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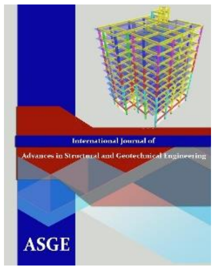

International Journal of Advances in Structural and Geotechnical Engineering

https://asge.journals.ekb.eg/

Print ISSN 2785-9509 *Online ISSN 2812-5142*

Special Issue for ICASGE'19

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ASGE Vol. 03 (04), pp. 90-105, 2019

International Conference on Advances in Structural and Geotechnical Engineering

ICASGE'19

25-28 March 2019, Hurghada, Egypt

STRUCTURAL OPTIMIZATION OF RC COMPOSITE GIRDERS IN PRE-FABRICATED BUILDINGS

Salah El-Din F. Taher[1], Ayman A. Seleemah[2], Hamdy M. Afefy[3], Safy Elrahman Samy[4]

[1]*Professor, Faculty of Engineering, Delta University for Science and Technology. On leave from Tanta University, Egypt*
E-mail: salah.taher@f-eng.tanta.edu.eg
[2]*Professor, Faculty of Engineering, Tanta University, Egypt*
E-mail: ayman.seleemah@f-eng.tanta.edu.eg
[3]*Professor, Faculty of Engineering, Tanta University, Egypt*
E-mail: Hamdy.afefy@f-eng.tanta.edu.eg
[4]*M.Sc. Student, Faculty of Engineering, Tanta University, Egypt*
E-mail: safyelrahman@f-eng.tanta.edu.eg

ABSTRACT

This paper presents cost optimization analysis of reinforced concrete composite girders in RC pre-fabricated buildings designed according to the Egyptian Code of Practice (ECP 203-2017). The adopted objective function was to minimize the total cost of the RC pre-fabricated building including the cost of composite girders, columns and foundations considering the cost of the materials and labor for reinforcement, concrete and formwork. The structure is modeled and analyzed using a Microsoft Excel- 2013 spreadsheet. The optimization process was performed at three different levels. In the first level, optimum column arrangement was attained while the optimum dimensions for all RC elements of the selected structural plan of the pre-fabricated buildings were studied in the second level. In the third level, a comprehensive study was conducted in order to determine the optimum dimensions and reinforcement of RC composite girders by Generalized Reduced Gradient (GRG) method. Finally, the cost improvement of three buildings of composite concrete is demonstrated, and the results of the optimum and traditional design procedures are compared.

Keywords: Composite Girders, Cost Optimization, Generalized Reduced Gradient, Horizontal Shear, Pre-Fabricated Buildings.

INTRODUCTION

The selection of suitable cross-section for RC beams and columns with minimum cost from many acceptable cross-sections is a major problem for engineers. Structural analysis and design usually involve both very complex procedures and a large number of variables, so the solution must be found repeatedly while the initial values of the variables are determined according to the sensitivity and experience of the designer. In addition, the number of analysis steps increases significantly if optimum values are found among all possible alternatives [1]. Mathematically by using optimization techniques the physical response of a structure can be described. An optimal solution is the most economic structure without messing up the purposes of the function to be served by the structure [2]. The total cost of the RC structure is the sum of the costs of its component materials including concrete, reinforcing steel and formwork [3].

There are some characteristics of composite RC girders that make their design improvements quite different from other structures. In improving the design of composite RC girders, the cross-sectional dimensions of the elements and reinforcing details should be determined. Thus, the number of design parameters could be even greater for the composite RC girders. Also, the durability and cracking requirements are two additional criteria that should be taken into consideration. All these requirements increase the number of design limitations of the optimization problem of composite RC girders [4]. The presence of optimization methods can be tracked to days of Newton, Euler, Bernoulli, Lagrange, Lagrange and Weirstrass [2]. The optimal design process is generally repetitive in nature, each of which involves a repetition process; (i) structure analysis under specific design loads for the design of known and (ii) redesign design variables to reduce the value of the objective function without breaking any of the variables constraints [4]. Optimization theory coupled with cheap computational power provides the practical possibility to improve upon the design process without the need for impractical, more complex analysis [5]. In general, most studies on improving composite RC girders, whether based on discrete or continuous value searches, have been successful with small RC structures using reduced structural models and fairly simple cost functions [6].

Most issues, such as the cost of materials and labor, have been ignored on member sizes. Also, in an attempt to reduce the size of the problems, assumptions about the number of different members of sizes are often simplified based on past practices. Although economic solutions in RC composite girders usually require designs where structural elements with similar functions have similar dimensions, the ideal characteristics and population of these groups should be chosen according to the optimization techniques rather than the predefined constraints. These issues, though not exhaustive, are addressed in this paper, by incorporating the most realistic costs and mitigating limitations on member geometries. This study and solutions are capable of producing the ideal cost designs for composite RC girders based on realistic cost data for materials, configuration and labor while meeting all ECP 203-2017 code requirements and design performance requirements. The optimization formula for composite RC girders has been developed to be solved. The standard Gradient (GRG) method is one of the classic optimization methods. This method was selected besides classical methods as it is already programmed in EXCEL SOLVER. Therefore, the user creates the design model and uses the SOLVER toolbox to run the optimization process. Is employed, which looks for high-value, optimized solutions that are rounded to separate design values. Separate modifications are made to the width and reinforcement of each element during search.

Ultimate design of reinforced concrete composite sections under bending

The composite section geometry of the reinforced concrete structure is defined by the following parameters, as shown in Fig. 1: lower steel area in the tension zone,A_s؛ upper steel area near the compression zone, A_s'; the steel for resisting the horizontal shear,$A_{s\,conecttor}$; the steel for shrinkage A_{Sshr}; the steel for negative and positive moment of the slab A_{s-ve} and A_{s+ve}; the slab thickness,t_s; the effective beam width, B; the beam width, b; the effective depth of the section, d; the concrete cover, dc. In the present work, the design variable in the optimization process is the ratioA_s' /A_s, and concrete dimension (d & b), for a given total area of reinforcement A_s + A_s', the objective function is to maximize the bending moment. As a matter of fact, for a given bending moment, the total area of reinforcement is the function of the ratioA_s' /A_s, which, for this reason, is the important design variable in terms of the limit state design of the section. The cover of steel is not considered as a design variable because it is fixed, in each case, by durability conditions. The equations are developed as a function of the non-dimensional variables a/d, b/B and t_s /d.

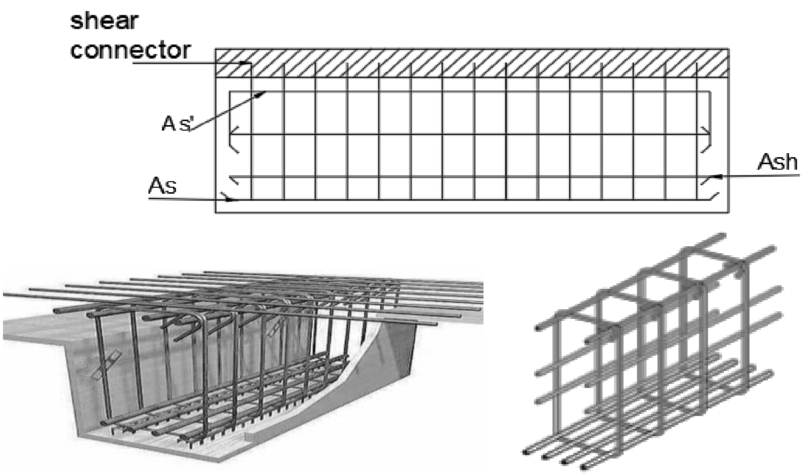

Fig. 1 Details of reinforcement for composite section.

HORIZONTAL SHEAR

Composite concrete girders and reinforced concrete slabs have become very popular in practice of civil engineering at present. In composite girders the two parts of concrete (the girder and the slab) are poured in different times. Different forms of elasticity, successive load applications, differential creep and deflation cause unequal stresses and tension in contiguous fibers of construction joints. The most important requirement is to make sure that both parts work compositely as one unit, because the bending and shear designs of the composite members are based on this assumption. The shear stress at the interface should therefore be limited to two parts. Therefore, one of the most important points in this study is to ensure the safety of the section and to ensure the cohesion of the slab and the beam under the influence of the horizontal force. Fig. 2 illustrates the developed horizontal shear between the web and the flange of composite girder considering different degrees of composite action.

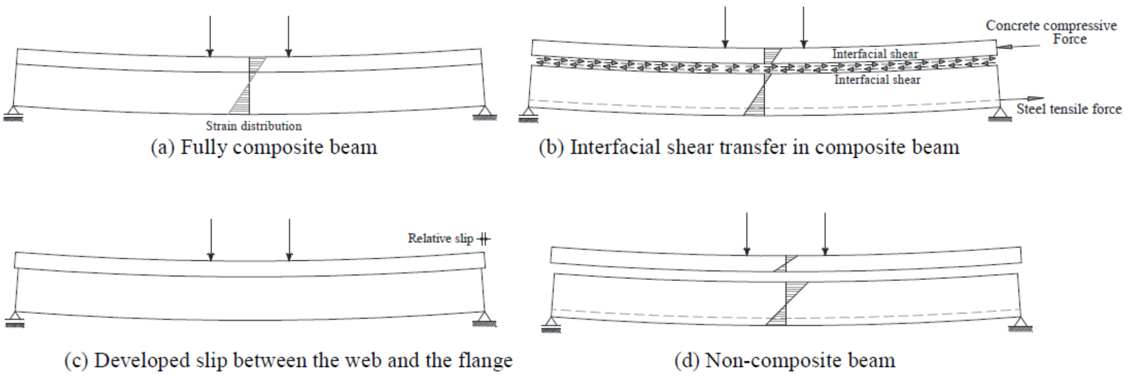

Fig. 2 Load-transfer mechanism in composite girders.

SHORED AND UNSHORED CONSTRUCTION

Shored means the entire composite section carries the total load including dead load and live load. In shored construction beam is temporarily supported by shoring until the slab is cast and cured for 28 days. Once the concrete is cured, girder and slab work as one integrated unit. The beam section carried only the dead load and the composite section loaded the live load. In un-shored structure, beam is acting by itself and has to have the strength to support the load of the wet concrete until it hardens. Once concrete cures, it becomes an integral part of the composite element.

CONNECTION BETWEEN SYSTEMS

In the current paper, the precast girders are supported on the cast in-situ columns provided with short bracket as depicted in Fig. 3, The girder is connected to the bracket by one of the two methods, either by using connector link extended between the bracket and the girder and then injected with grout, or by placing a serrated dowel inside the bracket and tied to its bearing pad in a special hole in the girder as illustrated in Fig. 3(b). Thus, full composite connection between the precast girders and the supporting brackets are ensured.

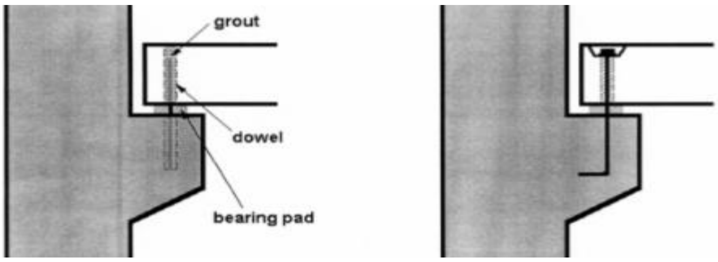

Fig. 3 (a) Connect the beam to the column using the grout (b) Connect the beam to the column using the serrated dowel.

As the connection between the precast girders and the topping slab, the vertical stirrups of the precast girders are extended in the slab to resist the developed horizontal shear force between them as depicted in Fig. 4.

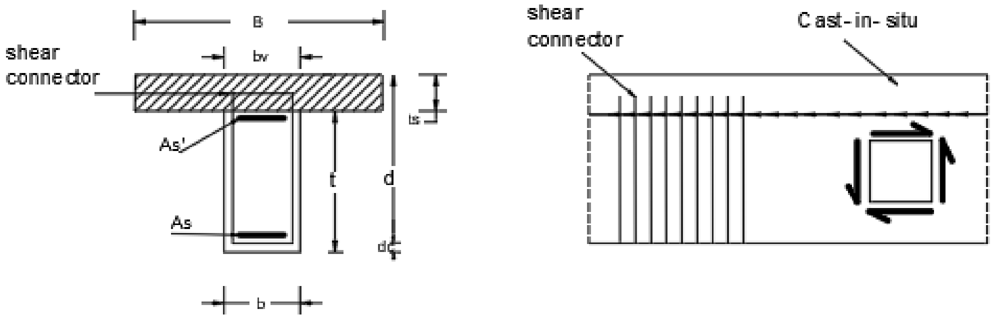

Fig. 4 Connection between precast girder and topping slab.

OPTIMIZATION ALGORITHEM

A routine was created using a Microsoft Excel 2013 spreadsheet to find the ideal cross-sectional dimensions for the RC composite girders system shown in Figs. 5 and 6. The built-in Excel algorithm was used as an improve tool to find the optimum solution. The genetic algorithm was introduced as an effective method because it included population size, mutation rate, mutation operator, and selection operator. It has many advantages and is a powerful algorithm with regard to its parameters. The objective of the optimization problem was to reduce the total cost of the specific area. The total cost includes the cost of each structural element taking into account the materials and labor for reinforcement, concrete and formwork.

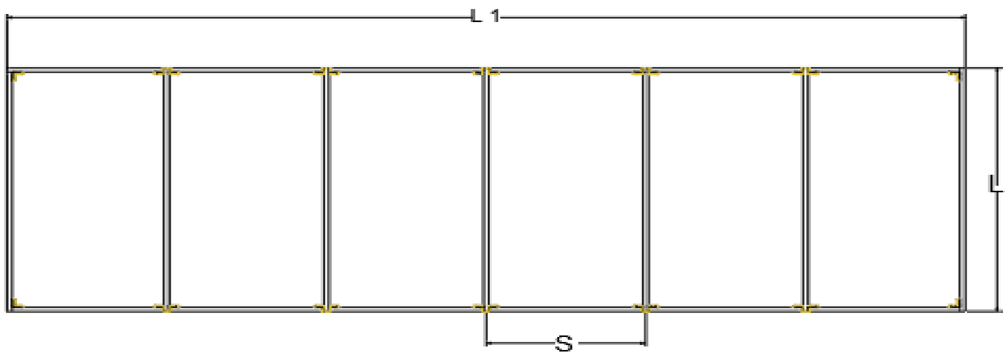

Fig. 5 Detail of composite system. S = Spacing between girders; L = Span of girder; L1 = Length of area.

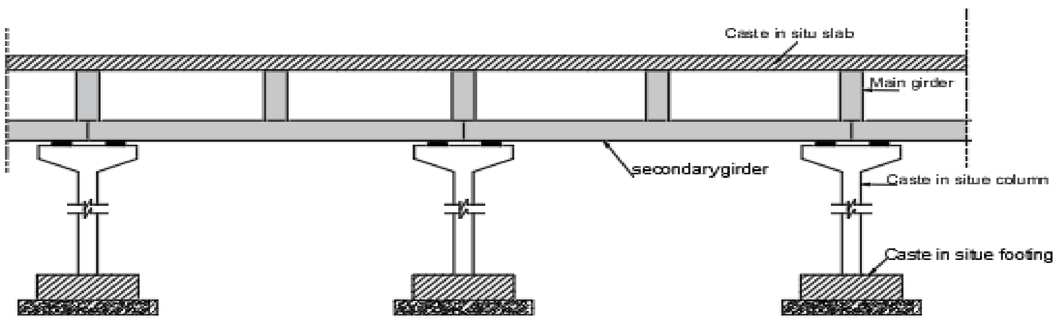

Fig. 6 Details of the connection between girders and columns as well as columns and foundations.

THE MODEL OF OPTIMAL DESIGN

In an optimization analysis, some parameters can be considered as fixed parameters, while others are considered as design ones. Design variables were determined so that the target function is the minimum cost. Some limitations, called design limitations, may limit acceptable values for design variables.

Fixed Parameters

For the current research, fixed parameters contain the strength of material, modulus of elasticity, unit weight for concrete and reinforcement, dead and live loads. Besides, the total cost of concrete and reinforcement is supposed to be proportional to the volume and weight of each material. Thus, the total cost of the building is calculated using constant parameters to calculate cost of unit weight for reinforcement and unit volume of concrete.

Design Variables

Design variables are the most important parameters in formulation of the optimization problem. Design variables must be independent of each other. If one of the design variables can be expressed in other terms, this variable can be eliminated from the model.

The considered design variables to describe the RC composite girder model are as the following:

- b = Beam width (integer values)
- d = Effective depth (real values)
- A_s = Area of steel (integer values)
- S = Spacing between girders (integer values)
- L = span of the girder (integer values)

Design Variables' bounds

The design variables that have been taken into account in the adopted model are included in the limits of variables resulting from different issues like the provisions of the code under constraints, aesthetic appearance of elements in the building, practical issues and availability of some of materials in the domestic market.

The following equations are the estimated boundaries of the model:

Effective depth:

$$d_{min} = h_{min} - d_b/2 - d_c - d_s \text{ , } d_{max} = h_{max} - d_b/2 - d_c - d_s \quad (1)$$

Effective width:

$$b \geq b_{min}, \ b \leq b_{max} \quad (2)$$

Where: b_{min} and b_{max} are chosen according to practical considerations and architectural constraints.

Area of steel:

$$A_s \geq A_{smin} \text{ , } A_s \leq A_{smax} \quad (3)$$

Where: A_{smin} and A_{smax} are chosen according to the ECP 203-2017 code.

Spacing between girders:

S = 3, 4 m

Span of the girders:

L ≥ 4, L ≤ 12

Where:

h_{min}= L/21, h_{max} is chosen according to architectural considerations, d_c is the cover of concrete, d_s Is the diameter of stirrups, b (in meter) [0.2, 0.4] i.e. 0.2 ≤ b ≤ 0.4 m, d (in meter)

Constraints

Design variables cannot be chosen randomly in many practical problems. Instead, they must meet specific functional and other specific requirements. Constraints must be met to produce an acceptable design which is collectively called design constraints. The limitations of design that was considered in this study are listed as follows:

Beams constrains

a- Geometric constraint:

The effective depth of the beam d_b (d_b=t-c, c is the concrete cover of reinforcing steel) is practically not less than 2 times the web width b_w

$$\frac{d_b}{2\,b_w} - 1.0 \leq 0.0 \tag{4}$$

b- Flexural capacity constraint:

Consideration of the effective width, B, contributing to the flexural resistance of the section depends on the relative location of the connecting slab with respect the acting moment. Thus, T- or L-section is considered for sagging moment while rectangular section is considered for hogging moment in the form as follows:

$$M_u \leq M_n \tag{5}$$

$$\frac{M_u}{A_s/\gamma_s\left\{d_b - \frac{A_s F_y/\gamma_s}{\frac{0.67 F_{cu}}{\gamma_s} b.a}\right\}} - 1 \leq 0.0 \tag{6}$$

c- Minimum and maximum spacing required between flexural bars as follows:

$$S \geq S_{min} \tag{7}$$

$$S_{min} = \text{max of } (\phi\text{max}, \phi\text{e}, \tfrac{1}{2} \text{ of max agg. Size}) \text{ mm} \tag{8}$$

$$S \leq S_{max} \tag{9}$$

$$\frac{S}{200} - 1.0 \leq 0.0 \tag{10}$$

d- Maximum and minimum ratios of required reinforcement as follows:

$$\frac{A_s}{b.d} - 1.0 \leq 0.0 \qquad 1 - \frac{A_s}{0.225\sqrt{\frac{F_{cu}}{F_y}}} \leq 0.0 \tag{11}$$

e- Shear design constrains may expressed as follows:

$$q_u < q_{u\,max} < 4 \text{ N}/mm^2 \tag{12}$$

$$q_u = \frac{Q_u}{b.d} \tag{13}$$

Maximum and minimum shear strength

$$\frac{0.7\sqrt{\frac{F_{cu}}{\gamma_c}}}{q_u} - 1 \leq 0.0 \qquad 1 - \frac{0.16\sqrt{\frac{F_{cu}}{\gamma_c}}}{q_u} \leq 0.0 \tag{14}$$

f- Horizontal shear constrains may expressed as follows:

$$Q_u\,ext \leq Q_{uh} \tag{15}$$

$$Q_{u\,ext} = \frac{Wu.L}{2} \quad kN \tag{16}$$

$$1 - \frac{q_{uh}}{1.35+0.5\frac{\mu v.F_y}{\gamma_s}} \leq 0.0 \qquad \frac{q_{uh}}{2.6} - 1 \leq 0.0\ N/mm^2 \tag{17}$$

$$\mu v \ = \frac{n\ A\o st}{b.s} \tag{18}$$

$$Q_{uh} = q_{uh}\ *\ d_b\ *\ b_w \quad KN \tag{19}$$

Q_u = maximum shear force, q_{uh} = maximum shear stress, Q_{uh} = maximum horizontal shear force, μv = Reinforcement ratio of the vertical stirrups

g- Deflection control constrains may expressed as follows:

$$For\ M_{cr} > M_a \qquad I = I_g \tag{20}$$

$$For\ M_a > M_{cr} \qquad I = I_e \tag{21}$$

$$I_e = \left(\frac{M_{cr}}{M_a}\right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{M_a}\right)^3\right] I_{cr} \tag{22}$$

$$\frac{\Delta}{250} - 1.0 \leq 0.0 \tag{23}$$

$$\Delta = \frac{5WL^4}{384EI} \tag{24}$$

$$M_{cr} = \frac{f_{ctr}\cdot I_g}{y_t} \tag{25}$$

$$f_{ctr} = 0.6\sqrt{f_{cu}} \qquad N/mm^2 \tag{26}$$

$\Delta_i \leq limit\ by\ ECP\ 203-2017\ code$, $\Delta_{total} \leq limit\ by\ ECP\ 203-2017\ code$

Where:
I_{cr} = Cracked moment of inertia less than I_g, I_g = Gross moment of inertia for full section, M_a = applied bending moment, M_{cr}= Cracking moment, y_t = Distant from neutral axes to the outermost tension fiber, Δ_i = Immediate deflection due to the existence of dead and live loads, Δ_{total} Long term deflection including the effect of creep.

h- Cracking Control Design constrains may expressed as follows:

$$\mathrm{w_k} = \beta.\mathrm{S_{rm}}.\varepsilon_{\mathrm{sm}} \leq \mathrm{w_{kmax}} \tag{27}$$

$$\frac{\beta.\mathrm{S_{rm}}.\varepsilon_{\mathrm{sm}}}{\mathrm{w_{kmax}}} - 1.0 \leq 0.0 \tag{28}$$

$$\mathrm{s_{rm}}\ (\mathrm{mm}) = \left(50 + 025\ \mathrm{k_1 k_2}\ \frac{\phi}{\rho_r}\right) \tag{29}$$

$$\varepsilon_{\mathrm{sm}} = \frac{\mathrm{f_s}}{\mathrm{E_s}}\left(1 - \beta_1\beta_2\left(\frac{\mathrm{f_{sr}}}{\mathrm{f_s}}\right)^2\right) \tag{30}$$

$$f_s = n \times \frac{M_a}{I_{cr}} \times (d-c) \tag{31}$$

$$\mathrm{f_{sr}} = \frac{M_{cr}}{I_{cr}} \times (d-c) \tag{32}$$

$$\rho_r = \frac{A_s}{A_{cef}} \tag{33}$$

$$A_{cef} = b \times t_{cef} \tag{34}$$

$$t_{cef} = 2.5(clear\ cover + {}^{\phi}/_{2}) \tag{35}$$

Where
β = coefficient that relates the average crack width to the design crack width, Φ = bar diameter in mm, β1= A coefficient that reflects the bond properties of the reinforcing steel, β2= coefficient that takes into account the duration of loading, k_1= coefficient that reflects the effect of bond between steel and concrete between cracks, k_2= coefficient that reflects the strain distribution over the cross section, f_s = stress in longitudinal steel at the tension zone, calculated based on the analysis of cracked section under permanent loads, f_{sr} = stress in longitudinal steel at the tension zone, calculated based on the analysis of cracked section due to loads causing first cracking (M_{cr}), ρ_r = Ratio of effective tension reinforcement, A_s = Area of longitudinal tension steel within the effective tension area, A_{cef} = Area of effective concrete section in tension.

Slabs' constrains

a- Geometric constraint:

The minimum slab thickness t_s min is 80mm

$$1.0 - \frac{t_s}{80} \leq 0.0 \tag{36}$$

b- Flexural capacity constraint:

Considering b_s=1.0m strip of the slab, the flexural capacity constraint is formulated for pure moment in the form (ultimate moment-nominal capacity≤0.0) as follows:

$$1.0 - \frac{1.0}{M_u}\left[\frac{A_s F_y}{\gamma_s}\left\{d_b - \frac{A_s F_y/\gamma_s}{1.33 F_{cu}{}^{b.a}/_{\gamma_c}}\right\}\right] \leq 0.0 \tag{37}$$

c- Shear strength constraint:

Shear resistance should be entirely resisted by concrete

$$1 - \frac{0.16\sqrt{\frac{F_{cu}}{\gamma_c}}}{q_u} \leq 0.0 \tag{38}$$

Objective Function

The objective function is to find an acceptable or appropriate design that meets the functional requirements and other requirements of the problem. There will be more than one acceptable design. The purpose of improvement is to choose the best one of the many accepted designs. A standard should therefore be chosen to compare different acceptable alternative designs and choose the best one. The standard, by which the design is improved, when expressed as a function of the design variables, defines the standard or the Meritor objective function. Selection of objective function was subject to the nature of the problem. Objective function is usually used to reduce unit weight and problems of structural design. In civil engineering structural designs, the target is usually taken as a reduction of cost. In a structural design, the design of the minimum weight may not be consistent with minimal stress design, and the design of the minimum stress may not be consistent with the maximum frequency design. Thus, the choice of objective function can be one of the most important decisions in the optimum design process.

The objective function for the simply supported reinforced concrete composite girders model is:

$$\textbf{MIN. COST} = C_c\,[(A_c - A_s)\,L] + C_s\,[A_s\,L] + C_f\,[A_f] + C_{prop}\,[n_{prop}] \tag{39}$$

Where:
C_c = Concrete cost per cubic meter, C_s = Reinforcement steel cost per ton, C_f = Cost of concrete formwork per cubic meter, C_{prop} = Cost of prop per cubic meter, A_c = cross-section Area of concrete, A_s = longitudinal reinforcement Area, A_f = formwork cross-section area, L = span,

VALIDATING OPTIMIZATION MODELE

To assess the accuracy of the generated optimization model the cost of the sectors produced by the algorithm with a 612 examples was done using the traditional analysis and compared.

Generalized Reduced Gradient (GRG) For Optimum Design of Girders

The database developed for optimum design of composite beams was used in accordance with the requirements of the ECP 203-2017 code, based on the previous equations, for Generalized Reduced Gradient (GRG) training. The design entry for the problem includes the following:

The total cost of composite girders was studied in two cases:

The first case: the cost was studied at a spacing of 3 m between the beams and b, H, L are variables. b= 0.2-0.4 m, H=0.4-1.5m, L= 4-15m.

The second case: the cost was studied at a spacing of 4 m between the beams and b, H, L are variables. b= 0.2-0.4 m, H=0.4-1.5m, L= 4-15m.

The results were compared in both cases to determine the lowest cost in each case.

The traditional Optimization Spreadsheet Models

A structural analysis was carried out for the two previous cases. A total of 612 examples were derived and compared. The lowest cost was determined for each span. Results were compared with the results presented by the program. Refer to Tables 1-4.

Table 1 Input variables

Symbol	variables	Value
E_C	Modulus of elasticity of concrete (MPa)	22000
E_s	Modulus of elasticity of steel (MPa)	200000
F_y	Yield strength of steel (N/mm^2)	360
$F_{y\ stirrups}$	Yield strength of stirrups (N/mm^2)	240
F_{cu}	Compressive strength of concrete(N/mm^2)	25
γ_y	Density of steel (kN/mm^3)	78.5
γ_c	Density of concrete (kN/mm^3)	25
DF	Partial factor for dead loads	1.4
Lf	Partial factor for live loads	1.6
F_c	Weight of finishes (kN/m^2)	1.5
LL	Weight of live load (kN/m^2)	3
S	Spacing between girders (mm)	2000,3000,4000,5000,6000
L	Span of the beam (mm)	8000,10000,12000
B	Width of girder (mm)	200,300,400
H	Total depth of girder (mm)	400-1200
d	Effective beam depth(mm)	—
t_s	Slab thickness(mm)	100,120,140,160,200,240

Table 2 Output variables

Symbol	Output
B	Optimum width of the girder (mm)
h	Optimum high of the girder (mm)
t_s	Optimum slab thickness (mm)
S	Optimum spacing between girders (mm)
A_s	Optimum area of longitudinal tension steel (mm^2)
$A_s{}'$	Optimum area of longitudinal compression steel (mm^2)

Table 3 Price for composite girder components

Component	Price (USD)	Unit
Steel	723	Per ton
Concrete	39	Per m^3

Formwork	14	Per m^3

Table 4 The lowest price is derived from the analysis of 612 cases at different spans

Span	Cost for spacing3m	Cost for spacing 4m
4	395	469
5	533	655
6	738	881
7	934	1110
8	1220	1476
9	1595	1991
10	2103	2626
11	2742	3618
12	3713	4609

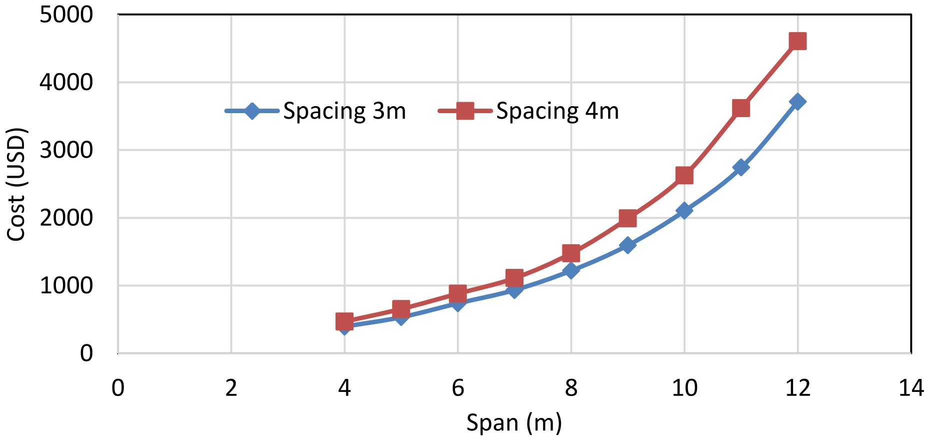

Fig. 7 Relation between span and cost for spacing 3 and 4 m.

From the previous relationship, it is clear that the grater the span the higher the cost due to the increase in the dimensions of the section in addition to the percentage of reinforcement and also increase the distance between the girders lead to increased cost because of the increase percentage of reinforcement.

Table 5 Optimum dimensions and the amount of reinforcement for each span at spacing of 3m between the beams.

Span	Width	High	Reinforcement ratio
4	200	1100	0.0053
5	200	800	0.0089
6	200	1000	0.0082
7	200	1200	0.0073
8	200	1200	0.0085
9	200	1200	0.0102
10	200	1200	0.0124
11	200	1200	0.0150
12	200	1200	0.0190

From Table 5 it is clear that the best section with span 7 meters because the stability of the dimensions of the section and the increase of span increasing the percentage of reinforcement ratio increases the total cost.

Table 6 Optimum dimensions and the amount of reinforcement for each span at spacing of 4m between the beams.

Span	Width	High	Reinforcement ratio
4	200	1300	0.0049
5	200	1500	0.0048
6	200	1200	0.0074
7	200	1500	0.0073
8	200	1500	0.0077
9	200	1500	0.0096
10	200	1500	0.0118
11	200	1500	0.0153
12	200	1500	0.0181

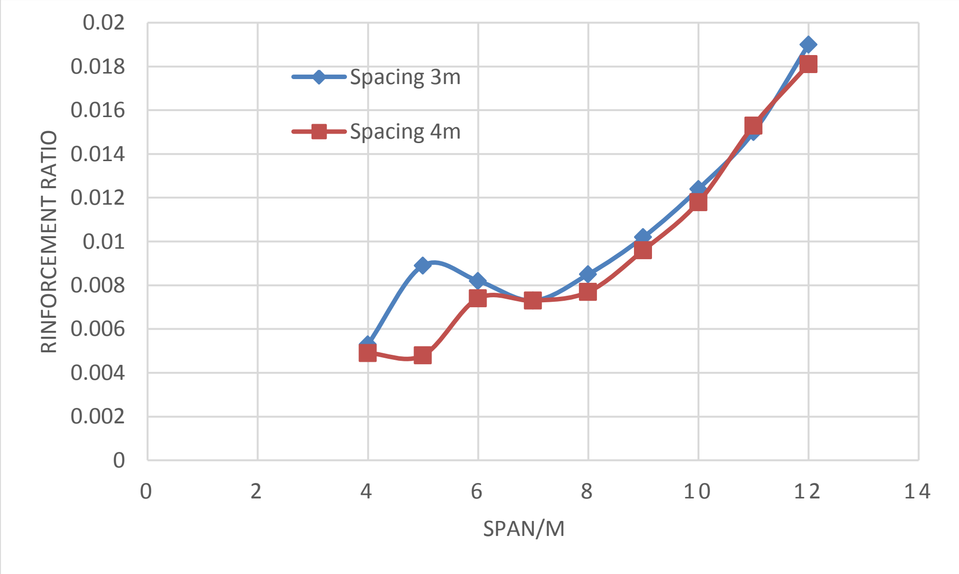

Fig. 8 Relation between span and reinforcement ratio at spacing's 3 and 4 m.

From **Fig. 8** it is clear that the maximum span is 7 meters for long spans because the stability of the dimensions of the section and the increase of span increasing the percentage of reinforcement ratio led to increases the total cost.

COMPARISON OF THE TOTAL COST FROM (GRG) AND THE TOTAL COST FROM ANALYSIS

The cost of the analysis and the cost resulting from the Excel spreadsheet using the generalized gradient (GRG) was compared. The difference in cost for GRG was as follows:

Table 7 Cost generated by the analysis and the cost resulting from (GRG) at spacing 3m

Span	Cost from analysis	Optimum cost from (GRG) for spacing 3m	Percentage %
4	395	381	4
5	533	521	2
6	738	679	8
7	934	853	9
8	1220	1044	14
9	1595	1280	20
10	2103	1631	22
11	2742	2074	24
12	3713	2811	24

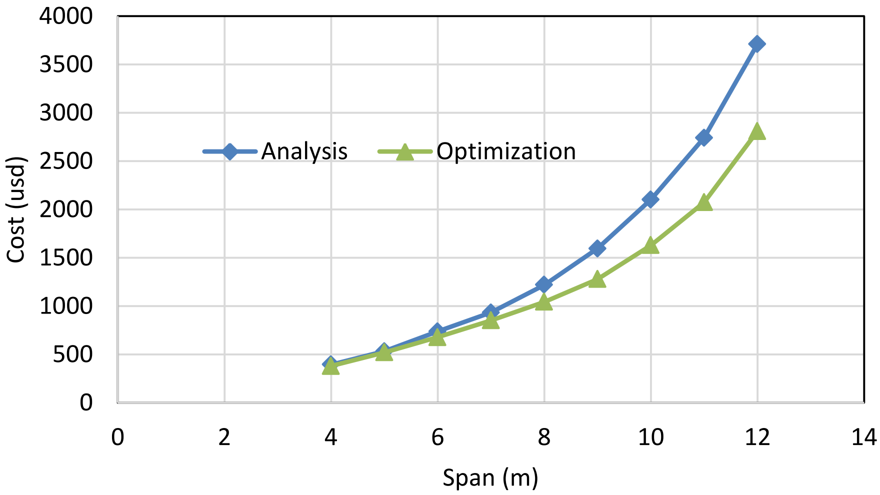

Fig. 10 Relation between span and Cost resulting from analysis and optimization at spacing 3m.

From the previous relationship, it is clear that at the same spans the cost is lower when using (GRG) method of obtaining the optimal cost as a result of obtaining the ideal dimensions, and also the cost is greatly reduced, up to 24%, at the large spans as shown in Table 7.

Table 8 cost generated by the analysis and the cost resulting from (GRG) at spacing 4m

Span	Cost from analysis	Optimum cost from (GRG) for spacing 3m	Percentage %
4	469	404	14
5	654	562	14
6	880	738	16
7	1110	933	16
8	1456	1192	18
9	1991	1563	21
10	2626	2036	22
11	3618	2817	22
12	4609	3675	20

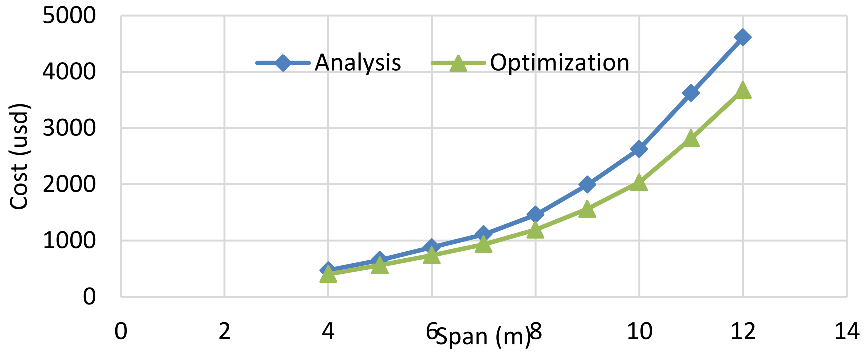

Fig. 11 Relation between span and Cost resulting from analysis and optimization at spacing 4m.

Of all the above, it is clear that GRG provides the time to get the best solution and thus get the optimal cost compared to the traditional analysis that needs a lot of time, but it requires the introduction of constraints, objective functionality and variables correctly.

Design examples

The optimum design was performed for three halls having different dimensions as listed in Table 9. The columns are planned, the concrete slabs were designed according to this The total cost of each .layout, where different distances were taken between the beams area was studied according to the different planning. The optimization of the bay was performed by Generalized Reduced Gradient (GRG) method, where all the constraints were performed according to the Egyptian Stander. The results were as shown in the table spacing 4m (10). In the first area, the best layout was at a distance between the beams equal 18 as well as the number of foundations, slab which had the number of columns 235*1200 mm. In the second area, the thickness was 160mm, dimensions of the beams spacing 5m which had the number of best layout was at a distance between the beams equal 12 as well as the number of foundations, slab thickness was 200mm, columns dimensions of the beams200*1200mm As shown in table(10) In the second area, the best spacing 4m which had the number of layout was at a distance between the beams equal 12 as well as the number of foundations, slab thickness was 160 mm, columns dimensions of the beams200*1100mm As shown in table.

Table 9 Areas covered by the study

Area	Dimension	
	L	L1
1	8	24
2	10	30
3	12	36

Table 10 Total cost at different areas at different column layout

Span	Spacing	NO. of column	As for composite girders	Total cost for un shored	Total cost for shored
	2		1435	19997	20123
8	3	12	1480	16834	16960
	4		1699	16156	16282
	2		1550	28303	28499
	3		1932	25462	25658
10	4	12	2503	26595	26791
	5		3606	27598	27794
	2		2232	47549	47829

	3		2960	43335	43615
	4	12	3966	43992	44272
12	5		5343	45865	46142
	6		6221	46790	47070

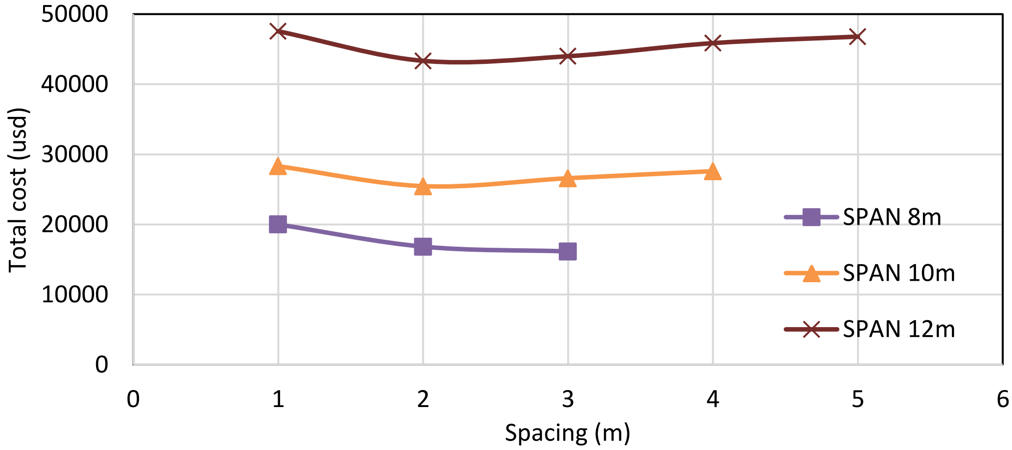

Fig. 12 Relation between spacing and total cost at different spans.

From this relationship it becomes clear that the lowest cost in the first area with 8m span is at a spacing 4m between girders and less expensive in the second and third region with 10, 12 m span respectively at a distance 3m between the girders.

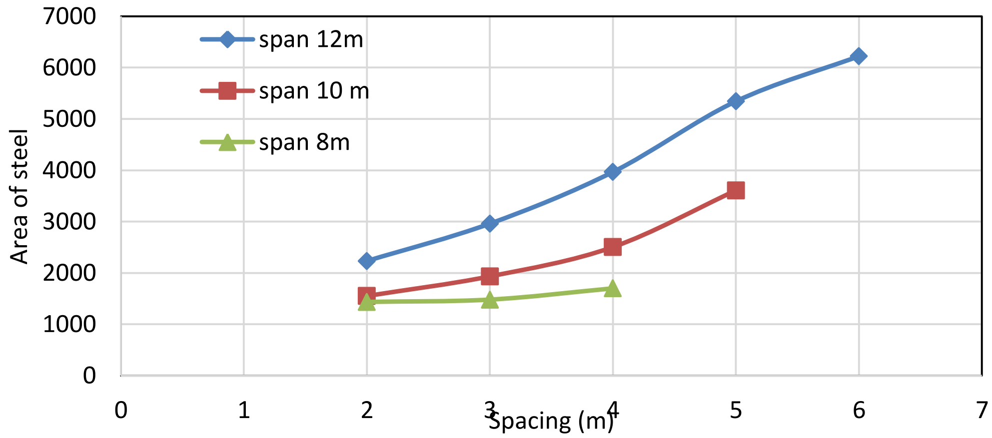

Fig. 13 Relation between spacing and area steel at different spans.

From the previous relationship it becomes clear that the greater the distance between the girders the greater the proportion of reinforcement, which leads to an increase in the total cost.

CONCLUSIONS

An optimization algorithm was built for the design of a long-span composite RC girders system. All assumptions, constraints, and variables were specified to minimize the cost of composite RC girders. The presented algorithm was verified by 612 example was done using the traditional analysis was compared.

A comparative study was performed for the composite RC girders bay to study the effects of the composite RC girders divisions, number of column and foundation, spacing between girders, from different spans.

The present optimal design for composite RC girders has important implications for the studied parameters that can be summarized as follows:

• The optimization of 612 composite RC girders, with different spacing divisions, did not show any significant difference in the total cost with short spans(3,4)m In the spacing of 3m, while the big difference in total cost was 24% this at long spans.

• Cost differences between Generalized Reduced Gradient (GRG) For Optimum Design of Beams and traditional Optimization Spreadsheet Models was shown in the long spans.

• The maximum span we can implement in composite RC girders is 12m.

• The greater the distance between the beams, the greater the proportion of reinforcement and thus increase the cost.

• Good layout of the columns clearly affects the cost of the structure of the origin positively where it reduces the cost.

• The greater the distance between the beams number of columns is fewer and the lower the cost of building.

In conclusion, GRG is one of the most valuable design methods and saves time to get the best solution, but requires the introduction of constraints, objective function of and variables correctly.

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