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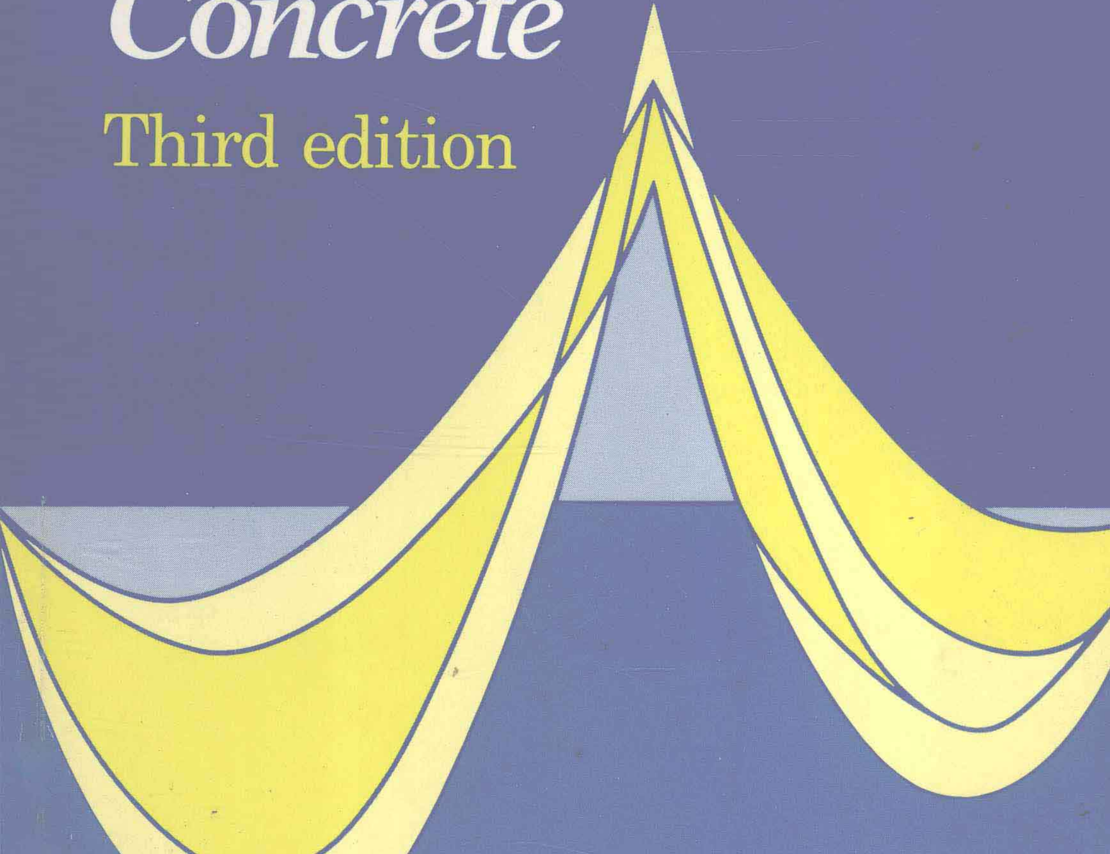
Reinforced and Prestressed Concrete

Third edition



Incorporating BS 8110 and microcomputer applications

E & FN SPON
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Reinforced and Prestressed Concrete

Third edition

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Preface to the Third Edition

The third edition conforms to BS 8110 and includes a new Chapter 12 on microcomputer programs. Like the earlier editions, it is intended as an easy-to-read main text for university and college courses in civil and structural engineering. The threefold aim of the book remains as before, namely:

(a) To explain in simple terms the basic theories and the fundamental behaviour of structural concrete members.
(b) To show with worked examples how to design such members to satisfy the requirements of BS 8110.
(c) To explain simply the technical background to the BS 8110 requirements, relating these where appropriate to more recent research.

Students will find the new edition helpful in their attempts to get to grips with the **why** as well as the **what** and the **how** of the subject.

For the convenience of those readers who are interested mainly in structural design to BS 8110, most of the chapters begin with a **Preliminary note** which lists those parts of the chapter that are directly concerned with BS 8110. However, structural design is not just BS 8110; hence the university or college student should pay attention also to the rest of the book, which has been written with the firm belief that the emphasis of an engineering degree course must be on a sound understanding of the fundamentals and an ability to apply the relevant scientific principles to the solution of practical problems. The authors wish to quote from a letter by Mr G. J. Zunz, co-Chairman of Ove Arup and Partners:

> You will see that generally my comments tend to place emphasis on getting the fundamentals straight. As my experience and that of my colleagues develops, I find more and more that it is the fundamentals that matter and those without a sound training in them suffer for the rest of their careers.

Acknowledgements

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The authors are grateful to Professor P. G. Lowe of the University of Auckland, Dr E. A. W. Maunder of Exeter University and Mr J. P. Withers of Trent Polytechnic for enlightening comments on parts of the earlier editions. They wish also to record, once again, their gratitude to Dr C. T. Morley of Cambridge University, Mr A. J. Threlfall of the C & CA, Dr C. D. Goode of Manchester University and Dr M. S. Gregory of Tasmania University for their valuable comments on the previous editions, on which the present edition has been built.

Extracts from the DoE's *Design of Normal Concrete Mixes* are included by courtesy of the Director, Building Research Establishment; Crown copyright Controller HMSO. Extracts from BS 8110 are included by kind permission of the British Standards Institution, Linford Wood, Milton Keynes, MK14 6LE, from which complete copies can be obtained. Extracts from the *Manual for the Design of Reinforced Concrete Building Structures* are included by kind permission of the Institution of Structural Engineers, 11 Upper Belgrave Street, London, SW1X 8BH, from which complete copies can be obtained.

The authors wish to thank Mrs Diane Baty for her excellent typing and Mr George Holland for the skilfully prepared drawings for the new edition. Finally, they wish to thank the publisher's editor Mr Mark Corbett and former editors Dr Dominic Recaldin and Mr David Carpenter; the book owes much of its success to their efforts, devotion and foresight.

F.K.K.
R.H.E.

Notation

The symbols are essentially those used in current British design practice; they are based on the principles agreed by the BSI, ACI, CEB and others.

A = cross-sectional area of member
A_c = area of concrete
A_{ps} = area of prestressing tendons
A_s = area of tension reinforcement; in eqns (6.9–1) and (6.11–6), A_s = area of longitudinal torsion reinforcement
A'_s = area of compression reinforcement
A_{sc} = area of longitudinal reinforcement in column; in Chapter 7, $A_{sc} = A'_{s1} + A_{s2}$
A_{sv} = area of both legs of a link
A'_{s1} = area of reinforcement near the more highly compressed face of a column section
A_{s2} = area of reinforcement in the less compressed face of a column section
a = deflection; moment arm
a_b = clear distance between bars (Fig. 5.4–1)
a_c = corner distance (Fig. 5.4–1)
a_u = additional eccentricity of slender column (eqn 7.4–5)
a_v = shear span
b = width of beam or column; effective flange width; width of slab considered
b_v = width of beam (see eqns 6.2–1 and 6.4–1), to be taken as b for a rectangular beam and as b_w for a flanged beam
b_w = width of rib or web of beam
d = effective depth; in Chapter 7, $d = h - d' = h - d_2$ for symmetrically reinforced columns
d' = depth from compression face to centroid of compression steel; in Chapter 7, d' = concrete cover to centroid of A'_{s1}
d_c = depth of concrete stress block
d_2 = concrete cover to centroid of A_{s2}
E = modulus of elasticity
E_c = modulus of elasticity of concrete

E_s = modulus of elasticity of steel
e = eccentricity
e_{add} = additional eccentricity due to slender column effect
e_{min} = design minimum eccentricity ($= 0.05h \leq 20$ mm in BS 8110)
e_p = eccentricity of line of pressure from centroidal axis of beam (sign convention: downwards is positive)
e_s = eccentricity of tendon profile from centroidal axis of beam (sign convention: downwards is positive)
e_t = eccentricity of transformation profile from centroidal axis of beam
F = design load
f = stress; strength; frequency
f_{amax} (f_{amin}) = maximum (minimum) allowable concrete stress under service conditions, compressive stress being positive
f_{amaxt} (f_{amint}) = maximum (minimum) allowable concrete stress at transfer, compressive stress being positive
f_b = anchorage bond stress
f_c = concrete compressive stress at compression face of beam; compressive stress in concrete
f'_c = concrete cylinder compressive strength
f_{cu} = characteristic cube strength of concrete
f_k = characteristic strength (eqn 1.4–1)
f_m = mean strength (eqn 1.4–1)
f_{pb} = tensile stress in prestressing tendons at beam failure
f_{pe} = effective tensile prestress in tendon
f_{pu} = characteristic strength of prestressing tendon
f_s = tensile stress in tension reinforcement; steel tensile stress in service
f'_s = compressive stress in compression reinforcement
f'_{s1} = compressive stress in column reinforcement A'_{s1}
f_{s2} = compressive stress in column reinforcement A_{s2}
f_t = cylinder splitting tensile strength of concrete; principal tensile stress
f_y = characteristic strength of reinforcement; in eqns (6.9–1) and (6.11–6), f_y = characteristic strength of longitudinal torsion reinforcement
f_{yv} = characteristic strength of links
f_1 (f_2) = concrete compressive prestress at bottom (top)face of beam section in service
f_{1t} (f_{2t}) = concrete compressive prestress at bottom (top) of beam section at transfer
G = shear modulus
G_k = characteristic dead load
g_k = characteristic dead load (distributed)
h = overall depth of beam or column section; overall thickness of slab; in Sections 7.4 and 7.5, h = overall depth of column section in the plane of bending
h_f = overall thickness of flange

h_{max} (h_{min})	= larger (smaller) overall dimension of rectangular section
I	= second moment of area
I_c	= second moment of area of cracked section
I_u	= second moment of area of uncracked section
K	= $M/f_{cu}bd^2$ (see eqn 4.6–4 and Tables 4.6–1 and 4.7–2); torsion constant (see eqn 6.8–3 and Table 6.8–1); optional reduction factor in slender column design (see eqns 7.4–6 and 7.5–5)
K'	= $M_u/f_{cu}bd^2$ (see eqns 4.6–5 and 4.7–5)
k_1 (k_2)	= characteristic ratios of stress block (see Figs 4.2–1, 4.4–1, 4.4–4 and 4.4–5)
l	= span length; anchorage bond length; (eqn 6.6–3a) column height; length of yield line
l_e	= effective column height (Table 7.2–1)
$\boldsymbol{l}_R$	= $\boldsymbol{l}_1 + \boldsymbol{l}_2 + \boldsymbol{l}_3 + \ldots$ where $\boldsymbol{l}_1$, $\boldsymbol{l}_2$, etc. are the vectors representing the yield lines that form the boundary to a rigid region
l_u	= ultimate anchorage bond length (Table 4.10–2 and eqn 6.6–3b)
M	= bending moment (sign convention if required: sagging moments are positive)
M_{add}	= additional moment due to lateral deflection of a slender column
M_d	= sagging moment due to dead load in prestressed beam
M_e	= bending moment computed from elastic analysis
M_i	= initial bending moment in column; sagging moment due to imposed load in prestressed beam
M_{imax} (M_{imin})	= maximum (minimum) sagging moment at section considered, due to imposed load
M_0	= ultimate strength in pure bending
M_p	= bending moment due to permanent load; plastic moment of resistance
M_r	= $M_{imax} - M_{imin}$
M_t	= bending moment due to total load; total bending moment including additional moment due to slender column effect
M_u	= capacity of singly reinforced beam (see eqn 4.6–5); ultimate moment of resistance
M_1	= primary moment (sagging) in prestressed beam
M_2	= secondary moment (sagging) in prestressed beam
M_3	= resulting moment (sagging) in prestressed beam: $M_3 = M_1 + M_2$
m	= yield moment per unit width of slab
m_1 (m_2)	= yield moment per unit width of slab due to reinforcement band number 1 (number 2) alone
m_n	= normal moment per unit length along yield line
m_{ns}	= twisting moment per unit length along yield line
N	= compressive axial load
N_{bal}	= compressive axial load corresponding to the balanced

condition (eqn 7.5–8)

N_{uz} = capacity of column section under pure axial compression (eqn 7.5–6)

P = prestressing force at transfer

P_c = effective prestressing force

P_{cmax} (P_{cmin}) = maximum permissible (minimum required) effective prestressing force

Q = point load

Q_k = characteristic imposed load

q = distributed load

q_k = characteristic imposed load (distributed)

r = radius of curvature; internal radius of hook or bend (see Fig. A–21)

$\frac{1}{r}$ = curvature

$\frac{1}{r_{cs}}$ = shrinkage curvature

$\frac{1}{r_{ip}}$ = instantaneous curvature due to permanent load

$\frac{1}{r_{it}}$ = instantaneous curvature due to total load

$\frac{1}{r_{lp}}$ = long-term curvature due to permanent load

$\frac{1}{r_m}$ = maximum curvature; curvature at critical section

s = reinforcement spacing

s_v = longitudinal spacing of links or shear reinforcement

T = torsional moment

T_i = torsional moment resisted by a typical component rectangle

T_0 = ultimate strength in pure torsion

V = shear force (see Fig. 9.2–5 for sign convention where such is required)

V_a = shear force resisted by aggregate interlock

V_b = shear resistance of bent-up bars (eqn 6.4–4)

V_c = shear force resisted by concrete; (in Section 9.6) ultimate shear resistance of concrete section

V_{c0} (V_{cr}) = ultimate shear resistance of concrete section which is uncracked (cracked in flexure)

V_{cz} = shear force resisted by concrete compression zone

V_d = shear force resisted by dowel action; dead load shear force

V_p = shear force due to prestressing (sign convention as in Fig. 9.2–5)

V_s = shear force resisted by the web steel

v = design shear stress ($V/b_v d$)

v_c = design shear stress for concrete only ($= V_c/b_v d$)

v_t = torsional shear stress

v_{tmin} = permissible torsional shear stress for concrete only
v_{tu} = maximum permissible torsional shear stress for reinforced section
v_u = maximum permissible shear stress for reinforced section
W_k = characteristic wind load
w_k = characteristic wind load (distributed)
x = neutral axis depth
x_1 = smaller centre-to-centre dimension of a link
y_1 = larger centre-to-centre dimension of a link
Z = elastic sectional modulus
Z_1 (Z_2) = elastic sectional modulus referred to bottom (top) face of section
z = lever-arm distance
α = $N/f_{cu}bh$; a ratio; an angle; prestress loss ratio
α_{conc} = N(concrete)$/f_{cu}bh$
α_c = modular ratio E_s/E_c
α_{s1} = $N(A'_{s1})/f_{cu}bh$
α_{s2} = $N(A_{s2})/f_{cu}bh$
β = $M/f_{cu}bh^2$; biaxial bending coefficient (Table 7.3–1); bond coefficient (Table 6.6–1); a ratio; an angle; inclination of shear reinforcement or prestressing tendon
β_a = slender column coefficient (eqn 7.4–5 and Table 7.5–1)
β_b = moment redistribution ratio (eqns 4.7–1 and 4.7–2)
β_{conc} = M (concrete)$/f_{cu}bh^2$
β_{s1} = $M(A'_{s1})/f_{cu}bh^2$
β_{s2} = $M(A_{s2})/f_{cu}bh^2$
γ = a ratio; an angle; a partial safety factor
γ_f = partial safety factor for loads
γ_m = partial safety factor for materials
ε = strain
ε_c = concrete compressive strain at compression face of section
ε_{cc} = concrete creep strain
ε_{cs} = concrete shrinkage; shrinkage strain
ε_{cu} = ultimate concrete strain in compression (= 0.0035 for BS 8110)
ε_0 = concrete strain when peak stress is reached
ε_s = tensile strain in tension reinforcement
ε'_s = compressive strain in compression reinforcement
ε'_{s1} = compressive strain in column reinforcement A'_{s1}
ε_{s2} = compressive strain in column reinforcement A_{s2}
θ = angle of torsional rotation per unit length
θ_A = vector representing rotation of rigid region A (sign convention: left-hand screw rule)
ν = Poisson's ratio
ϱ = tension steel ratio (A_s/bd)
ϱ' = compression steel ratio (A'_s/bd)
ϱ_v = web steel ratio (A_{sv}/bd)

σ = standard deviation
ϕ = bar size; an angle; creep coefficient
ϕ_1 = torsion function (eqns 6.8–1 to 6.8–3); acute angle measured anticlockwise from yield line to moment axis

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