Optimum Design of Reinforced Concrete Box Culvert by Using Deterministic Approach

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Abstract An optimum safe design is achieved for a reinforced concrete box culvert considering hydraulic, geotechnical and structural requirements and prices. To reach this intention, an optimization technique methodology is applied in estimation a safe design with a minimum price. The non-linear constrained optimization problem is generally expressed in terms of an objective function and constraints. Eleven design variables and forty constraint equations were employed in this work, with the total price of reinforced concrete box culvert as the objective function. The solution is obtained by means of developed computer software written in Visual BASIC. The computer software considers the Sequential Unconstrained Minimization Technique (SUMT), which is one of non-linear optimization techniques. In order to evaluate the influence of the input parameters on the box culvert design, the optimization program has been modified. The input design parameters are the discharge, head loss, length, entrance loss coefficient, Manning's roughness coefficient, angle of internal friction of soil, compressive strength of concrete, yield strength of steel, unit price of concrete, unit price of excavation, unit price of filling and unit price of steel. A parametric study is formed to examine the influence and significance of each input design parameter on the total price of box culvert.

1. Introduction
A road way occasionally must cross a small irrigation canal, ditch, or other small body of water. Normally, a bridge is so big and expensive solution to keep the roads right of way. If this the case, a box culvert is a perfect choice. Reinforced concrete box culverts can be classified according to the construction method into cast-in-place or precast [1]. Box culverts contain of two horizontal and two vertical slabs assembled monolithically and preferably appropriate for a railway bridge or a road passing with embankments crossing a stream with a limited flow [2]. There are several categories of culvert in terms of geometric shape and material. Reinforced concrete box culverts are commonly selected of the various culvert types.

Al-Rawi [3] applied optimization technique methodology in the form of deterministic approach to estimate a safe design of spread footing with a minimum cost. The author concluded that the unit price of concrete has the major effect on the spread footing cost. Al. Shukur et al [4] presented the optimal design of box culvert by utilizing Genetic Algorithms (GAs) method, which used as a tool box in MATLAB software version 2011, to optimize the structure. A parametric study was carried out to identify the initial population and population size. Al-Zaidee et al [5] studied the effect of soil-structure interaction on behavior of concrete culverts constructed in dry cohesionless soils. Jing Liu et al [6] examined the deformations and stresses characteristics of the soil-culvert structure. The design model of vertical soil pressure at the top of culvert was presented by [6].

The purpose of the conventional design process is to obtain a suitable or sufficient design, which merely fulfils the functional construction and taking into consideration the different code requirements of the case but does not deliver extremely over designed system. Generally, conventional design is a stage-by-stage
procedure and there will be more than one acceptable design. For selecting the best one out of the many appropriate designs available, optimization technique is presented now [7]. The optimization method can be an excellent tool for the designers to state many decisions in terms of optimization including economic and safe situations. Further, it should be mentioned that optimization is a design tool instead of a new method of design [8]. Optimization is utilized as a tool of obtaining the situations that provide the minimum or the maximum value of the function [9].

This study is concentrated on investigating the influence of different parameters on the optimum design of reinforced concrete box culvert by utilizing a non-linear optimization technique. The technique used in designing the structure with minimum cost is Sequential Unconstrained Minimization Technique (SUMT) which has not been well covered yet in the available literature.

2. The Penalty Method
The mathematical tool for completing the optimization procedure is the “penalty function method”. The basic strategy of the penalty method is when an auxiliary function (the penalty) is created from the constraints, each multiplied by a scalar parameter, and added to the objective function to generate a single unconstrained parametric function. Then the function is optimized continually for each of the arrangement of parameter values, producing an order of unconstrained optima that meets the solution of the original constrained problem [10]. The idea motivating the penalty function method is to convert the problem of minimizing:

$$Z = f(X)$$

exposed to particular constraint on ($X$) into the problem of obtaining the unconstrained minimum of

$$Z = f(X) + P(X)$$

where $P(X)$ is the penalty function. It is not single, but it is necessitated to have the property that if the constraints are violated then a great value will be provided to $Z$, so that the minimum of $Z$ will not occur outside the constraint region.

$$P(X) = \sum_{j=1}^{m} \frac{1}{g_j(X)} \quad (3)$$

$$Z = \phi(x, \xi) = f(x) + \xi \sum_{j=1}^{m} \frac{1}{g_j(x)}$$

where $\xi$ is a positive-valued scalar parameter called penalty parameter.

3. The SUMT Method of Fiacco and McCormick
The result of Equation (4) illustrates that it is probable to solve the constrained minimization problem (minimize $f(x)$ subjected to $g_j(x) \geq 0$) by solving the sequence of unconstrained problems. Consequently, the modified form of problem can be expressed by minimizing Equation (4). The unconstrained minimization of $\phi$ function is replicated for order of amounts of the penalty parameter ($\xi$). The result may be taken to meet to that of the original case (this is the cause why this method is called Sequential Unconstrained Minimization Technique (SUMT)) [7]. A computer software, first presented by [11], has been developed using Microsoft Visual Basic language to carry out the design of reinforced concrete box culvert.

4. Statement of the Problem
The problem involved in this article can be presented as follows:

The dimensions of the reinforced concrete box culvert are ($x_1$ and $x_2$) and a uniform thickness is ($x_3$). The box culvert is embedded at a depth ($x_4$). The different stresses that can be measured for the design of the reinforced concrete box culvert, with a constant cross-section along the length are shown in Figure (1). The box culvert rests on a uniform soil with properties ($c$, $\theta$, and $\gamma_s$) where $c$, $\theta$, and $\gamma_s$ are cohesion of soil, angle of internal friction of soil and unit weight of soil respectively. It is desired to design the reinforced concrete
box culvert according to ACI 318 [12] using optimization technique. It can be realized that there are eleven design variables to be optimized:

\[
x_i = \{x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}\}^T
\]

where:
- \(x_1\) = clear width of box culvert, (m);
- \(x_2\) = clear height of box culvert, (m);
- \(x_3\) = thickness of top slab, bottom slab and walls, (m);
- \(x_4\) = Depth of box culvert, (m);
- \(x_5\) = steel area of the outside layer in the top slab per unit length, (mm²);
- \(x_6\) = steel area of the inside layer in the top slab per unit length, (mm²);
- \(x_7\) = steel area of the outside layer in the walls per unit length, (mm²);
- \(x_8\) = steel area of the inside layer in the walls per unit length, (mm²);
- \(x_9\) = steel area of the outside layer in the bottom slab per unit length, (mm²);
- \(x_{10}\) = steel area of the inside layer in the bottom slab per unit length, (mm²);
- \(x_{11}\) = steel area for longitudinal reinforcement, (mm²).

![Figure 1. Typical section of reinforced concrete box culvert.](image)

5. Objective Function Formulation

The objective function is expressed in the form of total price of the reinforced concrete box culvert, see Figure 1.

\[
f(x) = \text{price of excavation} + \text{price of filling} + \text{price of concrete} + \text{price of steel} + x_1 U_{ex} + x_2 U_{fx} + x_3 U_{c} + x_4 U_{f} + x_5 U_{st} + x_6 U_{se} + x_7 U_{st} + x_8 U_{st} + x_9 U_{st} + x_{10} U_{st} + x_{11} U_{st}
\]

where:
- \(U_{ex}\) = unit price of excavation, (unit price per m³);
- \(U_{fx}\) = unit price of filling, (unit price per m³);
- \(U_{c}\) = unit price of concrete (labor and material), (unit price per m³);
- \(\rho_s\) = density of steel; = 7.85 (Ton/m³);
- \(U_{st}\) = unit price of steel (labor and material), (unit price per Ton).

The total quantity of steel achieved is increased by (10 percent) to balance for bar bending, overlapping, hooks ...etc. Furthermore, it should be mentioned that the values of prices considered the formwork, placing
of concrete, vibration, etc. and they are descriptive based on the prevalent rates of construction and may differ from place to place and time to time.

6. Constraints on the Problem
In reinforced concrete box culvert design, failure can be characterized into three general types of failure that a design should account for. These possible failures are: hydraulic, soil and structural failure. The constraints can be categorized into four types of constraints hydraulic, geotechnical, structural, and general constraints.

a. Hydraulic constraints
1. The culvert capacity flowing partially full with inlet control is:

$$g_1 = 1.2 \times x_2 - \sqrt{\frac{Q_1^2}{x_1^2}} - \frac{Q_2^2}{2x_1^2x_2^2} - \frac{K_{ex}Q_2^2}{2x_1^2x_2^2} \geq 0$$

(7)

2. The total head loss through the culvert flowing full is the sum of an entrance loss, exit loss and friction loss.

$$\Rightarrow g_2 = H - \frac{K_{ex}Q_2^2}{2x_1^2x_2^2} - \frac{K_{ex}Q_2^2}{2x_1^2x_2^2} - \frac{L_n^2Q^2}{\left(\frac{x_1x_2}{2(x_1 + x_2)}\right)^{\frac{4}{3}}x_1^2x_2^2} \geq 0$$

(8)

where: $K_{en}$ & $K_{ex} =$ entrance and exit loss coefficient; $Q =$ discharge; $g =$ acceleration of gravity.

The exit loss coefficient is generally set to 1.0 for a sudden expansion of flow [13].

3. The minimum mean velocity of culverts shall be selected of 0.61 meter per second [14].

$$\Rightarrow g_3 = \frac{Q}{x_1x_2} - 0.61 \geq 0$$

(9)

4. When velocities exceed about 3 (m/s), abrasion due to bed movement through the culvert and erosion downstream of outlet can increase significantly [15].

$$\Rightarrow g_4 = 3 - \frac{Q}{x_1x_2} \geq 0$$

(10)

b. Geotechnical constraints
1. Allowable soil pressure ($q_{all}$) must be greater than or equal to the maximum applied pressure ($q_{max}$).

The ultimate bearing capacity $q_{ult}$ can be calculated from the bearing capacity Equation [16].

$$\Rightarrow g_5 = c \cdot N_c \cdot s_c \cdot d_c + \gamma_c (x_1 + x_2 + 2x_3 + 0.3)N_q s_q \cdot d_q$$

$$+ 0.5 \cdot \gamma_s (x_1 + 2x_3 + 0.6)N_y s_y d_y - w_i . F_s \geq 0$$

(11)

where: $c =$ soil cohesion; $N_c, N_q, N_y =$ bearing capacity factors; $s_c, s_q, s_y =$ shape factors; $d_c, d_q, d_y =$ Hansen’s depth factor; $\gamma_c =$ unit weight of soil; $w_i =$ total applied load; $F_s =$ factor of safety.

2. Foundation immediate settlement ($\delta_i$) must not exceed a permissible limit. In this constraint, the equation of modulus of subgrade reaction is used.

$$\Rightarrow g_6 = 40 \times \delta_i \cdot \frac{c \cdot N_c \cdot s_c \cdot d_c + \gamma_c (x_1 + x_2 + 2x_3 + 0.3)N_q s_q \cdot d_q}{\gamma_s (x_1 + 2x_3 + 0.6)N_y s_y d_y} - w_i \geq 0$$

(12)

3. Consolidation settlement ($\delta_c$) should also be taken into consideration in the design process. The two major components of consolidation settlement investigated in this article are:

a- Normally consolidation settlement (OCR = 1)

$$\Rightarrow g_7 = \delta_c - c \cdot H^2 \log \left(\frac{\sigma_0' + \Delta P}{P_c}\right) \geq 0$$

(13)
where: $c_c$ = compression index; $H_o$ = thickness of sublayer; $e_o$ = initial void ratio; $\sigma'_o$ = initial average effective overburden pressure for sublayer; $\Delta P$ = increase of vertical pressure for sublayer; $P_c$ = maximum reconsolidation pressure.

b- Over consolidation settlement (OCR > 1)

- if $\sigma'_o + \Delta P \leq P_c$

  $\Rightarrow g_7 = \delta_e \left( -c_cH_o \log \frac{\sigma'_o + \Delta P}{\sigma'_o} \right) \geq 0$  \hspace{1cm} (14)

- if $\sigma'_o + \Delta P > P_c$

  $\Rightarrow g_7 = \delta_e \left( -c_cH_o \log \frac{P_c}{\sigma'_o} + c_cH_o \log \frac{\sigma'_o + \Delta P}{P_c} \right) \geq 0$  \hspace{1cm} (15)

where: $c_s$ = swell index.

c. Structural constraints

1. Box culverts and frames with clear span to rise ratios that exceed 4 are not recommended.

  $\Rightarrow g_8 = 4 \frac{x_1}{x_2} \geq 0$  \hspace{1cm} (16)

2. Top and bottom slabs thickness shall be determined according to Equation (15). In any case, the thickness of top and bottom slabs shall not be less than 200 mm [17].

  $t_{min} = (S \times 3.3 + 100.102$  \hspace{1cm} (17)

where: $t_{min}$ = minimum slab thickness; $S$ = perpendicular distance between wall centerlines.

  $\Rightarrow g_9 = x_3 - \left( (x_1 + x_3) \times 3.3 + 10 \right) 0.0102 \geq 0$  \hspace{1cm} (18)

  $\Rightarrow g_9 = x_3 - 0.2 \geq 0$  \hspace{1cm} (19)

3. Reinforced concrete box culvert must be reinforced with sufficient steel area to resist bending moments. The loads applied on the box culvert introduced as follows:

   The bending moments ($M_o$) in box culvert are worked out by Hardy Cross method of moment distribution as presented in the following steps. The bending moments obtained from these steps are used in finding the steel area.

   1. For each member, the stiffness ($K$) shall be measured.

      for opposite end fixed

      $K = \frac{4EI}{l}$

      for opposite end pinned or cantilever

      $K = \frac{3EI}{l}$

   where: $E$ = modulus of elasticity; $I$ = moment of inertia; $l$ = length of member.

   2. For each member, the distribution factors should be calculated at both ends.

   3. Determine carryover factors at both ends of each member.

   4. Calculating the fixed end moments for each member and assuming all joints are fixed.

   5. Equalize pinned to zero of cantilevered ends and distributes half the moment to the other end.

   6. Based on the distribution factor, distribute the unbalanced moments at all other joints to each adjacent member.
7. By using the carryover factors, carryover the distributed moments to the opposite ends of each member.  
8. Iterating steps 6 and 7 until moment imbalance at each joint approximates zero.

Computing the steel area \( (A_s) \) for bending, using the following equations [12].

\[
A_s = \frac{0.85 f'_c b d}{f_y} \left(1 - \sqrt{1 - \frac{2.62 M_e}{f'_c b d^2}}\right) 
\]

where: \( f'_c \) = compressive strength of concrete; \( f_y \) = yield strength of steel; \( b \) = section width; \( d \) = effective depth of section. This is a second-degree equation which can be solved using quadratic equation to have:

\[
\Rightarrow g_{11} = x_5 - \frac{0.85 f'_c b d}{f_y} \left(1 - \sqrt{1 - \frac{2.62 M_1 \times 10^6}{f'_c b d^2}}\right) \geq 0 
\]

where: \( M_1 \) = negative bending moment in the top slab of box culvert, (kN.m).

\[
\Rightarrow g_{12} = x_6 - \frac{0.85 f'_c b d}{f_y} \left(1 - \sqrt{1 - \frac{2.62 M_2 \times 10^6}{f'_c b d^2}}\right) \geq 0 
\]

where: \( M_2 \) = positive bending moment in the top slab of box culvert, (kN.m).

\[
\Rightarrow g_{13} = x_7 - \frac{0.85 f'_c b d}{f_y} \left(1 - \sqrt{1 - \frac{2.62 M_3 \times 10^6}{f'_c b d^2}}\right) \geq 0 
\]

where: \( M_3 \) = negative bending moment in the walls of box culvert, (kN.m).

\[
\Rightarrow g_{14} = x_8 - \frac{0.85 f'_c b d}{f_y} \left(1 - \sqrt{1 - \frac{2.62 M_4 \times 10^6}{f'_c b d^2}}\right) \geq 0 
\]

where: \( M_4 \) = positive bending moment in the walls of box culvert, (kN.m).

\[
\Rightarrow g_{15} = x_9 - \frac{0.85 f'_c b d}{f_y} \left(1 - \sqrt{1 - \frac{2.62 M_5 \times 10^6}{f'_c b d^2}}\right) \geq 0 
\]

where: \( M_5 \) = negative bending moment in the bottom slab of box culvert, (kN.m).

\[
\Rightarrow g_{16} = x_{10} - \frac{0.85 f'_c b d}{f_y} \left(1 - \sqrt{1 - \frac{2.62 M_6 \times 10^6}{f'_c b d^2}}\right) \geq 0 
\]

where: \( M_6 \) = positive bending moment in the bottom slab of box culvert, (kN.m).

4. Area of steel reinforcement for bending moments should not be less than minimum area of steel [12].

\[
\Rightarrow g_{17} = x_5 - 0.002 b \times x_3 \geq 0 
\]

\[
\Rightarrow g_{18} = x_6 - 0.002 b \times x_3 \geq 0 
\]

\[
\Rightarrow g_{19} = x_7 - 0.002 b \times x_3 \geq 0 
\]

\[
\Rightarrow g_{20} = x_8 - 0.002 b \times x_3 \geq 0 
\]

\[
\Rightarrow g_{21} = x_9 - 0.002 b \times x_3 \geq 0 
\]

\[
\Rightarrow g_{22} = x_{10} - 0.002 b \times x_3 \geq 0 
\]

5. Area of steel reinforcement for bending moments should not exceed the maximum area of steel \( (\rho_{\text{max}}) \) [12].

\[
\rho_{\text{max}} = 0.375 \times 0.85 \frac{f'_c}{f_y} 
\]

\[
\Rightarrow g_{23} = 0.375 \times 0.85 \frac{f'_c}{f_y} \times x_3 \geq 0 
\]
6. The minimum longitudinal reinforcement (for shrinkage and temperature) in the top slab, bottom slab and walls shall be provided as follows:

\[ g_{24} = 0.375(0.85)^2 f'c \frac{f_y}{f_y} x_6 \geq 0 \]  \hspace{1cm} (35)

\[ g_{25} = 0.375(0.85)^2 f'c \frac{f_y}{f_y} x_7 \geq 0 \]  \hspace{1cm} (36)

\[ g_{26} = 0.375(0.85)^2 f'c \frac{f_y}{f_y} x_8 \geq 0 \]  \hspace{1cm} (37)

\[ g_{27} = 0.375(0.85)^2 f'c \frac{f_y}{f_y} x_9 \geq 0 \]  \hspace{1cm} (38)

\[ g_{28} = 0.375(0.85)^2 f'c \frac{f_y}{f_y} x_{10} \geq 0 \]  \hspace{1cm} (39)

7. The longitudinal reinforcement in the top slab, bottom slab and walls should not be greater than maximum area of steel.

\[ g_{29} = x_{11} - 0.002 \times \left( (x_1 + 2 \times x_3)(x_2 + 2 \times x_3) - x_1 \times x_2 \right) \geq 0 \]  \hspace{1cm} (40)

4. Some constraints are presented herein to make the searching process and converging rate easier and faster. These constraints are:

\[ g_{35} = x_3 \geq 0 \]  \hspace{1cm} (46) \hspace{1cm} \Rightarrow g_{36} = 4 - x_2 \geq 0 \hspace{1cm} (49)

\[ g_{36} = x_4 \geq 0 \]  \hspace{1cm} (47) \hspace{1cm} \Rightarrow g_{39} = 0.6 - x_3 \geq 0 \hspace{1cm} (50)

\[ g_{37} = x_1 - x_2 \geq 0 \]  \hspace{1cm} (48) \hspace{1cm} \Rightarrow g_{40} = 30 - x_4 \geq 0 \hspace{1cm} (51)

7. Optimization Problem Identification

The final form of the optimization mathematical programming problem can be summarized to be:

Find \( X \) which minimize the objective function \( f(x) \)
\begin{equation}
    f(x) = (x_1 + 2x_3)(x_2 + 2x_3 + x_4)U_{ex} + (x_1 + 2x_3)x_4U_f + \left( (x_1 + 2x_3)(x_2 + 2x_3 - x_1)x_2 \right) U_e + x_3 \times 10^{-6}(x_1 + 2x_3) \rho_s U_{st} \\
    + x_6 \times 10^{-6} \times (x_1 + 2x_3) \rho_s U_{st} + 2x_2 \times 10^{-6} \times (x_2 + 2x_3) \rho_s U_{st} \\
    + 2 \times x_8 \times 10^{-6} \times (x_2 + 2x_3) \rho_s U_{st} + x_9 \times 10^{-6} \times (x_1 + 2x_3) \rho_s U_{st} \\
    + x_{10} \times 10^{-6} \times (x_1 + 2x_3) \rho_s U_{st} + x_{11} \times 10^{-6} \times \rho_s U_{st}
\end{equation}

Subjected to the inequality constraints

\[ g_j(x) \geq 0 \quad j = 1, 2, 3, \ldots, 40 \]

Where \( X \) is the vector of the design variables; \([x_1, x_2, \ldots, x_{11}]^T\)

The input file of the program includes the following:
- Length of culvert (\( L \)), discharge (\( Q \)), head loss (\( H \)) and Manning’s roughness coefficient (\( n \)).
- Entrance loss coefficient (\( K_{en} \)) and exit loss coefficient (\( K_{ex} \)).
- The unit weight of concrete (\( \gamma_c \)) and the unit mass of steel (\( \rho_s \)).
- The compressive strength of concrete (\( f'c \)) and the yield strength of steel (\( f_y \)).
- Vehicle live load of HS20 truck (\( P_{HS20} \)).
- The backfill and the base soil properties (\( \Theta, \gamma_f, \Theta_s, c, \gamma_s \)).
- Initial void ratio (\( e_0 \)), compression index (\( c_c \)) and swell index (\( c_r \)).
- Unit price for concrete (\( U_c \)), steel (\( U_{st} \)), excavation (\( U_{ex} \)) and backfilling (\( U_f \)).

8. Effect of Design Parameters on Total Price

A number of analyses have been carried out for studying the influence of the design parameters and the results are illustrated in Figure 2. It can be seen that the increase of the values of head loss (\( H \)) decreases the total price. While the increase of discharge (\( Q \)) increases the total price. Figure 2 reveals the response of the reinforced concrete box culvert price against the change of the design parameters under the cover of the optimization technique. The slope of the line joining any two points provides an indication of the importance of each parameter. A percentage difference is presented in this article for providing a clear idea about the importance of each parameter.

\[
    \text{% difference} = \frac{X - X_{ref}}{X_{ref}} \times 100
\]

where: \( X \) = investigated design value; \( X_{ref} \) = reference value.

For instance, the increase of the value of head loss from 0.15 (reference value) to 0.2 (% diff. = 33.33 %) will decrease the total price with an amount of (11.28 %). Thus, a graph can be drawn with percentage difference of design parameters as the X-axis and percentage difference of the total price as Y-axis. Figure 2 illustrates such a graph and obviously, the higher the slope of the line more important is the factor. The marks in Figure 2 are tabulated in a descending sequence regarding its significance and reveal that the discharge (\( Q \)), head loss (\( H \)), unit price of concrete (\( U_c \)) and unit price of steel (\( U_{st} \)) are the most important parameters in their effect, while the length (\( L \)) and unit price of filling have the lowest effect. Table 1 reveals a model about the rate of change of box culvert price according to a 20% increment and decrement in the design parameters.
Figure 2. %Change of Box Culvert Price versus %Change of Design Parameters.

It should be stated that all variables in the parametric study are operated simultaneously, fulfilling all the design requirements and searching for the minimum price which is the main target. The behavior of the design parameters around the reference value is unsymmetrical. Thus, the particular decrement and/or increment for each design parameter does not follow the same response degree. These unsymmetrical responses are different from one parameter to another.

Table 1. % Change of box culvert price corresponding to 20% increment and decrement of each design parameters.

| Increment of 20% in Design Parameter value | %Difference in Total price | Decrement of 20% in Design Parameter Value | %Difference in Total price |
|-------------------------------------------|---------------------------|--------------------------------------------|---------------------------|
| Q                                         | 16.74                     | Q                                          | -16.80                    |
| Ue                                        | 10.67                     | Ue                                         | -10.42                    |
| H                                         | -7.63                     | H                                          | 9.38                      |
| Ust                                       | 7.13                      | Ust                                        | -7.16                     |
| fy                                        | -5.17                     | fy                                         | 5.57                      |
| Ken                                       | 2.85                      | Ken                                        | -2.69                     |
| Uex                                       | 2.11                      | Uex                                        | -2.13                     |
| n                                         | 1.02                      | n                                          | 1.04                      |
| f'c                                       | -0.46                     | f'c                                        | 0.85                      |
| Uf                                        | 0.46                      | Uf                                         | -0.32                     |
| Θ                                         | -0.45                     | Θ                                          | -0.49                     |
| L                                         | 0.39                      | L                                          | -0.49                     |

9. Conclusions
In this work, the design of the reinforced concrete box culvert by using the application of the deterministic approach has been presented. From the results obtained, the following conclusions are drawn:

1. Optimization technique is demonstrated to be an influential tool in the design of reinforced concrete box culvert to obtain a safe economical design.
2. The method used to achieve the global minimum, which is Interior penalty method (SUMT), is powerful. However, it needs time and accuracy in the derivation of the equations.

3. Engineers can benefit from the percentage difference graphs in understanding the contribution of each parameter in the designing process.

4. The discharge takes a huge share of importance in the calculation of total price of box culvert.

5. Unit price of concrete is further significant than the other unit prices. Hence the total price of reinforced concrete box culvert consists of 51.86% of concrete price, 36.06% of steel reinforcement price, 10.54% of excavation price and 1.54% of filling price.

6. The compressive strength of concrete is less significant than the yield strength of steel in process of design reinforced concrete box culvert.

7. The behavior of the design parameters around the reference value is unsymmetrical. Thus, the particular decrement and/or increment for each design parameter does not follow the same response degree. These unsymmetrical responses are different from one parameter to another.

8. It can be remarked that there is about 5-10% decrease in the total price of reinforced concrete box culvert when Optimization Technique is used.

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