Notation

Abbreviations:

ADS	**A**utomated **D**esign **S**ynthesis
AISC	**A**merican **I**nstitute of **S**teel **C**onstruction
ASD	**A**llowable **S**tress **D**esign
BBM	**B**ranch and **B**ound **M**ethod
BS	**B**ritish **S**tandard
CHS	**C**ircular **H**ollow **S**ection
DM	**D**irect **M**ethod
FE	**F**inite **E**lement
GA	**G**enetic **A**lgorithm
LP	**L**inear **P**rogramming
LRFD	**L**oad and **R**esistance **F**actor **D**esign
NLP	**N**on-**L**inear **P**rogramming
NHF	**N**otional **H**orizontal **F**orce
OC	**O**ptimality **C**riteria
SA	**S**imulated **A**nnealing
SCI	**S**teel **C**onstruction **I**nstitute
SLP	**S**equential **L**inear **P**rogramming
SLS	**S**erviceability **L**imit **S**tates
SQP	**S**equential **Q**uadratic **P**rogramming
UB	**U**niversal **B**eam
UC	**U**niversal **C**olumn
ULS	**U**ltimate **L**imit **S**tates

Scalars:

a	Largest diagonal area of the largest area to the building
a_1, a_2, etc	Parameters of an equation
A	Area
A_{e}	Effective area
$A_{\mathrm{e},\, n^{\mathrm{mem}}}$	Effective area of the cross section of the member n^{mem}
A_{g}	Gross area
$A_{\mathrm{g},\, n^{\mathrm{mem}}}$	Gross area of the cross section of the member n^{mem}
A_{i}	Area of a hole
A_{n}	Net area
A_{v}	Shear area
$B_{n_{\mathrm{b}}}$	Length of the bay
C	Carry over factor for a fixed end member prevented from sidesway
C_{a}	Size effect factor
C^{av}	Convergence factor depends on the average value of the objective function
C^{cu}	Convergence factor depends on the current value of the objective function
C^{o}	Fraction of the design variable in the next loop related to the current loop
C_{pe}	External pressure coefficient
C_{pi}	Internal pressure coefficient
C^{r}	Random contribution fraction
C_{r}	Dynamic augmentation factor
E	Modulus of elasticity
E_{r}	Elite ratio
F^{av}	Average fittest design of the current generation
F^{best}	Best value of the objective function
F^{cu}	Fittest design of the current generation
F^{o}	Value of objective function corresponding to initial design

$F^{q}_{n^{\mathrm{mem}}}$	Applied axial force on the member n^{mem} under the loading case q
$F^{q}_{\mathrm{X},\, n^{\mathrm{mem}}}$, $F^{q}_{\mathrm{Y},\, n^{\mathrm{mem}}}$	Applied shear forces on the member n^{mem} under the loading case q in the X and Y directions
FF_{av}	Average fitness function
FF_i	Fitness function
FF_i^{new}	New fitness function of the surviving part
$F(\boldsymbol{x})$	Objective function
$gen^{\max}$	Maximum number of generations
G_s , $\tilde{G}_s$	Calculated and limited values of the inequality constraint
G_s^{cu}	Value of the current constraint
G_s^{U} , G_s^{L}	Value of the upper and lower bound of the constraint
$G^{\mathrm{Ser},\, q}_{t,\, n^{\mathrm{mem}}}$	Normalized serviceability constraints
$G^{\mathrm{Sle},\, q}_{n^{\mathrm{mem}}}$	Normalized slenderness constraints
$G^{\mathrm{Str},\, q}_{r,\, n^{\mathrm{mem}}}$	Normalized strength constraints
$G(\boldsymbol{x})$	Constraint function
$h_{n_{\mathrm{s}}}$	Height of the $n_{\mathrm{s}}{}^{\mathrm{th}}$ storey
H_{r}	Reference height of the building
$I_{\mathrm{X}}^{n_{\mathrm{s}}+1}$, $I_{\mathrm{Y}}^{n_{\mathrm{s}}+1}$	Second moment of area of the column in the storey level n_{s} about the X and Y axes
k_1 , k_2	Restraint coefficients of the column under consideration
k_1^{h} , k_2^{h}	Nearest higher integer number of k_1 and k_2 respectively
K_{b}	Bending stiffness of the beam under consideration
K_{C}	Bending stiffness of the column under consideration
$K_{\mathrm{e}} = A_{\mathrm{e}} / A_{\mathrm{n}}$	Cross-sectional area factor
K_{U} , K_{L} , K_{TL} , K_{BL} , K_{TR} and K_{BR}	Bending stiffness of the adjacent upper, lower, top-left, bottom-left, top-right and bottom-right columns respectively
λ	Number of sections in each catalogue
$\lambda_{n_{\mathrm{v}}}$	String length of the design variable n_{v}

$\lambda_{n_v}^{\mathrm{T}}$	String length of one individual
$L_{n^{\mathrm{mem}}}$	Length of member
$L_{n_{\mathrm{c}}^{\mathrm{mem}}}$	Length of a column $n_{\mathrm{c}}^{\mathrm{mem}}$
$L_{n_{\mathrm{b}}^{\mathrm{mem}}}$	Length of the beam $n_{\mathrm{b}}^{\mathrm{mem}}$
$L_{n_{\mathrm{br}}^{\mathrm{mem}}}$	Length of a bracing member $n_{\mathrm{br}}^{\mathrm{mem}}$
L^{eff}	Effective length
$L_{\mathrm{X}}^{\mathrm{eff}} / L$	Effective length factor
$(L_{\mathrm{X}}^{\mathrm{eff}} / L)_{i,\mathrm{cal}}$	Calculated value of the effective length factor
$(L_{\mathrm{X}}^{\mathrm{eff}} / L)_{i,\mathrm{dig}}$	Digitized value of the effective length factor
$L_{\mathrm{X},n_{\mathrm{b}}^{\mathrm{mem}}}^{\mathrm{eff}}$, $L_{\mathrm{Y},n_{\mathrm{b}}^{\mathrm{mem}}}^{\mathrm{eff}}$	Effective length of the beam $n_{\mathrm{b}}^{\mathrm{mem}}$ about the local X and Y axes
$L_{\mathrm{X},n_{\mathrm{br}}^{\mathrm{mem}}}^{\mathrm{eff}}$, $L_{\mathrm{Y},n_{\mathrm{br}}^{\mathrm{mem}}}^{\mathrm{eff}}$	Effective length of the bracing member $n_{\mathrm{br}}^{\mathrm{mem}}$ about the local X and Y axes
$L_{\mathrm{X},n_{\mathrm{c}}^{\mathrm{mem}}}^{\mathrm{eff}}$, $L_{\mathrm{Y},n_{\mathrm{c}}^{\mathrm{mem}}}^{\mathrm{eff}}$	Effective length of the column $n_{\mathrm{c}}^{\mathrm{mem}}$ about the local X and Y axes
$L_{\mathrm{X},n_{\mathrm{c}}^{\mathrm{mem}}}^{\mathrm{eff,Code}}$	Effective buckling length of a column $n_{\mathrm{c}}^{\mathrm{mem}}$ about the local X axis determined by BS 5950
$L_{\mathrm{X},n_{\mathrm{c}}^{\mathrm{mem}}}^{\mathrm{eff,DM}}$	Effective buckling length of a column $n_{\mathrm{c}}^{\mathrm{mem}}$ about the local X axis computed by the Direct Method
$L_{\mathrm{X},n_{\mathrm{c}}^{\mathrm{mem}}}^{\mathrm{eff,FE}}$	Effective buckling length of a column $n_{\mathrm{c}}^{\mathrm{mem}}$ about the local X axis evaluated by the Finite element method
m	Magnification factor for the moments produced at the ends of a fixed member, which is in a state of pure-shear sway due to axial force effect
$m_{n^{mem}}^{q}$	Equivalent uniform factor of the member n^{mem} under the loading case q
$\overline{M}$	Equivalent uniform moment
M_A	Maximum moment on the member or the portion of the member under consideration
$M_{\mathrm{b},n^{\mathrm{mem}}}$	Buckling resistance moment capacity of the member n^{mem}
M_{CX} , M_{CY}	Moment capacity of the section about the local X and Y axes in the absence of axial force

M_{X}, M_{Y}	Applied moment about the local X and Y axes respectively
$M^{q}_{\mathrm{CX},n^{\mathrm{mem}}}$, $M^{q}_{\mathrm{CY},n^{\mathrm{mem}}}$	Moment capacity of the member n^{mem} about the local X and Y axes under the loading case q
$M^{q}_{\mathrm{X},n^{\mathrm{mem}}}$, $M^{q}_{\mathrm{Y},n^{\mathrm{mem}}}$	Applied moment on the member n^{mem} about the local X and Y axes under the loading case q
n	Stiffness factor for a fixed end member, which is in a state of no-shear sway
n''	Stiffness factor for a hinged end member, which is in a state of no-shear sway
n^{mem}	Member number
$n_{\mathrm{b}}^{\mathrm{mem}}$	Beam number
$n_{\mathrm{c}}^{\mathrm{mem}}$	Column number
n_{g}	Number of groups
$n\varphi$	Number of holes
N	Number of parents
N^{mem}	Total number of members of a structure
N_{b}	Number of bays of a specified structure
$N_{\mathrm{b}}^{\mathrm{mem}}$	Total number of beams of a specified structure
N_{c}	Number of individuals corresponding to the crossover part of the population size
$N_{\mathrm{c}}^{\mathrm{mem}}$	Total number of columns of a specified structure
N_{e}	Number of individuals existing in the elite part of the population size
N_{p}	Population size
N_{r}	Number of individuals existing in the rest part of the population size
N_{s}	Number of storeys of a specified structure
N_{sur}	Number of individuals existing in the surviving part of the population size
$N_{\mathrm{p}}^{\mathrm{o}}$	Initial large population
$N_{\mathrm{Loop}}^{\max}$	Maximum number of loops
$N_{\mathrm{sol}}^{\max}$	Maximum number of feasible solutions
NU_{d}	Number of digits corresponding to mutation

O	Carry over factor for a fixed end member in a state of no-shear sway
p	Net pressure
p_{b}	Bending strength
p_{C}	Compressive strength
$p_{\mathrm{C},\, n^{\mathrm{mem}}}$	Compressive strength of the member n^{mem}
p_{e}	External pressure
p_{i}	Internal pressure
$p_{\mathrm{y},\, n^{\mathrm{mem}}}$	Design strength of the member n^{mem}
P	Load
P_{c}	Probability of crossover
P_{cr}	Critical load
$P_{\mathrm{cr}}^{\mathrm{DM}}$	Elastic critical buckling load which is computed by Direct Method
$P_{\mathrm{cr}}^{\mathrm{FE}}$	Elastic critical buckling load which is evaluated by Finite Element Method
P_{f}	Horizontal component of surface load acting on windward-facing walls
$P_{i,\,\mathrm{sel}}$	Probability of selection
P_{m}	Probability of mutation
P_{r}	Horizontal component of surface load acting on leeward-facing walls
$P_{\mathrm{X},\, n^{\mathrm{mem}}}$, $P_{\mathrm{Y},\, n^{\mathrm{mem}}}$	Shear capacities of the member n^{mem} in the X and Y directions
PF_{best}	Smallest penalised objective function
PF_i	Penalised objective function
PF_{worst}	Largest penalised objective function
$PF_{\mathrm{worst}}^{\mathrm{new}}$	New penalised objective function of the surviving part
Q	Loading case number
q_{cr}	Critical shear strength
q_{s}	Dynamic pressure
Q	Number of loading cases
r_i^{cu}	Randomly generated number between -0.5 and 0.5

$r_i^{\mathrm{cu,r}}$	Randomly generated number between 0 and 1.0
$r_{\mathrm{X},n^{\mathrm{mem}}}$, $r_{\mathrm{Y},n^{\mathrm{mem}}}$	Radius of gyration of the member n^{mem} about its local axis (X, Y)
S	Stiffness factor for a fixed end member prevented from sidesway
S''	Stiffness factor for a hinged end member prevented from sidesway
S_{a}	Altitude factor
S_{b}	Terrain and building factor
S_{d}	Directional factor
S_{p}	Probability factor
S_{s}	Seasonal factor
S_{v}	Plastic modulus of the shear area
S_{X}	Plastic modulus
SUM^{diff}	Sum of the square of the differences
u	Buckling parameter
U_s	Ultimate tensile strength
v	Slenderness factor
$V_{\mathrm{cr},n^{\mathrm{mem}}}$	Shear resistance of the member n^{mem}
V_{e}	Effective wind speed
V_{s}	Site wind speed
$W_{n^{\mathrm{mem}}}$	Mass per unit length of the member n^{mem}
x	Design variable
$x_{i,j}$	Design variable i from the sub-vector j
$x^{\mathrm{L}}_{n^{\mathrm{mem}}}$, $x^{\mathrm{U}}_{n^{\mathrm{mem}}}$	Value of the lower and upper limit of design variable
X , Y and Z	Local coordinate system
X′, Y′ and Z′	Global coordinate system
Y_s	Yield strength
$Z_{\mathrm{X},n^{\mathrm{mem}}}$	Elastic modulus of the member n^{mem}
$\alpha = 0.01$	Load factor
β	End moment ratio

δ_{all}	Allowable vertical displacement
$\delta_{n_{\text{b}}^{\text{mem}}}^{\max}$	Maximum vertical displacement within a beam
Δ'	Horizontal displacement of an end of a column which is in a state of pure-shear sway
Δ''	Horizontal displacement of an end of a column which is in a state of no-shear sway
Δ_{all}	Allowable horizontal displacement
$\Delta_{n_{\text{c}}^{\text{mem}}}^{\text{U}}$	Horizontal displacement of the upper end of a column
$\Delta_{n_{\text{c}}^{\text{mem}}}^{\text{L}}$	Horizontal displacement of the lower end of a column
$\Delta_{\text{X}',n_{\text{c}}^{\text{mem}}}^{\text{U}}$, $\Delta_{\text{X}',n_{\text{c}}^{\text{mem}}}^{\text{L}}$	Horizontal displacement of the upper and lower end of a column $n_{\text{c}}^{\text{mem}}$ in the X′ direction
$\Delta_{\text{Y}',n_{\text{c}}^{\text{mem}}}^{\text{U}}$, $\Delta_{\text{Y}',n_{\text{c}}^{\text{mem}}}^{\text{L}}$	Horizontal displacement of the upper and lower end of a column $n_{\text{c}}^{\text{mem}}$ in the Y′ direction
$\varepsilon = \sqrt{275/p_{\text{y}}}$	Design strength factor
$\varepsilon^{Tol,\,F}$	Feasibility tolerance of the objective function
$\varepsilon_s^{Tol,\,G}$	Feasibility tolerance of the constraints
$\varepsilon_i^{Tol,\,x}$	Feasibility tolerance of the design variable
ϕ_{s}	Sway index
$\phi_{\text{s.max}}$	Largest value for any storey of the sway index
γ_{e}	Factor of safety
γ_{f}	Load factor
γ_{l}	Load factor due to variability of loading
γ_{m}	Load factor due to variability of material strength
γ_{p}	Load factor due to variability of structural performance
$\lambda_{\text{cr}}^{\text{f}}$	Critical load factor
λ_{LT}	Equivalent slenderness
$\lambda_{\text{X},\,n^{\text{mem}}}$, $\lambda_{\text{Y},\,n^{\text{mem}}}$	Slenderness ratios of the member n^{mem} about the X and Y axes
θ	Angle of rotation
ρ	Ratio between the axial load and ($\pi^2 EI/L^2$)

ρ_{den}	Density of structural material

Vectors:

$\boldsymbol{x}$	Vector of design variables
$\boldsymbol{x}^{\text{best}}$	Vector of the best values of design variables.
$\boldsymbol{x}^{\text{cu}}$	Vector of the current values of design variables.
$\boldsymbol{x}_j$	Sub-vector of design variables
$\boldsymbol{x}^{\text{o}}$	Vector of initial values of design variables (initial design set)
D_j	Catalogue number j that contains the available sections corresponding to the sub-vector $\boldsymbol{x}_j$
ψ	Nodal displacement vector

Matrices:

$\boldsymbol{K}_{\text{CE}}$	Global elastic stiffness matrix
$\boldsymbol{K}_{\text{CG}}$	Geometric stiffness matrix