INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH & DEVELOPMENT

ISSN 2278 – 0211 (Online)

Steel-Concrete Composite Beam Design Using Genetic Algorithm

Dr. D. R. Panchal
Applied Mechanics & Structural Engineering Department, Faculty of Technical & Engineering
M. S. University of Baroda, Vadodara, Gujarat, India

Abstract:
The advantages of concrete and steel can be gained to the fullest extent by proportioning and integrating them efficiently. For finding out optimal combination of constituent materials in the composite beam, Genetic Algorithm (GA) is used in the present work. Microsoft VB is used to program the algorithm, keeping in view the simplicity, flexibility, effectiveness and user friendly features of the language. GA based routines are developed to find out optimum sections of steel beam and RCC slab and optimum number of shear connectors with the objective of minimizing cost of the beam using design method as per the Indian code, IS: 11384–1985. Plastic moment capacity, deflection and stress constraints are imposed to direct the search towards feasible region. The capability of the developed program is demonstrated by including optimum design examples of fixed and variable beam spacing considering with and without RCC slab.

Keywords*: Constraints, Connector, Deflection, Genetic Algorithm, Optimum*

1. Introduction

Composite construction is that in certain types of stressed conditions, the combination of a material strong in compression with one strong in tension makes a very economical union for its use in structures. In spite of wide acceptance of composite construction in the advanced countries, the method is yet to become popular in India. Exposure and experience of majority of professionals in India to steel-concrete composite design is considered to be low. Hence, even when steel-concrete composite construction should be the choice, designers and contractors use other alternative systems.

Life cycle cost analysis to determine the best possible options is rarely done. However, it is a fact of late, realizing various advantages of composite construction, engineers are increasingly designing composite structures made of structural steel and reinforced concrete to produce more efficient structures when compared to design using either material alone [1]. The present work is aimed at attracting structural engineers towards composite construction by economizing the structure through optimum design.

Genetic Algorithms (GAs) are very effective at finding optimal solution to a variety of problems [2]. It finds an optimal solution by generating population of solution strings randomly and improving the solutions in succeeding generations. Genetic Algorithms are stochastic, parallel search algorithms based on the mechanics of natural selection and the process of evolution.

Reproduction, crossover and mutation are the three basic operators required in the GA based program. Reproduction operator ensures the survival of the fittest. Based upon relative fitness in the population at a given iteration level fitter members kill weaker members and reproduce themselves. Crossover operator chooses any two members of the population randomly and the genetic information between the selected mates is transferred to get hopefully better offspring. Mutation operator enables the exploration of design space randomly in a global manner without involving large scale loss of evolved data structure.

In this paper a design procedure, which incorporates a simple Genetic Algorithm, for the optimum design of composite beam, is presented. For design purpose, the Limit State method is employed as per prevailing Indian standard [3]. Some of the design criteria are also considered as per EC4 [4]. The beam is designed to have sufficient bending strength and stiffness and to secure connection to the slab. The bending capacity of the section is evaluated on “plastic” analysis principles, whereas the serviceability performance is evaluated on elastic section analysis principles [3].

2. Bases of Composite Beam Design

In the case of the standard steel-concrete composite member, the units of the composite beam are

- The Steel Beam.
- The Concrete Slab which acts as a big cover plate.

- The Shear Connector.

The structural beam is usually of a material which carries tensile stresses efficiently, and the slab is of concrete, which has good compressive strength.

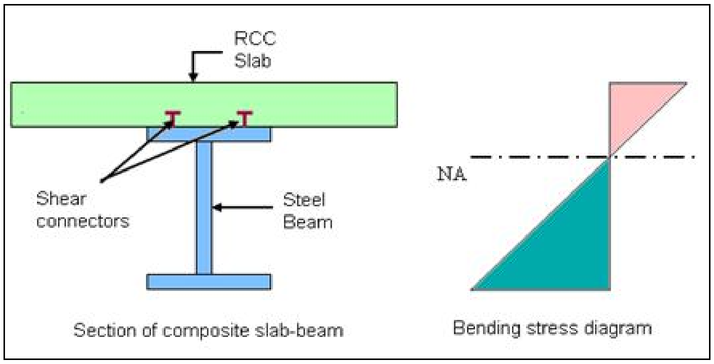


Figure 1: Steel - Concrete Composite Beam

In the composite slab-beam construction, the connectors tie the slab to the beam and force the slab to act in the longitudinal direction (Fig. 1). The slab is still designed as a one-way slab. In ordinary beam and slab construction, the beam cross section is usually symmetrical, and consequently the neutral axis (NA) is at the mid-depth of the steel beam. This places the top of the simple span beam in the compression and the bottom of the beam in tension. The major effect of the composite action is to force the beam and slab to act together, which shifts the neutral axis of the section upward towards the slab. This leaves the concrete cover plate (the slab) in compression and forces almost the whole steel beam into tension. Thus each of these materials is doing what it does best.

3. GA Based Optimum Design Problem Formulation

The following optimization parameters are considered in the development of GA based program.

3.1. Design Variables

The design variables for optimum design of steel-concrete composite beam are the c/c distance between beams, size of intermediate beams, size of end beams, type of shear connectors and thickness of RCC 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.

3.2. Constraints

Safety is of prime importance in any structural design. Thus, while optimizing any structural component there should be no compromise with safety. This require fulfillment of certain condition and constraints, violation of which would make the structure unsafe. The safe (feasible) design requires following constraints to be satisfied.

3.2.1. Plastic Moment Constraint

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.

Constraint : $M \leq Mp$

Penalty : $g_1 = \max (M / M_p - 1, 0)$

Where, M = Design moment and Mp = Plastic moment [3].

3.2.2. Deflection Constraint

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_{perm} – Permissible Deflection = L / 325.

3.2.3. Stress Constraints

Another serviceability Limit State is stress in the steel flange and stress in the concrete. As structural steel is not supposed to yield at service load, elastic analysis is employed in establishing the serviceability performance of composite beam.

1) Constraint for the stress in steel flange:

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

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

2) Constraint for the stress in concrete:
Constraint : $\sigma_{act,c} \leq \sigma_{per,c}$
Penalty : g4 = max ($\sigma_{act,c} / \sigma_{per,c}$-1,0)
Where, $\sigma_{per,c} = (f_{ck})_{cu} / 3$

3.2.4. Flexure constraint
The slab is designed as one-way continuous. The coefficients given in IS: 456-2000 [5] is used in the analysis of the slab. Required depth of slab is calculated from the maximum moment among all. The depth obtained from the solution string should be greater than required depth.

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

Constraint : $d_{req} \leq d_{provided}$
Penalty : g5 = max($d_{req} / d_{provided}$-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 $d_{provided =}$ Provided depth of the slab.

3.3. Objective Function
The objective function for the composite beam can be formulated as
O = (Cs * Wt) + (C_{st} * N) + C_{sl}
Where, Cs = Cost steel in Rs./Kg, Wt = Weight of beam in Kg, C_{st} = Cost of stud (shear connector) per number, N = Number of shear connectors and C_{sl} = Cost of slab which include cost of concrete and cost of steel in slab.

3.4. Penalty Function
Total penalty incurred for the infeasible solution is,

C = $\sum_{i=1}^{n} gi$ and

The penalized objective function Op is considered as,
O_p = (1 + K*C) * O

3.5. Fitness Function

$$F = \frac{1}{1+P_c}$$

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

4. Steps to Use Program

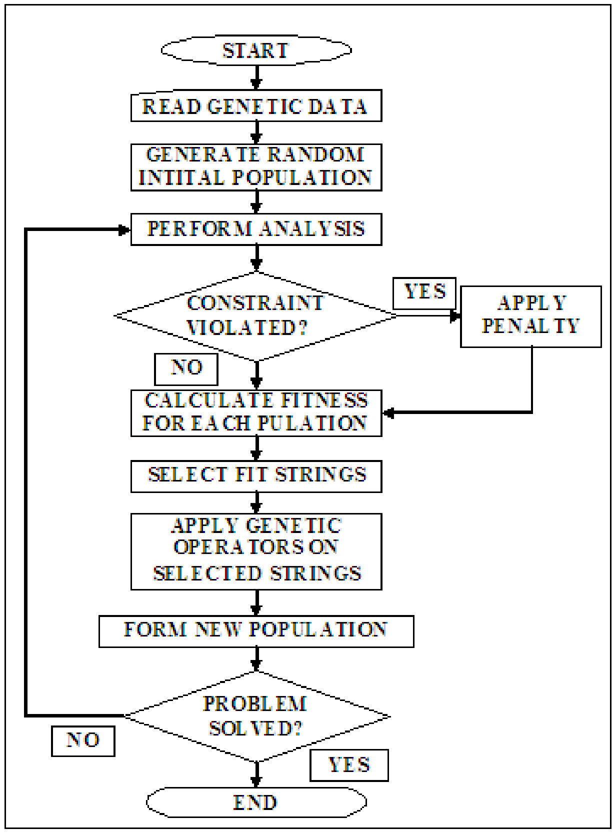
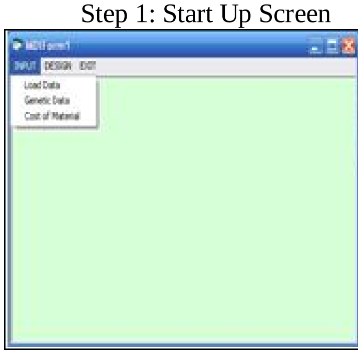


Figure 2: Flowchart of GA Based Optimization Procedure

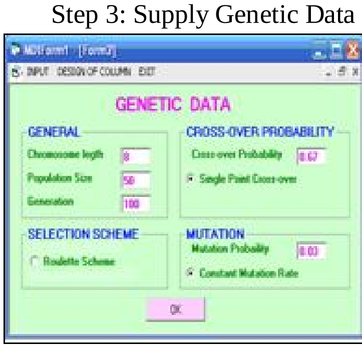
Screen shots of steps to use the program developed based on the flowchart depicted in Fig. 2 are given below.

Step 1: Start Up Screen

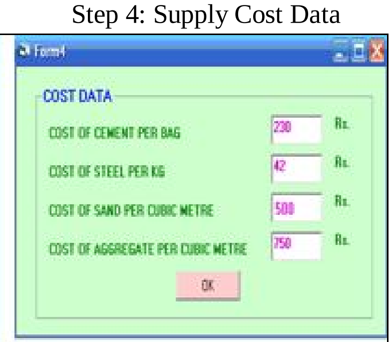


Step 2: Supply Load Data

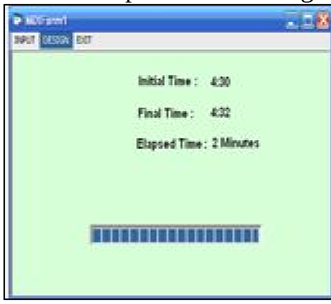
Step 3: Supply Genetic Data



Step 4: Supply Cost Data



Step 5: Run the Program



Step 6: View the Result

5. Design Example with Fixed Beam Spacing

Design of a simply supported steel-concrete composite beam with beam spacing of 3 m is considered here.

5.1. Input

❖ **Load Data:**

(1) Impose Load – 3 kN/m^2
(2) Partition Load – 1.5 kN/m^2
(3) Floor Finish Load – 0.5 kN/m^2
(4) Constructional Load – 0.75 kN/m^2
(5) Beam Span – 10 m
(6) C/C Distance Between Beam – 3 m
(7) Thickness of Slab – 125 mm
(8) Density of Concrete – 24 kN/m^3
(9) Yield Strength of Steel – 250 N/mm^2
(10) Characteristic Compressive Strength of Concrete ($(F_{ck})_{cu}$) – 30 N/mm^2

❖ **Genetic Data:**

(1) Population Size – 20
(2) Generation – 50
(3) Chromosome Length – 8
(4) Type of Cross-over – Single Point Crossover
(5) Cross-over Probability – 0.67
(6) Selection Scheme – Roulette Wheel Scheme
(7) Mutation Probability – 0.03

❖ **Design Constraints:**

(1) Plastic Moment (M_p)
(2) Maximum Permissible Deflection (δ) = L/325
(3) Maximum Permissible Stress in Steel (f_y)
(4) Maximum Permissible Stress in Concrete = $(f_{ck})_{cu}$ / 3

❖ **Objective Function:**

Cost of Beam + Cost of Shear Connector

5.2. Output

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

The final solution is obtained after 3 GA runs. Graph of generations v/s fitness (Fig. 3) indicates that the final solution is obtained in 33rd generation after which no further improvement is observed.

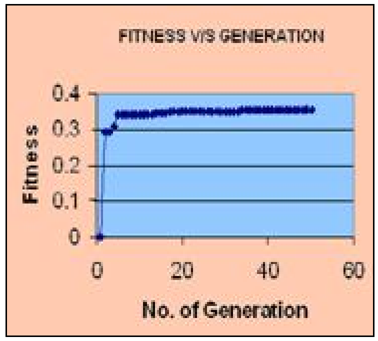


Figure 3: Generation History (Without RCC Slab)

6. Design Example with Variable Beam Spacing

6.1. Without Considering RCC Slab

Design of a simply supported steel-concrete composite beams for a building with plan area of 10 m x 20 m is taken up here. The cost of RCC slab is not included in the objective function.

6.1.1. Input

❖ **Load Data:**

(1) Impose Load – 3 kN/m^2
(2) Partition Load – 1.5 kN/m^2
(3) Floor Finish Load – 0.5 kN/m^2
(4) Constructional Load – 0.75 kN/m^2
(5) Plan area of Building – 20 m x 10 m
(6) Thickness of Slab – 125 mm
(7) Density of Concrete – 24 kN/m^3
(8) Yield strength of steel – 250 N/mm^2
(9) Characteristic Compressive strength of concrete ($(F_{ck})_{cu}$) – 30 N/mm^2
(10) Minimum and Maximum Value of Beam Spacing – (2 m - 5 m)

❖ **Genetic Data:**

(1) Population Size – 20
(2) Generation – 50
(3) Chromosome Length – 8
(4) Type of Cross-over – Single Point Crossover
(5) Cross-over Probability – 0.67
(6) Selection Scheme – Roulette Wheel Scheme
(7) Mutation Probability – 0.03

❖ **Design Constraints:**

(1) Plastic Moment (M_p)
(2) Maximum Permissible Deflection (δ) = L/325
(3) Maximum Permissible Stress in Steel = f_y
(4) Maximum Permissible Stress in Concrete = $(f_{ck})_{cu}$ / 3

❖ **Objective Function:**

Cost of Beam + Cost of Shear Connector

6.1.2. Output

- C/C Distance Between Beams – 5 m
- Size of Intermediate Beams – ISLB 500 @ 75.00 Kg/m
- Size of End Beams – ISLB 500 @ 75.00 Kg/m
- Type of Shear Connector – Channel connector of size 100 mm x 50 mm x 9.2 kg x 150 mm

The final solution is obtained after 3 GA runs and in 41 generation after which no further improvement is observed.

6.2. Considering RCC Slab

Design of a simply supported steel-concrete composite beam with plan area of 10 m x 20 m is considered next. In this case the cost of slab is also included in the objective function.

6.2.1. Input

❖ **Load data:**

(1) Impose Load – 3 kN/m^2
(2) Partition Load – 1.5 kN/m^2
(3) Floor Finish Load – 0.5 kN/m^2
(4) Constructional Load – 0.75 kN/m^2
(5) Plan area of Building – 20 m x 10 m
(6) Density of Concrete – 24 kN/m^3
(7) Yield Strength of Steel – 250 N/mm^2
(8) Characteristic Compressive Strength of Concrete ($(F_{ck})_{cu}$) – 30 N/mm^2

❖ **Genetic Data:**

(1) Population Size – 20
(2) Generation – 50
(3) Chromosome Length – 8
(4) Type of Crossover – Single Point Crossover
(5) Crossover Probability – 0.67
(6) Selection Scheme – Roulette Wheel Scheme
(7) Mutation Probability – 0.03

❖ **Cost Data:**

(1) Unit Cost of Cement – 230 Rs./Bag
(2) Unit Cost of Steel – 42 Rs./Kg
(3) Unit Cost of Sand – 500 Rs./m^3
(4) Unit Cost of Aggregate – 750 Rs./ m^3

❖ **Design Constraints:**

(1) Plastic Moment (M_p)
(2) Maximum Permissible Deflection (δ) = L/325
(3) Maximum Permissible Stress in Steel (f_y)
(4) Maximum Permissible Stress in Concrete = $(f_{ck})_{cu}$ / 3
(5) Depth of slab = $d_{req} = \sqrt{(M_{max} / Q.b)}$

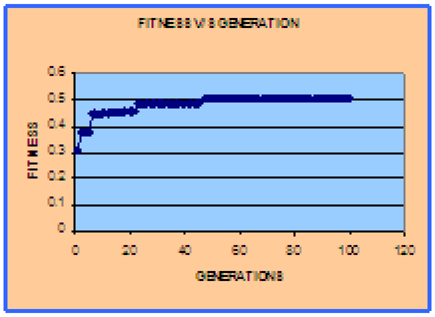
❖ **Objective Function:**

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

6.2.2. Output

- C/C distance between beams – 3m
- Intermediate beam – ISWB 300 @ 48.10 Kg/m
- End beam - ISWB 250 @ 40.9 Kg/m
- Type of stud – Headed stud of size 16 mm x 75 mm
- Slab thickness – 185 mm

In this case the final solution is obtained after 5 GA runs. Graph of generation v/s fitness (Fig. 4) indicates that the maximum fitness is 0.51. The cost is minimum at 45 generation (Fig. 5) after which no further improvement is observed.



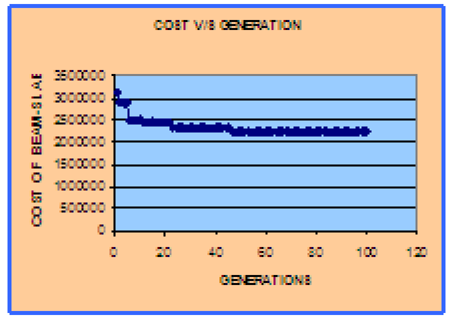


Figure 4: Generation V/S Fitness *Figure 5: Generation V/S Cost*

7. Conclusion

- It is clear from the results that the GA can successfully be used as soft computing tool for optimum design of composite beams.
- The software developed in Visual Basic 6.0 provides interactive user interface for easy data entry. It also facilitates viewing of intermediate results thorough an output file which is automatically created in notepad to see how search has progressed for finding optimum solution through generation by generation.
- For building of 10 m x 20 m plan area and C/C distance between beam of 3.0 m (8 Nos.), the section required is ISLB 450 @ 65.3 kg/m, which gives total weight of beams as 522.4 kg/m. After optimizing C/C distance between beams, the result indicates beam as ISLB 500 @ 75 kg/m at 5m spacing (5 Nos.), which gives total weight of beams as 375 kg/m. Thus numerical results of structural optimization problem of minimum weight design confirm the effectiveness of GA based software.
- Comparing the results obtained in composite beam without considering RCC slab and considering RCC slab, it is found that the optimum beam spacing in case of not consideration of slab is 5 m. While c/c distance between beams with consideration of slab is 3 m. This is because the cost of slab (cost of concrete + cost of steel) is included in the objective function.

8. References

1. Johnson R. P. (1994), "Composite Structures of Steel and Concrete", Vol. 1, Blackwell Scientific Publications, London.
2. Deb K. (1998), "Optimization for Engineering Design - Algorithm and Examples", Prentice Hall of India Private Limited, New Delhi.
3. IS: 11384 (1985), "Code of Practice for Composite Construction in Structural Steel and Concrete", Bureau of Indian Standards, New Delhi, 1986.
4. Eurocode 4 (1994), "Code of Practice for Design of Composite Steel and Concrete Structures", The Steel Construction Institute, Ascot.
5. IS: 456 (2000), "Code of Practice for Plain and Reinforced Concrete (Fourth Revision)", Bureau of Indian Standards, New Delhi