

ACI DESIGN HANDBOOK

In Accordance with the Strength Design Method of ACI 318-89

VOLUME 1 — Beams, One-Way Slabs, Brackets, Footings, and Pile Caps

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FOREWORD

The three volumes of the ACI Design Handbook are intended for use by persons having a general familiarity with the strength design method and with "Building Code Requirements for Reinforced Concrete (ACI 318-89)."

This volume, Volume 1, presents information for the engineering design and analysis of beams, slabs (one-way action), brackets, footings, and pile caps.

SECTIONS

Information is presented in four main sections: Design Procedures, Design Examples, Design Aids, and Commentary on Design Aids.

Design Procedures (white pages) indicate the order in which the various design considerations should be examined.

Design Examples (white pages) illustrate the use of the Design Aids (but are not intended to show how to design a structure).

Design Aids (buff pages) are tables and graphs intended to save the designer the effort of repeatedly performing routine calculations. All Design Aids apply to concrete having f'_c equal to 3 and 4 ksi used with Grade 60 steel reinforcement. Many Design Aids also apply to f'_c of 5 and 6 ksi and Grades 40 and 50 steel reinforcement. A note at the bottom of each Design Aid tells which Design Example illustrates the use of the table or graph.

Commentary on Design Aids (gray pages) gives the basis for the Design Aids.

For judicious application and optimum efficiency, users of this handbook should first acquaint themselves with the Commentary. Subsequent application of the Design Procedures in conjunction with the information obtained from the Design Aids should lead to problem solutions. Design Examples will help verify procedures and results. It is not, however, the objective of the handbook to teach the novice how to design in reinforced concrete. Readers are expected to be competent in design before attempting to use this handbook.

UPDATING TO ACI 318-89

This fifth edition of Volume 1 updates the Design Aids and their Commentary, Design Procedures, and Design Examples to conform to ACI 318-89, and differs from the fourth edition in these ways:

1. **Flexure**—No major changes have been made in this edition. FLEXURE 8.3.1 has been replotted to improve its graphical accuracy.

2. **Shear**—The simplified provisions for development of web reinforcement (Section 12.13, ACI 318-89) have been incorporated into SHEAR 6, replacing SHEAR 6.1

and 6.2 of the fourth edition. Also, Design Procedure 2 and 8 and FLOW CHART 1e have been revised to reflect the changes in Section 12.13 of ACI 318-89. The Design Aids, SHEAR 8.1 and 8.2 have been revised to reflect new two-way shear requirements for slabs and footings in Section 11.12.2 of ACI 318-89. The Commentary on SHEAR 6, SHEAR 8.1, and SHEAR 8.2 have been revised accordingly.

3. **Reinforcement**—This section of the fourth edition has been revised to reflect the major revisions in Chapter 12 (Development and Splices of Reinforcement) of ACI 318-89. REINFORCEMENT 17.1, 17.2, and 17.3 are new and they replace REINFORCEMENT 17 series of the fourth edition. Design Examples 6, 7, 8, 9, 10 are new and Design Examples 8, 9, 10 in the fourth edition were renumbered as Design Examples 11, 12, and 13. A new flow chart, FLOW CHART 5 (Determination of Tension Development Length), has been included to correlate with the steps in the Design Examples.

4. **Deflection**—No major changes have been made in this edition.

5. **Footings**—The Commentary on FOOTINGS 2.1 and 2.2 have been revised to reflect new two-way shear requirements for slabs and footings (Section 11.12.2 of ACI 318-89).

ACI COMMITTEE 340 AND ITS WORK

ACI Committee 340, Strength Design Handbook, was organized in 1958 for the purpose of preparing a handbook that would simplify the design of reinforced concrete structural elements using the strength design method in accordance with the ACI Building Code. The handbook was prepared in two volumes: Volume 1 covering beams, one-way-action slabs, footings, and other members except columns; and Volume 2 treating columns only. Volume I was issued in 1967; Volume 2 was ready first and published in 1964. Both volumes were in accordance with the 1963 version of the ACI Building Code.

In 1971 when ACI 318-71 was issued, Committee 340 was charged with revising the existing handbook material to bring it into accordance with that code. The resulting second edition of Volume 1, which incorporated some material on columns, was issued in 1973 and a second, corrected printing was published in 1974.

The August 1977 ACI JOURNAL carried "Step-by-Step Design Procedures in Accordance with the Strength Design Method of ACI 318-71," subsequently published as ACI Committee Report 340.3R-77.

While ACI 318-77 was being prepared for publication in the fall of 1977, Committee 340 was revising the handbook volumes accordingly. The resulting new edition of Volume 2 on columns was published in May 1978. In late 1978, a supplement to the Strength Design Handbook dealing with

two-way-action slabs and entitled *Slab Design in Accordance with ACI 318-77* was published.

The third edition of Volume 1, published in 1981, contained two Divisions: Division I dealt with beams, one-way slabs, brackets, footings, and pile caps and incorporated the Step-by-Step Design Procedures—all material being updated to ACI 318-77. Division II consisted of the two-way slab design supplement.

The fourth edition of Volume 1 was published in 1984. It was the revised edition of the third edition to conform to ACI 318-83, including new flow charts for design of members in flexure. Design of Two-Way Slabs was published as a supplement to Volume 1 in 1985.

The volume at hand is the fifth edition of Volume 1. The format for this edition is the same as the format of the fourth edition. With this edition, Design of Two-Way Slabs (Supplement to Volume 1) was made a separate volume, Volume 3 of the ACI Design Handbook.

HANDBOOK USERS' COMMENTS

ACI Committee 340 welcomes suggestions from users of this handbook on how to make future printings more useful. Comments should be directed to ACI Committee 340, American Concrete Institute, P.O. Box 19150, Detroit, Michigan 48219.

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NOTATION

This notation section defines symbols used in this volume covering beams, one-way slabs, brackets, footings, and pile caps, and their reinforcement.

Words in parentheses such as "(Flexure)" or "(Shear)" indicate portions of this handbook in which symbol is used.

a	= depth of equivalent rectangular stress block, in. (Flexure)
a_b	= maximum overhang beyond face of wall or column to satisfy beam shear in a one-way footing of given thickness, in. (Footings)
a_{bal}	= depth of equivalent rectangular stress block for balanced conditions, in. (Flexure)
a_c	= immediate deflection at midspan, in. (Deflection)
a_d	= immediate deflection due to dead load, in. (Deflection)
a_{d+l}	= immediate deflection due to dead load and live load, in. (Deflection)
a_f	= overhang of a footing beyond face of wall or column, in. (Footings)
a_l	= immediate deflection due to live load, in. (Deflection)
a_p	= maximum overhang beyond face of wall or column for a given thickness of unreinforced footing, in. (Footings)
a_n	= $\phi f_y (1 - 0.59\omega) / 12,000$, ft-kip/in., ³ a coefficient for computing reinforcement area A_s (Flexure)
a_n'	= $\phi f_y (1 - d'/d) / 12,000$, ft-kip/in., ³ a coefficient for computing reinforcement area A_s' (Flexure)
a_n''	= $\phi \left[\frac{87,000}{12,000} (1 - d'/d) \left(1 - \frac{d'/d}{c/d} \right) - \frac{0.85}{12,000} f_c' \left(1 - \frac{d'}{d} \right) \right]$, ft-kip/in., ³ a coefficient for computing reinforcement area A_s' when compression reinforcement does not yield (Flexure)
a_{nf}	= $\phi f_y (1 - h_f/2d) / 12,000$, ft-kip/in., ³ a coefficient for evaluating flange effects on moment in T-beams (Flexure)
A	= any area, sq in. or sq ft
	= $b_w t / n$ = effective tension area of concrete for crack control, sq in., per bar (Reinforcement)
A'	= $b_w t / n'$ = effective tension area of concrete

	for crack control in case bundled bars are used, sq in. per bar bundle (Reinforcement)
A_b	= area of an individual bar, sq in. (Reinforcement)
A_c	= area of concrete at cross section considered, sq in. (Flexure)
	= area of column, sq in. (Footings)
A_{cw}	= minimum area of tension reinforcement A_{sw} to keep neutral axis low enough for compression reinforcement to reach yield strain under factored load conditions, sq in. (Flexure)
A_f	= area of footing; area of panel, sq ft (Footings)
	= area of reinforcement in bracket or corbel resisting factored moment $[v_u a + N_{uc} (h - d)]$, sq in.
A_{fv}	= area of a footing contributing to perimeter shear (A_f minus area within the perimeter b_o), sq ft (Footings)
A_h	= area of shear reinforcement parallel to flexural tension reinforcement, sq in. (Shear)
A_n	= area of tension reinforcement to resist force N_{uc} on brackets, sq in. (Shear)
A_s	= area of nonprestressed tension reinforcement, sq in. (Flexure), (Shear)
A_s'	= area of compression reinforcement, sq in. (Flexure)
A_{sa}	= area of equally distributed reinforcement in short direction for two-way rectangular footings, sq in. (Footings)
A_{sf}	= area of tension reinforcement in tension zone required to counterbalance compressive force in overhanging portions of flanges in flanged section, sq in. (Flexure)
A_{st}	= total area of longitudinal reinforcement in a cross section, sq in.
A_{sw}	= area of tension reinforcement required to counterbalance compressive force in web or stem of flanged sections, or in concrete alone in beams reinforced in compression, sq in. (Flexure)
A_{s1}	= area of larger bars in a bundle, sq in. (Reinforcement)
	= area of tension reinforcement required under factored load conditions for a rectangular beam with tension reinforcement only (Flexure)

A_{s2}	= area of smaller bars in a bundle, sq in. (Reinforcement) = area of tension reinforcement required under factored load conditions to counterbalance compressive force contributed by compressive reinforcement, sq in. (Flexure)	d_{be}	= equivalent diameter for a bundle of bars, in. (Reinforcement)
A_{s3}	= maximum area of tension reinforcement at which depth of stress block a will be equal to or smaller than flange thickness h_f (Flexure)	d_{b1}, d_{b2}	= diameters of bars in bundles with two different sizes, in. (Reinforcement)
A_t	= area of one leg of a closed stirrup resisting torsion, within a distance s , sq in. (Shear)	d_c	= distance from extreme tensile surface to center of closest tensile reinforcing bar, in. (Reinforcement)
A_{tr}	= total cross-sectional area of transverse reinforcement (stirrup or tie) within a spacing s and perpendicular to plane of bars being spliced or developed, in. ²	d'_c	= distance from extreme tensile fiber to center of gravity of closest bundle or layer of bundles, in. (Reinforcement)
A_v	= total area of web reinforcement in tension within a distance s , measured in a direction parallel to longitudinal reinforcement, sq in. (Shear)	d_p	= diameter of pile at footing base (Footings)
A_{vf}	= area of shear friction reinforcement, sq in.	d_s	= nominal diameter of stirrups, in. (Shear) = distance from extreme tension fiber to centroid of tension reinforcement = $t/2$, in. (Reinforcement)
b	= width of compression face of member, in. (Flexure) = side of square footing, ft (Footings) = smaller dimension or width of rectangular footing or slab, ft (Footings)	D	= dead loads, or their related internal moments and forces
b_c	= pier or column dimension perpendicular to h , in. (Footings)	e	= eccentricity of axial load at end of beam, measured from centerline of beam, in. (Flexure)
b_o	= perimeter of pseudo-critical section (around concentrated loads or columns at distance $d/2$) in slabs and footings, in. (Footings)	e'	= eccentricity of axial load at end of member, measured from the centroid of the tension reinforcement, calculated by conventional methods of frame analysis, in. (Flexure)
b_w	= web width, in. (Flexure)	E_c	= modulus of elasticity of concrete, = $0.033w^{1.5}\sqrt{f'_c}$, ksi
c	= distance from extreme compression fiber to neutral axis, in. (Flexure)	E_s	= modulus of elasticity of steel reinforcement (= 29,000 ksi) (Flexure)
c_1	= size of rectangular or equivalent rectangular column, capital, or bracket measured in the direction of the span for which moments are being determined, in.	EI	= flexural stiffness of cross section for frame analysis, k-sq in. (Flexure) = flexural stiffness of compression member, k-sq in. (Flexure)
c_2	= size of rectangular or equivalent rectangular column, capital, or bracket measured transverse to the direction of the span for which moments are being determined	f'_c	= specified compressive strength of concrete, psi
C	= compression force, kips (Flexure)	f_{ct}	= average splitting tensile strength of lightweight aggregate concrete, psi (Shear)
C_c	= compression force in concrete, kips (Flexure)	f_r	= $7.5\sqrt{f'_c}$, modulus of rupture of concrete, psi
C_s	= compression force in reinforcement, kips (Flexure)	f_s	= calculated tension stress in reinforcement at service loads, ksi (Reinforcement)
d	= distance from extreme compression fiber to centroid of tension reinforcement, in. (Flexure)	f'_s	= calculated stress in reinforcement in compression, = $E_s\epsilon_s' \leq f_y$, psi (Flexure)
d'	= distance from extreme compression fiber to centroid of compression reinforcement, in. (Flexure)	f_t	= tensile stress in extreme fiber of a footing, psi
d_b	= nominal diameter of bar, in. (Reinforcement)	f_y	= specified yield strength of nonprestressed reinforcement, psi (Flexure)
		F	= a flexural coefficient = $\frac{bd^2}{12,000}$ or $\phi M_n / K_n$ (Flexure)
		h	= overall thickness of section or thickness of member (beam, one-way slab)
		h_c	= pier or column dimension parallel to investigated direction, in. (Footings)
		h_f	= flange thickness, in. (Flexure, Deflection) = footing thickness, in. (Footings)
		I	= moment of inertia of a section resisting

externally applied factored loads, in.⁴ (Shear)

I_{cr} = moment of inertia of a rectangular section 1 in. wide, in.⁴ (Deflection)

I_e = moment of inertia of cracked section transformed to concrete, in.⁴ (Deflection)

I_e = effective moment of inertia for computing deflections, in.⁴ (Deflection)

I_g = moment of inertia of gross concrete section about the centroidal axis, neglecting reinforcement, in.⁴ (Deflection)

I_{gt} = gross moment of inertia of T-section, in.⁴ (Deflection)

j_f = $(d - 0.5 h_f)/d$, ratio of lever arm between flanges centroid and centroid of tension reinforcement to effective depth d of a section (Flexure)

j_n = $(d - 0.5 a)/d$, ratio of lever arm between centroids of compression rectangular stress block and tension reinforcement to effective depth d of a rectangular section (Flexure)

k = moment coefficient for flexural members (Flexure)

K_{a1} = $1728 I^2 / 48 E_c$ = coefficient for immediate deflection of beams (Deflection)

K_{a2} = $a_c b / \delta_c w$ = coefficient for approximate immediate deflection (Deflection)

K_{a3} = coefficient relating moment at midspan to deflection at midspan (Deflection)

K_{cr} = $\frac{f_r}{12,000} \times \frac{h^2}{6}$, coefficient for computing cracking moment, kip-ft/in. (Deflection)

K_{crt} = section modulus coefficient for computing cracking moment of T-section (Deflection)

k_d = $2.53 \sqrt{q_s / \sqrt{f'_c}}$, coefficient for depth required for plain footings (Footings)

K_{I1} = I_{cr} / bd^3 = coefficient for moment of inertia of cracked rectangular sections with tension reinforcement only (Deflection)

K_{I2} = I_{cr} / bd^3 = coefficient for moment of inertia of cracked rectangular sections with compression reinforcement, or T-beams (Deflection)

K_{I3} = I_e / I_g , coefficient for effective moment of inertia (Deflection)

K_{I4} = $I_{gt} / (b_w h^3 / 12)$, coefficient for gross moment of inertia of T-beams (Deflection)

K_n = $12,000 \phi M_n / bd^3 = \phi f'_c \omega (1 - 0.59 \omega)$, strength coefficient of resistance, psi (Flexure)

K_{nf} = $\phi \frac{0.85 f'_c}{12,000} \left(\frac{b}{b_w} - 1 \right)$, coefficient for computing reinforcement area A_{sf} , psi (Flexure)

K_{tr} = $\frac{(b_w - 3.5)(h - 3.5)}{12} \alpha$, a coefficient for design of torsion reinforcement (Shear)

K_v = ρ_{vf} divided by the reinforcement ratio for shear friction reinforcement perpendicular to shear plane (Shear)

K_v = $\phi A_v f_y$, shear coefficient for stirrups (Shear)

K_{v1} = coefficient for footing depth based on one-way shear (Footings)

K_{v4} = $\phi [6.5 - 5.1 \sqrt{N_{uc} / V_u}] [1 + (64 + 160 \sqrt{(N_{uc} / V_u)^3} \rho) 0.5]$ (Shear)

K_{v5} = $2.0 - a/d$ (Shear)

K_{v6} = $4 / \left(2 + \frac{4}{\beta_c} \right) = 1 / \left(0.5 + \frac{1}{\beta_c} \right)$; a coefficient to correct perimeter shear strength for footings from that computed using $4 \sqrt{f'_c}$ to the appropriate lower strength when β_c exceeds 2 (Footings)

l = span length, ft or in. (Reinforcement, Shear)

l = long side of a rectangular footing, ft (Footings)

l_a = embedment length at support or at point of inflection, in. (Reinforcement)

l_d = development length, in. (Reinforcement)

l'_d = usable (available) anchorage length, in. (Reinforcement)

l_{db} = basic development length of straight bars, in., as specified in Sections 12.2.2 and 12.3.2 of ACI 318-89 (Reinforcement)

l_{dh} = development length of hooked bars, to exterior face of bar at the bend (see diagram on REINFORCEMENT 19), in. (Reinforcement)

l_{hb} = basic development length of standard hook in tension, in. (Reinforcement)

l_n = clear span measured face-to-face of supports (Reinforcement)

l_v = length of shearhead arm from centroid of concentrated load or reaction, in. (Shear)

l_1 to l_5 = minimum spans required for bar development depending on type of span and support and percentage of bars extended into the support, ft and in. (Reinforcement)

l_1 and l_2 = overhang of longitudinal wires past last transverse wire of wire fabric, in. (Reinforcement)

L = live loads, or their related internal moments and forces

M_a = maximum moment in member at stage for which deflection is being computed, in.-lb

M_c = moment at center of beam or a moment value related to the deflection, kip-ft (Deflection)

M_{cr} = cracking moment of gross concrete section = $I_g f_r / y_t$, in.-lb (Deflection)

M_d	= moment due to dead load, kip-ft (Deflection)	N_{uc}	= factored tensile force on bracket or corbel acting simultaneously with V_u , kips (Shear)
M_{d+l}	= moment due to dead load and live load, kip-ft (Deflection)	P	= service concentrated load on beam, kips (Deflection)
M_l	= moment due to live load, kip-ft (Deflection)	P_b	= nominal axial load strength (balanced strain conditions), kips (Flexure)
M_s	= moment at point of zero shear (Shear)	P_n	= nominal axial load strength at given eccentricity, kips (Flexure)
M_{s1}	= moment at left support, for deflection, kip-ft (Deflection)	P_u	= factored axial load at given eccentricity, kips (Flexure)
M_{s2}	= moment at right support, for deflection, kip-ft (Deflection)	q_s	= N_u/A_f , ksf (Footings)
M_n	= nominal moment strength at section, kip-ft (Flexure)	r	= radius of gyration of cross section of compressive member
M_{n1}	= nominal moment strength of a cross section before compression reinforcement and extra tension reinforcement are added = $M_n - M_{n2}$, kip-ft (Flexure)	s	= center-to-center spacing of bars, in. = center-to-center spacing of web reinforcement, in. (Shear)
M_{n2}	= that portion of M_n assigned to compression reinforcement or flange regions of I and T-sections, kip-ft (Flexure)	s_b	= clear spacing between bars, or bundles of bars, in. (Reinforcement)
M_{nc}	= nominal moment strength of a section with tension and compression reinforcement, kip-ft (Flexure)	s_1	= required stirrup distance, ft (Shear)
M_{nf}	= nominal moment strength of overhanging flanges of T-beam, kip-ft (Flexure)	s_1, s_2	= center-to-center spacing of reinforcement in either direction "1" or "2" (Shear)
M_{nw}	= nominal moment strength of a rectangular beam (or web of a T-beam) when reinforced for tension only, kip-ft (Flexure)	t	= thickness of tension area for crack control, in. (Reinforcement)
M_o	= total factored static moment (Flexure)	T	= tension force on reinforcement, kips (Flexure) = total tension force acting on a cross section, kips (Flexure)
M_u	= applied factored moment at a section, kip-ft (Flexure)	T_s	= nominal torsional moment strength provided by torsion reinforcement (Reinforcement)
M_{us}	= factored moment acting on a cross section if axial force N_u is considered to act at centroid of tension reinforcement, kip-ft (Flexure)	T_u	= factored torsional moment at section, in.-lb (Shear)
n	= modular ratio = E_s/E_c (Deflection) = equivalent number of bars = $\frac{\text{tensile reinforcement area}}{\text{largest bar area}}$, for crack control (Reinforcement) = number of longitudinal torsion bars (Shear) = number of bar diameters between center and perimeter of bend (Reinforcement) = number of bars in flexural tension reinforcement (Reinforcement)	v_c	= $(V_c/b_w d)$, nominal shear stress carried by concrete, psi (Shear)
n'	= equivalent number of bar bundles = $\frac{\text{projected surface of bundle}}{\text{actual surface of bundle}}$ (Reinforcement)	v_{cw}	= shear stress at diagonal cracking due to all factored loads, when such cracking is result of excessive principal tensile stresses in web, psi
N	= number of bars in a layer being spliced or developed at a critical section	v_n	= $V_n/(b_w d)$, nominal shear stress, psi (Shear)
N_s	= compressive force on reinforcement in a cross section, kips (Flexure)	v_s	= $V_s/(b_w d)$, nominal shear stress carried by shear reinforcement, psi (Shear)
N_u	= factored axial load normal to cross section occurring simultaneously with V_u —to be taken as positive for compression, negative for tension, and to include effects of tension due to shrinkage and creep, kips (Shear)	V_c	= nominal shear strength attributable to concrete, kips (Shear)
		V_s	= nominal shear strength attributable to shear reinforcement, kips (Shear)
		V_n	= nominal shear strength at a section, kips (Shear)
		V_u	= factored shear force, kips (Shear)
		w	= crack width, in. (Reinforcement)
		w_c	= unit weight of concrete, pcf
		w_d	= uniformly distributed factored dead load, kips per ft, or kips per sq in.
		w_l	= uniformly distributed factored live load, kips per ft, or kips per sq in.
		w_u	= factored load per unit length of beam (Flexure)
		x	= variable distance

x = shorter overall dimension of a rectangular part of a cross section, in. (Shear)
 x_{bc} = minimum clear spacing between bundled bars, in. (Reinforcement)
 x_e = distance from extreme tensile fiber to neutral axis, in. (Deflection)
 x_1 = shorter center-to-center dimension of a closed rectangular stirrup, in. (Shear)
 y = variable distance
 = longer overall dimension of a rectangular part of a cross section, in. (Shear)
 = centroidal distance from bottom of bundle for a group of bundled bars, in. (Reinforcement)
 y_t = distance from centroidal axis of gross section, neglecting reinforcement, to extreme fiber in tension, in.
 y_1 = longer center-to-center dimension of a closed rectangular stirrup, in. (Shear)
 z = quantity limiting distribution of flexural reinforcement (Reinforcement)

α (alpha) = angle between shear reinforcement and longitudinal axis of member, degrees (Shear)
 α_b = b/b_w (Deflection)
 α_s = constant used to compute V_c in nonprestressed slabs

α_t = $[0.66 + 0.33(y_1/x_1)] \leq 1.50$ (Shear)
 β (beta) = ratio of distance between extreme tensile fiber and neutral axis to distance between neutral axis and centroid of tensile reinforcement, x_e/x_c (Reinforcement)

β_c = design coefficient for deflections = $m\rho'/n\rho$; = $(n-1)\rho'/n\rho$; = $(b/b_w - 1)h_f/dn\rho$ (Deflection)
 = ratio of long side to short side of concentrated load or reaction area (Shear, Footings)

β_d = ratio of maximum factored axial dead load to maximum total factored axial load, where the load is due to gravity effects only in the calculation of P_c in Eq. (10-7), or ratio of the maximum factored sustained lateral load to the maximum total factored lateral load in that story in the calculation of P_c in Eq. (10-8)

β_f = ratio between long side and short side of rectangular footings (Footings)

β_h = h_f/h (Deflection)

β_u = ratio of c to d (Flexure)

β_v = $\sin \alpha + \cos \alpha$ for inclined stirrups (Shear)

β_1 = a coefficient relating depth of equivalent rectangular stress block to depth from compression face to neutral axis = 0.85 for $f'_c \leq 4.0$ ksi and $0.85 - 0.05(f'_c - 4.0)$ for $f'_c > 4.0$ ksi, ($\beta_1 \geq 0.65$) (Flexure)

γ_p (gamma) = moment at point of zero shear to simple span maximum moment (Shear)

δ (delta) = coefficient depending on type of span and degree of reinforcement (Deflection)
 $\Delta(\phi v_c)$ (Delta) = difference in ϕv_c for sand-lightweight and all-lightweight concrete of identical strength, f'_c , psi (Shear)

ϵ (epsilon) = unit strain, in./in. (Flexure)

ϵ_c = unit strain in concrete

ϵ_s = unit strain in tension reinforcement (Flexure)

ϵ_s' = unit strain in compression reinforcement (Flexure)

ϵ_y = f_y/E_s , nominal yield strain of reinforcement (Flexure)

λ (lambda) = a factor used in shear values: = 1.0 for normal weight concrete, = $f_{ci}^2/6.7^2 f'_c$ for lightweight concrete (Shear)

= ratio of ϕM_n with compression reinforcement to ϕM_n without compression reinforcement (Flexure)

= multiplier for additional long-time deflection = ratio of creep and shrinkage deflection to immediate deflection due to sustained loads (Deflection)

λ_m = a coefficient relating development length to minimum required span length
 $\geq \frac{l_d - l_a}{l}$ (Reinforcement)

μ (mu) = coefficient of friction (Shear)

ξ (xi) = time-dependent factor for sustained load (Deflection)

ρ (rho) = tension reinforcement ratio = A_s/bd (Flexure)

ρ' = compression reinforcement ratio = A_s'/bd (Flexure), (Deflection)

ρ_b = reinforcement ratio producing balanced conditions (Flexure)

ρ_{bc} = balanced percentage of reinforcement for a section with compression reinforcement (Flexure)

ρ_f = $A_{sf}/b_w d$ (Flexure)

ρ_{vf} = reinforcement ratio for shear friction reinforcement (Shear)

ρ_w = $A_s/b_w a$

ϕ = strength reduction factor

ϕ (phi) = 0.70 for axial compression, with or without flexure, in reinforced members other than those with spiral reinforcement [see ACI 318-89 Section 9.3.2.2]

= 0.85 for shear and torsion

= 0.90 for flexure in reinforced concrete, with or without axial tension, and for axial tension

ω = $\rho f_y/f'_c$ (Flexure)

(omega)

FLOW CHARTS

DESIGN PROCEDURES

FLOW CHARTS FOR DESIGN OF MEMBERS IN FLEXURE

This edition of the Design Handbook contains flow charts illustrating the logic sequences that were employed for the Design Procedures for design of members in flexure.

Flow Charts 1 illustrate the logic for Design Procedure 1 and Design Procedure 2 applied to the design of rectangular beams for both flexure and for shear requirements.

Flow Charts 2 illustrate logic for Design Procedure 3 and Design Procedure 4 applied to one-way slabs.

Flow Chart 3 illustrates the logic of Design Procedure 5 applied to beams that have depth restrictions.

Flow Chart 4 illustrates the logic of Design Procedure 6 applied to flanged cross sections for which the flanged portion is in compression due to flexure.

FLOW CHART FOR DETERMINATION OF TENSION DEVELOPMENT LENGTHS

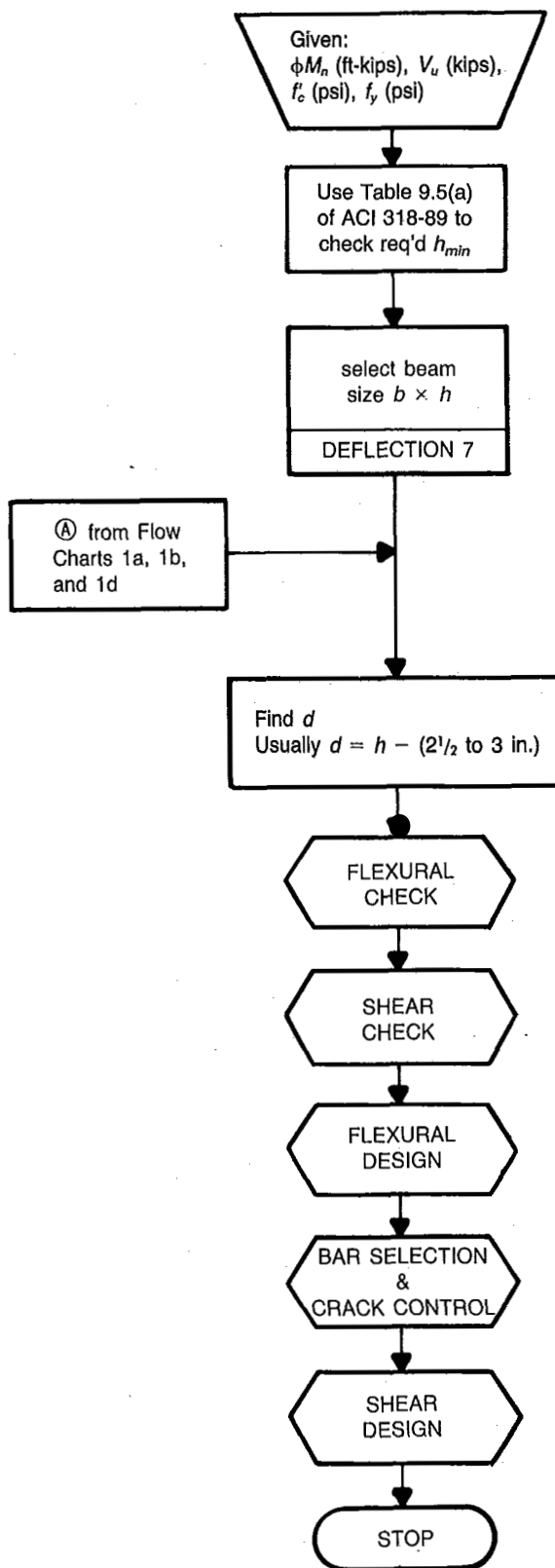
Flow Chart 5 illustrates application of provisions in ACI 318-89 Section 12.2 for development of deformed bars and deformed wire in tension, which replaced provisions previously set forth in earlier versions of ACI 318.

FLOW CHART 1 – BEAM DESIGN WITH NO CONSTRUCTION DEPTH RESTRICTIONS

Reference: Design Procedure 1

F
L
O
W

C
H
A
R
T

1

Explanations or Comments

Given: ϕM_n , V_u , f'_c , f_y
Find: $b \times h$, A_s

$$h = \ell / (\text{coefficient from Table 9.5(a) of ACI 318-89})$$

When the beam is attached to or supporting nonstructural elements likely to be damaged by large deflection, or when $h < h_{min}$, check deflection. For average conditions and preliminary purposes the approximate method (see under Deflection) will furnish fast results of sufficient accuracy. For limitations of deflection, see Table 9.5(b) in ACI 318-89.

see FLOW CHART 1a

see FLOW CHART 1b

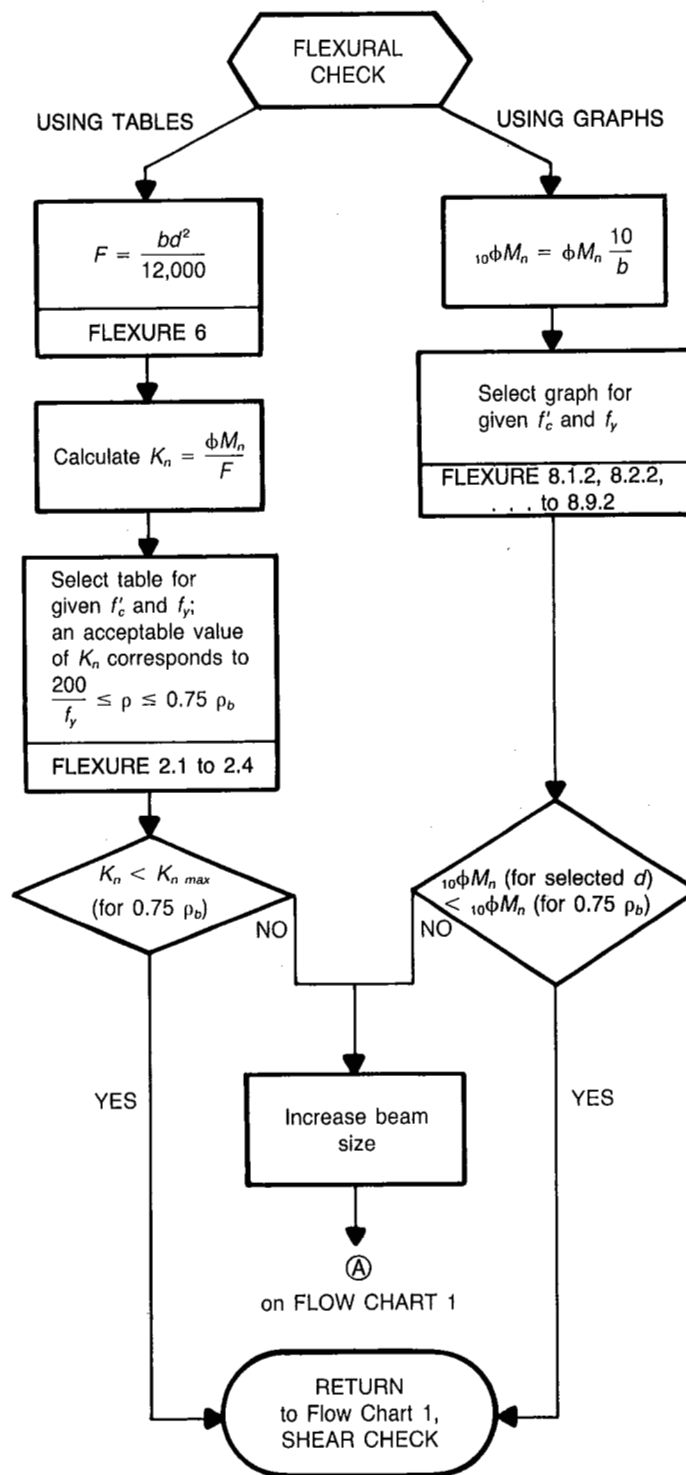
see FLOW CHART 1c

see FLOW CHART 1d

see FLOW CHART 1e

FLOW CHART 1a – FLEXURAL CHECK FOR BEAM DESIGN WITH NO CONSTRUCTION DEPTH RESTRICTIONS

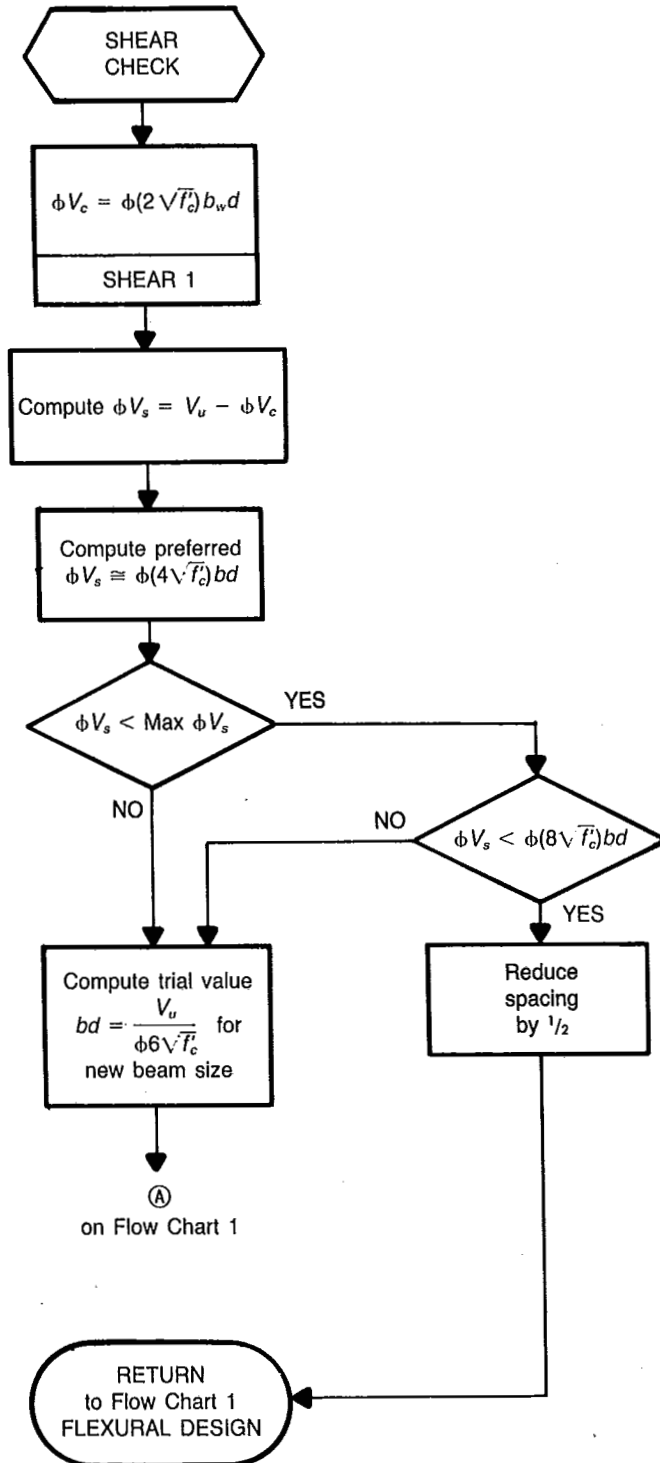
Reference: Design Procedure 1

Explanations or
CommentsExplanations or
CommentsAbsolute K_n max is value
above lower solid lineAdjust ϕM_n to that carried
by 10 in. wide beamOR use compressive steel
(see FLOW CHART 3)

FLOW CHART 1b—SHEAR CHECK FOR BEAM DESIGN WITH NO CONSTRUCTION DEPTH RESTRICTIONS

Reference: Design Procedure 1

FLOW
CHART
1b



Explanations or Comments

Determine factored shear V_u at critical section. Compute shear strength ϕV_c .

Check whether beam size is large enough even when shear reinforcement is used.

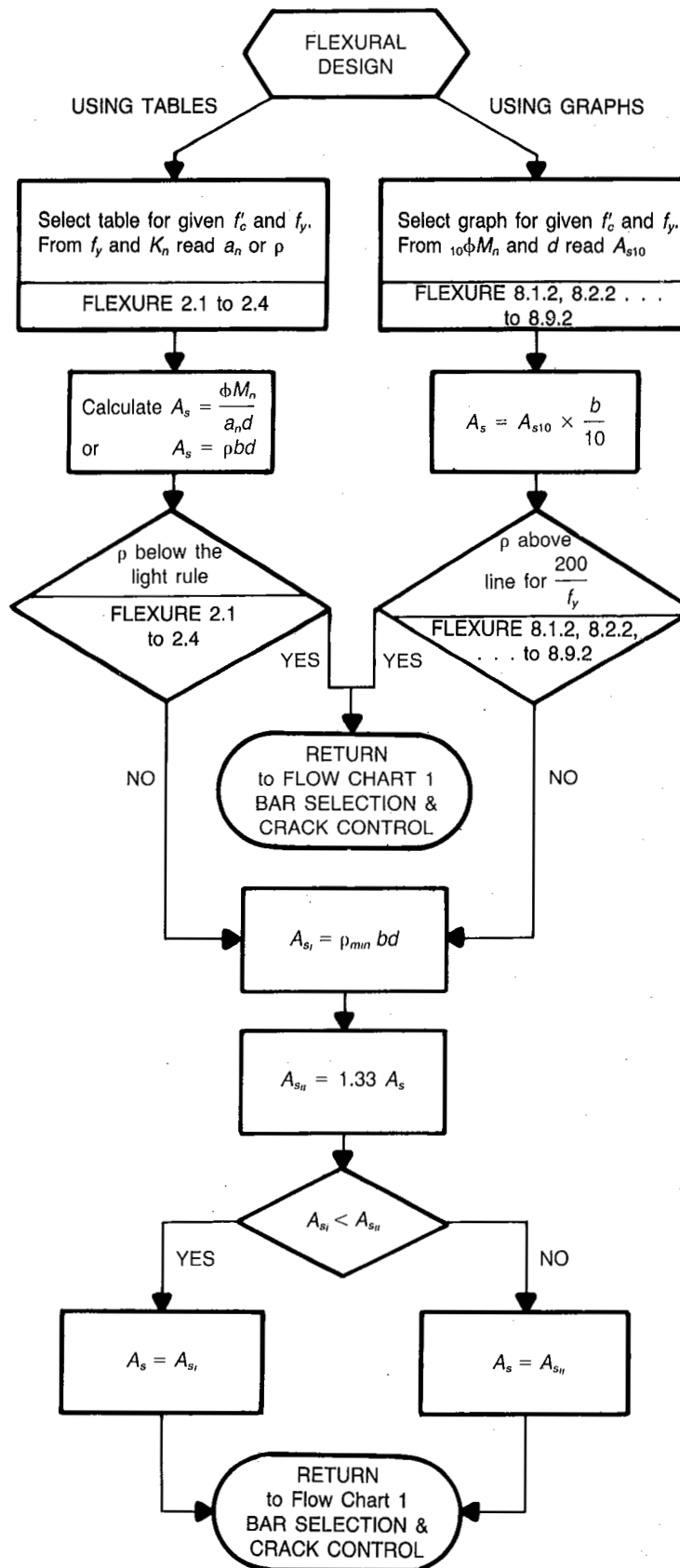
Code permits ϕV_s as high as $\phi(8\sqrt{f'_c})bd$ if supplementary spacing limits are observed.

**FLOW CHART 1c – FLEXURAL DESIGN FOR BEAM DESIGN WITH NO
CONSTRUCTION DEPTH RESTRICTIONS**

Reference: Design Procedure 1

Explanations or
CommentsExplanations or
Comments K_n from FLOW CHART 1a $_{10}\phi M_n$ from FLOW CHART
1a $A_s < A_{s \min}$? $A_s < A_{s \min}$?
$$\rho_m = \frac{200}{f_y} \text{ is}$$

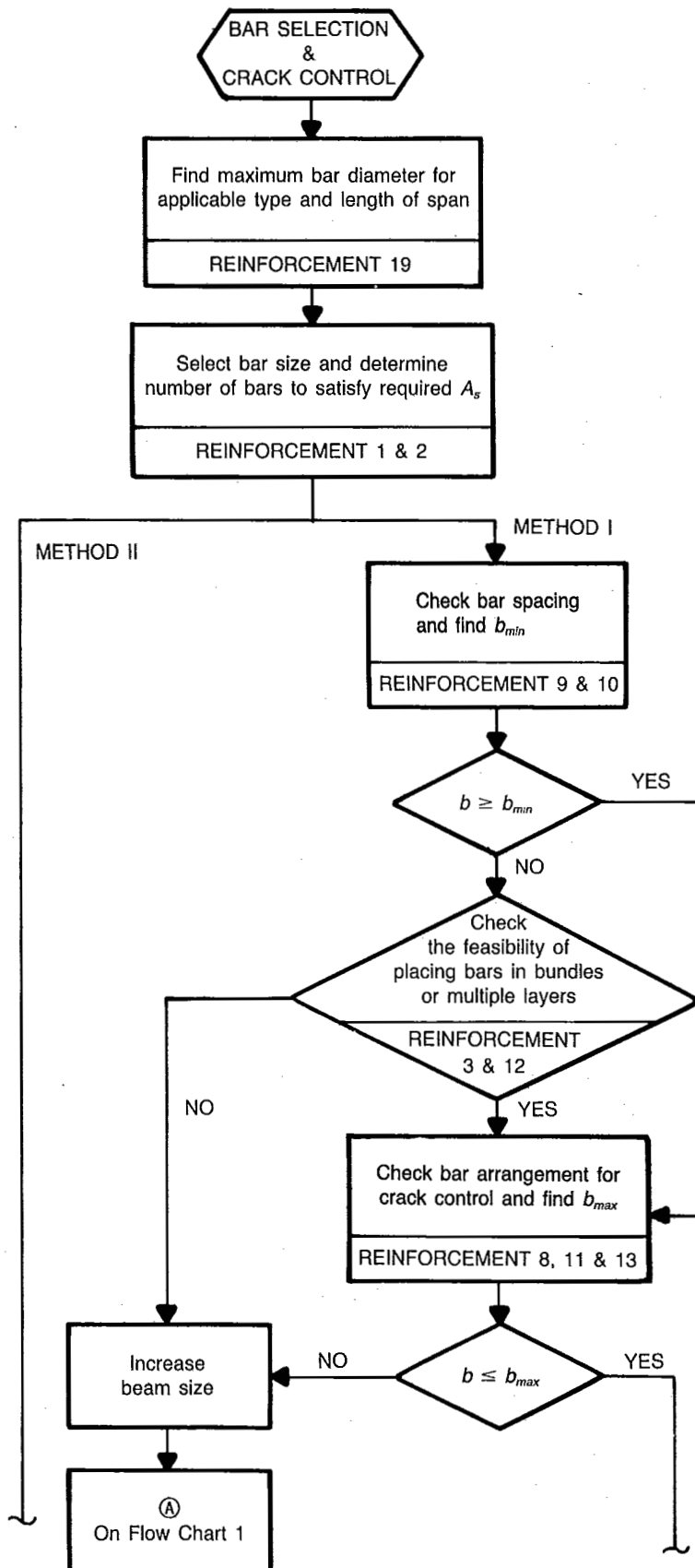
minimum reinforcement
requirement



FLOW CHART 1d – BAR SELECTION AND CRACK CONTROL FOR BEAM DESIGN WITH NO CONSTRUCTION DEPTH RESTRICTIONS

References: Design Procedures 1 and 4

FLOW CHART 1d



Explanations or Comments

Select table for the specified f'_c and f_y . Decide on portion of through-bars to be used and enter table with appropriate type of span and restraint; proceed to nearest smaller span and read maximum permissible bar diameter from table.
See also Step 2.1 of Design Procedure 4.
Select bar size and determine number of bars to satisfy required A_s .

Minimum required concrete protection:
For stirrups: $1\frac{1}{2}$ in.
For #6–#18 longitudinal bars exposed to earth or weather: 2 in.

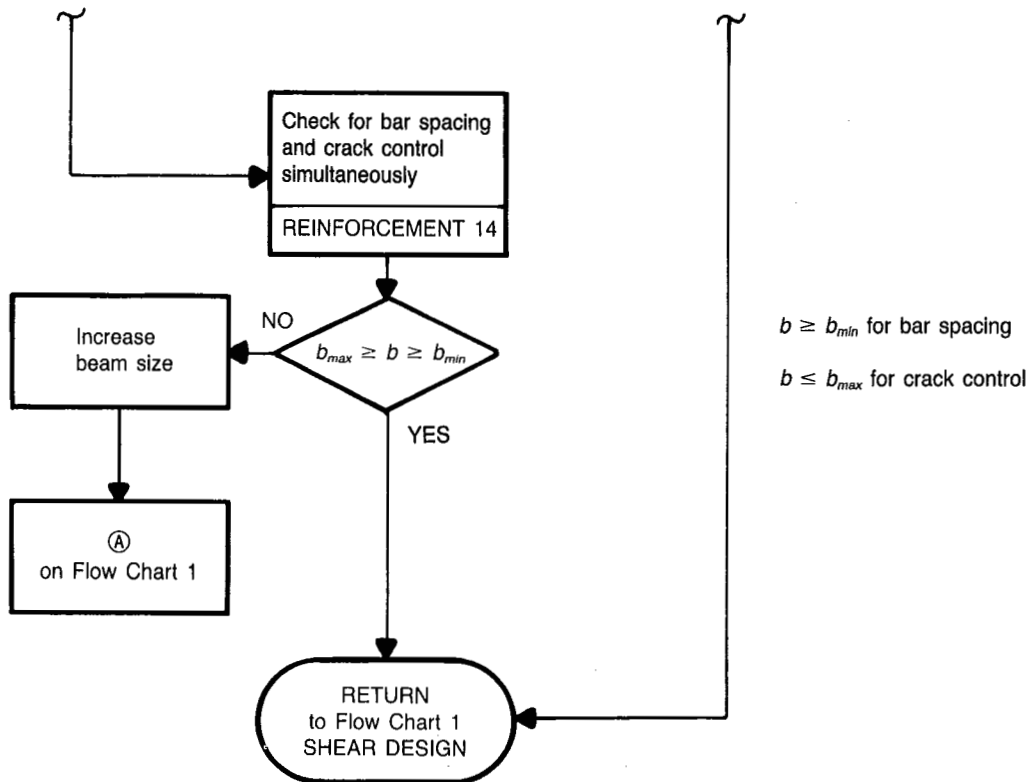
Minimum bar spacing:
Clear distance between bars: not less than d_b , nor 1 in.
Clear distance between layers: 1 in. If more than one layer is required, check for reduction in effective depth; enlarge beam size if necessary.

For properties of various combinations, see REINFORCEMENT 3. For spacing check minimum required web width.

Check whether provided effective tension area $A < A_{max}$ given in table or graph, or calculate $z = f \sqrt[3]{d_c A}$, or use REINFORCEMENT 14 to see whether provided b is between minimum b required for placement and maximum b permitted for crack control.

FLOW
CHART
1d

FLOW CHART 1d - CON'T

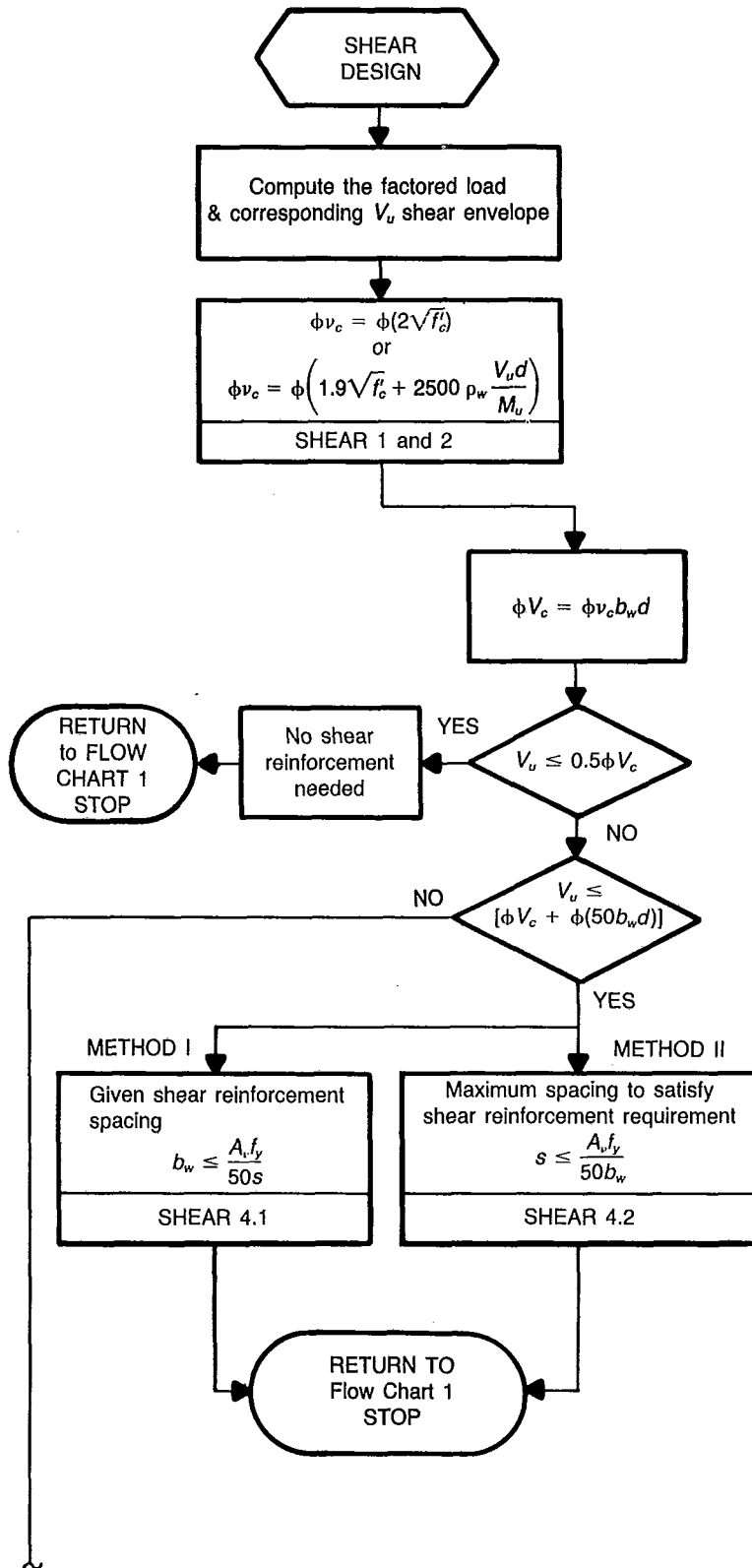


FLOW CHART 1e - SHEAR DESIGN FOR BEAM DESIGN WITH NO CONSTRUCTION DEPTH RESTRICTIONS

References: Design Procedure 1 and 2

FLOW
CHART
1e

Explanations or Comments



ϕv_c may be obtained as follows:
Using $\lambda f'_c$ enter SHEAR 1 to find ϕv_c
Or, using $\lambda f'_c$ and $\rho_w V_u d / M_u$, enter SHEAR 1 to find ϕv_c

$$\rho_w = A_s / b d \text{ for beams}$$

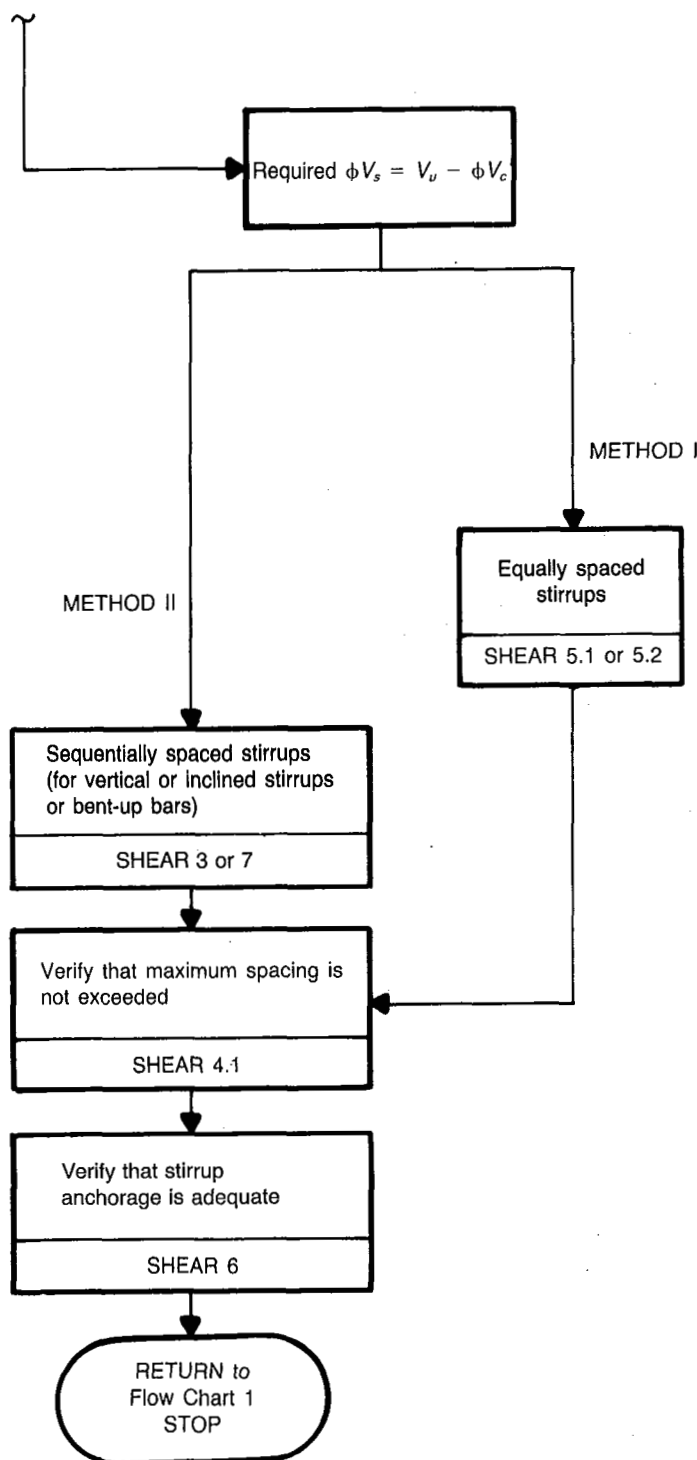
$$= A_s / b_w d \text{ for joists}$$

Or, for lightweight concrete, using f'_c and f_{ci} , find ϕv_c .

It is recommended that the predominant portion of the beam length have stirrup spacing of $d/2$ or less.

Stirrup spacing at critical section

FLOW CHART 1e - CON'T



Method I

Enter SHEAR 5.1 or 5.2 with maximum ϕV_s , where $\phi V_s = V_u - \phi V_c$ at critical section. Use beam effective depth d , and find stirrup spacing.

Note 1: When ϕV_s lies to right of heavy line, it means that minimum stirrups are required.

Note 2: Maximum ϕV_s may not exceed $\phi(8\sqrt{f'_c})b_w d$, which for the simplified method is $4\phi V_c$. When Max ϕV_s is too high, the beam size must be increased.

Locate point where spacing may be increased

Select various desired spacings, find corresponding ϕV_s values, then compute or scale the locations at which spacings can be increased.

Method II

Compute $\frac{\phi V_s}{\beta_v K_v d}$

$\beta_v = 1$ for vertical stirrups

$K_v = 51,000 A_v$ for Grade 60

$= 34,000 A_v$ for Grade 40

Compute length l_v from critical section to point where $V_u = 0.5\phi V_c$. Determine number of stirrups and spacing from SHEAR 3.

Enter with effective depth d , f_y , and stirrup size. Find maximum b_w or b . If beam is wider, maximum s must be reduced as given.

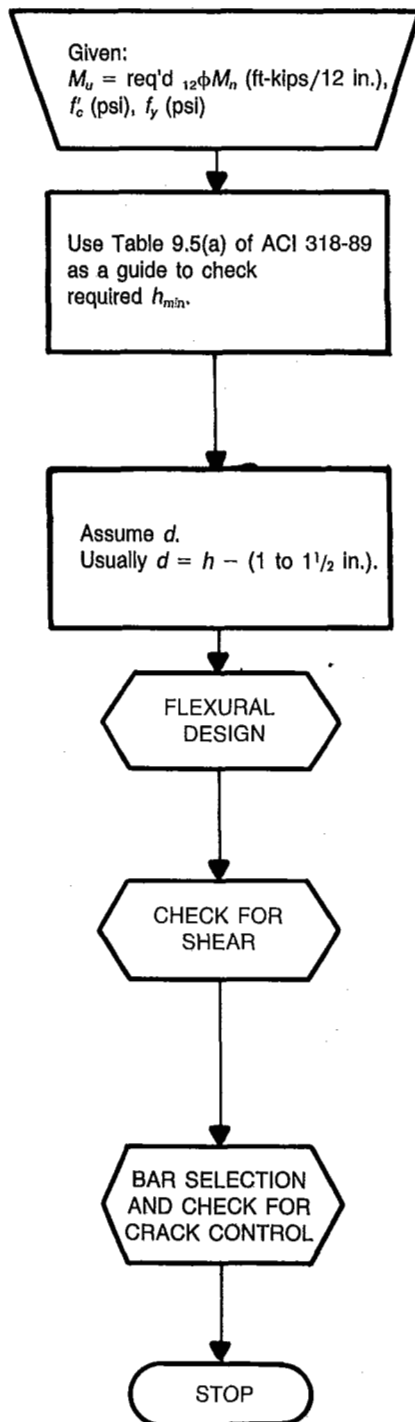
For #6, #7, or #8 stirrups with f_y greater than 40,000 psi, enter with f'_c , f_y , and stirrup size. Read minimum beam height h required and compare with h determined on basis of cover, reinforcement sizes, and given effective depth d . If beam h is insufficient, try smaller bar diameter and closer spacing for stirrups.

FLOW CHART 2 – DESIGN OF ONE-WAY SLABS

Reference: Design Procedure 3

F
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O
W

C
H
A
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T

2

Explanations or Comments

Assume h for design. If less than table limit, deflection will have to be checked whether or not member supports or is attached to nonstructural elements likely to be damaged by large deflection. For limitations for deflections see ACI 318-89 Table 9.5(b).

For average conditions and preliminary purposes the approximate method (see under Deflection) will furnish fast results of sufficient accuracy.

see FLOW CHART 2a

Check for shear is same as for beam with no construction depth restrictions (FLOW CHART 1b). Max V_u at d from face of support is determined for 12 in. wide strip; that is, $b_w = 12$ in.

Shear check of slabs is usually unnecessary except for heavily loaded short spans.

Check:

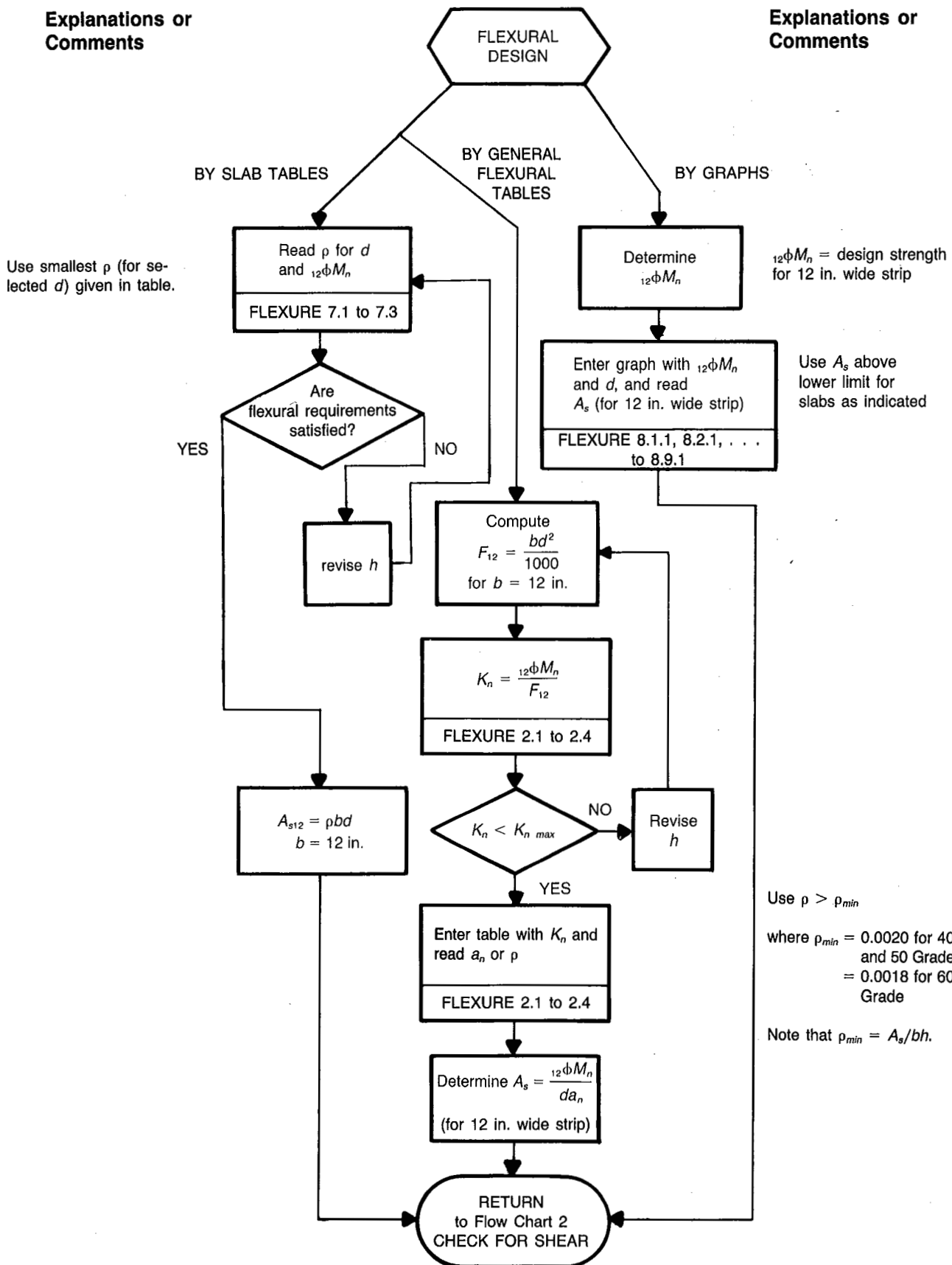
$\phi V_c \geq V_u$ at d from face of support, where for the simplified procedure

$$\phi V_c = \phi(2\sqrt{f'_c})b_w d$$

see FLOW CHART 2b

FLOW CHART 2a – FLEXURAL DESIGN FOR ONE-WAY SLABS

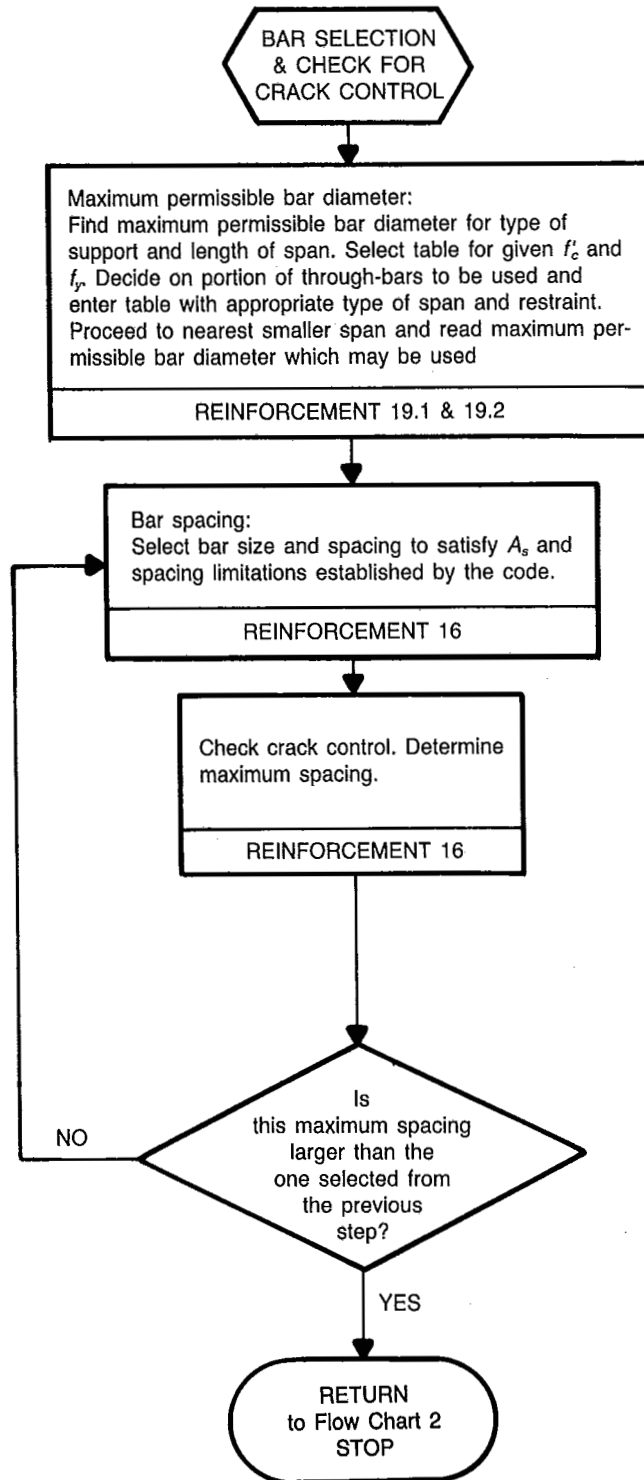
Reference: Design Procedure 3

Explanations or
CommentsExplanations or
Comments

FLOW CHART 2b – BAR SELECTION AND CRACK CONTROL FOR ONE-WAY SLABS

Reference: Design Procedure 3

FLOW
CHART
2b



Explanations or Comments

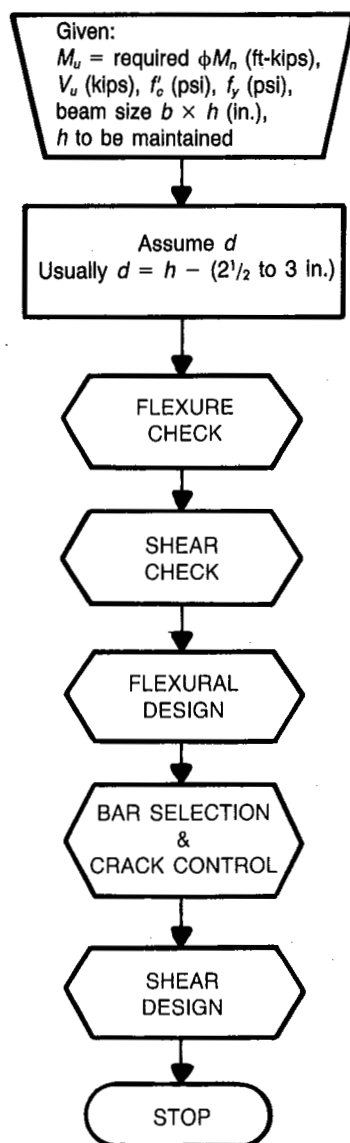
Minimum clear spacing: d_b or 1 in.
Maximum center-to-center spacing: $3h$ or 18 in.

Alternative method:

Evaluate $z = f_s \sqrt[3]{d_c A}$. For this equation, f_s may be assumed to be $0.6f_y$.
 $A = 2d_c s$, where s = center-to-center spacing of bars
 $z < 175$ kips/in. for interior exposure
 $z < 145$ kips/in. for exterior exposure

FLOW CHART 3 – BEAM DESIGN WITH CONSTRUCTION DEPTH RESTRICTIONS

Reference: Design Procedure 5



Explanations or Comments

See FLOW CHART 3a

Same as for beam with no construction depth restrictions (FLOW CHART 1b)

See FLOW CHART 3b

Same as for beam with no construction depth restrictions (FLOW CHART 1d).

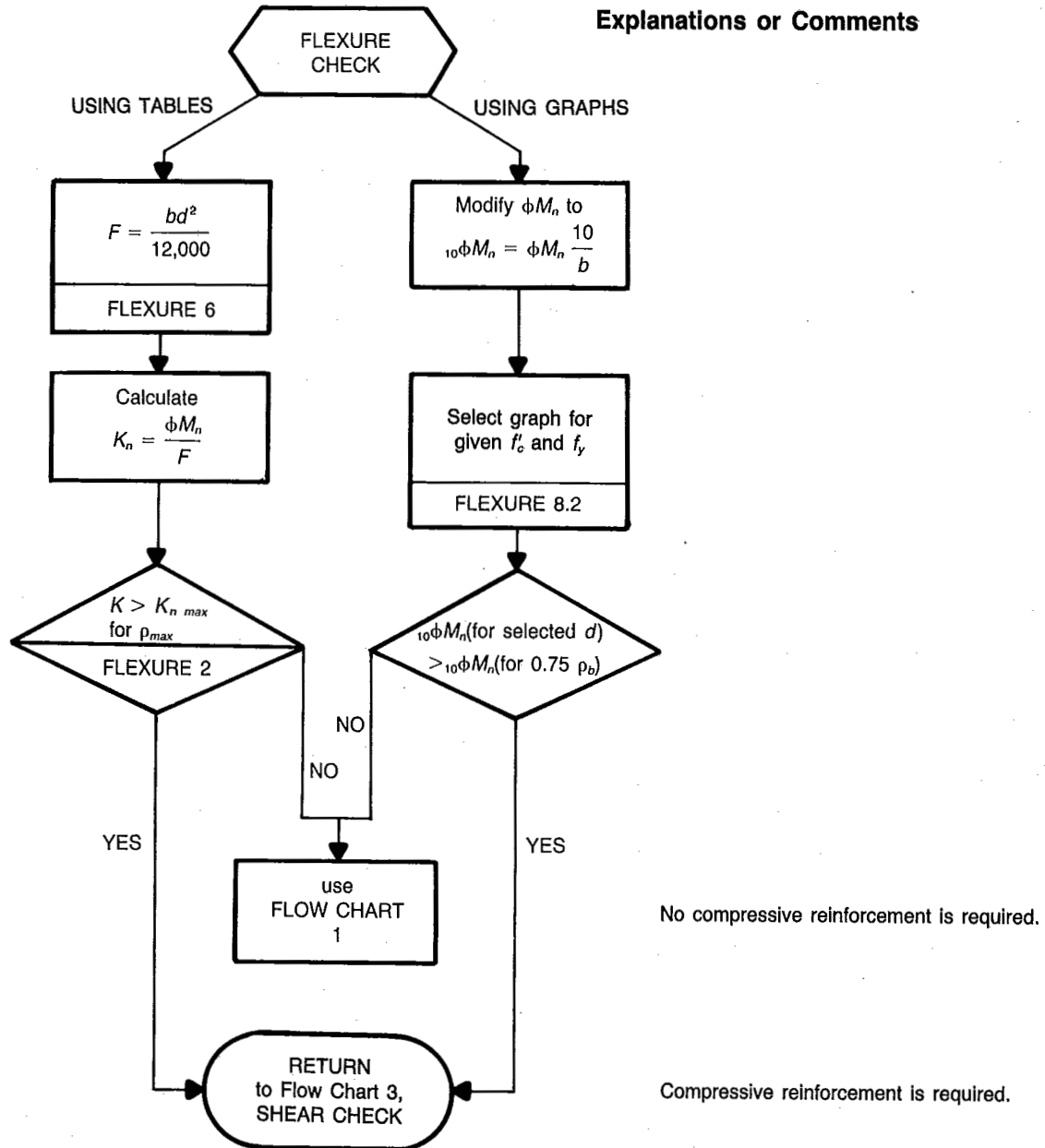
Compression steel must be enclosed by ties or stirrups.

Same as for beam with no construction depth restrictions (FLOW CHART 1e)

FLOW CHART 3a – FLEXURE CHECK FOR BEAM DESIGN WITH DEPTH RESTRICTIONS

Reference: Design Procedure 5

FLOW CHART 3a



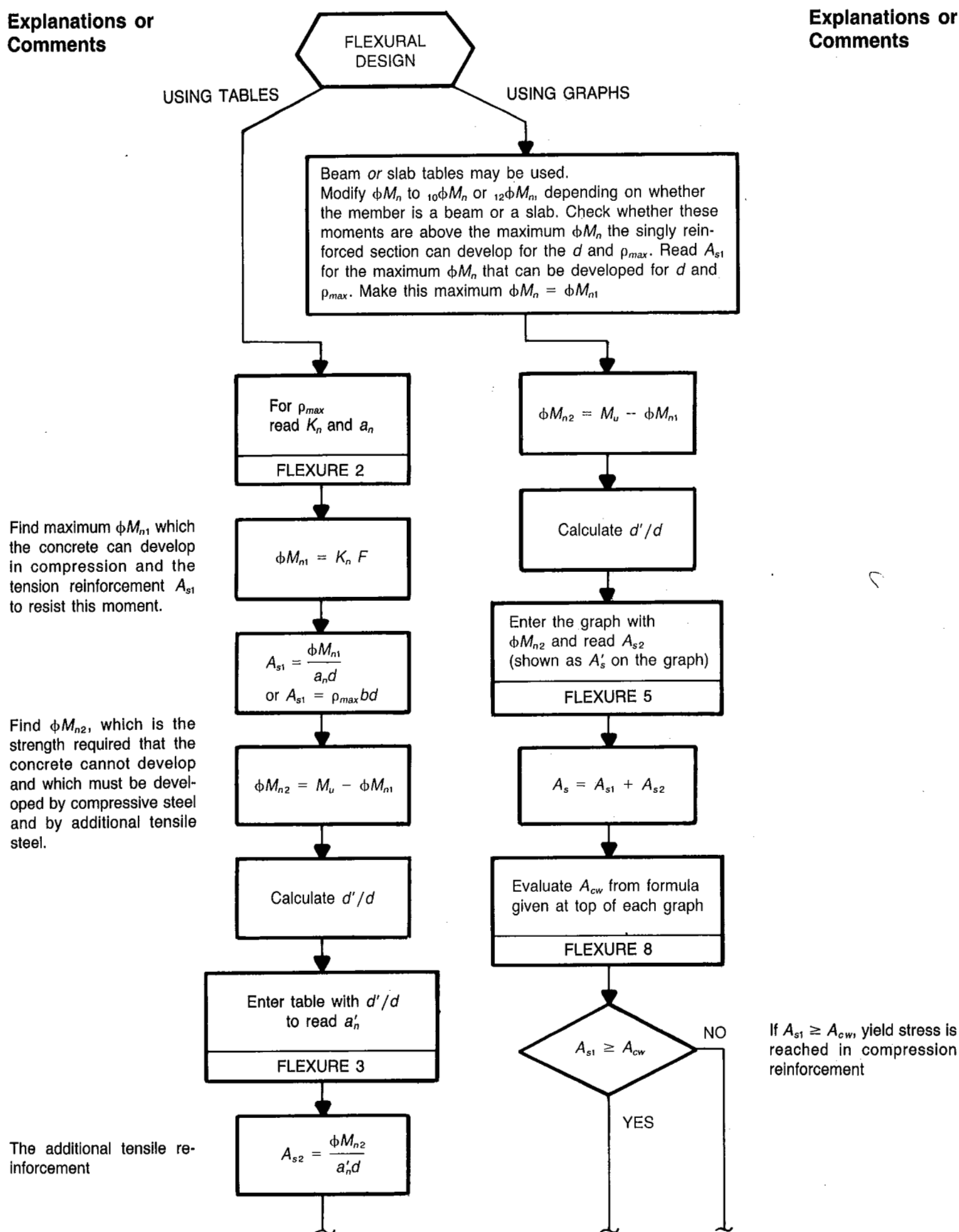
FLOW
CHART
3b

FLOW CHART 3b – FLEXURAL DESIGN FOR BEAM DESIGN WITH DEPTH RESTRICTIONS

Reference: Design Procedure 5

Explanations or
Comments

Explanations or
Comments

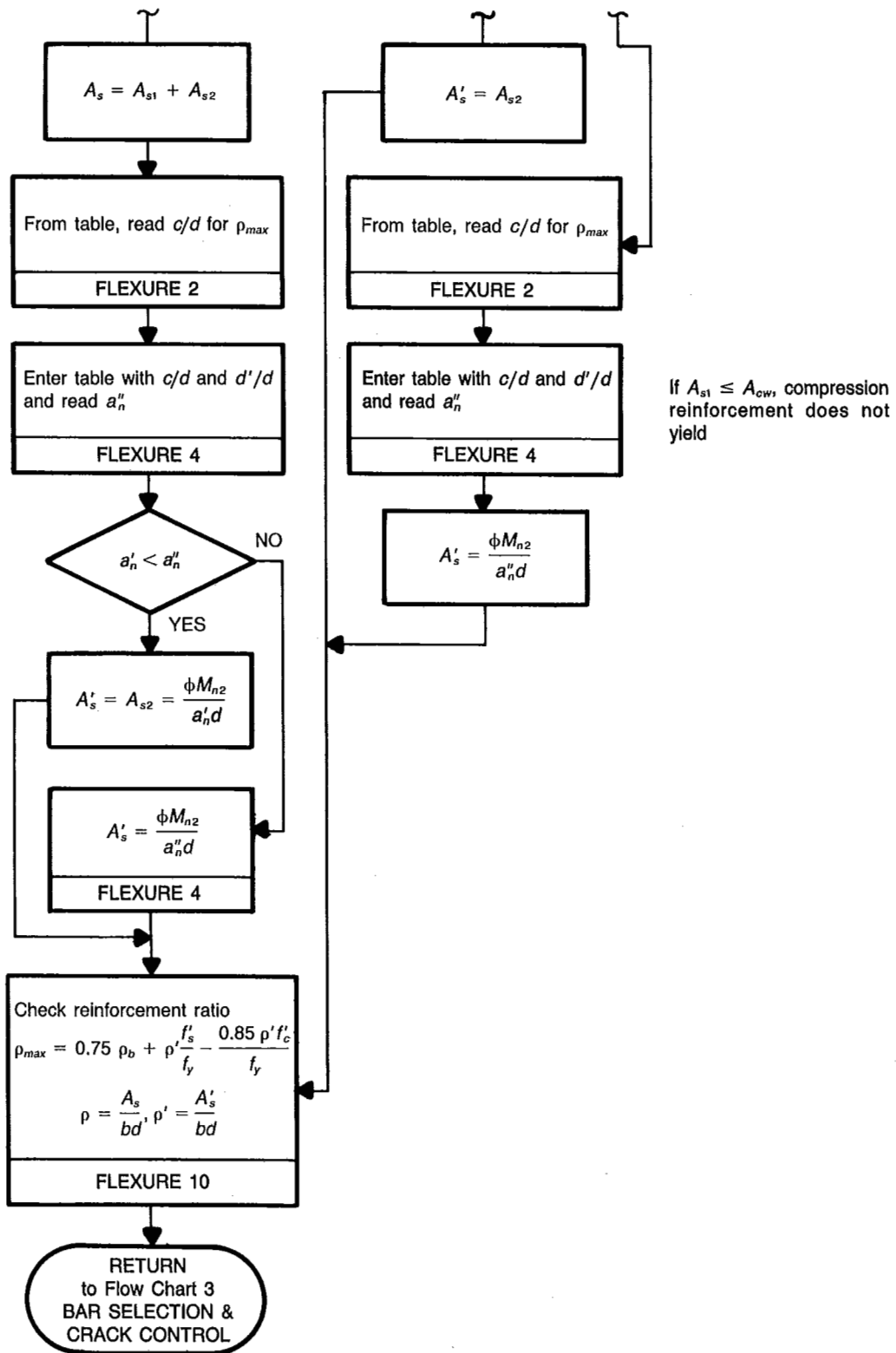


FLOW CHART 3b - CON'T

F
L
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R
T
3bDetermine A'_s , the compression steel.

If $a'_n < a''_n$, compression steel has reached yield stress and compressive reinforcement can be calculated approximately (i.e., neglecting effect of concrete displaced by compression reinforcement as the equation shown here.

If $a'_n > a''_n$, compression steel has not reached yield stress and A'_s must be calculated for lower stress



FLOW CHART 4 – DESIGN OF FLANGED SECTIONS

Reference: Design Procedure 6

Explanations or
CommentsCheck for flanged section
action

Given: required $\phi M_n = M_u$ (ft-kips),
 V_u (kips), f'_c and f_y (psi),
 web size ($b_w \times h$) (in.),
 flange thickness h_f (in.),
 beam spacing ℓ_2 (in.)

Apply only for conditions where flange is in compression. Evaluate effective flange width b according to code requirements; the smallest b governs

FLEXURE 6

$$\text{Calculate } F = \frac{bd^2}{12,000}$$

$$\text{Determine } K_n = \frac{\phi M_n}{F}$$

Enter table with K_n and read c/d

FLEXURE 1

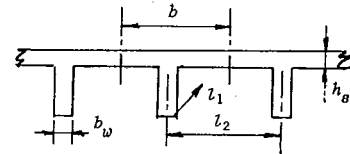
$$\text{Compute } \frac{a}{d} = \beta_1 \frac{c}{d}$$

$$\frac{h_f}{d} < \frac{a}{d}$$

NO

YES

Beam acts as a rectangular beam and design can proceed according to FLOW CHART 1 except for shear design, bar placement, and crack control; use b_w instead of b

Explanations or
Comments

$$\begin{aligned} b &\leq l_1/4 \\ &\leq b_w + 16h_s \\ &\leq l_2 \end{aligned}$$

FLOW CHART 4 – CON'T

F
L
O
W

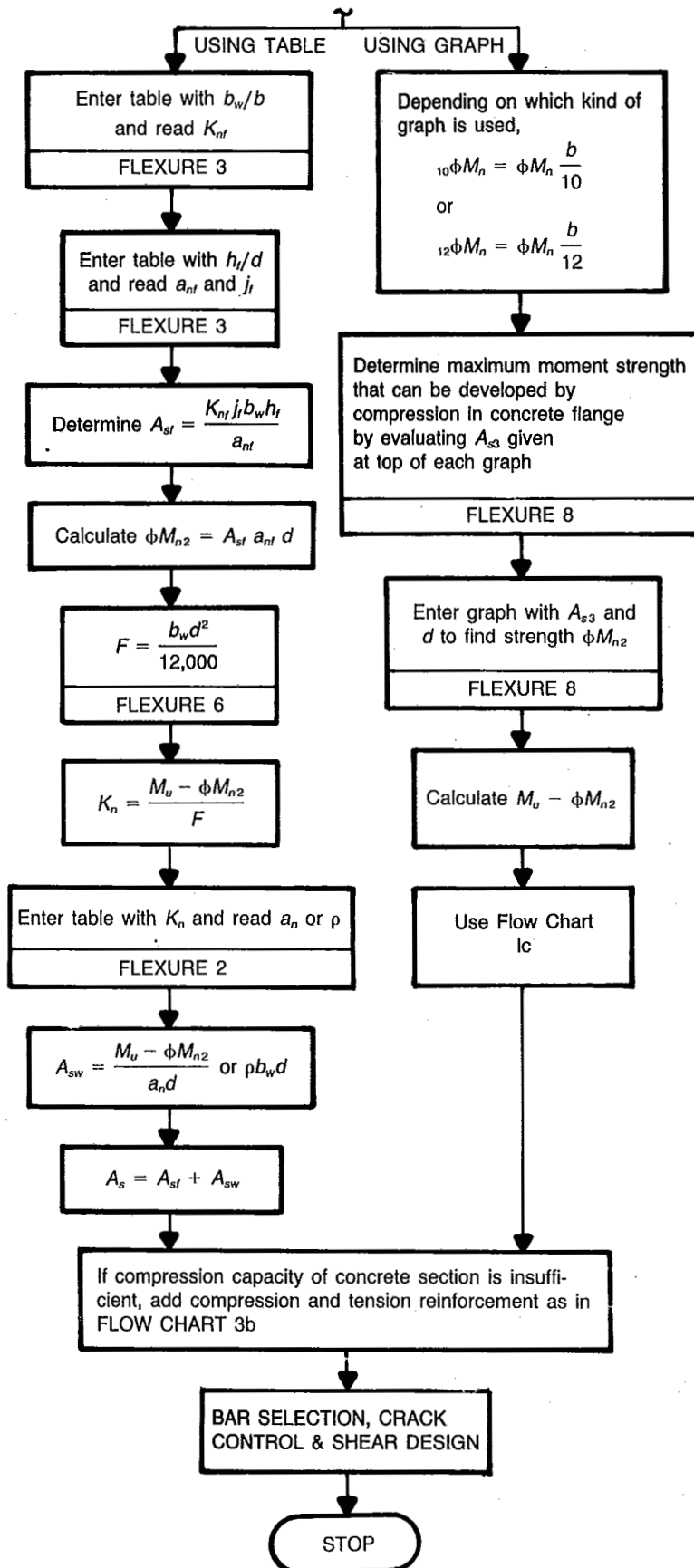
C
H
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4

Flange section design.

 ϕM_{n2} is the moment strength that can be developed by the compression of the flange concreteThe remainder of the strength ($M_u - \phi M_{n2}$) has to be developed by the rectangular web section without or with compression reinforcement.Modify moment ϕM_n to $_{10}\phi M_n$ or $_{12}\phi M_n$ depending on the type of member and use corresponding graph (beam or slab). b = effective flange width. $M_u - \phi M_{n2}$ is then the moment strength that has to be developed by the rectangular beam web b_w .

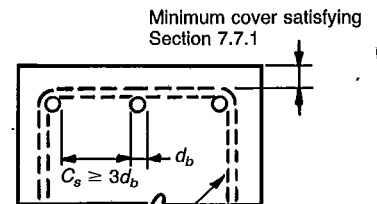
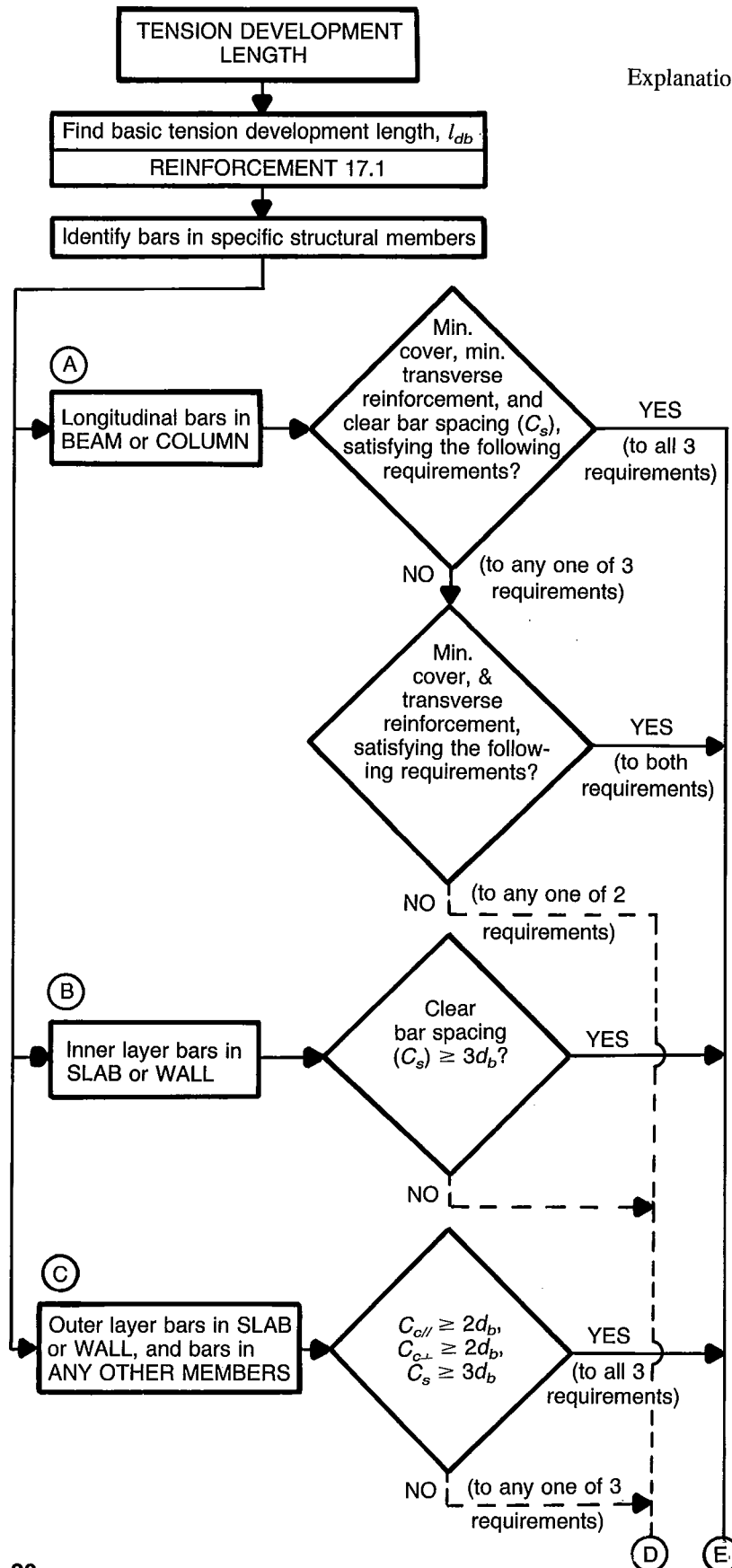
Follow flexural design for singly reinforced beams



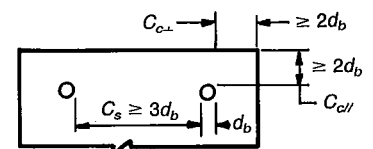
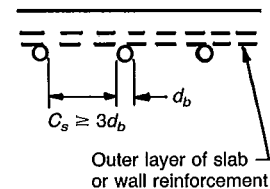
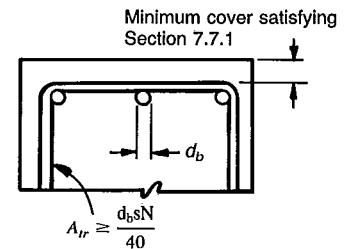
FLOW CHART 5—Determination of Tension Development Length

References: Design Aids, Reinforcement 17.1 & Reinforcement 17.2

Explanations or Comments



Ties meeting Section 7.10.5 or stirrups meeting Section 11.5.4 and 11.5.5.3 along development length

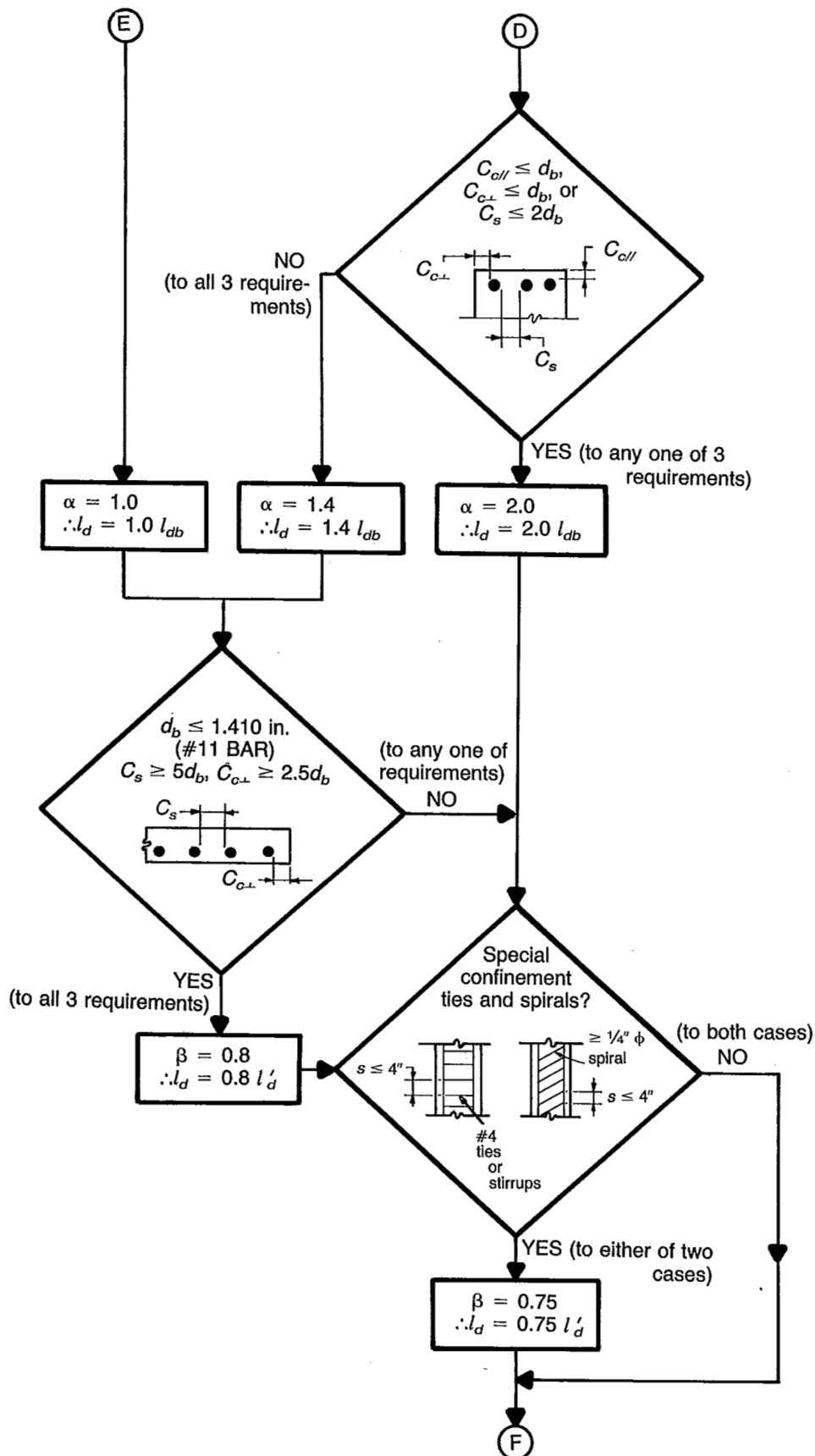


FLOW CHART 5—CON'T

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5



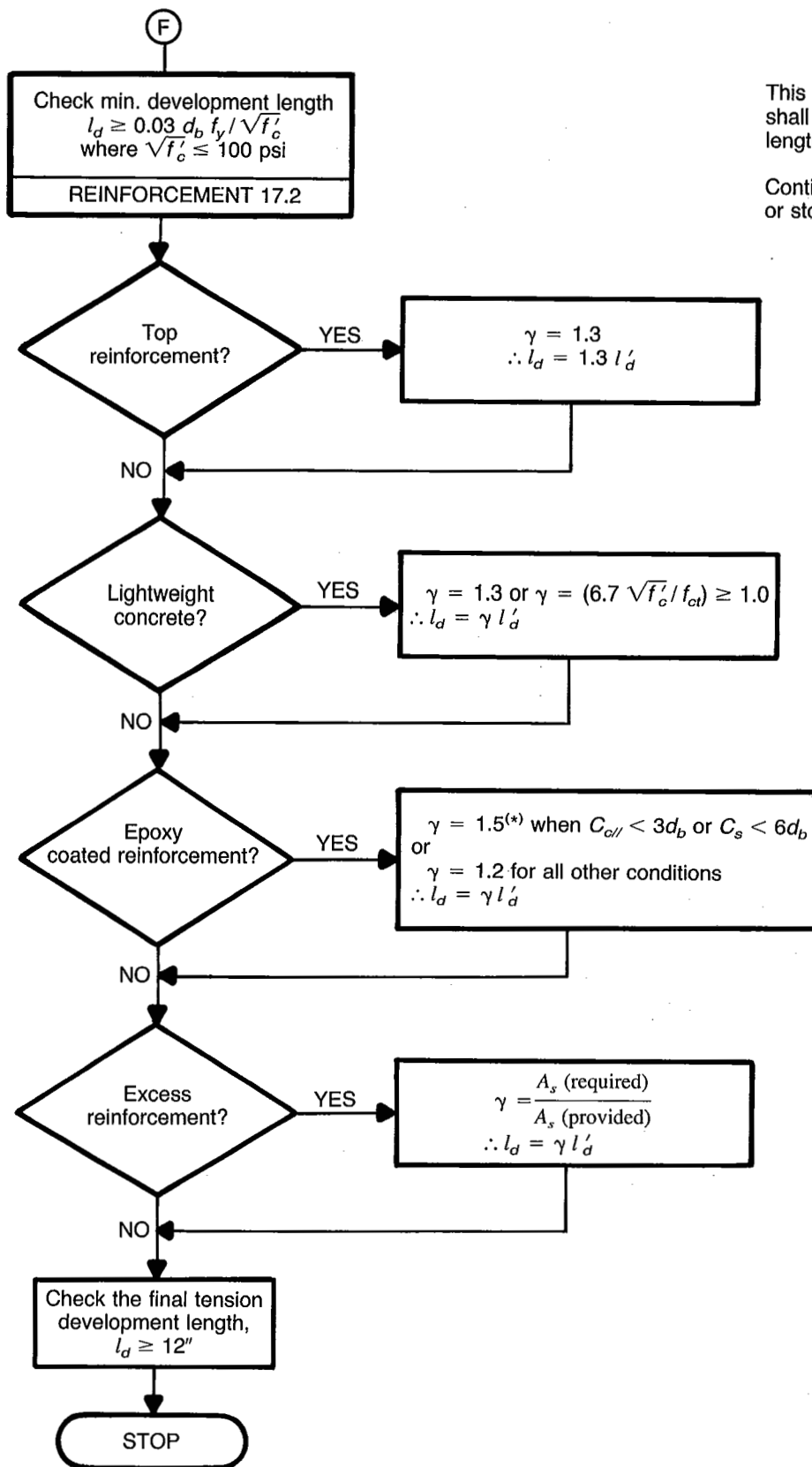
Continue checking further conditions for modifications or stop here if it is final.

Modifiers

α = basic modifiers
 β = reduction modifiers
 γ = special conditions modifiers

l'_d is a development length in the preceding step. l_d is a new modified development length.

FLOW CHART 5—CON'T



This min. development length check shall be made for all final development length determination.

Continue further condition check or stop here if it is final.

(*)
 The product of the factor for top reinforcement and the factor for epoxy coated reinforcement need not be taken greater than 1.7.

DESIGN PROCEDURE 1-BEAM DESIGN WITH NO CONSTRUCTION DEPTH RESTRICTIONS

ACI 318-89 Section	Step	Description	Design Aid
	Given Find	M_u = required ϕM_n (ft-kips), V_u (kips), f'_c (psi), f_y (psi) Beam size: $b \times h$ (in.) Reinforcement: A_s (in. ²)	
Table 9.5(a)	1. Preliminary work	1.1. For guidance determine from ACI 318-89 Table 9.5(a) the h_{min} below which deflections must be computed, even when excessive deflection may cause no damage to nonstructural attached elements. 1.2. Select beam size $b \times h$ <i>Note:</i> When the beam is attached to or supporting non-structural elements likely to be damaged by large deflection, or when $h < h_{min}$, check deflection. For average conditions and preliminary purposes the approximate method (see under Deflection) will furnish fast results of sufficient accuracy. For limitations of deflection, see Table 9.5(b) in ACI 318-89 Find $d = h - (2\frac{1}{2} \text{ to } 3 \text{ in.})$	DEFLEC- TION 7
Table 9.5(b)	2. Flexural check	Tables or graphs can be used. 2.1a. If tables are used: $F = \frac{bd^2}{12,000}$ Determine $F = \frac{bd^2}{12,000}$ or read from handbook table for b and d . Calculate $K_n = \phi M_n / F$ Select table for given f'_c and f_y . Check if $K_n < K_{nmax}$ for 0.75 ρ_b for selected f_y (above lower solid line). Otherwise enlarge beam size. Preferably select K_n based on: $\frac{1}{3} \rho_{max} < \rho < \frac{2}{3} \rho_{max}$ 2.1b. If graphs are used: Adjust ϕM_n to that carried by 10 in. wide beam: $_{10} \phi M_n = \phi M_n \frac{10}{b}$ Select graph for given f'_c and f_y . Check that $_{10} \phi M_n$ for selected d is smaller than $_{10} \phi M_n$ for 0.75 ρ_b . Otherwise enlarge beam size. Preferably base selection on: $\frac{1}{3} \rho_{max} < \rho < \frac{2}{3} \rho_{max}$	FLEXURE 2 FLEXURE 6 FLEXURE 2.1 to 2.4 FLEXURE 8 FLEXURE 8.1.2, 8.2.2, ... to 8.9.2
10.3.1			
10.3.3			
10.3.3			
11.1.3 11.3.1.1	3. Shear check	3.1. Determine factored shear V_u at critical section. Compute shear strength ϕV_c . $\phi V_c = \phi(2\sqrt{f'_c}) b_w d$ Check whether beam size is large enough even when shear reinforcement is used. $\phi V_s = V_u - \phi V_c$ $\text{Max } \phi V_s = \phi(8\sqrt{f'_c}) b_w d$ $= 4\phi V_c$ Preferably $\text{max } \phi V_s \leq \phi(4\sqrt{f'_c}) b d$ If actual $\phi V_s / (b_w d) > \phi(8\sqrt{f'_c})$, then increase beam size. For design of shear reinforcement, see Step 4.3 of this design procedure.	SHEAR 1 Shear Exam- ple 1
11.5.6.8			

ACI 318-89 Section	Step	Description	Design Aid
10.3.1	4. Flexural design 4.1 Calculation of reinforcement.	4.1a. Using tables: Select table for given f_c' and f_y; read a_n or ρ from table for given f_y and K_n determined above under Step 2. Calculate A_s: $A_s = \frac{\phi M_n}{a_n d} \text{ or } A_s = \rho b d$ For bar selection and A_{smin}, see Step 4.1c of this design procedure. 4.1b. Using graphs: Select beam table for given f_c' and f_y. Revise ϕM_n to $_{10}\phi M_n$ as in Step 2.1b. Read A_{s10} (A_s for 10 in. wide beam) from graph for $_{10}\phi M_n$ and d. Determine total A_s: $A_s = A_{s10} (\text{from graph}) \times b / 10$	FLEXURE 2.1 to 2.4 FLEXURE 8.1.2, 8.2.2, ... to 8.9.2
10.5		4.1c. Check A_s for minimum reinforcement ratio using tables; ρ should be below upper heavy line. Using graphs: ρ should be above line for $\rho = \frac{200}{f_y} \text{ (graph limit)}$ If $A_s < A_{smin}$, increase A_s as follows: $A_s = \rho_{min} b d, \text{ where } \rho_{min} = \frac{200}{f_y}$ or $A_s = 1.33 (A_s \text{ computed for strength})$ Use whichever A_s requirement is smaller.	FLEXURE 2.1 to 2.4 FLEXURE 8.1.2, 8.2.2, ... to 8.9.2
Chapter 12	4.2. Bar selection	4.2a. Find maximum bar diameter for applicable type and length of span. Select table for the specified f_c' and f_y. Decide on portion of through-bars to be used and enter table with appropriate type of span and restraint; proceed to nearest smaller span and read maximum permissible bar diameter from table. See also Step 2.1 of Design Procedure 4. Select bar size and determine number of bars to satisfy required A_s.	REINFORCEMENT 19
7.6		4.2b. Check for bar spacing: See whether selected $b \geq b_{min}$ required to accommodate number of bars of selected size. If not satisfied, either increase b or place bars in bundles or multiple layers. See also Step 2.2 of Design Procedure 4.	REINFORCEMENT 1 and 2 REINFORCEMENT 9, 10, and 12
10.6		4.2c. Check selected bar arrangement for crack control: Check whether $b \leq b_{max}$ permitted to satisfy crack control (see also under crack control Step 2.3 of Design Procedure 4). REINFORCEMENT 14 can be used to check Steps 4.2b and 4.2c simultaneously.	REINFORCEMENT 8, 11, and 13 REINFORCEMENT 14

ACI 318-89 Section	Step	Description	Design Aid
11.1.1	4.3. Shear reinforcement	<i>Note:</i> Design aids SHEAR 1 and 2 have been prepared for $\phi V_c / (b_w d) = \phi v_c$ for both the simplified expression in ACI 318-89, Eq. (11-3), and the more detailed expression, Eq. (11-6). For design purposes, SHEAR 1 and 2 are given in unit stress format. 4.3a. Determine the factored shear V_u diagram. 4.3b. Determine maximum shear ϕV_c attributable to the concrete. Since the strength requirement of ACI 318-89 states $V_u \leq [\phi V_n = \phi V_c + \phi V_s]$ it will usually be convenient to use ϕV_c and ϕV_s as the computed quantities. $\phi V_c = \phi v_c b_w d$ $= [\text{handbook value}] b_w d$ For detailed evaluation of ϕv_c for various conditions, see Step 2 of Design Procedure 2. 4.3c. Determine shear ϕV_s required to be taken by stirrups or other shear reinforcement: $\text{Required } \phi V_s = V_u - \phi V_c$ Select size of stirrups or bent-up bars and determine spacing. For sequentially spaced stirrups, use SHEAR 3. For equal spaced stirrups, use SHEAR 5.1 and 5.2. For anchorage of stirrups, use SHEAR 6. For inclined stirrups or bent-up bars, use SHEAR 7. General Rules for the Provision of Shear Reinforcement: Where $V_u \leq 0.5 \phi V_c$, no shear reinforcement required. Where $0.5 \phi V_c < V_u \leq [\phi V_c + \phi(50 b_w d)]$ minimum shear reinforcement required. Where required $\phi V_s \leq \phi(4 \sqrt{f'_c}) b_w d$, or where $V_u \leq 3(\phi V_c)$ for the simplified method, $s_{max} = \frac{d}{2} \text{ for stirrups}$ $= d \text{ for bent-up bars}$ Where $\phi(4 \sqrt{f'_c}) b_w d < \text{Required } \phi V_s \leq \phi(8 \sqrt{f'_c}) b_w d,$ or where $3(\phi V_c) < V_u \leq 5(\phi V_c)$ for the simplified method, $s_{max} = d/4 \text{ for stirrups}$ $= d/2 \text{ for bent-up bars}$ Required $\phi V_s > \phi(8 \sqrt{f'_c}) b_w d$, or $V_u > 5(\phi V_c)$ for the simplified method, is not permitted by ACI 318-89.	SHEAR 1 and 2 SHEAR 1 and 2 SHEAR 3 SHEAR 5.1 and 5.2 SHEAR 6 SHEAR 7
11.5.5.1 11.5.5.3 and 11.5.6.2 11.5.4 11.5.6.8			

ACI 318-89 Section	Step	Description	Design Aid
11.5.6.2		4.3d. Formulas for design of shear reinforcement Maximum spacing to satisfy strength requirement: STIRRUPS $s \leq \left[\frac{\phi A_v f_y d}{\phi V_s} \text{ or } \frac{\phi A_v f_y d}{V_u - \phi V_c} \right]$	
11.5.6.3		BENT-UP BARS $s \leq \left[\frac{\phi A_v f_y d (\sin \alpha + \cos \alpha)}{\phi V_s} \right]$ or $\left[\frac{\phi A_v f_y d (\sin \alpha + \cos \alpha)}{V_u - \phi V_c} \right]$ $(\sin \alpha + \cos \alpha) = \beta_v$	SHEAR 7
11.5.5.3		4.3e. Minimum shear reinforcement Maximum spacing to satisfy minimum shear reinforcement requirement: $s \leq \frac{A_v f_y}{50 b_w}$ or for a given shear reinforcement spacing, $b_w \leq \frac{A_v f_y}{50 s}$	SHEAR 4.2 SHEAR 4.1

DESIGN PROCEDURE 2-DETAILED SHEAR DESIGN FOR VARIOUS CONDITIONS

ACI 318-89 Section	Step	Description	Design Aid
	Given	Service loading, beam dimensions (b_w and d), material properties (f_y and f_c')	
9.2.1	1. Factored load	Compute factored load and corresponding V_u shear envelope.	
11.1.3.1	2. Shear at critical section	Compute shear V_u at distance d from face of support.	
11.3.1.1 11.3.2.1	3. Shear attributable to concrete	The strength may be expressed $\phi V_c = \phi v_c b_w d$ where for the simplified method $\phi v_c = \phi(2\sqrt{f_c'})$ and for the more detailed method $\phi v_c = \phi \left(1.9\sqrt{f_c'} + 2500\rho_w \frac{V_u d}{M_u} \right)$ ϕv_c may be obtained as follows: Using $\lambda f_c'$ enter SHEAR 1 to find ϕv_c Or, using $\lambda f_c'$ and $\rho_w V_u d / M_u$, enter SHEAR 1 to find ϕv_c. $\rho_w = A_s / bd \text{ for beams}$ $= A_s / b_w d \text{ for joists}$ Or, for lightweight concrete, using f_c' and f_{cr}, find ϕv_c.	SHEAR 1 SHEAR 1 SHEAR 2
11.5.5.1	4. Establish design category for stirrups	Category 1: $V_u \leq 0.5\phi V_c$ No stirrups needed. Category 2: $0.5\phi V_c < V_u \leq [\phi V_c + \phi(50b_w d)]$ Minimum stirrups required. Category 3: $V_u > [\phi V_c + \phi(50b_w d)]$ Stirrups required for computed shear.	
11.1.1 11.5.5.3 11.5.6	5. Stirrup spacing at critical section	Enter with maximum ϕV_s, where $\phi V_s = V_u - \phi V_c$ at critical section. Use beam effective depth d, and find stirrup spacing. Note 1: When ϕV_s lies to right of heavy line, it means Category 2 controls. Note 2: Maximum ϕV_s may not exceed $\phi(8\sqrt{f_c'})b_w d$, which for the simplified method is $4\phi V_c$. When Max ϕV_s is too high, the beam size must be increased.	SHEAR 5.1 or 5.2
11.5.6.8	6. Locate point where spacing may be increased	Method 1 Select various desired spacings, find corresponding ϕV_s values, then compute or scale the locations at which spacings can be increased.	SHEAR 5.1 or 5.2

ACI 318-89 Section	Step	Description	Design Aid
11.5.5.1		Method 2	
		Compute $\frac{\phi V_s}{\beta_v K_v d}$	SHEAR 7
		$\beta_v = 1$ for vertical stirrups	SHEAR 7
		$K_v = 51,000 A_v$ for Grade 60 $= 34,000 A_v$ for Grade 40	SHEAR 3
		Compute length l_v from critical section to point where $V_u = 0.5 \phi V_c$ Determine number of stirrups and spacing	SHEAR 3 and Shear Ex- amples 4, 5, and 7
11.5.4.1 11.5.4.2 11.5.4.3	7. Verify that maxi- mum spacing is not exceeded	Enter with effective depth d , f_y , and stirrup size. Find maximum b_w or b If beam is wider, maximum s must be reduced as given.	SHEAR 4
12.13.2	8. Verify that stirrup anchorage is adequate.	For #6, #7, or #8 stirrups with f_y greater than 40,000 psi, enter with f'_c , f_y , and stirrup size. Read minimum beam height h required and compare with previously selected h . If selected h is less than required minimum, increase h to minimum.	SHEAR 6

DESIGN PROCEDURE 3-DESIGN OF ONE-WAY SLABS

ACI 318-89 Section	Step	Description	Design Aid
	Given	M_u = required $_{12}\phi M_n$ (ft-kips/12 in. wide strip, f'_c , f_y (psi))	
9.5	1. Preliminary work	Determine minimum thickness h depending on length and type of span, using ACI 318-89 Table 9.5(a) as a guide. Assume h for design. If less than table limit, deflection will have to be checked whether or not member supports or is attached to nonstructural elements likely to be damaged by large deflection.	
Table 9.5(a)		For limitations for deflections see ACI 318-89 Table 9.5(b).	
Table 9.5(b)		See also note for Step 1.2 of Design Procedure 1.	
10.3.1	2. Flexural design	2a. Using slab tables: Assume d: usually $d = h - (1 \text{ to } 1\frac{1}{2} \text{ in.})$ Read ρ for d and $_{12}\phi M_n$. Preferably base selection on $\frac{1}{3} \rho_{max} < \rho < \frac{2}{3} \rho_{max}$ Check whether flexural requirements are satisfied; if not, revise h. $A_{s12} = \rho b d \text{ in.}^2/\text{ft}; b = 12 \text{ in.}$ 2b. Using general flexure tables: Assume d as above Determine $F = \frac{b d^2}{12,000}$ For $b = 12 \text{ in.}$, $F = \frac{d^2}{1000}$ $K_n = \frac{_{12}\phi M_n}{F_{12}}; \text{ check } K_n < K_{nmax}$ Preferably select K_n based on $\frac{1}{3} \rho_{max} < \rho < \frac{2}{3} \rho_{max}$ Enter table with K_n and read a_n or ρ $A_s = \frac{_{12}\phi M_n}{d a_n} \text{ or } \rho 12 d \text{ in.}^2 / 12 \text{ in. wide strip}$ 2c. Using graphs: Determine $_{12}\phi M_n$ (design strength for 12 in. wide strip). Enter graph with $_{12}\phi M_n$ and d, and read A_s (for 12 in. wide strip). Preferably base selection on $\frac{1}{3} \rho_{max} < \rho < \frac{2}{3} \rho_{max}$	FLEXURE 7.2 to 7.3 FLEXURE 2.1 to 2.4 FLEXURE 6 FLEXURE 2.1 to 2.4 FLEXURE 8.1.1, 8.2.1, ... to 8.9.1 FLEXURE 7.1 to 7.3 FLEXURE 2.1 to 2.4 FLEXURE 8.1.1, 8.2.1, ... to 8.9.1
	3. Check for A_{smin}	If slab tables are used: Use smallest A_s (for selected d) given in table. If general flexure tables are used: Use $\rho > \rho_{min}$ where $\rho_{min} = 0.0020$ for 40 and 50 Grade = 0.0018 for 60 Grade Note that $\rho_{min} = A_s / b h$. If graphs are used: Use A_s above lower limit for slabs as indicated.	
7.12			
7.12 10.3.1			

ACI 318-89 Section	Step	Description	Design Aid
Chapter 11	4. Check for shear	Same as for Step 3 of Design Procedure 1. Max V_u at d from face of support is determined for 12 in. wide strip; that is, $b_w = 12$ in. Shear check of slabs is usually unnecessary except for heavily loaded short spans. Check: $\phi V_c \geq V_u$ at d from face of support, where for the simplified procedure $\phi V_c = \phi(2\sqrt{f'_c})b_w d$	
Chapter 12	5. Bar selection	Same as for Step 4.2 of Design Procedure 1. Select size and spacing of bars to satisfy required A_s . Check for maximum spacing: $<3h$ or 18 in.	REINFORCE- MENT 19.1 and 19.2
7.6.5			REINFORCE- MENT 15 and 16
10.6	6. Check for crack control	Check selected bar spacing s for crack control and revise if necessary. $s < s_{max}$ <i>Note:</i> For bar selection and crack control, see also Design Procedure 4, Steps 1.1 to 3.	

DESIGN PROCEDURE 4—BAR SELECTION, BAR SPACING, AND CRACK CONTROL

DESIGN PROCEDURE 4

ACI 318-89 Section	Step	Description	Design Aid
Chapter 12	Given	A_s (in. ²), b (in.), concrete clear cover, type of exposure.	
	1. Slabs	1.1. Maximum permissible bar diameter. Find maximum permissible bar diameter for type of support and length of span. Select table for given f'_c and f_y. Decide on portion of through-bars to be used and enter table with appropriate type of span and restraint. Proceed to nearest smaller span and read maximum permissible bar diameter which may be used. 1.2. Bar spacing Select bar size and spacing to satisfy A_s and spacing limitations established by the code. Minimum clear spacing: d_b or 1 in. Maximum center-to-center spacing: $3h$ or 18 in. 1.3. Crack control. Determine maximum spacing from REINFORCEMENT 16 or evaluate $z = f_s \sqrt[3]{d_c A}$. For this equation, f_s may be assumed to be $0.6f_y$. $A = 2d_c s$, where s = center-to-center spacing of bars $z < 175$ kips/in. for interior exposure $z < 145$ kips/in. for exterior exposure	REINFORCEMENT 19.1 and 19.2 REINFORCEMENT 15 REINFORCEMENT 16
7.6.1 7.6.5 10.6			
Chapter 12	2. Beams	2.1. Maximum permissible bar diameter. Find maximum permissible bar diameter for type of support and length of span as for Step 1.1 above. 2.2. Bar spacing. Select size and number of bars considering: 2.2a. The minimum required area of reinforcement, A_s; 2.2b. The minimum required concrete protection: For stirrups: $1\frac{1}{2}$ in. For #6–#18 longitudinal bars exposed to earth or weather: 2 in. 2.2c. Minimum bar spacing: Clear distance between bars: not less than d_b nor 1 in. Clear distance between layers: 1 in. If more than one layer is required, check for reduction in effective depth; enlarge beam size if necessary. 2.3. Crack control. Check whether provided effective tension area $A < A_{max}$ given in table or graph, or calculate $z = f \sqrt[3]{d_c A}$ as under Step 3 of Design Procedure 1, or use REINFORCEMENT 14 to see whether provided b is between minimum b required for placement and maximum b permitted for crack control. REINFORCEMENT 14 can be used to check Steps 2.2 and 2.3 simultaneously.	REINFORCEMENT 19.1 and 19.2 REINFORCEMENT 1 and 2 REINFORCEMENT 9 and 10 REINFORCEMENT 9 and 10 REINFORCEMENT 8 and 8.1 REINFORCEMENT 11 REINFORCEMENT 14
7.7.1			
7.6.1			
10.6			

ACI 318-89 Section	Step	Description	Design Aid
7.6.6	3. Bundled bars	For properties of various combinations, see REINFORCEMENT 3 3.1. Spacing Check minimum required web width. 3.2. Crack control Check maximum permissible web width. Steps 3.1 and 3.2 can be checked simultaneously by using REINFORCEMENT 14	REINFORCEMENT 3 REINFORCEMENT 12 REINFORCEMENT 13 REINFORCEMENT 14

DESIGN PROCEDURE 5-BEAM DESIGN WITH CONSTRUCTION DEPTH RESTRICTIONS

ACI 318-89 Section	Step	Description	Design Aid
	Given	M_u = required ϕM_n (ft-kips), V_u (kips), f'_c , f_y (psi). Beam size $b \times h$ (in.), h to be maintained. Assume d : usually $d = h - (2\frac{1}{2} \text{ to } 3 \text{ in.})$	
	1. Preliminary		
	2. Flexure	2a. Using tables: Determine $F = \frac{bd^2}{12,000}$ or use FLEXURE 6. Calculate $K_n = \phi M_n / F$ If $K_n > K_{nmax}$ for ρ_{max} , concrete section is insufficient and compressive reinforcement is required.	FLEXURE 6 FLEXURE 2
10.3.3		2b. Using graphs: Modify ϕM_n to $_{10}\phi M_n = \phi M_n \frac{10}{b}$ Enter graph with d . If required $_{10}M_n$ is beyond limit for $0.75\rho_b$, compressive reinforcement is required.	FLEXURE 8.2
10.3.3	3. Shear	Same as for beam with no construction depth restrictions (Design Procedure 1).	
	4. Flexural design	4a. Using tables: 4a.1. Find maximum ϕM_{n1} which the concrete can develop in compression and the tension reinforcement A_{s1} to resist this moment. For ρ_{max} read: K_n and a_n . $\phi M_{n1} = K_n F$ and the reinforcement is $A_{s1} = \frac{\phi M_{n1}}{a_n d} \text{ or } \rho b d$	FLEXURE 2
10.3.3 10.3.1		4a.2. Find ϕM_{n2} which is the strength required that the concrete cannot develop and which must be developed by compressive steel and by additional tensile steel. $\phi M_{n2} = M_u - \phi M_{n1}$. Determine d'/d . Enter table with d'/d to read a'_n . The additional tensile reinforcement is then $A_{s2} = \frac{\phi M_{n2}}{a'_n d}$ and the total tension steel $A_s = A_{s1} + A_{s2}$. Determine A'_s , the compression steel. Read c/d for ρ_{max} from FLEXURE 2 Enter FLEXURE 4 with c/d and d'/d and read a''_n . Compare a''_n with a'_n . The smaller governs.	FLEXURE 3
10.3.1	Tension steel		FLEXURE 2 FLEXURE 4
10.3.1	Compression steel	4a.3. If $a'_n < a''_n$, compression steel has reached yield stress and compressive reinforcement can be calculated approximately (i.e., neglecting effect of concrete displaced by compression reinforcement) as $A'_s = A_{s2} = \frac{\phi M_{n2}}{a'_n d}$	

ACI 318-89 Section	Step	Description	Design Aid
		4a.4. If $a_n' > a_n''$, compression steel has not reached yield stress and A_s' must be calculated for lower stress $A_s' = \frac{\phi M_{n2}}{a_n'' d}$	FLEXURE 4
		4a.5. Check reinforcement ratio $\rho_{max} = 0.75\rho_b + \rho' \frac{f_s'}{f_y} - \frac{0.85 \rho' f_c'}{f_y}$ $\rho = \frac{A_s}{bd} \quad \rho' = \frac{A_s'}{bd}$	FLEXURE 10
7.11.1		4a.6. Bar selection, crack control, and shear design, same as for beam with no construction depth restrictions (Design Procedure 1). Compression steel must be enclosed by ties or stirrups.	
10.3.1		4b. Using graphs: 4b.1. Beam or slab tables may be used. Modify ϕM_n to $_{10}\phi M_n$ or $_{12}\phi M_n$, depending on whether the member is a beam or a slab. Check whether these moments are above the maximum ϕM_n the singly reinforced section can develop for the d and ρ_{max}. Read A_{s1} for the maximum ϕM_n that can be developed for d and ρ_{max}. Evaluate A_{cw} from formula given at the top of each graph. If $A_{s1} \geq A_{cw}$, yield stress is reached in compression steel. (If $A_{s1} < A_{cw}$, see Step 4a.4.)	FLEXURE 8
10.3.1		4b.2. Determine moment that cannot be developed by concrete. Required $\phi M_{n2} = M_u - \phi M_{n1}$ ϕM_{n1} is strength developed with ρ_{max} for singly reinforced beam. Determine d'/d and enter FLEXURE 5 with ϕM_{n2} and read A_s'.	FLEXURE 5
10.3.1		4b.3. Tension steel Total tension reinforcement $A_s = A_{s1} + A_{s2}$	
10.3.1		4b.4. Compression reinforcement. If $A_{s1} > A_{cw}$, yield stress is reached in compression reinforcement. For this case, neglecting displaced concrete, $A_s' = A_{s2}$. Find a_n'' as under Step 4a.2. The compression reinforcement is then $A_s' = \frac{\phi M_{n2}}{a_n'' d}$ If $A_{s1} < A_{cw}$, compression reinforcement does not yield.	FLEXURE 8
7.11.1		4b.5. Check reinforcement ratio Compression steel must be enclosed by ties or stirrups as under Steps 4a.5 and 4a.6. 4b.6. Bar selection, crack control, shear design, same as in Design Procedure 1.	FLEXURE 10