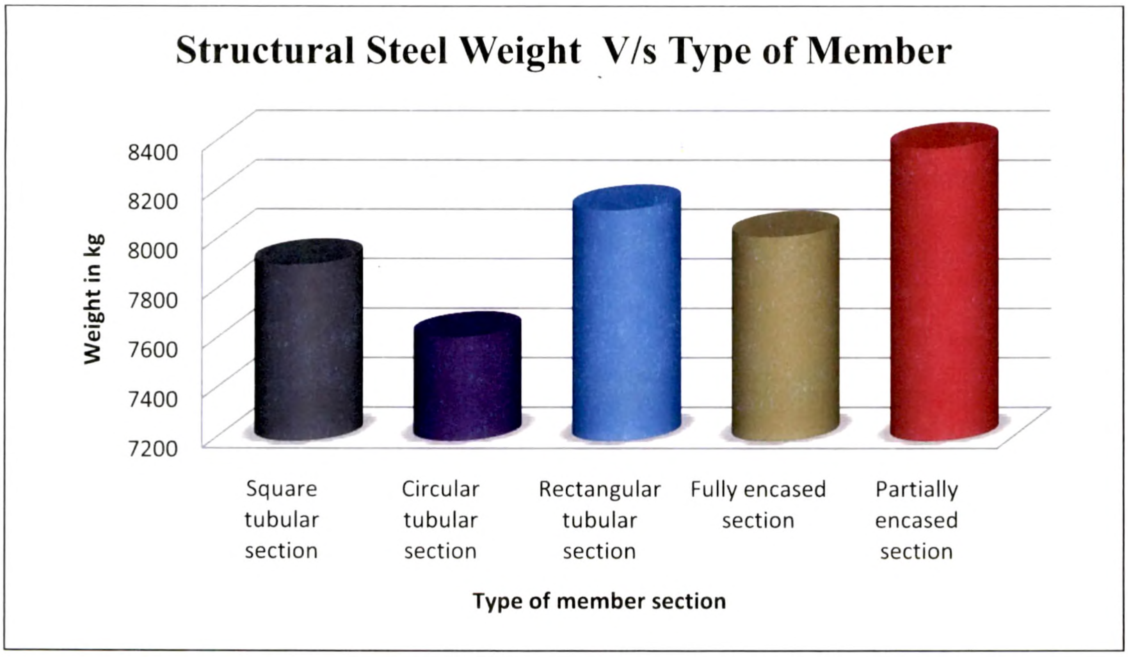


Fig. 9.18 Comparison of Weight