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Optimum Cross Section and Longitudinal Profile for Unstiffened Fully Composite Steel Beams

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ABSTRACT

Composite steel beam is commonly used element in multistory steel buildings today. The composite action between the concrete deck and the steel beam reduces both steel weight and deflection, accordingly, enhance floor economy and serviceability. Many earlier researches were carried out to optimize the design of the composite steel beams under both static loading and dynamic behavior. None of these researches was concerned in optimizing the cross section or the longitudinal profile of built-up composite steel beams. The aim of this research is to develop simple and practical equations to determine the optimum cross section dimensions and optimum longitudinal profile for both shored and un-shored simply supported built-up fully composite steel beams. These equations were developed using (GRG) solving technique considering residential buildings loads and (ASD) design method. Also, the research presented an example for utilizing the developed equations.

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1. Introduction

Connecting steel beams to concrete decks to form composite floors are commonly used in multi-story steel buildings today. Using this system reduces both weight and cost of floors and increase their stiffness and severability. Composite floors could be classified as follows:

- Construction wise, composite floor may be shored or un-shored. Shored floor is supported during concrete casting and till concrete hardening, accordingly, composite section support all loads. On the other hand, un-shored floor is casted without supporting and hence, weights of steel and concrete are supported by steel section only while the rest of loads are supported by the composite section.
- Steel section, it could be truss (angels or hollow section members) or beam (hot rolled section, built up section or castellated beam) or other girder type such as vierendeel.
- Composite action, when the shear connectors between steel section and concrete deck are strong enough to prevent any slippage, the floor is called fully composite. If part of the slippage is permitted, the floor is called partially composite.

Optimizing the design of composite floors was intensively addressed in the last twenty years. Many researchers tried different optimization techniques such as Non-Linear Programming (NLP), Artificial Neural Network (ANN), Genetic Algorithm (GA), Ant Colony (AC), Harmony Search (HS). Fig 1 summarized some of the previous researches regarding this issue.

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2. Objective

Despite of the previous efforts in optimizing the design of composite floors, there still some unsatisfied points which need farther studies such as:

- Optimizing the composite beams using (ASD) method
- Optimizing the section of built up composite beams
- Optimizing the longitudinal profile of the composite beams (curtailment)
- Presenting the optimization results in usable form (formulas or charts)
- The effect of construction sequence (shored or un-shored)

The objective of this research is to cover the above mentioned points by presenting a set of equations to determine the optimum section dimensions at any location along the built up fully composite beam considering the used construction sequence and based on (ASD) method.
This research is concerned in optimizing the steel weight only and it is not involved in designing the shear connectors.

Researcher	Year	Research description
Hojjat Adeli, Hongjin Kim	2001	It optimized the design of composite beams according to the (LRFD) of the (AISC) using the integer-discrete nonlinear programming, and then mixed the results using neural dynamics model.
Hongjin Kim, Hojjat Adeli	2001	Floating-point genetic algorithm was used to optimize the (LRFD) design of composite floors according to (AISC)
S. Kravanja, S.Silih	2002	The well-known Non-Linear Programming (NLP) approach was used to optimize the design of both trusses and beams composite floors according to Euro code
Christopher M. Foley, Warren K. Lucas	2004	Used Genetic Algorithm (GA) to optimize the design of both composite and non-composite floors according to (AISC) considering vibration criteria
Uroš Klanšek, Stojan Kravanja	2006	This research is the 1st part of two parts series, it was considering in direct production costs including material costs, power consumption and the labor costs.
Uroš Klanšek, Stojan Kravanja	2007	This research is the 2nd part which was concerning in optimizing the design of composite floors using Non-Linear Programming (NLP) approach.
S. Kravanja, U. Klanšek	2008	Suggested an optimization technique for both truss and beam composite floors according to Euro code using nonlinear programming (NLP)
Ahmed B. Senouci, Mohammed S. Al-Ansari	2009	Presented a Genetic Algorithm (GA) model to optimize the design of composite beams according to the (LRFD) of the (AISC) considering the effect of span and loads.
A. Kaveh, A. Shakouri Mahmud Abadi	2010	Optimized the design of composite floors according to the (LRFD) of the (AISC) using both traditional and improved harmony search algorithm
Kaveh, M. Ahangaran	2012	A continuation of the previous research using social harmony search technique.
Victoria E. Roşca, Elena Axinte, Carmen E. Teleman	2012	Presented an optimization technique for composite beams design according to (EN-1994-1-1/2006) using Non-Linear Programming (NLP) approach.
B. Blachowski, W. Gutkowski	2014	Estimated the minimum weight of steel in composite floors to satisfy the design requirements under human induced vibrations
Andrew J. Unander	2016	This thesis studied the design of composite floors statistically based on a database contains 640 existing buildings to estimate the range of the optimum steel weight per unit area of floor.
Hamid Eskandari, Tahereh Korouzhdeh	2016	Matlab was used to generate a database of 20,000 composite beams to produce a contour map of cost with respect to affecting parameters.
Rong He, Guo Ding, Yue Yang, Liwei Ye	2016	Investigated the effect of optimizing the composite floors of super tall buildings on their lateral stiffness's and serviceability's.
Tahereh Korouzhdeh, Hamid Eskandari-Naddaf & Morteza Gharouni-Nik	2017	Used Improved Ant Colony (IAC) technique to optimize the design of composite beams according to the (LRFD) of the (AISC), research results indicated that the efficiency of improved technique superseded the original one.
A. R. Silva, T. A. Rodrigues	2019	Modeled the composite beam using FEM to generate a data base, and then applied sequential linear programming technique to optimize the design.
N. M. Yossef, S. Taher	2019	Uses Genetic algorithm (GA) technique to optimize the design of castellated beams in composite floors with respect to section dimensions and opening size.
Tahereh Korouzhdeh, Hamid Eskandari-Naddaf	2019	Suggested a cost-safety optimization technique based on standardized formulation using (LRFD) design method, the results were verified and compared with those from (AI) techniques.

Fig 1: Summary for some earlier researches

3. Methodology

The main difficulty of optimizing the composite beam is the large number of parameters that affect the design. These parameters could be classified as follows:

- Geometrical parameters: beams span, spacing, section dimensions and type of supports
- Material parameters: concrete strength, steel grade and creep factor
- Loading parameters: values of dead, superimposed and live loads
- Construction parameters: shored or un-shored construction method

In order to organize and facilitate the research, the following assumptions are considered:

- To reduce the number of the considered parameters beams span, spacing, type of support and load value will be presented using one parameter which is the total bending moment at the considered section along the beam.
- For residential, offices and commercial buildings, the ratio of own weight (concrete deck + steel beams) to the total load (own weights + superimposed loads +live loads) is considered one third.
- The considered concrete cube strength (Fcu) is 25.0 MPa, accordingly, the ratio between elastic modulus of steel and concrete (Modular ratio) (n) and creep factor are 10.0 & 2.0 respectively.
- The optimization will consider the un-shored construction sequence as reference to optimize the shored condition.
- All calculations and equations are in (ton & cm)

The considered parameters in this research and their values are:

- The considered beam is fully composite.
- Concrete deck thickness starts with minimum value of 10 cm and increased during the design if the stresses exceeded the allowable limit
- Effective width of concrete deck is considered 12 times its thickness. Accordingly, beam span and spacing between beams shall not be less than 12 and 48 times deck thickness.
- Steel grades between steel (24/37) and steel (36/52) are considered.
- Total bending moment is ranged between 250 to 5000 cm.ton

Generally, the design of composite beams is divided into two phases, the first before concrete hardening and second after concrete hardening. According to previous assumptions, in reference case (un-shored), the steel section will support one third of the total moment during the first phase, while the composite section will support two thirds of the total moment during the second phase. The final stresses on the section are the summation of the stresses from both phases. To calculate the stresses of each phase, proprieties of both steel and composite sections are calculated using MS Excel sheet, Fig. 2 illustrates the terms used in the calculations

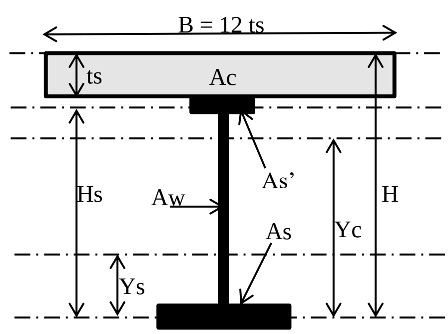

Fig 2: The considered Built Up composite beam section

Calculation of section properties is based on the following assumptions:

- Upper and lower steel plates are modeled as steel areas (As' & As respectively) acting at their centers of gravity
- Concrete deck is considered as equivalent steel area acts in the deck center of gravity, the equivalent area equals (Ac = 12 ts . ts / 2 n) where (2 n) is the modular ratio (n) times creep factor (2).
- The web plate is modeled as rectangular area with height equal to distance between upper and lower plates centers and thickness equals to the minimum value that keeps the section in non-compacted category. (Hs/tw = 190/ √ fy) where (fy) is the yield stress in (ton/cm2).
- Thicknesses of steel plates are neglected, and hence, H ≈ Hs + ts

Since (ts) value started with 10.0 cm, hence, the equivalent steel area of the RC deck (Ac) started with (12x10x10/20=60 cm2) where (n=10). Accordingly, section proprieties are governed by only three parameters (As'), (As) and (Hs).

Now, the optimization issue is reduced to simple question, what is the combination of (As'), (As) and (Hs) for a certain given bending moment that gives minimum weight and maintain the stresses in the section below the allowable limits. To answer this question, both actual and allowable stresses must be calculated.

Since the section is classified as non-compact section, there is no reduction in section properties due to local buckling and hence the actual stresses for certain phase equals to the bending moment of this phase divided by corresponding section modulus. On other hand, the allowable normal stresses for non-compact section is (0.58 fy) and no reduction due to lateral torsional buckling is considered. It means that upper flange should be temporarily braced out of plane till concrete hardening. Stress in concrete deck shall not exceed 6.0 MPa (= 0.25 Fcu).

In order to find out the optimum combination of (As'), (As) and (Hs) for certain bending moment, an add-in tool to MS Excel software is used, the tool is called "Solver", it can figure out the combination of certain variables values that minimize or maximize the target function under certain governing conditions. It is based on well-known mathematical technique called "Generalized Reduced Gradient" (GRG) Nonlinear Solving. This technique depends on changing the values of the affecting variables gradually while monitoring the governing conditions until the partial derivatives of the target function equals zero. In addition to the basic (GRG) technique, "Solver" tool enhances the searching performance by using automatic scaling for research intervals which adjusts the magnitude of change in each variable value for each iteration step.

Using the previously described "Solver" tool, the optimum combination of (As'), (As) and (Hs) values is investigated for certain bending moment under the following governing conditions:

- Stress in upper plate shall not exceed (0.58 fy) during the 1st phase
- Summation of stress in upper plate shall not exceed (0.58 fy) for both 1st & 2nd phases
- Summation of stress in lower plate shall not exceed (0.58 fy) for both 1st & 2nd phases
- Stress in concrete deck shall not exceed (6.0 MPa) during the 2nd phase

A complete database of 36 records is generated using the previous discussed technique (12 values of bending moment by 3 values of yield stress). Each record contains the total bending moment, the optimized values of (As'), (As), (Hs), the corresponding (Aw) value, the total steel section area (Ast) and the stresses in both 1st and 2nd phases besides the yield stress. The generated database is attached in the appendix. The generated database is based on un-shored condition where the bending moment of the 1st phase is about one third of the total bending moment.

Finally, the following correlations are carried out between database parameter's using built in power regression tool in MS Excel software.

- Total bending moment (M) and corresponding steel section height (Hs)
- Total bending moment (M) and corresponding total steel section area (Ast)
- Total steel section area (Ast) and corresponding upper steel plate area (As')
- Total steel section area (Ast) and corresponding lower steel plate area (As)
- Total steel section area (Ast) and corresponding web steel plate area (Aw)

Fig's 3, 4, 5, 6, 7 show the previous correlations respectively.

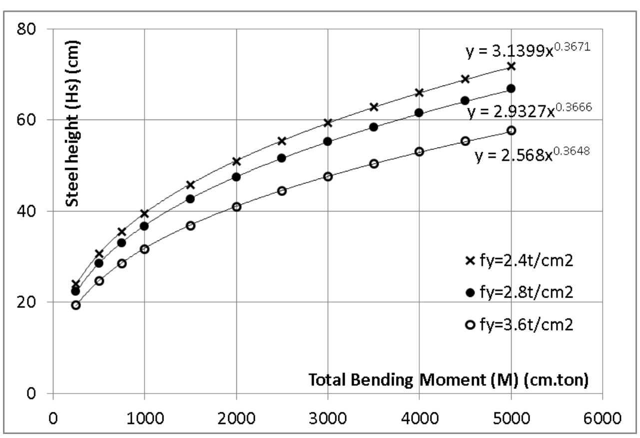

Fig 3: Relations between Total bending moment (M) and optimized steel section height (Hs) [ts=10cm, B=12 ts, Fcu=25MPa]

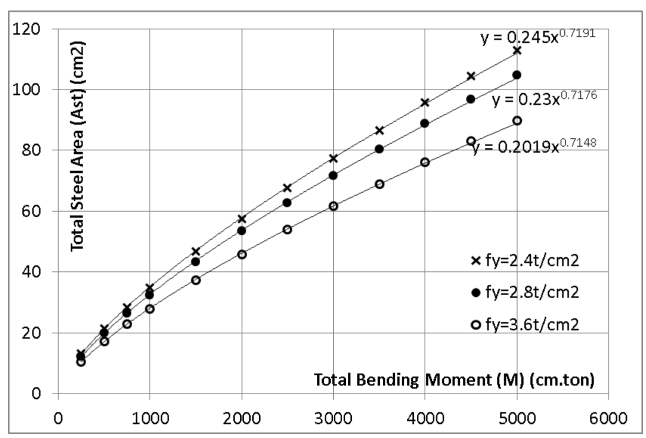

Fig 4: Relations between Total bending moment (M) and optimized total steel section area (Ast) [ts=10cm, B=12 ts, Fcu=25MPa]

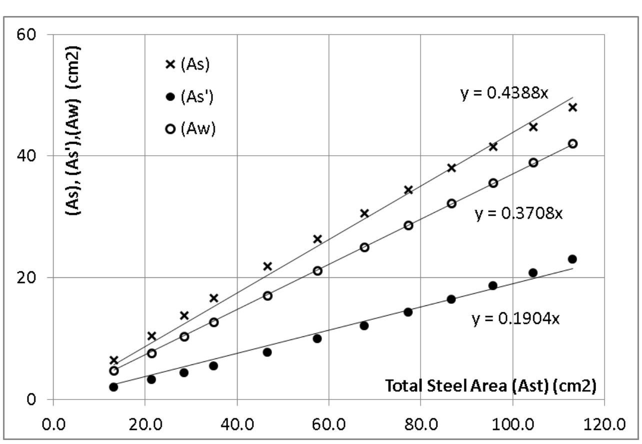

Fig 5: Relations between Optimized total steel section area (Ast) and (As), (As'), (Aw) for fy=2.4t/cm^2 [ts=10cm, B=12 ts, Fcu=25MPa]

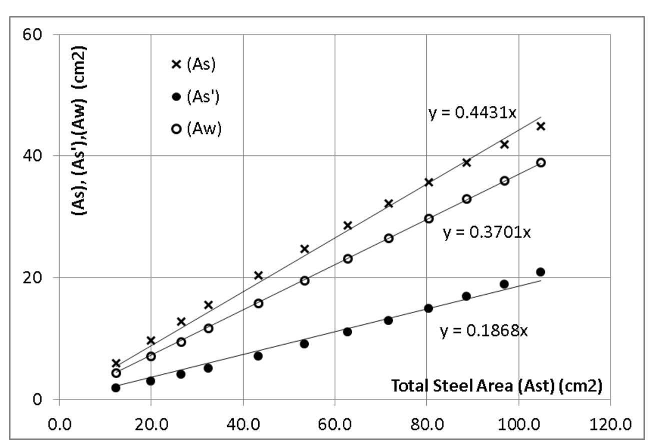

Fig 6: Relations between Optimized total steel section area (Ast) and (As), (As'), (Aw) for fy=2.8t/cm^2 [ts=10cm, B=12 ts, Fcu=25MPa]

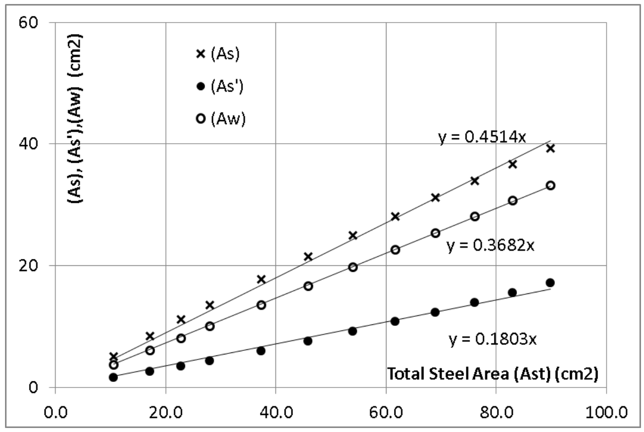

Fig 7: Relations between Optimized total steel section area (Ast) and (As), (As'), (Aw) for fy=3.6t/cm^2 [ts=10cm, B=12 ts, Fcu=25MPa]

4. Results and dissections

4.1. For un-shored composite beams

The summarized results in Fig's 3, 4, 5, 6, 7 show the following:

- Fig 3 shows the following regression:

$Hs = 3.14 (M)^{0.367}$ for $fy = 2.4\ t/cm^2$

$Hs = 2.93 (M)^{0.366}$ for $fy = 2.8\ t/cm^2$

$Hs = 2.57 (M)^{0.365}$ for $fy = 3.6\ t/cm^2$

These three equations could be reduced to the following equation

$$Hs = 4.86 (fy)^{-0.5}(M)^{0.366} \approx 4.5\sqrt[4]{\frac{(\sqrt{M})^3}{fy^2}} \quad \text{……………} (1)$$

- Fig 4 shows the following regression:

$Ast = 0.245 (M)^{0.72}$ for $fy = 2.4\ t/cm^2$

$Ast = 0.230 (M)^{0.72}$ for $fy = 2.8\ t/cm^2$

$Ast = 0.200 (M)^{0.72}$ for $fy = 3.6\ t/cm^2$

These three equations could be reduced to the following equation

$$Ast = 0.384 (fy)^{-0.5}(M)^{0.72} \approx 0.3\sqrt[4]{\frac{M^3}{fy^2}} \quad \text{……………} (2)$$

- Fig's 5, 6, 7 show the following regression:

$As \approx 0.45\ Ast$ …………… (3)

$As' \approx 0.20\ Ast$ …………… (4)

$Aw \approx 0.37\ Ast$ …………… (5)

- Dimensions of steel plates should be selected to maintain the whole section non-slender

$Hs / tw \leq 190 / \sqrt{fy}$ …………… (6)

$Bf / tf \leq 40 / \sqrt{fy}$ …………… (7)

4.2. 4.2 For shored composite beams

In shored condition, the composite section supports all the loads. Since concrete deck can resist all compressive forces without the upper steel plate, then, the optimum area of the upper flange is always equals zero and that is why the previous technique can't be used to optimize the shored composite beams. Another solution is to use the developed equations (1) to (7) with equivalent total moment as follows:

$Ft = (0.35\ M / Z\ st) + (0.65\ M / Z\ comp)$ for optimized un-shored beam … (8)

$Ft = (0) + (1.00\ M' / Z\ comp)$ for optimized shored beam … (9)

Referring to database records, the ratio (Z st / Z comp) equals to:

$(Z\ st / Z\ comp) = 0.734$ for $fy = 2.4\ t/cm^2$

$(Z\ st / Z\ comp) = 0.722$ for $fy = 2.8\ t/cm^2$

$(Z\ st / Z\ comp) = 0.700$ for $fy = 3.6\ t/cm^2$

Where Z st is the section modulus of the steel section and Z comp is the equivalent section modulus of the composite section.
Accordingly, the average value for (Z st / Z comp) ≈ 0.72, by substituting in Eq. (8) and solving Eq.'s (8) & (9), the equivalent total moment for shored condition (M') equals 0.88 that for un-shored condition (M).

4.3. Optimizing the composite beam profile

Since the optimized steel section dimensions are related directly to the total bending moment at the section, then, several sections along the beam could be optimized according to the bending moment distribution. It should be clearly noted that this study is concerned only in simply supported composite beams where concrete deck is always under compression.
For simply supported composite beam subjected to uniformly distributed load, optimization of beam profile should respect the following conditions:

- No sudden changes in beam height or flanges width
- All changes in beam height and flanges widths should be linear
- All beam sections should have the same steel grade

Fig. 8 shows the normalized bending moment distribution along the beam, the theoretically calculated optimized steel height (Hs) from Eq. (1) and the proposed practical optimized steel height (Hs). The proposed optimized profile divides the span into three parts as follows:

- The middle half span with constant optimized section for the maximum total bending moment (M).
- The mirror left and right quarters with tapered web and flange plates as follows:
    - Web thickness is the same as the middle part
    - Section height is linearly reduced from the height of the middle part at ¼ and ¾ of span to half that height at the supports
    - Flange areas are linearly reduced from the optimized values for (0.75M) at ¼ and ¾ of span to the optimized value for (0.4M) at the supports
    - Flanges thickness should be calculated from the sections at ¼ and ¾ the span to maintain the cross section non-slender.

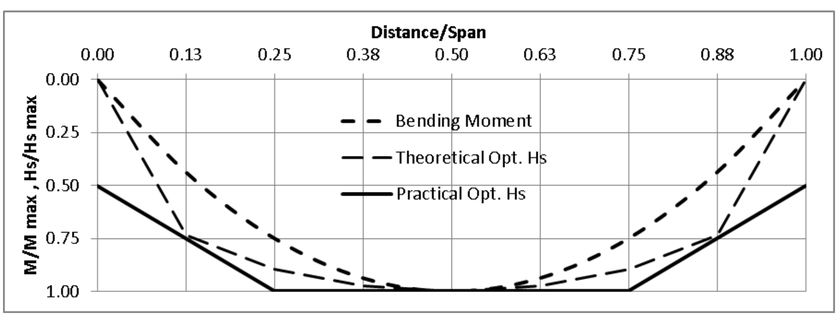

Fig. 8: Normalized bending moment distribution of (M / M max), theoretically calculated optimized (Hs) and proposed practical optimized (Hs) for simply supported beam subjected to uniformly distributed load

4.4. Shear stress in web

Since the composite beam section is optimized based on only the bending moment, the shear stress in the web plate should be checked. Since maximum shearing force occurs at support where section height is half the middle one and the web plate has a constant thickness. Then the slenderness ratio of the web plate at support (Hs/tw) = 190 / 2$\sqrt{fy}$ = 95/$\sqrt{fy}$. At this slenderness ratio, the allowable shear stress in web is (0.35 fy). Accordingly, the maximum allowable shear force is (0.35 fy . Aw)

$$Q\ max = 0.35\ fy\ (0.37 \times 0.384\ (fy)^{-0.5}(M)^{0.72})$$
$$= 0.05\ (fy)^{0.5}\ (M)^{0.72}$$

For simple beam subjected to uniformly distributed load (Q = 4 M /L)

$$L\ min = 80\ (fy)^{-0.5}(M)^{0.28} \quad \text{…………… (10)}$$

If the beam span which has a maximum bending moment of (M) is less than (L min), then web plate thickness should be increased or additional stiffeners should be used at support zone to resist the shearing force. As maintained before, the beam span should not be less than 48 times the concrete deck thickness to maintain the effective width 12 times the deck thickness. For concrete deck thickness of 10cm, the minimum beam span is approximately 5.0m.

4.5. Beam deflection

The deflection of simple beam subjected to uniformly distributed load could be calculated as follows:

$$\Delta = 5\ M\ L^2 / (48\ E\ .\ Ic)$$

Most design codes considered two serviceability limits, one for the total load (Δ TL = L/250) and the other for the live load (Δ LL = L/360). Considering ($E=2100$ t/cm^2) and the serviceability limit is (Δ TL= L/250), then the maximum allowable span (L max = 80 Ic / M). If the span exceeded this limit, camber should be used.

Considering (M LL= 0.25 M) and the serviceability limit is (Δ LL= L/360), then the maximum allowable span (L max = 224 Ic / M). If the span exceeded this limit the section must be increased. Referring to database records, the second moment of inertia of the composite section (Ic) equals:

Ic = 34.1 M for fy = 2.4 t/cm^2

Ic = 28.5 M for fy = 2.8 t/cm^2

Ic = 19.8 M for fy = 3.6 t/cm^2

These three equations could be reduced to the following equation

Ic = 112.5 (fy)$^{-1.35}$ M

Accordingly, the maximum allowable span equals to:

L max = 9000 (fy)$^{-1.35}$ to satisfy (Δ TL= L/250) …… (11)

L max = 25200 (fy)$^{-1.35}$ to satisfy (Δ LL= L/360) …… (12)

From Eq.(11) & (12), the span that satisfies the two serviceability limits considering (fy = 3.6 t/cm^2) is 16.0 m and it is increasing with reducing the (fy) value. Hence, the optimized sections satisfy the serviceability limits.

5. Comparison With Earlier Optimization Techniques

Tahereh Korouzhdeh et al (2017) presented a numerical example to optimize the design of both shored and un-shored fully composite simple beam using five different optimization techniques. This example was carried out using the proposed formulas to illustrate their efficiency as follows:

Design a simply supported composite girder with span of 6.0m subjected to super imposed load of 0.30 t/m^2, Live load of 0.20 t/m^2 if the spacing is 2.0m for shored case and 4.0m for un-shored case, (fy= 2.4 t/cm^2).

5.1. For un-shored condition

Concrete deck thickness	= 10 cm	
Concrete deck effective width	= 120 cm	
Concrete deck weight	= 0.1 x 4.0 x 2.5	= 1.00 t/m
Assume steel section weight	= 0.05 t/m	
Total service load	= 0.05 + 1.0 + 2.0 (0.3+0.2)	= 2.05 t/m

For middle zone:

M	= 100 x 2.05 x (6)^2 / 8	= 923	cm.t	
Hs	= 4.86 (2.4)$^{-0.5}$ (923)$^{0.366}$	= 38.2	cm	
Ast	= 0.384 (2.4)$^{-0.5}$ (923)$^{0.72}$	= 33.8	cm^2	
As	= 0.45 x 33.8	= 15.2	cm^2	≈ 155x10 mm
As’	= 0.20 x 33.8	= 6.8	cm^2	≈ 85 x 8 mm
Aw	= 0.37 x 33.8	= 12.5	cm^2	≈ 380x3 mm

For edge zone

0.75 M	= 0.75 x 923	= 692	cm.t	
Ast	= 0.384 (2.4)$^{-0.5}$ (692)$^{0.72}$	= 27.5	cm^2	
As	= 0.45 x 27.5	= 12.4	cm^2	≈ 155x8 mm
As’	= 0.20 x 27.5	= 5.5	cm^2	≈ 85 x 7 mm
0.40 M	= 0.40 x 923	= 369	cm.t	
Ast	= 0.384 (2.4)$^{-0.5}$ (369)$^{0.72}$	= 17.5	cm^2	
As	= 0.45 x 17.5	= 9.7	cm^2	≈ 100x8 mm
As’	= 0.20 x 17.5	= 3.5	cm^2	≈ 50 x 7 mm

Check shear stress in web

L min	= 80 (2.4)$^{-0.5}$ (923)$^{0.28}$	= 349	cm	< 600 cm OK

5.2. For shored condition

Concrete deck thickness	= 10 cm	
Concrete deck effective width	= 120 cm	
Concrete deck weight	= 0.1 x 2.0 x 2.5	= 0.50 t/m
Assume steel section weight	= 0.05 t/m	
Total service load	= 0.05 + 0.5 + 2.0 (0.3+0.2)	= 1.55 t/m

For middle zone:

M	$= 0.88 \times 100 \times 1.55 \times (6)^2 / 8$	= 614	cm.t	
Hs	$= 4.86\ (2.4)^{-0.5}\ (614)^{0.366}$	= 32.9	cm	
Ast	$= 0.384\ (2.4)^{-0.5}\ (614)^{0.72}$	= 25.2	cm^2	
As	= 0.45 x 25.2	= 11.3	cm^2	≈ 145x 8 mm
As'	= 0.20 x 25.2	= 5.0	cm^2	≈ 85 x 6 mm
Aw	= 0.37 x 25.2	= 9.3	cm^2	≈ 320x2.5 mm

For edge zone

0.75 M	= 0.75 x 614	= 461	cm.t	
Ast	$= 0.384\ (2.4)^{-0.5}\ (461)^{0.72}$	= 20.5	cm^2	
As	= 0.45 x 20.5	= 9.2	cm^2	≈ 145x 7 mm
As'	= 0.20 x 20.5	= 4.1	cm^2	≈ 85 x 5 mm
0.40 M	= 0.40 x 614	= 246	cm.t	
Ast	$= 0.384\ (2.4)^{-0.5}\ (246)^{0.72}$	= 13.0	cm^2	
As	= 0.45 x 13.0	= 5.9	cm^2	≈ 85 x 7 mm
As'	= 0.20 x 13.0	= 2.6	cm^2	≈ 55 x 5 mm

Check shear stress in web

L min	$= 80\ (2.4)^{-0.5}\ (614)^{0.28}$	= 312	cm	< 600 cm OK

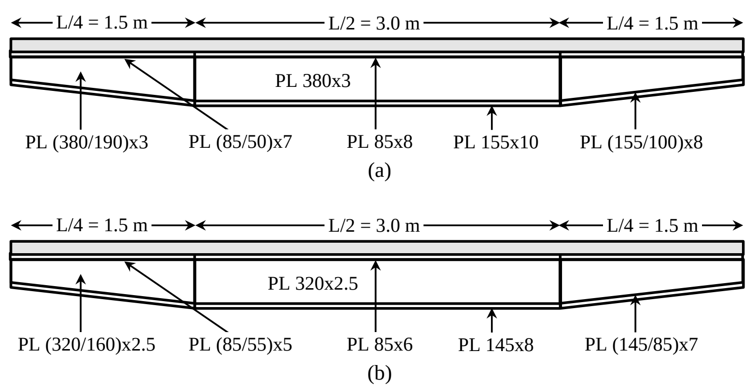

Fig. 9: The optimized beams from design example, (a) un-shored, (b) shored

Fig 9 presents the optimized shored and un-shored beams from pervious example. The total weight of the shored and un-shored beams are 98 and 135 kg respectively. Table 1 summarizes the comparison with earlier techniques.

Table 1 – Comparison between proposed formulas and earlier optimization techniques.

Optimization Technique	Un-shored case			Shored case		
	ts (cm)	Fcu (kg/cm2)	W steel (kg)	ts (cm)	Fcu (kg/cm2)	W steel (kg)
Harmony Search (HS)	8	250	233	11	350	115
Improved Harmony Search (IHS)	8	350	233	11	300	115
Highly Reliable Harmony Search (HRHS)	8	350	233	11	250	115
Segmented Harmony Search (SHS)	8	300	233	11	350	115
Ant Colony Optimization (ACO)	-	-	-	8	200	169
Improved Ant Colony Optimization (IACO)	10	300	158	9	300	100
Proposed formulas	10	250	135	10	250	98

The summarised comparison in Table 1 shows that the proposed formulas provided a better optimization than the earlier techniques and the second best optimization technique is the Improved Ant Colony Optimization (IACO).

6. Conclusions

The results of this research could be concluded as follows:

- This research successfully used the (GRG) mathematical technique to minimize the weight of steel the steel section of fully composite, simply supported steel beams in shored an un-shored condition using (ASD) design method.
- The generated optimized database using (GRG) technique is presented mathematically by set of developed equations that used to calculate the optimized height of the steel section and the areas of its flanges and web
- The generated database showed that 10 cm thick concrete deck with compressive strength of 25 MPa is enough for fully composite beam section subjected to total bending moment up to 50 m.ton, which is enough for most residential and office buildings.
- Optimum cross section dimensions for shored composite beam could be determined using the developed equations considering equivalent total moment equals to 88% of the similar un-shored composite beam.
- The optimum longitudinal profile of composite beam is divided into middle half span with constant cross section and two edge quarter spans with tapered web and flange plates.
- The optimum cross section calculated using the developed equations satisfies both shear stresses the serviceability conditions.
- Comparing the results (GRG) technique with those from earlier optimization techniques showed that (GRG) is more efficient than earlier techniques.
- Farther studies may be carried out to use the same technique to optimize composite and non-composite hybrid steel girders.

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Appendix A. The generated database

fy	M	Optimized section dimensions							Stresses of 1st phase		Stresses of 1st + 2nd phases		
		ts	H	Hs	As'	Aw	As	Ast	fst	fsb	Fc*	fst	fsb
2.4	250	10.0	34.1	24.1	2.0	4.7	6.4	13.2	-1.4	0.7	-1.2	-1.4	1.4
	500	10.0	40.6	30.6	3.2	7.7	10.5	21.4	-1.4	0.7	-1.5	-1.4	1.4
	750	10.0	45.5	35.5	4.4	10.3	13.8	28.5	-1.3	0.7	-1.7	-1.4	1.4
	1000	10.0	49.4	39.4	5.5	12.7	16.7	34.9	-1.3	0.6	-1.9	-1.4	1.4
	1500	10.0	55.8	45.8	7.7	17.1	21.9	46.7	-1.2	0.6	-2.2	-1.4	1.4
	2000	10.0	61.0	51.0	9.9	21.2	26.4	57.5	-1.1	0.6	-2.4	-1.4	1.4
	2500	10.0	65.4	55.4	12.1	25.0	30.6	67.7	-1.1	0.6	-2.7	-1.4	1.4
	3000	10.0	69.3	59.3	14.3	28.7	34.4	77.4	-1.0	0.6	-2.8	-1.4	1.4
	3500	10.0	72.8	62.8	16.4	32.2	38.1	86.7	-1.0	0.6	-3.0	-1.4	1.4
	4000	10.0	76.1	66.1	18.6	35.6	41.5	95.7	-1.0	0.6	-3.1	-1.4	1.4
	4500	10.0	79.1	69.1	20.8	38.9	44.8	104.5	-0.9	0.6	-3.3	-1.4	1.4
	5000	10.0	81.8	71.8	23.0	42.1	48.0	113.0	-0.9	0.6	-3.4	-1.4	1.4
2.8	250	10.0	32.4	22.4	1.9	4.4	6.0	12.3	-1.6	0.8	-1.4	-1.5	1.6
	500	10.0	38.5	28.5	3.0	7.1	9.8	19.9	-1.6	0.8	-1.7	-1.6	1.6
	750	10.0	43.1	33.1	4.1	9.5	12.9	26.5	-1.5	0.8	-1.9	-1.6	1.6
	1000	10.0	46.7	36.7	5.1	11.8	15.6	32.5	-1.5	0.7	-2.1	-1.6	1.6
	1500	10.0	52.6	42.6	7.1	15.8	20.4	43.4	-1.4	0.7	-2.4	-1.6	1.6
	2000	10.0	57.4	47.4	9.1	19.6	24.7	53.4	-1.3	0.7	-2.7	-1.6	1.6
	2500	10.0	61.5	51.5	11.0	23.1	28.6	62.8	-1.3	0.7	-2.9	-1.6	1.6
	3000	10.0	65.2	55.2	13.0	26.5	32.2	71.8	-1.2	0.7	-3.2	-1.6	1.6
	3500	10.0	68.5	58.5	15.0	29.8	35.6	80.4	-1.2	0.7	-3.3	-1.6	1.6
	4000	10.0	71.5	61.5	16.9	32.9	38.9	88.7	-1.1	0.7	-3.5	-1.6	1.6
	4500	10.0	74.3	64.3	18.9	36.0	42.0	96.9	-1.1	0.7	-3.6	-1.6	1.6
	5000	10.0	76.9	66.9	20.9	39.0	44.9	104.8	-1.1	0.7	-3.8	-1.6	1.6
3.6	250	10.0	29.4	19.4	1.7	3.8	5.1	10.6	-2.1	1.1	-1.8	-2.0	2.1
	500	10.0	34.8	24.8	2.6	6.1	8.4	17.1	-2.1	1.0	-2.1	-2.1	2.1
	750	10.0	38.6	28.6	3.5	8.1	11.2	22.8	-2.0	1.0	-2.4	-2.1	2.1
	1000	10.0	41.7	31.7	4.4	10.0	13.6	28.0	-2.0	1.0	-2.6	-2.1	2.1
	1500	10.0	46.8	36.8	6.0	13.5	17.8	37.3	-1.9	1.0	-3.0	-2.1	2.1
	2000	10.0	50.9	40.9	7.6	16.7	21.6	45.9	-1.8	1.0	-3.3	-2.1	2.1
	2500	10.0	54.5	44.5	9.2	19.8	25.0	53.9	-1.7	0.9	-3.6	-2.1	2.1
	3000	10.0	57.6	47.6	10.8	22.6	28.2	61.6	-1.7	0.9	-3.9	-2.1	2.1
	3500	10.0	60.5	50.5	12.4	25.4	31.2	69.0	-1.6	0.9	-4.1	-2.1	2.1
	4000	10.0	63.1	53.1	14.0	28.1	34.0	76.1	-1.6	0.9	-4.3	-2.1	2.1
	4500	10.0	65.5	55.5	15.6	30.7	36.7	83.0	-1.5	0.9	-4.5	-2.1	2.1
	5000	10.0	67.7	57.7	17.2	33.3	39.3	89.8	-1.5	0.9	-4.7	-2.1	2.1

* All units are in (ton & cm) except for concrete stress (Fc) in MPa