Optimum Design of Reinforced Concrete One-Way Ribbed Slabs Using Genetic Algorithm

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Abstract
This paper deals with the problem of optimum design of reinforced concrete one-way ribbed using genetic algorithms. ACI-Coefficient method is used for the structural analysis and design of slabs. The cost function represents the cost of concrete, steel, and formwork for the slab. The design variables are taken as slab thickness, spacing between ribs, lower width of ribbed, upper width of ribbed, depth of rib, depth of beam, shear reinforcement spacing of ribs, bar diameter and spacing of top slab, depth of the neutral axis from bottom fiber, beam width, and areas of flexural reinforcement at moment critical section along ribs and beams. The constraints include the constraints of the joist construction constraints stated by ACI-code, constraints on the top slab thickness to satisfy fire resistance, constraints on the areas of steel reinforcement to satisfy the flexural and the minimum area requirements, the constraints on the total slab thickness to satisfy deflection, and flexural behavior. The parameters were taken in this study included: the span length(4-12)m, the compressive of concrete(25-60) MPa, the strength of steel (345-600)MPa, the live load (2-7)KN/m², unit cost ratio(cost of concrete/cost of steel)(0.1-0.35), aspect ratio (1-2), the formwork cost(10,000-22,000)ID. The results show that, when discussed the span length, the ratio of (total slab depth/span length) should be (1/18-1/4) using G.A, to get the optimum slab design. It is also concluded that the optimum ratio of (depth of rib/lower rib width) is to be ranged within (1.243-2.917) using G.A. The optimum (rib spacing /span length) ratio is found to be ranged from (1/40– 1/5) using G.A, the results also showed that the range of the optimum (slab thickness/spacing of rib) ratio is found to be ranged as (1/4-1/2) using G.A, in order to find the optimum solution.

A computer program is written using MATLAB for the implementation of structural analysis and the design of one-way ribbed slabs by the ACI coefficient method. The optimization process is performed using the built-in genetic algorithm toolbox of MATLAB.

KEYWORDS: ribbed slab, optimum design, genetic algorithm

Introduction
One way ribbed slabs is a reinforced concrete slab, also called joist slab, that supported by reinforced concrete ribs or joists. The ribbed slab is a structural element consists of combination of regularly ribs, usually tapered and uniformly spaced and supported on girders that rest on columns and a top slab. The spacing between ribs is formed by temporary removable forms, or filled with permanent fillers made of light weight hollow blocks of standard dimensions[1]. (Fig.1).

Figure (1): Ribbed Slab.
Hadi (2001) [2], studied the optimum design of reinforced concrete continuous beams by genetic algorithms. The requirements of Australian standards for concrete structures (AS3600) were applied for solving the optimum design of continuous reinforced concrete T and L shape beams. The objective function was taken including the cost of concrete and steel reinforcement. The design variables included the depth of beam, width of beam, bar diameter, diameter of stirrup, number of reinforcing bars, and number of stirrups. The design constraints according to As 3600 included the flexural strength, minimum ratio reinforcement, spacing between bars, and maximum shear force. It can be seen that the genetic algorithm creates a population of many individuals (solutions) to evolve according to specified selection rules (reproduce, mutate and crossover) to a solution that minimizes the cost function. The conducted evaluation proved that genetic algorithms gains the goal of optimization of T beams quickly without using a high level of mathematics. Finally, as GA is proved as a versatile method, it can be applied for the optimum design of other structural elements easily.

A.C. Galeb and Z.F. Atiyah (2011) [3], studied the optimum design of reinforced concrete (two-way ribbed) waffle slabs. She applied genetic algorithm technique to solve this optimization problem. Two cases she was formulated an optimal a waffle slab with solid heads and a waffle slab with band beams along column. The purpose of minimizes the objective function representing the cost of concrete, steel and formwork for the slab. The design variables considered were, the dimensions and the amount of reinforcement for slab and beam in addition to the spacing between ribs and beams. Many constraints were taken into formulation of the problems, these were the constrains on dimension of ribs, top slab thickness, cover of concrete. The constrains on the areas of steel and minimum area to satisfy the flexural and the longitudinal reinforcement of band beam. This optimization problem was discussed by writing a computer program using Matlab. In order to evaluated the developed system by a number of examples were designed and analyzed using the direct design method. The result also appeared that the increment population size promoted the optimum cost value because the variety of large size population ,also found the last optimum solution in a less number of generations.

A.Kaveh and A.Abadi (2011) [4], studied cost optimization of reinforced concrete one-way ribbed slabs. The objective function was considered the cost of materials slabs and beam also cost of formwork. The optimum design was depended on the American concrete institute's ACI 318-05 standard. The purpose of function was minimized the cost design of slab, subjected to many constraints utilizing the harmony search algorithm. A numerical case is showed to explain the execution of the algorithm and a sensibility analysis was perfect. For investigated the influences of beam span and the cost optimization of loading the ribbed slab by conducting a parametric. Three modules used in this method were a design module that results the design of one way ribbed slab , a cost module that calculated the optimum total cost of one way ribbed slab and an optimization module that seeking for optimal design cost . This simple method can be used to solve another engineering design problems to minimized the total cost. The results of parametric was showed when increased span length the dimensions represented the dimensions of rib spacing ,rib depth and slab thickness will increased . for spans with length of larger than 9 m , the ACI code constrains bound the optimal design result for different loading values and gave the same result .In the span with lengths of small than 9 m, different the loading affects the optimal value result and gave various optimal designs for each loading. A.C. Galeb and T.Ibrahim (2014) [5], studied the optimum dimension of post – tension concrete waffle slabs using the equivalent from design method was solved for structural design and analysis of slab .The objective function represented the cost of concrete, steel, strand tendons, duct, strout, anchorages device and formwork. The design variable were taken the dimensions of slab and spacing between ribs, in addition the area of strand tendons and steel. The optimum dimension appeared that ratio the span to depth 1/23 to 1/25 given an economic slab cost and utilized 750×750 dome with 150 mm rib was checked minimum cost and weight, also was showed the increasing balance load, slab thickness, steel weight and total weight decrease, tendon weight increase and the ratio balance load 95% given minimum cost. When used the minimum slab thickness gave the minimum cost and weight, For span larger than 14 m it was repaired to used more than minimum slab thickness because the maximum dome depth was 500mm which will increased total weight
and cost and for span smaller than 6 m, total depth available was larger than required because minimum dome depth was 200 mm, which will increased total weight and cost. A computer program is written using Matlab to formulate the problem and perform the structural analysis and design of those slabs by the ACI-Coefficient method.

The aim of this study to solve the problem of the optimum design one-way ribbed slab using genetic algorithms method.

Formulation of the Objective Function

The sum of costs of materials (concrete and steel reinforcement) and formwork is considered as the objective function which should be minimized. The total cost of the slab can be stated as:

\[ C = C_c \times V_c + C_s \times W_s + C_f \times A_f \]  

where:

- \( C \) = Total cost function.
- \( C_c \) = Cost of concrete per unit volume (I.D/m3).
- \( C_s \) = Cost of steel per unit volume (I.D/ton).
- \( C_f \) = Cost of formwork per unit area (I.D/m2).
- \( V_c \) = Concrete volume (m3).
- \( W_s \) = Weight of steel (ton).
- \( A_f \) = Surface area of the form (m2).

Formulation of the constraints

1- Ribs shall have a depth not more than 3.5 times the minimum width of rib [6]:
2- Ribs shall not be less than 100 mm in width.
3- Slab thickness must be larger than or equal to \( \frac{1}{12} \) spacing.
4- At every section of a flexural member where tensile reinforcement is required, the area of steel reinforcement shall not be less than \( A_{S_{\min}} \) given by, \( \frac{1.4}{f_y} \times b \times d \leq A_s \) [6]:
5- At every section of a flexural member where tensile reinforcement is required, the area of steel reinforcement shall not be less than \( A_{S_{\min}} \) given by \( \frac{0.25 \sqrt{f_c}}{f_y} \times b \times d \leq A_s \) [6]:
6- Lower rib width not greater than its upper width.
7- Deflection requirements, beam depth \( \geq \frac{l}{18.5} \) [6]:
8- Maximum Spacing of Top bars (Crack control) \( Z = 999 \) MPa exterior exposure, [6]:
9- Depth from bottom to N.A not greater than depth of rib.
10- The moment capacity of the section must be greater than the applied moment of ribs and beams
11- Shear capacity of the section multiplied by (1.1) must be greater than the applied shear.
12- Sections are tension-controlled if the net tensile strain in the extreme tensile steel (\( \epsilon_t \)) is equal to or greater than 0.005 when the concrete in compression reaches its assumed strain limit of 0.003[6].

Genetic Algorithm
Genetic Algorithms (GAs) can solve such problems efficiently, and in most cases lead to the global optimum with a high probability. Holland [7], was the first who introduced the method of GAs in a systematic way. The basic ideas of analysis and design based on the principles of biological evolution in the work of Rechenberg can be found. Philosophically, GAs method are rely on theory Darwin’s of survival of the fittest.

Genetic algorithms are based on the principle of natural evolution. The three basic elements of natural evolution, reproduction, crossover, and mutation are included in the genetic algorithms search procedure. Genetic algorithms (GAs) have the following differences from the traditional methods optimization:

1- A population of points is used for starting the solution instead of a single initial point. If the number of design variables is assumed $n$, usually, the population size is taken as $2n$ to $4n$. Several points will be utilized as candidate solutions, so GAs are less likely to trap at a local optimum.

2- Genetic algorithms (GAs) use the values of the objective function the derivatives are not used.

3- In Gas, the design variables are represented by a series of binary variables in natural genetics that corresponding to the chromosomes. Thus the algorithms search method was naturally applicable for solving discrete and integer programming problems. For continuous design variables, the series length can be varied to obtain any desired resolution.

4- The objective function value corresponding to a design vector plays a key role of fitness in natural genetics.

5- In every new generation, a new group of strings is produced using randomized parents selection and crossover of the old set of strings generation. Although randomized, Genetic algorithms (GAs) are not simple random search techniques. They efficiently explore the new set with the available knowledge to obtain a new generation with better fitness (objective function) value.

![Figure (2): Genetic Algorithm Flowchart [7].](image)

**Presentation of the Problem**

In this typical application, one-way ribbed slab consists of three by three equal span length, square panels, is considered Fig.(3). The span length ($l$) is 5m, the slab is subjected to a total load representing its self-weight, a dead load of 2kN/m2, and a live load of 3kN/2. Other data are: the concrete compressive strength =28MPa,
the yield stress of steel=420MPa, the yield stress of shear reinforcement steel=275MPa, the unit weight of steel=7.85 ton/m3, the unit weight of concrete=24kN/m3, the concrete cover of ribs =20mm, the concrete cover of beam=40mm, the depth of beam is taken as to be equal to the depth of ribs, the cost of concrete per unit volume =175000 (I.D/m3 ), the cost of steel per unit weight=900000 (I.D/ton), the cost of stirrups per unit weight =600000 (I.D/ton), the stirrups bar diameter=10mm, and the cost of formwork per unit area =10000 (I.D/m2).

The design variables are taken as:

1) Slab thickness
2) Clear spacing between ribs
3) Lower width of ribs
4) Upper width of ribs
5) Negative steel reinforcement of ribs
6) Depth of ribs
7) Shear reinforcement spacing for ribs
8) Bar diameter for top slab.
9) Bar spacing for top slab.
10) The distance from lower end of ribs to the neutral axis.
11) Beams width.
12) Areas of flexural steel reinforcement at critical sections.

The solution of this problem by the genetic algorithm and simulated annealing is shown in Table (1).

Table (1): Results of Optimum Design of the Typical Application using Genetic Algorithm Method.

| Method                      | G.A |
|-----------------------------|-----|
| Slab Thickness (mm)         | 200 |
| Depth of rib (mm)           | 347 |
| Total slab Depth (mm)       | 765 |
| Spacing between Ribs (mm)   | 238 |
| Lower width of rib (mm)     | 213 |
| Upper width of rib (mm)     | 212 |
| (\(a\)) As of rib (mm²)    | 228 |
| Shear Spacing (mm)          | 271 |
| Bar Dia (Top) (mm)          | 12  |
| Bar Spacing of Top slab (mm)| 424 |
| N.A depth (mm)              | 250 |
| Beam width (mm)             | 200 |
| (\(a\)) As of beam L1 (mm²) | 1179|
| (\(a\)) As of beam L2 (mm²) | 115 |
| (\(a\)) As of beam L3 (mm²) | 147 |
| (\(a\)) As of beam L4 (mm²) | 176 |
| (\(a\)) As of beam L5 (mm²) | 125 |
| (\(a\)) As of beam L6 (mm²) | 131 |
| (\(a\)) As of beam L7 (mm²) | 786 |
| (\(a\)) As of beam L8 (mm²) | 686 |
| (\(a\)) As of beam L9 (mm²) | 593 |

| Section                      |     |
|------------------------------|-----|
| Total depth/ Span Length     | 1.7 |
| Rib Spacing/ Span Length     | 1.9 |
| Top Slab Thickness/ Rib space| 1.9 |
| Rib depth/ Lower width       | 2.657|
| Beam depth/ Beam width       | 2.286|
| Volume of Concrete (m³)      | 98.716|
| Weight of Steel (Ton)        | 12.835|
| Area of Formwork (m²)        | 577.161|
| Cost (I.D)                   | 2663579|
It can be noted from Table (1), the total slab depth to span length ratio is found to be 1/7 to obtain the optimum solution, compared to the minimum slab thickness ratio 1/18.5 stated in the code limitation for deflection controlling.

The results of Table (1) showed also that the optimum rib spacing to span length ratio is to be (1/9). The ACI-Code limitations for the joist construction state that the slab thickness to rib spacing ratio should be greater than (1/12). The optimum solution of the above problem shows that this ratio should be equal to 1/3 to get the optimum cost of the ribbed slab.

From this table it can be observed that the ratio of (depth of rib/lower rib width) and the ratio of (depth of beam/beam width) are to be (2.657) and (2.268) respectively to obtain the optimum solution. The joist construction limitations stated that the (depth of rib/lower rib width) ratio should not be greater than (3.5), which is satisfied for the above results.

**Results and Discussions**

The following presentations can be drawn from the study for the one-way ribbed slabs cases that considered:

**For the span lengths that are considered in this study (4m-12m)**, Table (2) presents the optimum values of the design variables and cost function for several span lengths using G.A the following can be noted:

1- The ratio of (total slab depth/span length) should be (1/18-1/4) using G.A to get the optimum slab design.

2- The optimum ratio of (depth of rib/lower rib width) is found to be ranged within (1.243-2.917), using G.A. Comparing to the limitation of ACI joist construction for this ratio, which is 3.5.

**Table (2):** Optimum Values of the Design Variables for Various Values of Span Length using the Genetic Algorithm.
3- The optimum (rib spacing/span length) ratio is ranged from (1/40 – 1/5) using G.A.

4- The range of the optimum (slab thickness/spacing of rib) ratio is found to be ranged as (1/4-1/2) using G.A, in order to find the optimum solution, comparing to the limitation of ACI joist construction for this ratio, which is not less than 1/12.

![Figure (4): The Optimum Costs for various Span Lengths by Using G.A Method.](image)

3- For the compressive strength of concrete values considered in this study (25MPa to 60MPa) it is concluded that:

5- The (total slab depth/span length) ratio should be within the range (1/9-1/5) using G.A, in order to obtain the optimum solution.

6- The optimum (rib spacing/span length) ratio is ranged from (1/17–1/13) using G.A.

7- The range of the optimum (slab thickness/spacing of ribs) ratio is found to be ranged as (1/3-1/2) using G.A.

8- The optimum ratio of (depth of rib/lower rib width) is within the range (1.041-2.363) using GA.
Table (3): Optimum Values of the Design Variables for Various Values of Compressive of Concrete using the Genetic Algorithm.

| Compressive of concrete (MPa) | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 |
|-------------------------------|----|----|----|----|----|----|----|----|
| Spacing of ribs (mm)          | 352| 341| 335| 337| 356| 300| 300| 301|
| Thickness slab (mm)           | 133| 138| 162| 148| 125| 123| 126| 123|
| Depth of rib (mm)             | 457| 413| 412| 415| 495| 895| 895| 824|
| Total Depth (mm)              | 570| 525| 574| 565| 1020|1019|1018|980|
| Lower width (mm)              | 460| 388| 399| 399| 399| 399| 399| 399|
| Upper width (mm)              | 408| 401| 401| 415| 420| 400| 400| 450|
| (a) AS of rib (mm)            | 170| 170| 170| 170| 170| 170| 170| 170|
| Shear spacing (mm)            | 500| 500| 500| 500| 500| 499| 499| 480|
| Bar, Dia(Top) (mm)            | 10 | 10 | 11 | 10 | 6  | 6  | 6  | 6  |
| Bar, Spacing(Top) (mm)        | 450| 450| 441| 380| 147| 144| 144| 450|
| N.A depth (mm)                | 100| 100| 100| 100| 100| 100| 100| 100|
| Beam width (mm)               | 200| 200| 200| 200| 200| 200| 200| 200|
| (a) As of beam, L_b (mm)      | 171| 141| 186| 123| 227| 114| 114| 196|
| (b) As of beam, L_b (mm)      | 114| 114| 155| 142| 148| 191| 191| 113|
| (c) As of beam, L_b (mm)      | 617| 600| 514| 148| 177| 186| 186| 132|
| (d) As of beam, L_b (mm)      | 2824|2743|2855|2434|189|132|132|113|
| (e) AS of beam (mm)           | 145| 126| 128| 115| 119| 144| 145| 115|
| (f) AS of beam, L_b (mm)      | 197| 125| 161| 113| 150| 181| 182| 222|
| (g) AS of beam, L_b (mm)      | 195| 188| 147| 140| 122| 119| 119| 207|
| (h) AS of beam, L_b (mm)      | 980| 980| 981| 921| 980| 980| 980| 980|
| (i) AS of beam, L_b (mm)      | 980| 980| 980| 980| 980| 980| 980| 980|

For the values of yield strength of steel that are considered in this study (345MPa-600MPa):

9- The (total slab depth/span length) ratio should be within the range (1/10-1/8) using G.A, in order to obtain the optimum solution.

10- The optimum (rib spacing/span length) ratio is ranged from (1/8-1/7) using G.A, for the optimum solution.

11- The range of the optimum (slab thickness.spacing of ribs) ratio is found to be ranged as (1/6-1/3) using G.A.

12- The ratio of (depth of rib/lower rib width) is ranged from (1.094-2.307), while the ratio of (depth of beam/beam width) is found to be (1.315-2.553) to obtain the optimum solution by G.A.
Table (4): Optimum Values of the Design Variables for Various Values of Yield of Strength using the Genetic Algorithm.

| Yield of Strength (MPa) | 345  | 420  | 460  | 520  | 600  |
|------------------------|------|------|------|------|------|
| Spacing of ribs (mm)   | 401  | 402  | 440  | 475  | 460  |
| Thickness slab (mm)    | 197  | 188  | 193  | 192  | 225  |
| Depth of rib (mm)      | 321  | 312  | 311  | 318  | 330  |
| Total Depth (mm)       | 500  | 500  | 644  | 615  | 553  |
| Lower width (mm)       | 279  | 285  | 280  | 219  | 290  |
| Upper width (mm)       | 279  | 285  | 380  | 230  | 300  |
| (Opt)AS of rib (mm^2)  | 340  | 309  | 117  | 117  | 353  |
| Shear spacing (mm)     | 500  | 500  | 500  | 500  | 500  |
| Bar Dia (Top) (mm)     | 6    | 6    | 6    | 6    | 6    |
| Bar Spacing (Top) (mm) | 96   | 91   | 144  | 146  | 85   |
| N.A depth (mm)         | 346  | 139  | 134  | 146  | 113  |
| Beam width (mm)        | 256  | 215  | 203  | 200  | 251  |
| (Opt) As of beam L1 (mm^2) | 116  | 123  | 196  | 165  | 236  |
| (Opt) As of beam L2 (mm^2) | 115  | 120  | 638  | 117  | 127  |
| (Opt) As of beam L3 (mm^2) | 114  | 715  | 669  | 151  | 980  |
| (Opt) As of beam L4 (mm^2) | 192  | 874  | 3440 | 3589 | 2927 |
| (Opt) As of beam L5 (mm^2) | 112  | 114  | 113  | 113  | 126  |
| (Opt) As of beam L6 (mm^2) | 123  | 1141 | 3104 | 3311 | 833  |
| (Opt) As of beam L7 (mm^2) | 133  | 313  | 149  | 118  | 167  |
| (Opt) As of beam L8 (mm^2) | 1611 | 1211 | 1437 | 859  | 1120 |
| (Opt) As of beam L9 (mm^2) | 1662 | 1162 | 1392 | 827  | 1143 |

For the values of live load that are considered in this study (2kN/m2-7kN/m2):

13- The (total slab depth/span length) ratio should be ranged (1/9-1/4) using G.A, in order to obtain the optimum solution.

14- The optimum (rib spacing/span length) ratio is ranged from (1/17– 1/9) using G.A.

15- The range of the optimum (slab thickness/spacing of ribs) ratio is found to be ranged as (1/3-1/2) using G.A.

16- The ratio of (depth of rib/lower rib width) ranged from (0.998-3.333), while the ratio of (depth of beam/beam width) is found to be (1.730-5.000) to obtain the optimum solution by G.A.
Table (5): Optimum Values of the Design Variables for Various Values of Live Load using the Genetic Algorithm.

| Live Load (kN/m²) | 1 | 3 | 4 | 5 | 6 | 7 |
|-------------------|---|---|---|---|---|---|
| Spacing of Ribs (mm) | 266 | 338 | 309 | 391 | 358 | 558 |
| Depth of rib (mm) | 247 | 200 | 230 | 164 | 199 | 192 |
| Total Depth (mm) | 581 | 545 | 1155 | 1155 | 492 | 332 |
| Lower width (mm) | 256 | 275 | 300 | 330 | 379 | 490 |
| Upper width (mm) | 556 | 215 | 409 | 400 | 400 | 400 |
| (top) NO of ribs (mm) | 117 | 218 | 184 | 233 | 233 | 244 |
| Upper spacing (mm) | 571 | 371 | 550 | 550 | 437 | 500 |
| (top) NO of beams, L (m) | 19 | 12 | 6 | 6 | 6 |
| (top) A of beam, L (mm) | 113 | 112 | 422 | 113 | 124 | 165 |
| (top) A of beam, L (mm) | 112 | 176 | 113 | 183 | 141 | 154 |
| (top) A of beam, L (mm) | 21 | 980 | 155 | 432 | 980 | 980 |
| (top) A of beam, L (mm) | 585 | 133 | 585 | 865 | 865 | 865 |

For the values of unit cost ratio (concrete cost/steel cost), that are considered in this study (0.1 - 0.35), it concluded that:

17-The (total slab depth/span length) ratio should be found (1/4) using G.A, in order to obtain the optimum solution.

18-The optimum (rib spacing /span length) ratio is ranged from (1/17 – 1/16) using G.A. The range of the optimum (slab thickness/spacing of ribs) ratio is found (1/2) using G.A.

19-The ratio of (depth of rib/lower rib width) is ranged from (2.412-2.5), while the ratio of (depth of beam/beam width) is found to be (3.859-4.000) to obtain the optimum solution by G.A.
Table (6): Optimum Values of the Design Variables for Various Values of Unit Cost using the Genetic Algorithm.

| Unit cost | 0.10  | 0.15  | 0.20  | 0.25  | 0.30  | 0.35  |
|-----------|-------|-------|-------|-------|-------|-------|
| Spacing of Ribs (mm) | 200  | 200  | 200  | 200  | 200  | 200  |
| Thickness of slab (mm) | 12.5  | 12.5  | 12.5  | 12.5  | 12.5  | 12.5  |
| Depth of slab (mm) | 500  | 500  | 500  | 500  | 500  | 500  |
| Total Depth (mm) | 150  | 150  | 150  | 150  | 150  | 150  |
| Lower width (mm) | 400  | 400  | 400  | 400  | 400  | 400  |
| Upper width (mm) | 400  | 400  | 400  | 400  | 400  | 400  |
| Cont. as of rib (mm$^3$) | 105  | 105  | 105  | 105  | 105  | 105  |
| Cont. as of beam L (mm$^3$) | 1300  | 1300  | 1300  | 1300  | 1300  | 1300  |
| Cont. as of beam L (mm$^3$) | 1300  | 1300  | 1300  | 1300  | 1300  | 1300  |
| Beam width (mm) | 250  | 250  | 250  | 250  | 250  | 250  |
| Beam thickness (mm) | 10  | 10  | 10  | 10  | 10  | 10  |
| Cost (USD) | 200  | 200  | 200  | 200  | 200  | 200  |

Figure (8): The Optimum Costs for Unit Cost Using G.A Method.

For the values of aspect ratio that are considered in this study (1- 2):

Table (7): Optimum Values of the Design Variables for Various Values of Aspect Ratio using the Genetic Algorithm.
The (total slab depth/span length) ratio should be within the range (1/10-1/7) using G.A, in order to obtain the optimum solution.

The optimum (rib spacing/span length) ratio is ranged from (1/17 – 1/7) using G.A.

The range of the optimum (slab thickness/spacing of ribs) ratio is found to be ranged as (1/6-1/2) using G.A.

The ratio of (depth of rib/lower rib width) is ranged as (1.244-2.657), while the ratio of (depth of beam/beam width) is found to be within the range (1.579-2.834) to obtain the optimum solution by G.A.

For the values formwork cost that are considered in this study that are ranged between (10,000 and 22,000) I.D, the following were concluded:
Table (8): Optimum Values of the Design Variables for Various Values of Cost formwork using the Genetic Algorithm.

| Cost Formwork (I.D) | 10000 | 15000 | 20000 | 25000 | 30000 | 35000 | 40000 | 45000 | 50000 |
|---------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Spacing of Ribs (mm)|       |       |       |       |       |       |       |       |       |
| Thickness slab (mm) |       |       |       |       |       |       |       |       |       |
| Depth of rib (mm)   |       |       |       |       |       |       |       |       |       |
| Total Depth (mm)    |       |       |       |       |       |       |       |       |       |
| Lower width (mm)    |       |       |       |       |       |       |       |       |       |
| Upper width (mm)    |       |       |       |       |       |       |       |       |       |
| (cosh) of rib (mm)  |       |       |       |       |       |       |       |       |       |
| Slab spacing (mm)   |       |       |       |       |       |       |       |       |       |
| Bar Dia (Top) (mm)  |       |       |       |       |       |       |       |       |       |
| Bar Spacing (Top)   |       |       |       |       |       |       |       |       |       |
| N.A. depth (mm)     |       |       |       |       |       |       |       |       |       |
| Beam width (mm)     |       |       |       |       |       |       |       |       |       |
| (AS) as beam, L (mm)|       |       |       |       |       |       |       |       |       |
| (AS) as beam, L (mm)|       |       |       |       |       |       |       |       |       |
| (P) as beam, L (mm) |       |       |       |       |       |       |       |       |       |
| (P) as beam, L (mm) |       |       |       |       |       |       |       |       |       |
| Beam spacing (mm)   |       |       |       |       |       |       |       |       |       |
| Total Depth Span    |       |       |       |       |       |       |       |       |       |
| Slab Thickness      |       |       |       |       |       |       |       |       |       |
| Ribs depth/Lower rib|       |       |       |       |       |       |       |       |       |
| Beam depth/Beam width|       |       |       |       |       |       |       |       |       |

24- The (total slab depth/span length) ratio should be within the range (1/9-1/4) using G.A, in order to obtain the optimum solution.

25- The optimum (rib spacing/span length) ratio is ranged from (1/17–1/12) using G.A, for the optimum solution. The range of the optimum (slab thickness-spacing of ribs) ratio is found (1/3-1/2) using G.A.

26- The ratio of (depth of rib/lower rib width) ranged from (1.070-3.500), while the ratio of (depth of beam/beam width) is found to be (1.768-3.999) to obtain the optimum solution by G.A.

![Figure (10): The Optimum Costs for Cost Formwork Using G.A Method.](image)

Conclusions

1- When the results of the optimum design of one-way ribbed slabs are compared with the two-way ribbed slabs and four cases of flat slabs found in table(9), it is concluded that: For the range of span
length (7-12) m, the one way ribbed slab is more economical than the two ribbed slab, and it can be observed for span (12)m the one way ribbed slab is more economical than the flat slab without edge beam, and for span (10)m the one way ribbed slab is more economical than the flat slab with edge beam and flat plate with and without edge beam.

2- It can be observed from figure (4) that the cost of slab increases as the span length increases.

3- Using of concrete compressive strength equal to 28MPa with steel yield strength of 420MPa, gives the smallest amount of concrete and steel reinforcement.

4- It can be observed from figure (5) that the cost increases by increasing the compressive strength of concrete.

5- The using of yield strength of steel (345-600) MPa with concrete compressive strength 28MPa will give the values of concrete volume and steel weight increases by increase the yield of steel expect 520MPa using G.A.

6- Figure (6) represents the optimum cost values obtained using G.A, it can be observed that the optimum cost of slab is obtained with fy=345MPa and fc' =28MPa.

7- Figure (7), it can be showed the cost increases by increase the live load is ranged from (2-5)KN/m2, and begin decreases at live load (6-7)KN/m2.

8- Figure (8, 9, 10), it can be observed when the parameters increases the cost increase.

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