Optimum Design of Reinforced Concrete Flat Slabs

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ABSTRACT

This paper deals with the problem of optimum design of reinforced concrete flat slabs by genetic algorithm. Four case studies are discussed; flat slabs with and without edge beams, and, flat-plate with and without edge beams. The cost function represents the cost of concrete, steel reinforcement, and formwork. The design variables are: the effective depth of the slab, dimensions of drop panel, the area of flexural reinforcement at the critical sections of slab, and of edge beams. The constraints are taken on slab dimensions, and area of steel reinforcements. The results showed that the optimum ratio of (effective depth /span length) are within the ranges (1/39-1/27) for flat slabs without edge beams, (1/43-1/30) for flat slabs with edge beams , (1/30-1/23) for flat-plate without edge beams and (1/35-1/25) for flat-plates with edge beams. It is also found, that for same span length, the flat slab without edge beams is more economical slab types.

Keywords: optimum design, genetic algorithms, flat slabs, flat plates, reinforced concrete slabs.

التصميم الامثل للسقوف الخرسانية المسلحة المسطحة باستخدام الخوارزميات الجينية

الخلاصة

يتركز موضوع هذه الدراسة على حل مسألة التصميم الانشائي الامثل للسقوف الخرسانية المسطحة والالواح المسطحة باستخدام الخوارزميات الجينية. المسائل التي درست شملت اربع حالات: الحالة الاولى تمثل سقف مسطح بدون جسور خارجية والحالة الثانية تمثل سقف مسطح مع جسور خارجية الحالة الثالثة تمثل لوح مسطح بدون جسور خارجية اما الحالة الرابعة فتمثل لوح مسطح مع جسور خارجية. دالة الهدف في هذه الدراسة عبرت عن كلفة الخرسانة وكلفة حديد التسليح وكذلك كلفة القالب للسقف بأكمله. وحددت متغيرات التصميم بما يلي: العمق الفعال للسقف، ابعاد الجزء النازل، وحديد التسليح للانحناء في مناطق العزوم القصوى وكذلك حديد التسليح للجسور الخارجية في حاله وجودها. اما المقيدات فقد شملت مقيدات على ابعاد السقف وكمية حديد التسليح. بينت النتائج المستحصلة من الدراسة بأن نسبة العمق الفعال الى طول الفضاء يجب ان تكون (1/39-1/27) للوصول للتصميم الامثل للسقوف المسطحة بدون جسور خارجية بينما في حالة السقوف المسطحة مع جسور جانبية فيجب ان تكون النسبة (1/43-1/30). اما في حالة الالواح المسطحة بدون جسور خارجية فان هذه النسبة تكون (1/30-1/23) و (1/35-1/25) في حالة وجود الجسور الجانبية.

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Notations

A_f	Surface area of the form (mm^2)
A_{sadd}	Additional reinforcement in negative reinforcement of column strip
A_{sb}	reinforcement in the edge beams
A_{sc+}	positive reinforcement in the column strip
A_{sc-1}	exterior negative reinforcement in the column strip
A_{sc-2}	interior negative reinforcement in the column strip
A_{sm-}	negative reinforcement in the middle strip
A_{sm+}	positive reinforcement in the middle strip
b	strip width.
C	Total cost function
C_c	Cost of concrete per unit volume (I.D/mm^3)
C_f	Cost of formwork per unit area (I.D/mm^2)
C_s	Cost of steel per unit mass (I.D/ton)
d_b	effective depth of the beam.
db	effective depth of beam
ln	the clear span in the long direction (m)
m_b	maximum moment along the beam.
mb	maximum moment in beam
mc_1	Exterior negative moment in column strip.
mc_2	Interior negative moment in column strip.
mc_3	Positive moment in column strip.
mm_1	Negative moment in middle strip.
mm_2	Positive moment in middle strip.
m_u	ultimate applied moment at the specified section.
Q_c	Concrete volume (mm^3)
t_t	Ratio of concrete cover to effective depth of the slab
w_b	width of the beam.
wb	width of beam
W_s	Weight of steel (ton)

INTRODUCTION

A flat slab floor is a reinforced concrete slab supported directly by concrete columns without the use of intermediary beams. The slab may be of constant thickness throughout or, in the area of column it may be thickened as a drop panel. The column may also has a constant section or it may be flared to form a column head or capital (Figure1(a,b)). The drop panels are effective in reducing the shearing stresses where the column is liable to punch through the slab, and they also provide an increased moment resistance where the negative moments are greatest. Sahab et al. (2005) presented cost optimization of reinforced concrete flat slab buildings according to the British-Code of Practice (BS8110). The objective function was the total cost of the building including the cost of floors, columns and foundations. The cost of each structural element covered that of material and labor for reinforcement, concrete and formwork. Cost optimizations for three reinforced concrete flat slab buildings were illustrated and the results of the optimum and conventional design procedures were compared. The design optimization of three reinforced concrete flat slab buildings with different structural features and number of story was illustrated and the following conclusions were drawn: the greater the number of story in the reinforced concrete flat slab building, in other words, the greater the number of structural elements, the greater the cost savings achieved using design optimization, and the column layout optimization of flat slab buildings can produce substantial savings as regards the total structural cost of the building, and cost of floors constitutes the major part of the total structural cost of reinforced concrete flat slab buildings. AL-Tabtabai et al. (1999) proposed a method to design cost- optimum slab formwork components. They applied Genetic Algorithm technique to solve this optimization problem. The cost of form components and labor involved were considered for the formulation of the objective function. The bending moment, shear, maximum deflection, imposed ACI- code provisions, were used as constraints for the optimization problem. A new approach to design the concrete slab formwork using Genetic Algorithm was proposed in this paper. The objective is to design the formwork in a most economical way with maximum functionality. Ibrahim (1999) used mathematical programming techniques to minimize the cost of reinforced concrete T-beam floor. The floor system consisted of one-way continuous slab and simply supported T-beam. A formulation based on an elastic analysis and the ultimate strength method of design with the consideration of serviceability constraints as per ACI 318-89 code is presented. The formulation of optimization problem had been made by utilizing the interior penalty function method as an optimization method with the purpose of minimizes the objective function representing the cost of one-meter length of the floor system. This cost included cost of concrete, reinforcement, and formwork. The design variables considered were, the dimensions and the amounts of reinforcement for the slab and beams in addition to the spacing between the beams. The effect of various parameters on the optimum design had also been studied. These parameters were the compressive strength of concrete, yield strength of steel, concrete cost ratios, and formwork cost ratios. Galeb and Atiya [5] (2010) dealt with the problem of optimum design of reinforced concrete waffle slabs using genetic algorithms. Two case studies are discussed; the first is a waffle slab with solid heads, and the second is a waffle slab with band beams along column centerlines. Direct design 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 the effective depth of the slab, ribs width, the spacing between ribs, the top slab thickness, the area of flexural reinforcement at the moment critical sections, the band beams width, and the area of steel reinforcement of the beams. The constraints include the constraints on dimensions of the rib, and the constraints on the top slab thickness, the constraints on the areas of steel reinforcement to satisfy the flexural and the minimum area requirements, the constraints on the slab thickness to satisfy flexural behavior, accommodate reinforcement and provide adequate concrete cover, and the constraints on the longitudinal reinforcement of band beams. Results that obtained were showed that the population size of genetic algorithm, affects the obtained optimum solution. Also, it was concluded that, for waffle slab with solid heads, the ratio of effective depth to span length should be (1/28 to 1/19) to get the optimum design, while for waffle slab with band beams along columns centerlines, it should be (1/33 to 1/18).

The aim of this study is to solve the problem of the optimum structural design of reinforced concrete flat slabs and flat plate using the genetic algorithm. Specifying the optimum values of the various design variables are also one of the main objectives of this study.

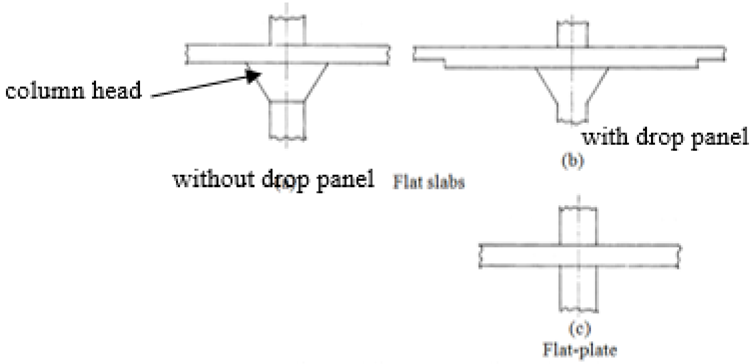


Figure (1) Flat Slab and Flat Plate Systems

Formulation of the Optimization Problem
Case (1) Flat slab without edge beam
Formulation of the Objective Function

The cost 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:

$$C = C_C \times (Q_C) + C_S \times (W_S) + C_f \times (A_f) \quad \ldots(1)$$

where,
C= Total cost function
C_c= Cost of concrete per unit volume (I.D/mm3)
C_s=Cost of steel per unit mass (I.D/ton)
C_f= Cost of formwork per unit area (I.D/mm2)
Q_c= Concrete volume (mm3)
W_s= Weight of steel (ton)
A_f= Surface area of the form (mm2)

Formulation of the Constraints:

The following limitations are considered as constraints:

1- For slabs without interior beam spanning between the supports and having a ratio of long to short span not greater than 2, the minimum thickness shall be in accordance with the provisions of Table (1) and shall not be less than (100 mm),i.e.,

$$h \geq 100mm$$

$$0.100 \leq (1+t_t) \times d$$

$$g_1 = 1 - \frac{(1+t_t) \times d}{0.1} \leq 0 \quad \ldots(2)$$

From Table (1), the minimum slab thickness for an exterior panel with drop panel and without edge beam, can be found using linear interpolation as ln /33, so,

$$h = \frac{ln}{33}$$

$$g_2 = \frac{ln}{33} - (1+t_t) \times d \leq 0$$

$$g_2 = 1 - (1 + t_t) \times \frac{33d}{\ln} \leq 0 \quad \dots (3)$$

where,
ln =the clear span in the long direction (m)
t_t= Ratio of concrete cover to effective depth of the slab
2- At every section of a flexural member where tensile reinforcement is required, the area of steel reinforcement shall not be less than A_{Smin} given by:

$$A_{S\min} = \frac{0.25 \times \sqrt{f_c^{'}}}{f_y} \times b \times d \quad \dots (4)$$

or

$$A_{S\min} = \frac{1.4 \times b \times d}{f_y} \quad \dots (5)$$

$$A_S \geq A_{S\min}$$

$$A_{S\min} - A_S \leq 0$$

$$g_3 = 1 - \frac{\mathrm{A_{sc\text{-}1}} \times f_y}{0.25 \times \sqrt{f_c^{'}} \times b \times d} \leq 0 \quad \dots (6)$$

$$g_4 = 1 - \frac{\mathrm{A_{sc\text{-}2}} \times f_y}{0.25 \times \sqrt{f_c^{'}} \times b \times d} \leq 0 \quad \dots (7)$$

$$g_5 = 1 - \frac{\mathrm{A_{sc+}} \times f_y}{0.25 \times \sqrt{f_c^{'}} \times b \times d} \leq 0 \quad \dots (8)$$

$$g_6 = 1 - \frac{\mathrm{A_{sm\text{-}}} \times f_y}{0.25 \times \sqrt{f_c^{'}} \times b \times d} \leq 0 \quad \dots (9)$$

$$g_7 = 1 - \frac{\mathrm{A_{sm+}} \times f_y}{0.25 \times \sqrt{f_c^{'}} \times b \times d} \leq 0 \quad \dots (10)$$

where
$A_{sc\text{-}1}$: exterior negative reinforcement in the column strip
$A_{sc\text{-}2}$: interior negative reinforcement in the column strip
A_{sc+}: positive reinforcement in the column strip
$A_{sm\text{-}}$: negative reinforcement in the middle strip
A_{sm+}: positive reinforcement in the middle strip
As same as above, constraints (g_8 , g_9 ,g_{10} ,g_{11} ,g_{12}) for steel area in short direction can be found.

3- Sections are tension-controlled if the net tensile strain in the extreme tensile steel (ε_t) is equal to or greater than 0.005 when the concrete in compression reaches its assumed strain limit of 0.003.

$$\varepsilon_t > 0.005$$

$$\varepsilon_t = \left(\frac{0.003}{c_t}\right) \times d - 0.003 \qquad \ldots(11)$$

$$c_t = \left(\frac{\dfrac{A_S \times f_y}{0.85 \times f_c^{'} \times b}}{\beta_1}\right)$$

$$\left(\left(\frac{0.003}{\dfrac{A_S \times f_y}{0.85 \times \beta_1 \times f_c^{'} \times b}}\right)\right) \times d - 0.003 - 0.005 > 0$$

$$g_{13} = \left(\left(\frac{0.003}{\dfrac{A_S \times f_y}{0.85 \times \beta_1 \times f_c^{'} \times b}}\right)\right) \times d - 0.008 > 0$$

$$g_{13} = 0.008 - \left(\left(\frac{0.003}{\dfrac{A_S \times f_y}{0.85 \times \beta_1 \times f_c^{'} \times b}}\right)\right) \times d \le 0$$

$$g_{13} = 1 - \frac{0.31875 \times \beta_1 \times f_c^{'} \times b \times d}{\mathrm{A_{sc\text{-}1}} \times f_y} \le 0 \qquad \ldots(12)$$

$$g_{14} = 1 - \frac{0.31875 \times \beta_1 \times f_c^{'} \times b \times d}{\mathrm{A_{sc\text{-}2}} \times f_y} \le 0 \qquad \ldots(13)$$

$$g_{15} = 1 - \frac{0.31875 \times \beta_1 \times f_c^{'} \times b \times d}{\mathrm{A_{sc+}} \times f_y} \le 0 \qquad \ldots(14)$$

$$g_{16} = 1 - \frac{0.31875 \times \beta_1 \times f_c^{'} \times b \times d}{\mathrm{A_{sm-}} \times f_y} \le 0 \qquad \ldots(15)$$

$$g_{17} = 1 - \frac{0.31875 \times \beta_1 \times f_c' \times b \times d}{\mathrm{A}_{\mathrm{sm+}} \times f_y} \le 0 \qquad \ldots(16)$$

As same as above, constraints (g_{18}, g_{19}, g_{20}, g_{21}, g_{22}) for steel area in short direction can be derived.

4- The moment capacity of any section must be greater than the applied moment i.e., $M \ge M_i$

$$M = \phi \rho b d^2 f_y \left(1 - 0.59 \rho \frac{f_y}{f_c'}\right)$$

$$M = \phi \frac{A_S}{b \times d} b d^2 f_y \left(1 - 0.59 \frac{A_S}{b \times d} \frac{f_y}{f_c'}\right)$$

$$g_{23} = 1 - \frac{1}{m_u}\left[\phi A_S d \ f_y \left(1 - 0.59 \frac{A_S}{b \times d} \frac{f_y}{f_c'}\right)\right] \le 0 \qquad \ldots(17)$$

Where:

m_u= ultimate applied moment at the specified section.

so,

$$g_{23} = 1 - \frac{1}{mc_1}\left[\phi A_{sc-1} \times d \times f_y \left(1 - 0.59 \frac{A_{Sc-1}}{b \times d} \frac{f_y}{f_c'}\right)\right] \le 0 \qquad \ldots(18)$$

$$g_{24} = 1 - \frac{1}{mc_2}\left[\phi A_{sc-2} \times d \times f_y \left(1 - 0.59 \frac{A_{Sc-2}}{b \times d} \frac{f_y}{f_c'}\right)\right] \le 0 \qquad \ldots(19)$$

$$g_{25} = 1 - \frac{1}{mc_3}\left[\phi A_{sc+} \times d \times f_y \left(1 - 0.59 \frac{A_{Sc+}}{b \times d} \frac{f_y}{f_c'}\right)\right] \le 0 \qquad \ldots(20)$$

$$g_{26} = 1 - \frac{1}{mm_1}\left[\phi A_{sm-} \times d \times f_y \left(1 - 0.59 \frac{A_{sm-}}{b \times d} \frac{f_y}{f_c'}\right)\right] \le 0 \qquad \ldots(21)$$

$$g_{27} = 1 - \frac{1}{mm_2}\left[\phi A_{sm+} \times d \times f_y \left(1 - 0.59 \frac{A_{sm+}}{b \times d} \frac{f_y}{f_c'}\right)\right] \le 0 \qquad \ldots(22)$$

As same as above, constraints (g_{28}, g_{29}, g_{30} ,g_{31} ,g_{32}) for steel area in short direction can be formulated.

where,

mc_1=Exterior negative moment in column strip.

mc_2=Interior negative moment in column strip.

mc_3=Positive moment in column strip.
mm_1=Negative moment in middle strip.
mm_2=Positive moment in middle strip.
b = strip width.

5- Punching Shear Constraint:
The two-way shear strength of slab section must be greater than the applied shear stress at the critical section.
At distance (d/2) from face of drop panel for corner column.

$$\frac{\phi}{3}\times\sqrt{f_c'}\times b_o\times d \geq Vu$$

$$g_{33} = 1 - \frac{\frac{0.7}{3}\left[\left(l_1' + d/2\right) + \left(l_2' + d/2\right)\right]\times d}{\left\{0.25\times l_{p1}\times l_{p2} - \left[\left(l_1' + d/2\right) + \left(l_2' + d/2\right)\right]\right\}\times Facctored\ Load} \leq 0 \quad \ldots(22)$$

At distance (d_1/2) from face of corner column.

$$g_{34} = 1 - \frac{\frac{0.7}{3}\left[\left(c_1 + d_1/2\right) + \left(c_2 + d_1/2\right)\right]\times d}{\left\{0.25\times l_{p1}\times l_{p2} - \left[\left(c_1 + d_1/2\right) + \left(c_2 + d_1/2\right)\right]\right\}\times FacctoredLoad} \leq 0 \quad \ldots(23)$$

d_1 = effective depth of drop panel
c_1 and c_2 = dimensions of column.

6) Dimensions of drop panel

$$\frac{lp}{3} \leq Ld \leq \frac{lp}{2}$$

$$\frac{hs}{4} \leq t_d \leq \frac{hs}{2}$$

$$g_{35} = 1 - \frac{6\,l_1'}{lp_1} \leq 0 \quad \ldots(24)$$

$$g_{36} = 1 - \frac{6\,l_2'}{lp_2} \leq 0 \quad \ldots(25)$$

$$g_{37} = 1 - \frac{4\,t_d}{l(1+t_t)\,d} \leq 0 \quad \ldots(26)$$

Now, the optimization problem can be stated as follows:
Find the values of the design variables (d, L_d, w_d, t_d) and (A_{sc-1} , A_{sc-2} , A_{sc+}, A_{sm-} , A_{sm+}) in long and short direction , which minimize the cost function (C) under the constraints ($g_1$to g_{37}) stated above.

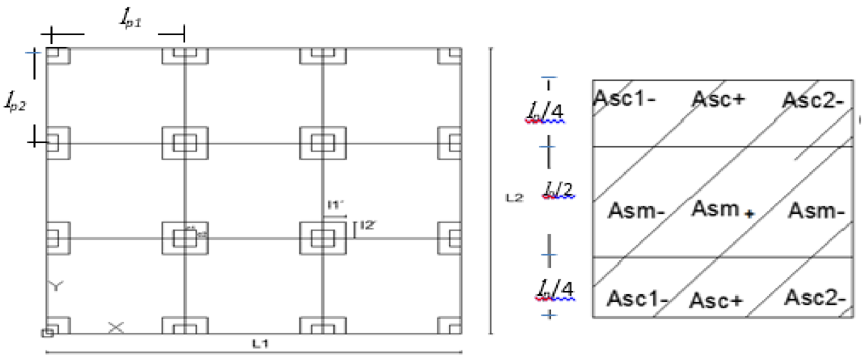


Figure (2) Definitions of the Design Variables

Case (2) Flat slab with edge beam

Cost Function

As in the previous case (1), the total cost function is stated as:

$$C = C_C \times (Q_C) + C_S \times (W_S) + C_f \times (A_f) \qquad \ldots(27)$$

Formulation of the Constraints

1- The minimum thickness shall be in accordance with the provisions of Table (1) and shall not be less than (100 mm),i.e.,

$$h \geq 100mm$$

$$0.100 \leq (1+t_t) \times d$$

$$g_1 = 1 - \frac{(1+t_t) \times d}{0.100} \leq 0 \qquad \ldots(28)$$

From Table (1), the minimum slab thickness for an exterior panel with drop panel and without edge beam, can be found using linear interpolation as ln /36, so,

$$h = \frac{l_n}{36}$$

$$g_2 = 1 - \frac{36}{l_n} - (1+t_t)\, d \leq 0 \qquad \ldots(29)$$

The constraints from (g_3 to g_{37}) as the same previous case (1) for flat slab, (punching shear check for interior column) .

2) Reinforcement of edge beam

$$g_{38} = 1 - \frac{1}{m_b}\left[\phi A_{sb+} \times db \times fy\left(1 - 0.59 \frac{A_{sb+}}{wb \times d} \times \frac{fy}{f_c^{'}}\right)\right] \leq 0 \qquad \ldots(30)$$

where;

m_b =maximum moment along the beam.

d_b = effective depth of the beam.

w_b= width of the beam.

A_{sb} =reinforcement in the edge beams

Case (3) Flat Plate without Edge Beam
Cost Function
As in the previous case, the total cost function is stated as:

$$C = C_C \times (Q_C) + C_S \times (W_S) + C_f \times (A_f) \quad \ldots(31)$$

Formulation of the Constraints
1- For slabs without interior beam spanning between the supports and having a ratio of long to short span not greater than 2, the minimum thickness shall be in accordance with the provisions of Table (1) and shall not be less than (125 mm),i.e.,

$$h \geq 125mm$$
$$0.125 \leq (1 + t_t) \times d$$
$$g_1 = 1 - \frac{(1 + t_t) \times d}{0.125} \leq 0 \quad \ldots(31)$$

From Table (1), the minimum slab thickness for an exterior panel with drop panel and without edge beam, can be found using linear interpolation as:

$$h = \frac{l_n}{30}$$
$$g_2 = 1 - \frac{(1 + t_t) \times d \times 30}{l_n} \leq 0 \quad \ldots(32)$$

The constraints from (g_3 to g_{33}) are as the same previous case for flat slab, (punching shear check for one case at distance d/2 from column).

2) Additional reinforcement at slab –column connection for a direct transfer of moment to column, it is necessary to concentrate part of steel reinforcement in column strip with effective width (column width +3h_s).

$$g_{34} = 1 - \frac{1}{m_f}\left[\phi As_{add} \times d \times fy\left(1 - 0.59\frac{As_{add}}{c2 + 3hs \times d}\frac{fy}{f_c'}\right)\right] \leq 0 \quad \ldots(33)$$

where

$$m_f = \gamma_f \times M_u$$

A_{sadd} =Additional reinforcement in negative reinforcement of column strip
3) Check shear stress due to.

The shear stress produced by the portion of unbalanced moment (Mu), must be combined with the shear stress produced by shearing force due to vertical load, for corner column.

$$v_u = \frac{V_u}{A_c} + \frac{\gamma_v M_u c_1}{J}$$

$$\frac{J}{c} = \frac{2b_1^2 \times d\left(b_1 + 2b_2\right) + d^3\left(2b_1 + b_2\right)}{6b_1}$$

$A_c = (2b_1+b_2\ )d$

$$v_u = \frac{V_u \times (0.25 \times l_{p1} \times l_{p2} - b_1 \times b_2)}{A_c} + \frac{\gamma_v M_u c_1}{J} = R + K$$

$$\frac{\phi}{3}\sqrt{f_c^{'}} \geq R + K$$

$$g_{35} = 1 - \frac{\frac{\phi}{3}\sqrt{f_c^{'}}}{R + K} \leq 0 \qquad \ldots(34)$$

Case (4) Flat Plate with Edge Beam Cost Function

As in the previous case (3), the total cost function is stated as:

$$C = C_C \times \left(Q_C\right) + C_S \times \left(W_S\right) + C_f \times \left(A_f\right) \qquad \ldots(35)$$

Formulation of the Constraints

1- For slabs without interior beam spanning between the supports and having a ratio of long to short span not greater than 2, the minimum thickness shall be in accordance with the provisions of Table (4-1) and shall not be less than (125 mm),i.e.,

$$h \geq 125mm$$

$$0.125 \leq \left(1 + t_t\right) \times d$$

$$g_1 = 1 - \frac{\left(1 + t_t\right) \times d}{0.125} \leq 0 \qquad \ldots(36)$$

From Table (1), the minimum slab thickness for an exterior panel with drop panel and without edge beam, can be found using linear interpolation as

$$h = \frac{l_n}{33}$$

$$g_2 = 1 - (1 + t_t) \times d\,\frac{33}{l_n} \leq 0 \qquad \ldots\ldots(37)$$

The constraints from (g_3 to g_{34}) are as the same previous case (2) for flat plate.

2) Reinforcement of edge beam

$$g_{38} = 1 - \frac{1}{m_b}\left[\phi A_{sb+} \times d_b \times fy\left(1 - 0.59\frac{A_{sb+}}{w_b \times d} \times \frac{fy}{f_c^{'}}\right)\right] \leq 0 \qquad \ldots(38)$$

Where;

m_b =maximum moment in beam
d_b = effective depth of beam
w_b= width of beam

3) Check shear stress due to.
The shear stress produced by the portion of unbalanced moment (mv), must be combined with the shear stress produced by shearing force due to vertical load, for interior column.

$$v_u = \frac{V_u}{A_c} + \frac{\gamma_v M_u c_1}{J}$$

$$\frac{J}{c} = \frac{2b_1^2 \times d\left(b_1 + 2b_2\right) + d^3\left(2b_1 + b_2\right)}{6b_1}$$

$Ac = (2b_1+b_2)\, d$

$$v_u = \frac{V_u \times (0.25 \times l_{p1} \times l_{p2} - b_1 \times b_2)}{A_c} + \frac{\gamma_v M_u c_1}{J} = R + K$$

$$\frac{\phi}{3}\sqrt{f_c^{'}} \geq R + K$$

$$g_{35} = 1 - \frac{\frac{\phi}{3}\sqrt{f_c^{'}}}{R + K} \leq 0 \qquad \text{……(36)}$$

Genetic Algorithm

Genetic Algorithms (GAs) are global optimization techniques developed by John Holland in 1975 (Sivanandam, S.N., 2008) . They belong to the family of evolutionary algorithms that search for solutions to optimization problems by "evolving" better and better solutions. A genetic algorithm begins with a "population" of solutions and then chooses "parents" to reproduce. During reproduction, each parent is copied, and then parents may combine in an 0analog to natural crossbreeding, or the copies may be modified, in an analog to genetic mutation. The new solutions are evaluated and added to the population, and low quality solutions are deleted from the population to make room for new solutions. As this process of parent selection, copying, crossbreeding, and mutation is repeated, the members of the population tends to get better. When the algorithm is halted, the best member of the current population is taken as the solution to the problem posed. Then, the genetic algorithm loops over an iteration process to make the population evolve. Each iteration consists of the following steps:

1) Selection: the first step consists of selecting individuals for reproduction. This selection is
done randomly with a probability depending on the relative fitness of the individuals so that
best ones are often chosen for reproduction than poor ones.

2) Reproduction: in the second step, offspring is bred by the selected individuals. For generating new chromosomes, the algorithm can use both recombination and mutation.

3) Evaluation: then the fitness of the new chromosomes is evaluated.
4) Replacement: during the last step, individuals from the old population are killed and replaced by the new ones.
The algorithm is stopped when the population converges toward the optimal solution. The Genetic Algorithm process is described through the flowchart in Figure (3).

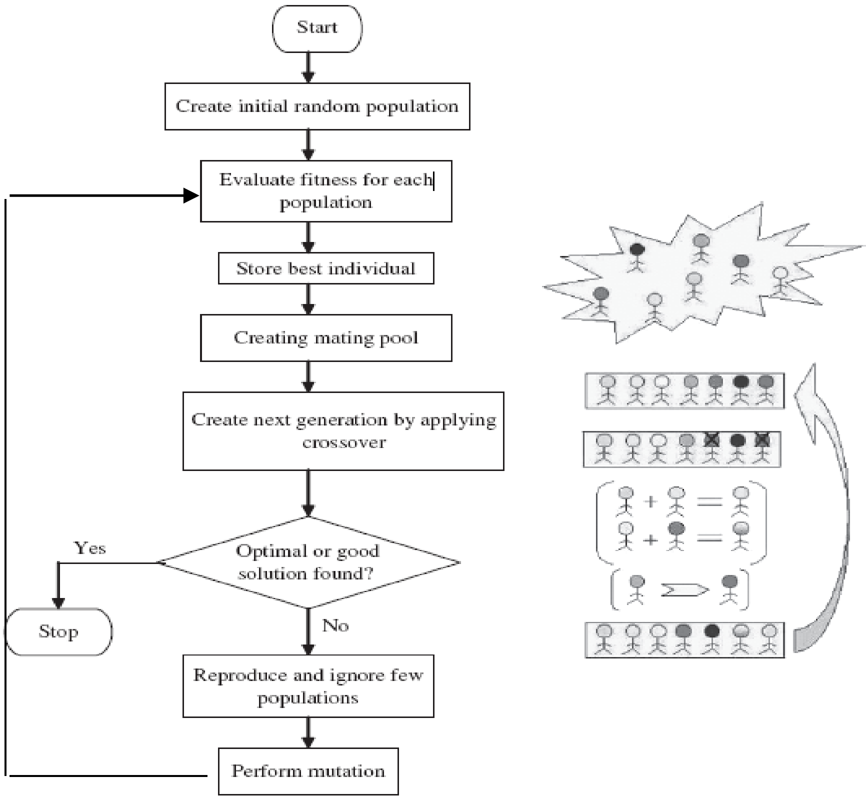


Figure (3) Flowchart of Genetic Algorithm

Results and Discussions

The above four cases were studied and solved using simple genetic algorithm. The built-in toolbox of Matlab software is utilized to perform the genetic algorithm. A discussion and comparison among the results are presented here.
Figure (4) shows the change in total cost of the four types of slabs with span length under a 3kN/m2 live load. It can be noted from this figure that the flat slab without edge beam is more economical than the other three types for the specified range of span length (6-15m). It may be also noted that the difference in total cost increases as the span length increases.

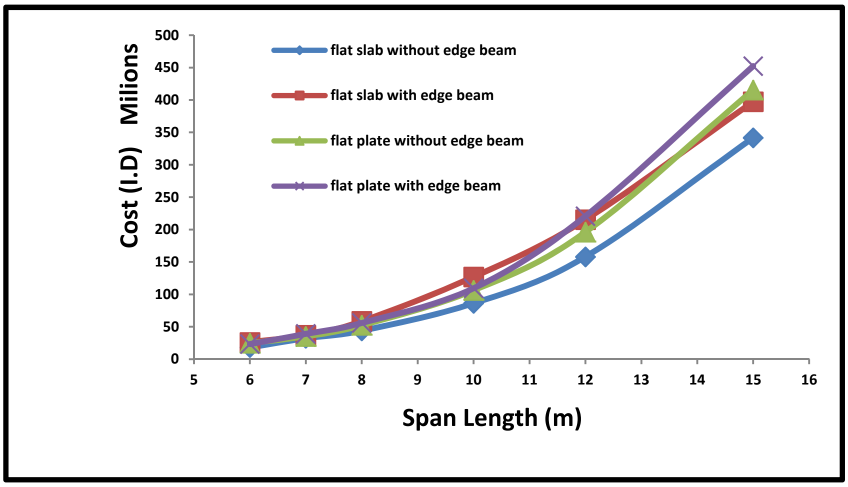


Figure (4) Cost Versus Span Length

Figure (5) shows the change in total cost of the four types of slabs with column size changing under a 3kN/m2 live load, for span length=6m. It can be noted from this figure that the flat slab without edge beam is more economical than the other three types for the specified range of column sizes (300-600mm).

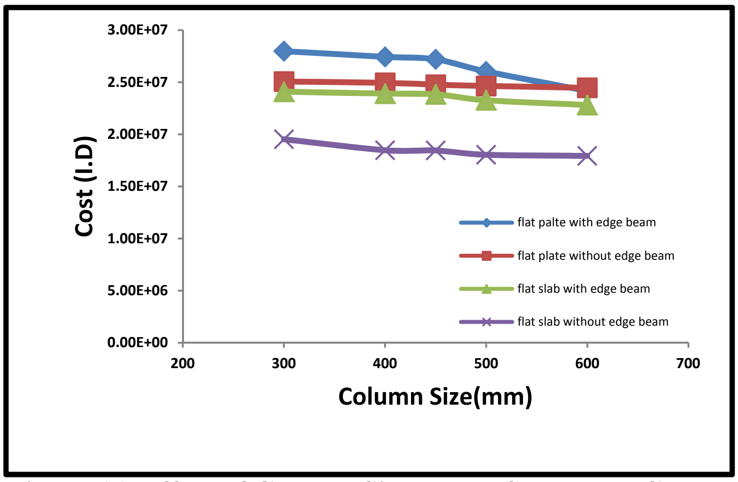


Figure (5) Effect of Column Size on the Slab Total Cost

In order to illustrate the effect of the unit costs of the concrete and steel, the cost function can be written in the following form:

$$\frac{C}{C_S} = \frac{C_C}{C_S} \times (Q_C) + (W_S) + \frac{C_f}{C_S} \times (A_f)$$

Figure (6) shows that the increasing of the ratio $\left(C_C / C_S\right)$ leads to decrease the total slab cost.

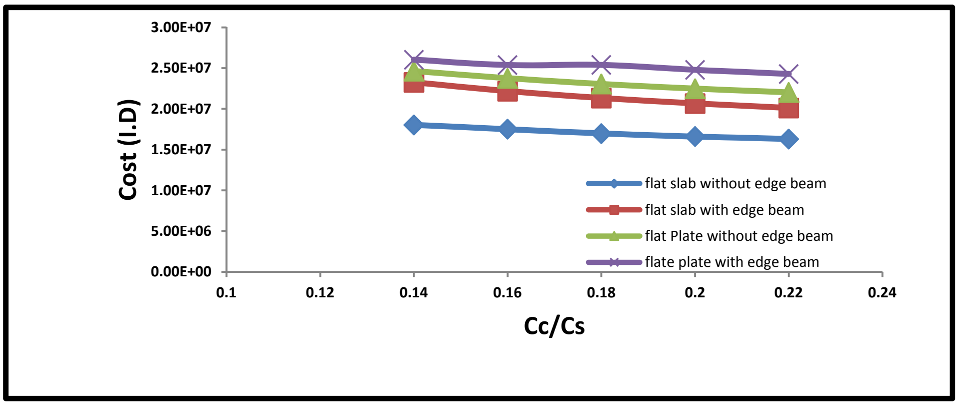


Figure (6): Effect of Material Costs Ratio

Figure (7) shows that the changing in the material costs ratio has a little effect on the effective depth of the slab.

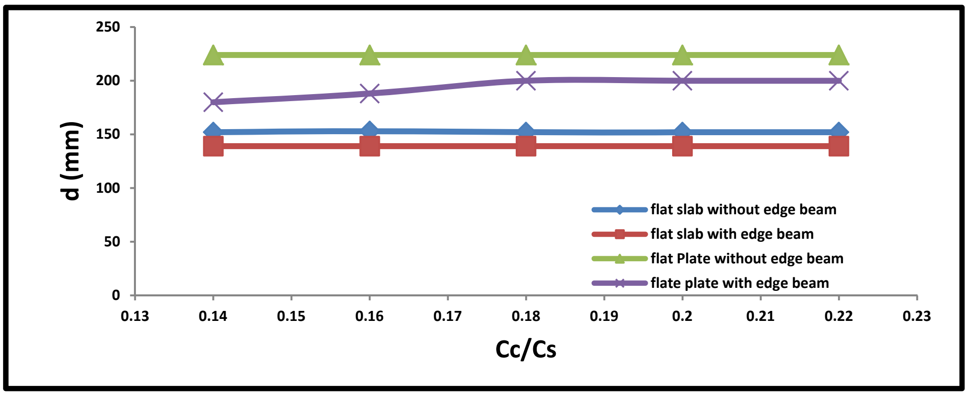
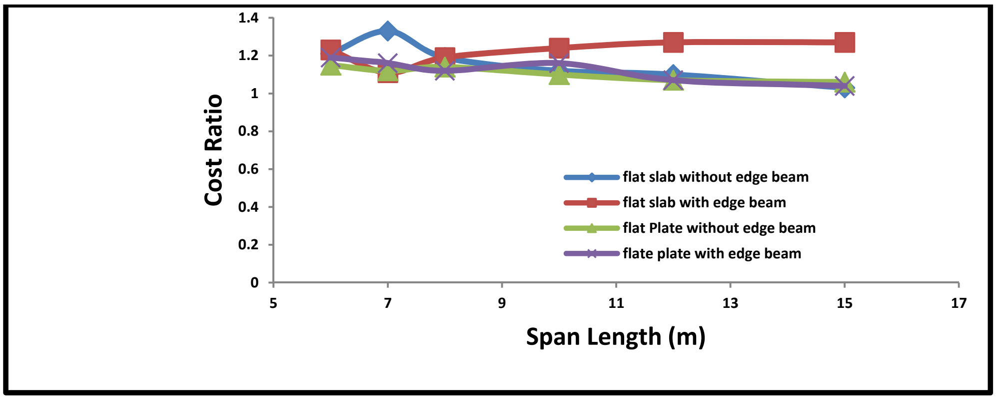


Figure (7): Effective Depth Versus Material Costs Ratio

In order to study the effect of cost of formwork on the optimum solution, the cost function can be written in the following form:

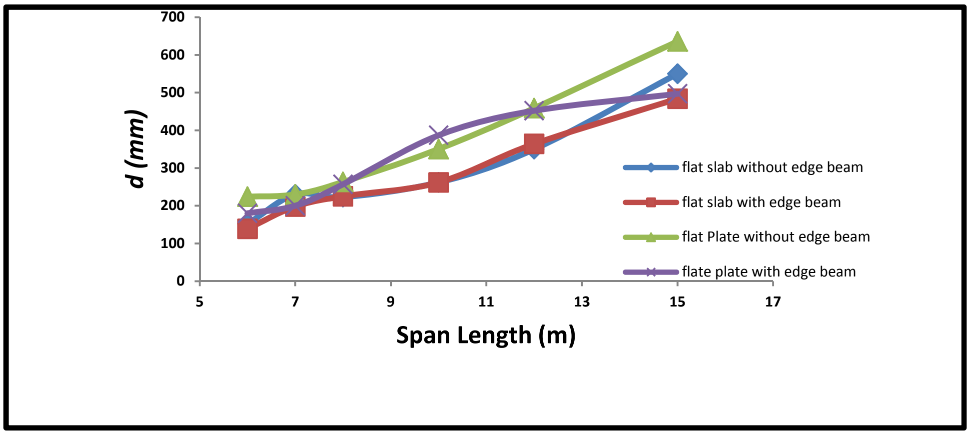
$$C = C_C \times (Q_C) + C_S \times (W_S)$$



Figure(8): Cost Ratio Variation with Span Lengt

Figure (8) shows the optimum ratio of the total cost of the slab including cost of formwork to the total cost of the slab without the cost of formwork.

Figure (9) shows the optimum values of the slab effective depth versus the span length. It may be noted that the flat slab with edge beam has the smaller effective depth.



Figure(9): Slab Effective Depth Versus Span Length

Table (2) presents the optimum values of the ratio of the effective depth of the slab to span length. It may be noted that for flat slab without edge beam, the ratio should be ranged between 1/39 and 1/27 to get the optimum design of the slab, for the specified span length range (6-15m). While, for the flat slab with edge beams, the optimum ratio should be in the range (1/43-1/30). For the flat plates without edge beams, the optimum design will be obtained when the ratio is in the range (1/30-1/23) and for flat plate with edge beams it should be in the range (1/35-1/25).

Table (1) Minimum Thickness of Slabs without Interior Beams

f_y (MPa)	Without drop panels			With drop panels		
	Exterior panels		Interior panels	Exterior panels		Interior panels
	Without edge beams	With edge beam		Without edge beams	With edge beams	
280	$\frac{\ell_n}{33}$	$\frac{\ell_n}{36}$	$\frac{\ell_n}{36}$	$\frac{\ell_n}{36}$	$\frac{\ell_n}{40}$	$\frac{\ell_n}{40}$
420	$\frac{\ell_n}{30}$	$\frac{\ell_n}{33}$	$\frac{\ell_n}{33}$	$\frac{\ell_n}{33}$	$\frac{\ell_n}{36}$	$\frac{\ell_n}{36}$
520	$\frac{\ell_n}{28}$	$\frac{\ell_n}{31}$	$\frac{\ell_n}{31}$	$\frac{\ell_n}{31}$	$\frac{\ell_n}{34}$	$\frac{\ell_n}{34}$

Table (2): Optimum Values of (Effective depth/ Span length) Ratio

Span Length(m)	(Effective Depth/Span Length)Ratio			
	Flat Slab without Edge Beam	Flat Slab with Edge Beam	Flat Plate without Edge Beam	Flat Plate with Edge Beam
6	1/39	1/43	1/26	1/33
7	1/30	1/35	1/30	1/35
8	1/35	1/35	1/30	1/31
10	1/38	1/38	1/28	1/25
12	1/34	1/32	1/26	1/26
15	1/27	1/30	1/23	1/30

Conclusions

1. For Flat slab without edge beams, the ratio of effective depth to span length should be within the range (1/39-1/27) to get the optimum design, while for flat slab with edge beams, it should be within (1/43-1/30), for Flat- Plate without edge beams, the ratio should be within the range (1/30-1/23) to get the optimum design, while for flat-plate with edge beams, it should be within (1/35-1/25).
2. The decreasing in the column size, leads to increase the slab thickness and the total cost of the slab.
3. For flat slab without edge beams, the cost of formwork is found to be about (3%-17%) from the total cost, for flat slab with edge beams about (18%- 21%), for flat-plate without edge beams about (5% - 13%), and for flat-plate with edge beams (3%-15%).
4. In the cases of absence of edge beams, it is found that the effect formwork on the total cost of the slab decreases as the span length increases.
5. For the same span length, it is found that the flat slab without edge beams is more economical compared with the other studied types.

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