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Optimum design of reinforced concrete columns employing teaching-learning based optimization

Gebrail Bekdaş *, Sinan Melih Niğdeli

Department of Civil Engineering, İstanbul University, 34320 İstanbul, Turkey

ABSTRACT

In structural engineering, the design of reinforced concrete (RC) structures needs an initial de-sign for cross sectional dimensions. After these dimensions are defined, the design constraints and the required reinforcement bars are calculated. But the required reinforcement area is not exactly provided since the size of rebars are fixed. At the end of the design, the security measures are provided, but the designer has no idea for the optimization of the design in mean of economy. For that reason, a powerful search methodology can be programed by using metaheuristic algorithms. In this study, optimum design of reinforced concrete columns was investigated by using an education based metaheuristic algorithm called teaching-learning based optimization (TLBO). In the methodology, the slenderness of the columns is also taken into consideration by using a simple approach given in the ACI 318 design code. In this approach, the factored design flexural moments are defined according to the buckling load and axial load of columns. The design variables of the problem include cross section dimension of the column and the detailed reinforcement design and the optimization objective is the minimization the maximum material cost of the column. Differently from the other metaheuristic algorithms, the decision of the optimization type (global or local search) is not defined by using a probability parameter in TLBO. In optimization, two phases of TLBO; teacher (global search) and learner (local search) phases are consequently applied in search of best design variables. The proposed approach is effective for the structural optimization problem.

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1. Introduction

In the design of reinforced concrete (RC) members, a design engineer decides several initial element dimensions and these dimensions are used in the detailed design of the reinforcements. The experience of engineer effects the economic design of RC member. The only way is to find a better design is to try several member sizes if a design software is used. These trials may be several times, but it cannot be thousand times. For that reason, optimization is needed to carry out iterations. Thus, an optimum design ensuring all design constraints can be found. The optimum design methods are proposed for several RC members such as frames (Balling and Yao, 1997; Guerra and Kiousis, 2006), beams (Barros et al., 2005; Barros et al., 2012; Ferreira et al., 2003), prestressed concrete bridges (Sirca and Adeli, 2005), columns (Gil-Martin et al., 2010) and slabs (Ahmadkhanlou and Adeli, 2005).

By using mathematical methods, it is only possible to find optimum results with some assumptions. In order to carry out a practical optimization, metaheuristic methods are suitable. The one of the metaheuristic methods used in the optimum design of RC members is genetic algorithm (GA). GA is used in the design of beams (Coello et al., 1997; Govindaraj and Ramasamy, 2005; Fedghouche and Tiliouine, 2012), columns (Rafiq and Southcombe, 1998), frames (Rajeev and Krishnamoorthy, 1998; Camp et al., 2003; Lee and Ahn, 2003; Govindaraj and Ramasamy, 2007). In order to provide effective optimum

* *Corresponding author*. Tel.: +90-212-4737070 ; Fax: +90-212-4737180 ; E-mail address: bekdas@istanbul.edu.tr (G. Bekdaş)
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results, several algorithms can be combined in a single method. Rath et al. (1999) combined GA with sequential quadratic programming (SQP) for optimum design of RC members. Similarly, simulated annealing (SA) and Hook-Jeeves method are used with GA by Leps and Sejnoha, (2003) and Sahab et al. (2005), respectively.

In several studies (Paya et al., 2008; Paya-Zaforteza et al., 2009; Ceranic et al., 2001; Yepes et al., 2008), SA is employed in the optimization of RC members. Perea et al. (2008) optimized RC frames of bridges by using a methodology employing SA, the threshold accepting, random walk and the descent local search. Fiber-reinforced composite plates are optimized by Rama Mohan Rao and Shyju, (2010). SA and tabu search (TS) are combined in the method.

Another metaheuristic algorithm used in the optimum design of RC members is big bang big crunch algorithm (Camp and Akin, 2012; Camp and Farah Huq, 2013; Kaveh and Sabzi, 2012). The music inspired harmony search (HS) algorithm developed by Geem et al. (2001) is used in the optimization of RC retaining walls (Kaveh and Abadi, 2011), RC continuous beams (Akin and Saka, 2010), RC frames (Akin and Saka, 2012) and RC beams (Bekdaş and Nigdeli, 2012) and columns (Bekdaş and Nigdeli, 2014; Nigdeli et al., 2015). Also, bat algorithm (BA) is employed for optimum design of RC columns (Bekdaş and Nigdeli, 2016).

In this paper, teaching-learning based optimization developed by Rao et al. (2011) is employed for the detailed optimum design of RC columns and results are compared with the results obtained by employing HS (Bekdaş and Nigdeli, 2014) and BA (Bekdaş and Nigdeli, 2016). In the methodology, the slenderness effect is considered by using moment magnification factor and the design of RC column is carried out according to ACI318 regulation. The methodology is coded in Matlab and the result is obtained for different heights of the column in order to see the effect of the slenderest.

2. Methodology

The teaching and learning process of a class is the inspiration of teaching-learning based optimization (TLBO) method. In a class, two phases of education are used. These phases are teacher and learner phases which are consequently applied.

As all numerical optimization algorithms, the problem must be defined. The problem data contain possible ranges of design variables, design constraints and algorithm parameters. The design variables of the RC column optimization are breadth (b_w), height (h), number and size of bars in face (web or essential reinforcement), size of shear reinforcements and distance of shear reinforcements.

The design constants are shown in Table 1 with the values used in numerical example. TLBO is lucky in algorithm parameters because the population of class is only defined by a user. Since two phases of the algorithm are consequently applied, a probability to choose the type of the optimization is not needed. In generation of new design variables, a teaching factor (TF) is used but it is not a user defined value. TF is randomly assigned and may be 1 or 2.

Table 1. Design constant and ranges of design variables.

Definition	Value
Range of web width, b_w	250 mm-400 mm
Range of height, h	300 mm-600mm
Longitudinal reinforcement (ϕ)	16 mm-30 mm
Shear reinforcement (ϕ_v)	8 mm-14 mm
Effective length factor in buckling, k	1.2
Clear cover, c_c	30mm
Max. aggregate diameter, D_{max}	16 mm
Yield strength of steel, f_y	420 MPa
Comp. strength of concrete, f'_c	25 MPa
Elasticity modulus of steel, E_s	200000 MPa
Specific gravity of steel, γ_s	7.86 t/m^3
Specific gravity of concrete (γ_c)	2.5 t/m^3
Cost of the concrete per m^3	40 $
Cost of the steel per ton	400$

After the required values are defined, an initial solution matrix is generated. These matrix contains vectors assigned with randomly generated design variables and the number of these vectors are equal to population number of the class.

Also, the objective functions of all possible designs in the vectors are calculated by controlling ACI 318 requirements and if a constraint violation is observed, the objective function defined as Eq. (1) is penalized with a huge cost.

$$min\, f(x) = C_c V_c + C_s W_s\,, \quad (1)$$

In the objective function, the cost of the column is calculated and C_c, C_s, V_c and W_s are cost of concrete per m^3, cost of the steel per ton, total concrete volume and total weight of steel, respectively.

After generation of the initial solution matrix, the best solution ($X_{teacher}$) (solution with minimum objective function) is chosen as a teacher. Thus, a new solution ($X_{new,i}$) is found according to Eq. (2) in teacher phase by modifying old solution ($X_{old,i}$) of the i^{th} vector in the class. rnd(0,1) is a random number between 0 and 1 while X_{mean} is the mean of the class.

$$X_{new,i} = X_{old,i} + rand(0,1)\cdot(X_{teacher} - T_F\cdot X_{mean})\,. \quad (2)$$

Then, student phase starts and Eq. (3) is used in generation.

$$X_{new,i} = \begin{cases} X_{old,i} + rnd(0,1)\cdot(X_i - X_j);\ f(X_i) > f(X_j) \\ X_{old,i} + rnd(0,1)\cdot(X_j - X_i);\ f(X_i) < f(X_j) \end{cases}. \quad (3)$$

In this generation, j^{th} and k^{th} solutions are the existing solution matrix and these vectors are randomly chosen. The phases are consequently applied for a defined iteration number. The results are updated if the solution of the objective function is lower than the existing one. Thus, the convergence of the optimum results is provided.

3. Numerical Example

In the study, RC columns with different length are optimized. The external loads are taken as 2000 kN, 50 kNm and 50 kN for axial force, flexural moment and shear force, respectively. The optimum results are given in Table 2. Table 2 also contains the results of HS (Bekdaş and Nigdeli, 2014) and BA (Bekdaş and Nigdeli, 2016).

4. Conclusions

The optimum values of RC column are investigated for different length of RC columns. Thus, the slenderness effect can be seen from the optimum results. In all length cases, the external forces are taken as the same but the increase of the total cost does not show a linear increase for long columns. The difference of cost is resulting from the increase of the dimensions and quality of reinforcements. By the increase of the cross-sectional dimensions, a possible reduction of quantity of shear reinforcements can be also seen from the results.

The employed metaheuristic algorithm called TLBO is effective to find the same optimum results with BA. TLBO method has no user defined parameters. The only user defined parameters is the population of the class. The effectiveness of BA is depended to the algorithm parameters. In that case, TLBO is a suitable algorithm in use of methodologies for RC design.

Table 2. Design constant and range.

	HS			BA			TLBO		
Length of the column (l)	3m	4m	5m	3m	4m	5m	3m	4m	5m
Breadth of the column (b_w) (mm)	400	300	300	400	300	300	400	300	300
Height of the column (h) (mm)	400	550	600	400	550	600	400	550	600
Bars in each face	1Φ20+1Φ18	2Φ16	2Φ16	3Φ16	2Φ16	2Φ16	3Φ16	2Φ16	2Φ16
Web reinforcement in each face	1Φ18	1Φ16+1Φ18	2Φ18	1Φ16	1Φ16+1Φ18	2Φ18	1Φ16	1Φ16+1Φ18	2Φ18
Shear reinforcement diameter (mm)	Φ8	Φ8	Φ8	Φ8	Φ8	Φ8	Φ8	Φ8	Φ8
Shear reinforcement distance (mm)	170	240	270	170	240	270	170	240	270
Optimum cost ($)	38.58	52.27	69.97	38.22	52.27	69.97	38.22	52.27	69.97

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