Review article

Improvements in meta-heuristic algorithms for minimum cost design of reinforced concrete rectangular sections under compression and biaxial bending

G. Sánchez-Olivares *, A. Tomás

Department of Civil Engineering, Universidad Politécnica de Cartagena (UPCT), Paseo Alfonso XIII, 52, 30203 Cartagena, Murcia, Spain

A B S T R A C T

A numerical procedure is proposed in this paper for achieving the minimum cost design of reinforced concrete rectangular sections under compression and biaxial bending by using biologically-inspired meta-heuristic optimization algorithms. The problem formulation includes the costs of concrete, reinforcement and formwork, obtaining the detailed optimum design in which the section dimensions and the reinforcement correspond to values used in practice. The formulation has been simplified in order to reduce the computational cost while ensuring the rigor necessary to achieve safe designs. The numerical procedure includes the possibility of using high-strength concrete and several design constraints, such as minimum reinforcement and limiting the neutral axis depth. Two numerical examples are presented, drawing comparisons between the results obtained by ACI318 and EC2 standards.

© 2016 Elsevier Ltd. All rights reserved.

Contents

---

* Corresponding author.
  E-mail address: gregorio.sanchez@upct.es (G. Sánchez-Olivares).

Nomenclature

$A_{c,i}$	area of concrete cross section for the individual i
$A_{s,i}$	area of tension reinforcement for the individual i
$A_{s,\min,i}$	minimum area of tension reinforcement for the individual i
A'_s	area of compression reinforcement
$A'_{s,i}$	area of compression reinforcement for the individual i
$A'_{s,\min,i}$	minimum area of compression reinforcement for the individual i
$A_{st,i}$	total area of reinforcement for the individual i
$A_{st,\min,i}$	minimum total area of reinforcement for the individual i
b	width of rectangular cross section
b_i	width of rectangular cross section for the individual i. Design variable
$b_{\max,i}$	maximum width of rectangular cross section for the individual i
b^U	upper bound for the design variable b_i
$b(y^*_k)$	width of the k-th fiber at distance y^*_k from centre of gravity of section about x^*-axis
c_c	the clear cover of tension reinforcement (mm)
C_1	first coefficient for load eccentricity strength constraint $g_{s2,i}$
C_2	second coefficient for load eccentricity strength constraint $g_{s2,i}$
d	effective height
d_i	effective height for the individual i
d_x	distance from left face of cross section to centroid of the closest reinforcing bars (x-axis)
d'_x	distance from right face of cross section to centroid of the closest reinforcing bars (x-axis)
d_y	distance from bottom face of cross section to centroid of the closest reinforcing bars (y-axis)
d'_y	distance from top face of cross section to centroid of the closest reinforcing bars (y-axis)
E_s	modulus of elasticity of reinforcement (in EC2)
f	objective function to be minimized
$\bar{f}$	global optimum of f
f_i	objective function for the individual i
f^*_i	normalized objective function for the individual i
f'_c	specified compressive strength of concrete
f_{cd}	design compressive strength of concrete (in EC2)
f_{ck}	characteristic compressive strength of concrete (in EC2)
f_{ctm}	mean value of axial tensile strength of concrete (in EC2)
f_y	specified yield strength of reinforcement
f_{yd}	design yield strength of reinforcement (in EC2)
f_{yk}	characteristic yield strength of reinforcement (in EC2)
F_i	fitness function for the individual i
F'_i	modified fitness function for the individual i
$g_{As,i}$	minimum tension reinforcement constraint for the individual i
$g_{A's,i}$	minimum compression reinforcement constraint for the individual i
$g_{Ast,i}$	minimum total reinforcement constraint for the individual i
$g_{duct,i}$	ductility constraint for the individual i
g_j	violated constraint
$g_{sp,\max,i}$	maximum spacing of reinforcement constraint for the individual i
$g_{sp,\min,i}$	minimum spacing of reinforcement constraint for the individual i
$g_{s1,i}$	resistance constraint against combined flexure and axial load for the individual i
$g_{s2,i}$	load eccentricity strength constraint for the individual i
g^*_i	sum of violated constraints multiplied by (-1) for the individual i
h	height of rectangular cross section
h_i	height of rectangular cross section for the individual i. Design variable
k	current iteration
$k_{\max}$	maximum number of iterations
$L_{f,i}$	length of form for the individual i
m	integer for attractiveness β
mvi	number of violated constraints for the individual i
M_{Rd}	design moment resistance of cross section (in EC2)
M_u	factored moment at cross section (in ACI318)
M_x	moment about x-axis
M_{x*}	moment about x^*-axis
$M_{x,Ed}$	design value of the applied internal bending moment about x-axis (in EC2)
$M_{x,n}$	nominal moment about x-axis at cross section (in ACI318)
$M_{x,n,i}$	nominal moment about x-axis at cross section for the individual i
$M_{x,Rd}$	design moment resistance of cross section about x-axis (in EC2)
$M_{x,Rd,i}$	design moment resistance of cross section about x-axis for the individual i
$M_{x,u}$	factored moment about x-axis at cross section
M_y	moment about y-axis
M_{y*}	moment about y^*-axis
$M_{y,Ed}$	design value of the applied internal bending moment about y-axis (in EC2)
$M_{y,n}$	nominal moment about y-axis at cross section (in ACI318)
$M_{y,n,i}$	nominal moment about y-axis at cross section for the individual i
$M_{y,Rd}$	design moment resistance of cross section about y-axis (in EC2)
$M_{y,Rd,i}$	design moment resistance of cross section about y-axis for the individual i
$M_{y,u}$	factored moment about y-axis at cross section
n	exponent for calculation of σ_c (in EC2)
nf	number of fibers in cross section
nr	number of reinforcing bars in cross section
$n_{x,i}$	number of bars at the bottom side of the section. Design variable
$n'_{x,i}$	number of bars at the top side of the section. Design variable
$n_{y,i}$	number of bars at the left side of the section. Design variable
$n'_{y,i}$	number of bars at the right side of the section. Design variable
N_{Ed}	design value of the normal applied axial compression load to cross section (in EC2)
NF	population size of fireflies
N_{Rd}	design axial resistance of cross section (in EC2)
$N_{Rd,i}$	design axial resistance of cross section for the individual i
N_z	axial compression load about z-axis
N_{z*}	axial compression load about z^*-axis
$\mathbf{p}^k_i$	spatial coordinate vector of the i-th firefly at the k-th iteration
$\mathbf{p}^k_j$	spatial coordinate vector of the j-th firefly at the k-th iteration
$\mathbf{p}^{k+1}_i$	spatial coordinate vector of the i-th firefly at the $(k+1)$-th iteration
$p^k_{i,l}$	l-th spatial coordinate of the i-th firefly at the k-th iteration
$p^k_{j,l}$	l-th spatial coordinate of the j-th firefly at the k-th iteration
P_c	price of concrete, used in objective function (€/m^3)