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Using genetic algorithms method for the paramount design of reinforced concrete structures

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Abstract. Genetic Algorithms (GAs) have found the best design for reinforced concrete frames. The design of the optimum beam sections by GAs has been unified. The process of the optimum-design sections has satisfied axial, flexural, shear and torsion necessities based on the designing code. The frames' function has contained the function of both concrete and reinforced steel besides the function of the frames' formwork. The results have revealed that limiting the dimension of frame-beam with the dimension of frame-column have increased the optimum function of the structure, thereby reducing the reanalysis requirement for checking the optimum-designed structures through GAs.

Keywords: optimum-design; GA; space frame; reinforced concrete

1. Introduction

Many researchers have been conducted several researches in order to improve the design of structures for their better performance (Suhatril *et al.* 2019, Arabnejad Khanouki *et al.* 2010, Shariati *et al.* 2010, Arabnejad Khanouki *et al.* 2011, Daie *et al.* 2011, Shariati *et al.* 2011a, Shariati *et al.* 2011b, Sinaei *et al.* 2011, Jalali *et al.* 2012, Shariati *et al.* 2012a, Shariati *et al.* 2012, Mohammadhassani *et al.* 2014a, Mohammadhassani *et al.* 2014b, Shariati *et al.* 2014, Khorramian *et al.* 2015, Shah *et al.* 2015, Arabnejad Khanouki *et al.* 2016, Khorramian *et al.* 2016, Shah *et al.* 2016, Shahabi *et al.* 2016, Shahabi *et al.* 2016, Shariati *et al.* 2017, Toghroli *et al.* 2017, Heydari and Shariati 2018, Ismail *et al.* 2018, Nosrati *et al.* 2018, Shariati *et al.* 2018, Wei *et al.* 2018, Chen *et al.* 2019, Katebi *et al.* 2019, Li *et al.* 2019, Milovancevic *et al.* 2019, Shariati *et al.* 2019, Trung *et al.* 2019). The attempts have been widely used in improvement of frames with composite beams (Moghaddam *et al.* 2009, Sinaei *et al.* 2011, Fanaie *et al.* 2012, Shariati *et al.* 2012, Shariati 2013, Shariati *et al.* 2015, Fanaie *et al.* 2016, Safa *et al.* 2016a, Shariati *et al.* 2016, Toghroli *et al.* 2016, Mansouri *et al.* 2017, Hosseinpour *et al.* 2018, Paknahad *et al.* 2018, Shariati *et al.* 2011c, Toghroli *et al.* 2018c, Davoodnabi *et al.* 2019, Luo *et al.* 2019, Xie *et al.* 2019, Shariati 2008). Application of soft computing methods in different field of civil engineering has been used in many researches recently (Hamidian *et al.* 2012, Toghroli *et al.* 2014, Aghakhani *et al.* 2015, Mohammadhassani *et al.* 2015, Toghroli 2015, Mansouri *et al.* 2016, Safa *et al.* 2016b, Safa *et al.* 2016c, Toghroli *et al.* 2016, Zhou *et al.* 2016, Khorami *et al.* 2017a, Mansouri *et al.* 2017, Sadeghipour Chahnasir *et al.* 2018, Sedghi *et al.* 2018, Shariat and Shariati 2018, Toghroli *et al.* 2018a, Zandi *et al.* 2018, Liu *et al.* 2009). GAs as one of these methods has been applied to attain the optimum function and values of a space-frame adjusted to various load cases (Eslami *et al.* 2014, Gandomi *et al.* 2014, Golafshani *et al.* 2014, Joshi *et al.* 2014, Shao et al. 2018, Shao *et al.* 2015, Chopra *et al.* 2016, Faradonbeh *et al.* 2016, Shao *et al.* 2018, Zhou *et al.* 2019, Armaghani *et al.* 2014, Armaghani *et al.* 2015). GA has unified the optimum dimensions of the beams to make the optimum results as an applicable way for all span length (Alqedra *et al.* 2011, Augusto *et al.* 2012, Zhou *et al.* 2012, Mola-Abasi *et al.* 2013, Huang *et al.* 2015, Sadeghipour Chahnasir *et al.* 2018). After taking the optimum variables, a suboptimum process has been occurred to attain the nearest suboptimum dimensions to the optimum ones with the least function to the designed section adjusted to many design constraints. The cross-sectional area-variation between the optimum and sub-optimum resolution have been added or subtracted from the reinforcement rate when transformed to an equivalent area. Later, the sub-optimum resolution has been selected

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from a pre-determined database containing all the available cross sections resisted on the applied loads. Therefore, the materials' effects have revealed the effectuality of GAs with more constrained problem.

GAs is widely used offering an optimum solution to few more structural members, say to attain an optimum resolution in Fiber Reinforced Polymer (FRP) design, strengthened the reinforced concrete beams adjusted to few design constraints like moment capacity, maximum plate width and fiber-peel off at shear crack (confining the shear force to the shear resisting for members with no shear reinforcement (Ardalan *et al.* 2009, Mola-Abasi *et al.* 2013, Eslami *et al.* 2014, Mohammadhassani *et al.* 2014c, Momenzadeh *et al.* 2017, Andalib *et al.* 2018, Bazzaz 2018, Hosseinpour *et al.* 2018, Nasrollahi *et al.* 2018, Paknahad *et al.* 2018, Sadeghipour Chahnasir *et al.* 2018, Zandi *et al.* 2018). Other methods like peridynamics are able to study material behavior of the FRPs, Fiber-Reinforced Composites (FRCs), and other application (Behzadinasab *et al.* 2018, Bobaru *et al.* 2018, Mehrmashhadi *et al.* 2019a, Mehrmashhadi *et al.* 2019b).

Two various data-bases (flexural & shear) have been applied to present the plates and sheets of FRP standardized (size and properties) due to its dealing with discrete manufactured design variables in market size (Ardalan *et al.* 2009, Sinaei *et al.* 2011, Abedini *et al.* 2017, Luo *et al.* 2019, Sajedi and Shariati 2019). The constraints have been incorporated on an optimized problem by providing a penalty in objective function, and applied as the following examples: 1) flexural strengthening has been needed on shear strengthening usage to discard the concrete cover rip off, however, in 2nd example, the flexural and shear strengthening are used in the design. Flexural and shear capacities of various concrete designs are comprehensively discussed in (Shariati *et al.* 2016, Hosseinpour *et al.* 2018, Paknahad *et al.* 2018).

GAs has applied to weight reduction in steel trusses. The constraints material strength and buckling stability are gained according to Eurocode 3: Design of steel structures used in algorithm (Vishal *et al.* 2010, Sarkar *et al.* 2012, Singh *et al.* 2013, Toghroli *et al.* 2014, Fanaie *et al.* 2015, Arabali *et al.* 2016, Freeman *et al.* 2016, Shariati *et al.* 2016, Toghroli *et al.* 2016, Behera *et al.* 2017, Khorramian *et al.* 2017, Nosrati *et al.* 2018, Sadeghipour Chahnasir *et al.* 2018, Toghroli *et al.* 2018b, Zhou *et al.* 2018, Zhou *et al.* 2019). Material strength for concrete and concrete-steel structures has been extensively studied in the past (Ghassemieh and Bahadori 2015, Bahadori and Ghassemieh 2016, Toghroli *et al.* 2016, Khorramian *et al.* 2017, Paknahad *et al.* 2018, Ziaei-Nia *et al.* 2018, Abedini *et al.* 2019, Davoodnabi *et al.* 2019, Luo *et al.* 2019, Xie *et al.* 2019).

A simultaneous optimization has been performed in terms of shape, size and topology through the basic arbitrary positioned nodes resulting that the descended model for topology optimization has offered solutions, regarded as 6-64 nodes.

GAs has applied to offer the optimum function design of reinforced concrete beams and pre stressed concrete beams (Alqedra *et al.* 2011, Zehui *et* al. 2019,, Farzad *et al.* 2017, Shi *et al*. 2019). The outcome has shown 27.9 % to 16.7 % functional saving for 4m and 8m RC beam Span, but 29.8 % and 17.8 % for 10m and 20m in PC beam function, accordingly, the whole section-function has been raised by the compressive strength increment. Other optimal designs are available in (Meti *et al.* 2018, Shariat *et al.* 2018, Nejadsadeghi *et al.* 2019).

GAs has used to offer the optimum function of pre cast concrete floor (Ferreira 2001, Sofge 2002, Herrera and Lozano 2003, Liang *et al.* 2006, Nan-Ying *et al.* 2006, Ardalan *et al.* 2009, Jain *et al.* 2009). The main function has been shaped focusing on the function of materials' consumption, labor, manufacturing, indirect functions, storage, transporting, assembling, taxes and profits (Alqedra *et al.* 2011, Shi *et al.* 2018, Vakili *et al.* 2013, Farzad *et al.* 2017, Shafieifar *et al.* 2017). In this study, introducing two new genetic operators, *Transgenic* has automatically changed the strands' number to keep the first layer's number larger than the second layer because it has resisted over a smaller bending moment (Augusto *et al.* 2012).

The second one as *Twins* has been conducted to check the similarity of the individuals from elitism, moreover, in case of any similarity, one of the twins has been placed to crossover, so the next one in that level has been considered to the elitism.

GA has applied to perform an optimum-designing for cantilever retaining walls of various heights. The ordinary design model has been applied to compare the outcome showing the efficiency of GA on the conventional designing models (Vishal *et al.* 2010, Sarkar *et al.* 2012, Singh *et al.* 2013, Esmaeili *et al.* 2014, Toghroli *et al.* 2014, Fanaie *et al.* 2015, Arabali *et al.* 2016, Freeman *et al.* 2016, Shariati *et al.* 2016, Toghroli *et al.* 2016, Behera *et al.* 2017, Khorramian *et al.* 2017, Nosrati *et al.* 2018, Sadeghipour Chahnasir *et al.* 2018, Toghroli *et al.* 2018b, Sari *et al.* 2018).

For optimum-design of reinforced concrete slabs, (Mola-Abasi *et al.* 2013, Sadeghipour Chahnasir *et al.* 2018) have maintained GA. Two types of reinforced concrete slabs, supporting only one-way slab and cantilever slab, have been taken to the design. Functional reduction about 18.92% and 6.78% have been envisioned for reinforced cantilever and one-way slab, juxtaposed with the previous studies.

In the current research, a main function has been defined. In the following, the designing limitations have been demonstrated to get the optimum frame-design after defining the applied optimization method. In the end, a space-frame example has been solved to check the efficiency of the designing process in a specified outcome.

2. Design procedure

To find the optimum functional design of continuous beam and column with its totally load conditions (axially, uni-axially and biaxial loaded) through GAs, and also to gain the optimum performance of planning and spacing frames beside the materials' impact on the optimum- design values, MATLAB is developed checking the axiality, uniaxially and biaxially loading of designed columns through a new element separating each of those resolutions based on their value. Optimal deigns of other types of frame were discussed in (Khorami *et al.* 2017a, Khorami *et al.* 2017b).

In addition to material functions, the function of space-frame has included the function of formwork. Following the market, the rate of r representing the function of steel C_s to the function of concrete C_c is around 75, also the rate of r_f representing the function of formwork C_f to the function of concrete C_c is around 0.4, totally adopted in this research:

For Continuous beam

$$C_t = C_c \times b_{beam} \times \{ (d + t) + r \times \rho_{beam} \times d \} + C_f \times \{ (2 \times (d + d^{-})) + b_{beam} \}$$

For Axially loaded column

$$C_t = C_c \times b_{column} \times h \times \{ 1 + (r \times \rho_{column}) \} + C_f \times \{ 2 \times (b_{column} + h) \}$$

For Uni-axially loaded column

$$C_t = C_c \times b_{column} \times h \times \{ 1 + (r \times (\rho_{ten} + \rho_{com})) \} + C_f \times \{ 2 \times (b_{column} + h) \}$$

For Biaxially loaded column

$$C_t = C_c \times b_{column} \times h \times \{1+(r \times (\rho_{ten,x} + \rho_{com,x} + \rho_{ten,y} + \rho_{com,y})\} + C_f \times \{2 \times (b_{column}+h)\}$$

The program has combined the function of continuous beams with any function of 3 loaded columns' type based on e_{all} variable to gain the function of the whole space-frame. The design value obtained by the program usage has included the design values of the continuous beam and the column in any loading.

3. Strategy limitations

The design constraint for the space frame has comprised the design constraints of continuous beam constraints (the cross sectional dimension of beam and reinforcement rate at 3 sections at least across the beam span) and column constraint (the cross-sectional dimension of column and the reinforcement rate in any cross-section face). Noting that a constraint has been used to control the designed members' dimensions. This constraint has confined the beam-dimensions within the column-dimensions, unless this would bring the shortcoming of finding the beams' minimal function combined with the columns' minimal function, led to no minimal frame function production. In case of the adoption of this process in finding the minimal function design of a space-frame, few shortcomings have been presented, thereby making the designed frame with non-applicable dimension. To resolve the shortcomings, trading processes have to be used between the optimum designed beam and the optimum designed column to gain another optimum designed dimensions in beam and column. The new dimensions have provided a minimal function of entire structure, and it is varied from the minimal function of combining the optimum beam function and the optimum column function, likewise the pare to optimum principle of raising one function against reducing the other one to gain a compromised resolution for both. The structure, designed optimally, has been computed linearly at first through the assumed dimension(s) in the applied loads (STAAD Pro. 2006) to achieve the required data outcomes for the optimum-designs like moments, shear and torsion in beams, and axial loads with moments in various directions in columns. The loads' eccentricity on column e has been measured in two directions (X / Y), then e has been juxtaposed with e_{all}, differently separating the solutions of loaded columns. The variable of this parameter has been regarded as 0.1 × h, when e is lower than e_{all} in all directions, resulting to the neglecting of the moment's affection in that direction, then the column has been designed uni-axially. When e is lower than e_{all} in other direction, the moment's influence in that direction has been discarded; accordingly, the column has been designed axially, unless the column has been designed bi-axially. When the optimum frame function has been attained, the frame members' optimum dimensions have been applied to calculate the structure to certify that the designed sections of beam and column are adequately efficient to resist on the applied loading in the code borders while the software has also fulfilled its objective.

4. Strategy limitations for beams

A reinforced concrete beam has included a structural potential more than the factored used load providing the characteristics spotted by ACI Code, while this code has limitations on the cross-sectional geometry of a beam, position and amount of steel reinforcement for all loads.

Dimensions have been applied as design variables, followed by the reinforcement level calculated based on the mentioned variables and topology optimization (Mohammadhassani *et al.* 2015, Mansouri *et al.* 2016, Safa *et al.* 2016c, Toghroli *et al.* 2016, Mansouri *et al.* 2017, Sadeghipour Chahnasir *et al.* 2018). In contrast, in this study, it has been applied as both reinforcement level as a design value beside the dimensions (give the minimal function) and also has the influence of shear and torsion on these optimum dimensions beside other constraints, utilized to diagnose the major values, thereby resisting the used loads (in many ways) and staying in the boundaries of the applied code to provide an optimum, real and functional solution. The first constraint equation means

$$\frac{k \times w \times L^2}{0.9(\rho \times b \times d \times f_y \times (d - \frac{(\rho \times b \times d \times f_y / 0.85 \times f'_c \times b)}{2}))} - 1 \le 0$$

is utilized to make 3 values of the section as ρ (reinforcement rate), b (beam-width) and d (beam effective-depth) carrying the lowest variables and resisting the used moment on that section. Equation below have represented the constraints, applied to block the reinforcement level from exceeding the highest variable nor below the lowest variable defined by ACI Code.

$$1 - \frac{\rho}{\rho_{\min}} \le 0$$

$$\frac{\rho}{\rho_{\max}} - 1 \le 0$$

Equation: $1 - \frac{h}{h_{min}} \leq 0$ has been applied to ensure the optimum section without a depth lower than the one controlling 1) the elastic deflection, 2) ACI code (9.5.2.2), and 3) Building Code Requirements, while regarding the influences of cracking and reinforcement on member stiffness.

To provide more real dimension, equations $1.5 - \frac{h}{b} \leq 0$ and $\frac{h}{b} - 2.5 \leq 0$ have kept the optimum depth rate to the optimum width rate in 1.5 to 2.5 mm (designer-specified).

Keeping the optimum width's dimension as 200 - 500 mm, the optimum depth in 300 - 1250 mm has been applied in equations below (designer-specified):

$$(1 - \frac{b}{200mm} \leq 0) \ \ and \ \ (\frac{b}{500mm} - 1 \leq 0)$$

$$(\frac{h}{1250mm} - 1 \leq 0) \ \ and \ \ (1 - \frac{h}{300mm} \leq 0)$$

To decrease the unsightly cracking, and to block the crushing of surface concrete because of the raised compressed stress provided by shear and torsion, equation:

$$\frac{\sqrt{\left(\frac{V_u}{bd}\right)^2 + \left(\frac{T_u P_h}{1.7A_{oh}^2}\right)^2}}{\phi\left(\frac{V_c}{bd} + 0.66\sqrt{f_c'}\right)} - 1 \leq 0$$

has been offered to confined the optimum dimension in this case. No excessive limitations have been specified in reinforcing steel for shear and torsion, because it has depended on the dimension of the section prior to be gained optimally, in the following, if the steel area has been applied as a constraint, then the solution direction would reinforce the section with lower or no reinforcement. Therefore, the mentioned solution has not been considered to be a general optimum, however, it has been regarded as an optimum design as a specific case optimized before starting the resolution. Furthermore, in terms of shear and torsion, the right decision to extra section optimization is to limit the cross-sectional dimensions by code specification and to define the steel-reinforcement's area by designer, followed by its optimization in the process of bar selection.

Ultimately, equations:

$$(1 - \frac{Bars\_Spacing}{Bars\_Diameter} \leq 0) \ \ or \ \ (1 - \frac{Bars\_Spacing}{25mm} \leq 0)$$

$$(1 - \frac{Layers\_Spacing}{25mm} \leq 0)$$

$$\frac{b}{column\_width} - 1 \leq 0$$

have been applied for the reinforcement topology by the section, regarding the minimum space among the selected bars.

5. Strategy limitations for columns

The core notion of the load contour model of this research is the biaxial transformation shortcoming into the equivalent uniaxial one by the below

$$\left(\frac{M_{nx}}{M_{ox,bal}}\right)^{\alpha} + \left(\frac{M_{ny}}{M_{oy,bal}}\right)^{\alpha} - 1.0 \leq 0$$

Thereafter, this equation has been nominated as a new design constraint led to the uni-axially problem solving with M_{nx} regarding e_x equals to 0 and M_{ny} regarding e_y equals to 0. Then the new constraint has transformed the resolved affection of the process into a biaxial bending shortcoming for M_{nx} and M_{ny}. The first two constraints have been regarded to limit the used force with the balanced force of the section; also the used moment has been confined to the balanced moment of the section, meaning that e is lower or equal to the balance.

$$P - P_{bal} = 0$$

$$\left(\frac{e}{e_{bal}} - 1\right) \leq 0$$

$$P_{bal} = 0.85 \times f_c' \times a \times b + f_{s,com}' \times \rho_{com} \times b \times h - f_{s,ten} \times \rho_{ten} \times b \times h$$

$$M_{bal} = 0.85 \times f_c' \times a \times b \times \left(y^- - \frac{a}{2}\right) + f_{s,com}' \times \rho_{com} \times b \times h \times \left(y^- - d^-\right)$$
$$+ f_{s,ten} \times \rho_{ten} \times b \times h \times \left(\left(h - d^-\right) - y^-\right)$$

$$a = \beta 1 \times c_{bal} = \beta 1 \times \left(\frac{0.003 \times E_s}{(0.003 \times E_s) + f_y} \times \left(h - d^-\right)\right)$$

$$y^- = \frac{0.85 \times f_c' \times b \times \left(h^2/2\right) + \rho_{com} \times b \times h \times f_{s,com}' \times d^- + \rho_{ten} \times b \times h \times f_{s,ten} \times \left(h - d^-\right)}{0.85 \times f_c' \times b \times h + \rho_{com} \times b \times h \times f_{s,com}' + \rho_{ten} \times b \times h \times f_{s,ten}}$$

$$e_{bal} = M_{bal} / P_{bal}$$

$$e = M_u / P_u$$

$$f_{s,com} = f_y - 0.85 f_c'$$

$$\bar{f}_{s,ten} = f_y$$

E_s as 200000 MPa

Where:

P_u as Nominal strength

M_u as Nominal bending strength

$$\left(\frac{M_{nx}}{M_{ox,bal}}\right)^{\alpha} + \left(\frac{M_{ny}}{M_{oy,bal}}\right)^{\alpha} - 1.0 \leq 0$$

$$M_{ox,bal} = 0.85 \times f_c' \times a \times b \times \left(x^- - \frac{a}{2}\right) + f_{s,com}' \times \rho_{com} \times b \times h \times \left(x^- - d^-\right)$$
$$+ f_{s,ten} \times \rho_{ten} \times b \times h \times \left(\left(h - d^-\right) - x^-\right)$$

$$M_{oy,bal} = 0.85 \times f_c' \times a \times h \times \left(y^- - \frac{a}{2}\right) + f_{s,com}' \times \rho_{com} \times b \times h \times \left(y^- - d^-\right)$$
$$+ f_{s,ten} \times \rho_{ten} \times b \times h \times \left(\left(b - d^-\right) - y^-\right)$$

Table 1 The frame's optimum design result

Variables	Without member interaction	With member interaction
ρ tension – rounded	0.0027	0.0015
ρ compression – rounded	0.0078	0.009
A_s tension	452 mm^2	226 mm^2
Tension bar no.	4 φ 12	2 φ 12
A_s compression	1232 mm^2	1473 mm^2
Compression bar no.	2 φ 28	3 φ 25
Bar no. – 3	2 φ 28 + 2 φ 25	2 φ 32 + 1 φ 25
Stirrups – zone 1	2700(0–1.2379 m)	2400(0-1.1915m)
Stirrups – zone 2	262.25(1.2379-1.4)	240(1.1915-1.35m)

Also, the plastic centroid in these equations (x^- - y^-) has been provided in 2 directions (X - Y) with no interaction between the bars' position formerly described. Since in slender column constraint, these 2 directions have been regarded by the replacement of the height with the width in other direction.

The reinforcement rate constraint has included 4 elements as 2 reinforcement rates for any direction, for tension and compression face, equation:

$$\left[\left\{\frac{\left((k_b \times l_u)/(\sqrt{(b\times h^3/12)/(b\times h)})\right)}{22}\right\}-1\right]\leq 0$$

$$\left[\left\{\frac{\left((k_b \times l_u)/(\sqrt{(h\times b^3/12)/(b\times h)})\right)}{22}\right\}-1\right]\leq 0$$

The reinforcement rate constraint has included 4 elements as 2 reinforcement rates for any direction, for tension and compression face, equation

$$\left(\frac{(\rho_{ten,x}+\rho_{com,x}+\rho_{ten,y}+\rho_{com,y})}{0.08}\right)-1\leq 0$$

$$1-\left(\frac{(\rho_{ten,x}+\rho_{com,x}+\rho_{ten,y}+\rho_{com,y})}{0.01}\right)\leq 0$$

Regarding the below equations, the reinforcement rate in one direction has been excluded, if the column has been designed uni-axially; or has represented the whole section's rate by one variable, if the column has been designed axially.

Regarding the cross-sectional dimensions, the minimum and maximum dimensions have been defined as shown in the below equations below in terms of the height and width without limiting them by any rate among them.

$$1-\frac{b}{0.3 or 0.25}\leq 0$$

$$1-\frac{h}{0.3 or 0.25}\leq 0$$

$$\frac{b}{1.0}-1\leq 0$$

$$\frac{h}{1.0}-1\leq 0$$

$$1-\frac{b}{beam\_width}\leq 0$$

After gaining the optimum design values, similar stages to find the sub- optimum resolution applied in beam section have been utilized in sub- optimum column section.

6. Strategy of plane frame

The aforementioned instance has checked the validity of the written program in terms of multi objective optimizations. The combination of the optimum beam and column has not commonly provided the optimum design of a plane frame due to the confinement among the adjacent members (previously described). A single bay one story plane frame with 3.5m height and 4.0m span length has optimally been designed with r as 75, r_f as 0.4 and the properties of material are f_c' as 30 MPa and f_y as 400 MPa. The beam is in 3 critical moments as *M1* as 100 kN.m, *M2* as 200 kN.m and *M3* as 300 kN.m. Regarding a maximal shear V_u of 500 kN with no torsion, while the column is in P_n as 2000 kN and M_n as 300 kN.m. The formwork has been considered to find the optimum frame design function; besides the long column constraint has been come with k_b as 1. The frame has been designed twice: 1) a separate solution has been adopted with no interaction between the members; however, 2) this interaction has been applied as another constraint in the designing process. In the following, the outcomes have been juxtaposed, indicating the effect of optimally frame-designing as one unit not separated. This small confinement as the width of the designed beams has been confined by the width of the designed column, accordingly, the function of the frame has been raised almost (2 %) more than the separate optimum resolution and this ratio has been increased on using more limitations (like presence of torsion) for this case. The significant discrepancies of two cases' function have indicated that the column optimum-design has not been influenced by the member confining, however, the discrepancies of total function have been related to the beam optimum-design due to the shear impact on cross-sectional dimension, and in case of any usage of torsion to the section, and the discrepancy has been increased. Mightily, the torsion has highly affected the cross sectional dimensions of the beam.

7. Space frame

The used frame has been loaded with a uniformly distributed floor loading of 12 kN / m^2 beside its weight, with a uniform line loading of 20 kN / m on the beams allocated B1, B2, B4 and B6, also a concentrated load of 200 kN has been used to the same beams. The material's characteristics are: f_c' as 28 MPa and f_y as 400 MPa.

Firstly, the frame has been computed linearly with

Table 2 Beam for the analysis repetition

Variables	Beam B1	Beam B2	Beam B3	Beam B4 And B6	Beam B5 and B7	Beam B8
Reinforcement - 1	2 φ 10	2 φ 10	2 φ 12	2 φ 14	2 φ 20	2 φ 8
Reinforcement - 2	2 φ 10	2 φ 10	2 φ 16	2 φ 14	2 φ 12	2 φ 8
Reinforcement - 3	2 φ 10	2 φ 10	2 φ 12	2 φ 16	2 φ 12	2 φ 8
Torsion 1-3	2 φ 8	2 φ 8	2 φ 10	2 φ 8	2 φ 10	2 φ 8
Torsion -2	2 φ 8	2 φ 8	2 φ 10	2 φ 8	2 φ 10	2 φ 8
Stirrups (0-1.9)	155	155	155	150	155	155
Stirrups (1.9-2.3)	0.0	0.0	0.0	140	155	0.0

STAAD Pro. 2006 to achieve the moments, shear and torsion which is used to any member section, required in the optimum design with GAs. All column sections have been allocated as (400 × 400 mm) with the height of .5 m, respectively, in beam sections, they have been allocated as (300 × 600 mm) in the initial steps of analysis. The initial dimensions applied to the frame analysis have been substituted by GAs design's dimensions, therefore, the entire frame has been re-analyzed based on the new optimum dimensions with similar used load to measure the optimum designed section of the members against the used loading. The mentioned process has been iterated until the optimum section has not witnessed any alteration in its design values. The constraint of this instance has contained a long column constraint with k_b as 0.6, and also the plastic centroid has been adjusted. The half of space-frame has been designed by GAs to simplify the solution, adding thatthe members with lower function have indicated high stability in last optimum-designed section within an earlier repetition of analyzing. Though the sections with higher function have wobbled by the number of analysis iteration, the sections have still stayed within the narrow curbs. Looking at the design values while controlling the function of column C1, the design values causing this variation are the reinforcement rates in *X* direction because of the large moment in this direction. Moreover, the column's resisting to the used loading has been distributed among these columns by repetition of the analysis, thereby providing applicable optimum-design to space-frame while handling the applied loads together.

The function and constraints history of column C1 have indicated that the optimum solution has been gained after ninth (9th) repetition with 0 constraints violation. Regarding other members of the frame, they have few constant optimum design values by the analysis repetitions.

The optimum design values of last analysis repetitions in beam - column are listed in Table (2).

8. Three stories with two bays

Three story space-frames have been loaded with a floor load of 12 kN / m^2 on all the stories, and all the beams have been loaded with a line load of 15 kN / m except the ones of the roof, loaded with a line load of 8 kN / m beside the frame's self-weight. The concrete compressed strength is $f_c^{'}$ as 28 MPa and the yield stress is f_y as 400 MPa. All column sections have been allocated at first by the dimensions of (400 × 400 mm) with a height of 4 m, and all the beam sections have been allocated by the dimensions of (300 × 500 mm), altered based on the optimum design outcomes by GAs. Thereafter, a re-analysis with a new optimum-design section has been conducted until the optimum section convergence. The frame's function has included the formwork's function beside the materials' function. On the other hand, another design constraint has been defined based on ACI – Code (10.3.6): Design axial strength φP_n of compression members should not be more than $\varphi P_{n,\max}$, calculated by the equation below to non – pre-stressed members with tie reinforcement

$$\varphi P_{n,max} = 0.8\varphi\,[0.85\, f_c^{'}\,(A_g - A_s) + f_y A_s\,]$$

9. Conclusions

According to the results of this study, there wouldn't be any requirement for any reanalysis as linear or non-linear to measure the capacity of the designed section, in case of sufficient design constraints of the applied algorithm and the capability of reliable outcome achievement. Furthermore, there wouldn't be any violations of it through the design process, otherwise, the use of a penalty function to bring the resolution to the nearest optimum has been recommended.

The study has also concluded that through the raise of applied torsion on beams, the optimum reinforcement ratio no longer has been decreased by the raised steel at some level, accordingly, in terms of optimum dimensions; it has no longer been increased by the steel increment. This is because when a design variable has reached to its limitations, the other design value has handled the used torsion at that level, even if the use of first design value to resist the used torsion is highly cost.

The study has also indicated that more design charts are available for diverse variables of moments to cover as much optimum-design diagram as possible for beam sections, for columns, various load conditions and material characteristics.

On the other hand, by confining the width of the designed beams by the width of the designed column, the function of the optimum frame has been raised. For further studies: more design constraints could be taken for highly difficult engineering shortcomings (non-linear relations) to gain specified / accurate outcomes.

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