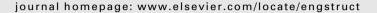


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Review article

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



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ABSTRACT

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.

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Nomenclature

$A_{c,i}$	area of concrete cross section for the individual i	h_i	height of rectangular cross section for the individual i.
$A_{s,i}$	area of tension reinforcement for the individual i	•	Design variable
$A_{s,\min,i}$	minimum area of tension reinforcement for the individ-	k	current iteration
3,,.	ual i	k_{\max}	maximum number of iterations
A'_s	area of compression reinforcement	$L_{f,i}$	length of form for the individual i
$A'_{s,i}$	area of compression reinforcement for the individual <i>i</i>	m	integer for attractiveness β
$A'_{s,\min,i}$	minimum area of compression reinforcement for the	mvi	number of violated constraints for the individual <i>i</i>
3,111111,1	individual i	M_{Rd}	design moment resistance of cross section (in EC2)
$A_{st,i}$	total area of reinforcement for the individual i	M_u	factored moment at cross section (in ACI318)
$A_{st,\min,i}$	minimum total area of reinforcement for the individual <i>i</i>	M_{x}^{u}	moment about x-axis
b	width of rectangular cross section	M_{x*}	moment about x^* -axis
b_i	width of rectangular cross section for the individual <i>i</i> .	$M_{x,Ed}$	design value of the applied internal bending moment
21	Design variable	***X,Eu	about x-axis (in EC2)
$b_{{ m max},i}$	maximum width of rectangular cross section for the	$M_{x,n}$	nominal moment about x-axis at cross section (in
- IIIax,i	individual i	X,11	ACI318)
b^{U}	upper bound for the design variable b_i	$M_{x,n,i}$	nominal moment about x -axis at cross section for the
$b(y^*_k)$	width of the k -th fiber at distance y_k^* from centre of	***X,11,1	individual i
2 (J K)	gravity of section about x^* -axis	$M_{x,Rd}$	design moment resistance of cross section about <i>x</i> -axis
c_c	the clear cover of tension reinforcement (mm)	***x,Ku	(in EC2)
C_1	first coefficient for load eccentricity strength constraint	$M_{x,Rd,i}$	design moment resistance of cross section about x -axis
CI	g _{s2,i}	1 11 X,Ka,1	for the individual i
C_2	second coefficient for load eccentricity strength con-	$M_{x,u}$	factored moment about <i>x</i> -axis at cross section
C2	straint g _{s2,i}	M_y	moment about y-axis
d	effective height	M_{y*}	moment about y*-axis
d_i	effective height for the individual <i>i</i>	-	design value of the applied internal bending moment
d_x	distance from left face of cross section to centroid of the	$M_{y,Ed}$	about y-axis (in EC2)
u_{χ}	closest reinforcing bars (<i>x</i> -axis)	M	nominal moment about <i>y</i> -axis at cross section (in
ď _x	distance from right face of cross section to centroid of	$M_{y,n}$	ACI318)
u _X	the closest reinforcing bars $(x-axis)$	М.	nominal moment about y-axis at cross section for the
d	distance from bottom face of cross section to centroid of	$M_{y,n,i}$	individual i
d_y	the closest reinforcing bars (y-axis)	М	
ď	distance from top face of cross section to centroid of the	$M_{y,Rd}$	design moment resistance of cross section about <i>y</i> -axis (in EC2)
d'_y		M	
г	closest reinforcing bars (y-axis)	$M_{y,Rd,i}$	design moment resistance of cross section about <i>y</i> -axis
E_s	modulus of elasticity of reinforcement (in EC2)	M	for the individual <i>i</i>
$rac{f}{\overline{f}}$	objective function to be minimized	$M_{y,u}$	factored moment about <i>y</i> -axis at cross section
	global optimum of f	n f	exponent for calculation of σ_c (in EC2)
f_i	objective function for the individual <i>i</i>	nf	number of fibers in cross section
f _i *	normalized objective function for the individual i	nr	number of reinforcing bars in cross section
f_c	specified compressive strength of concrete	$n_{x,i}$	number of bars at the bottom side of the section. Design
f_{cd}	design compressive strength of concrete (in EC2)		variable
f_{ck}	characteristic compressive strength of concrete (in EC2)	$n'_{x,i}$	number of bars at the top side of the section. Design
f_{ctm}	mean value of axial tensile strength of concrete (in EC2)		variable
$f_{\mathbf{y}}$	specified yield strength of reinforcement	$n_{y,i}$	number of bars at the left side of the section. Design
$f_{yd} \ f_{yk}$	design yield strength of reinforcement (in EC2)		variable
f_{yk}	characteristic yield strength of reinforcement (in EC2)	$n'_{y,i}$	number of bars at the right side of the section. Design
F_i	fitness function for the individual <i>i</i>	.,	variable
F'_i	modified fitness function for the individual i	N_{Ed}	design value of the normal applied axial compression
$g_{As,i}$	minimum tension reinforcement constraint for the indi-		load to cross section (in EC2)
	vidual i	NF	population size of fireflies
$g_{A's,i}$	minimum compression reinforcement constraint for the	N_{Rd}	design axial resistance of cross section (in EC2)
	individual i	$N_{Rd,i}$	design axial resistance of cross section for the individual
$g_{Ast,i}$	minimum total reinforcement constraint for the indi-		i
	vidual i	N_z	axial compression load about z-axis
$g_{duct,i}$	ductility constraint for the individual i	N_{z*}	axial compression load about z^* -axis
g_j	violated constraint	\mathbf{p}_i^k	spatial coordinate vector of the i -th firefly at the k -th
$g_{sp,\max,i}$	maximum spacing of reinforcement constraint for the		iteration
	individual i	\mathbf{p}_{j}^{k}	spatial coordinate vector of the j -th firefly at the k -th
$g_{sp,\min,i}$	minimum spacing of reinforcement constraint for the		iteration
	individual i	$\mathbf{p}^{k+1}{}_{i}$	spatial coordinate vector of the i -th firefly at the $(k + 1)$ -
$g_{s1,i}$	resistance constraint against combined flexure and axial		th iteration
	load for the individual i	$p_{i,l}^k$	<i>l</i> -th spatial coordinate of the <i>i</i> -th firefly at the <i>k</i> -th iter-
$g_{s2,i}$	load eccentricity strength constraint for the individual i		ation
g _i *	sum of violated constraints multiplied by (-1) for the	$p_{j,l}^k$	<i>l</i> -th spatial coordinate of the <i>j</i> -th firefly at the <i>k</i> -th iter-
	individual i	J.	ation
h	height of rectangular cross section	P_c	price of concrete, used in objective function (€/m³)

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