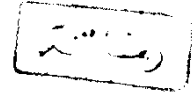

A NUMERICAL IDENTIFICATION FOR NEW PARAMETERS INFLUENCING BOND BEHAVIOR

- with special regard of steel strain -

*A Thesis
Submitted For The Ph.D Degree
In Civil Engineering*



BY

Taha Moussa Auf Hamada

B. Sc., Suez Canal University, 1981.

M. Sc., Suez Canal University, 1988.

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UNDER THE SUPERVISION OF

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Karlsruhe University

Prof. Dr. Eng. M. Nassef

Cairo University

Prof. Dr. A. K. Abdel Khalik

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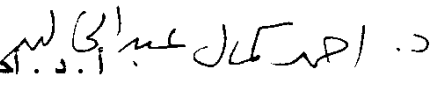
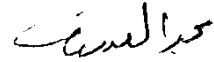
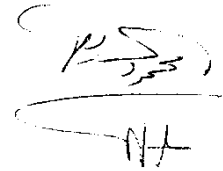
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NOTATION

A	=	parameter in failure criterion, Eq. (5.3);
a_0, a_1, a_2	=	parameter in Eq. (4.16);
B	=	parameter in failure criterion, Eq. (5.3);
b_0, b_1, b_2	=	material constants in Eq. (4.16);
C_{ijkl}	=	material elastic tensor in Eq. (5.11);
D	=	parameter in Eq. (5.4);
d_{max}	=	maximum grain size;
d_s	=	nominal diameter of reinforcing steel;
d_x	=	length;
c_y	=	concrete cover, see Fig. (2.26);
E	=	Young's modulus,
E_A	=	Young's modulus, see Fig. (5.8) and Eq. (5.8);
$E_c = \sigma_c / \epsilon_c$	=	secant value of Young's modulus at uniaxial compressive failure;
E_f	=	secant value of Young's modulus at triaxial compressive failure;
E_i	=	initial Young's modulus;
E_M	=	Young's modulus, see Fig. (5.8) and Eq. (5.8);
E_{MN}	=	Young's modulus, see Fig. (5.8) and Eq. (5.8);
E_s	=	secant value of Young's modulus;
F	=	force in reinforcing deformed bar;
f_{ci}	=	compressive stress on crack surface (positive quantity);
f_{ct}	=	tensile strength of concrete;
G_b	=	tangential bond modulus;
G_c	=	shear modulus of cracked concrete in Eq. (5.15);
G_f	=	Fracture energy;
G_r	=	the stiffness of spring in direction r ;
G_t	=	the forces transferred by dowel action;

I_1	=	σ_{ii} = first invariant of stress tensor;
i & k	=	nodal points;
J	=	$\cos 3\theta = (3\sqrt{3}/2) (J_3/J^{3/2}_2)$ invariant;
J_2	=	second invariant of stress deviator tensor;
J_3	=	third invariant of stress deviator tensor;
K	=	factor which represents the effect of the "deformity" (ribbed surface configuration);
k_1	=	parameter in failure criterion, Eq. (4.12);
k_2	=	parameter in failure criterion, Eq. (4.12);
k'	=	σ_t / σ_c ; ratio of uniaxial tensile to compressive strength;
L	=	embedment length of reinforcing steel bar;
M	=	total number of nodes on body Γ^A ;
M_c	=	number of nodes on body Γ^A inside the contact zone;
N	=	total number of nodes on body Γ^B ;
N_c	=	number of nodes on body Γ^B inside the contact zone;
P_c	=	compressive meridian;
$P_1 - P - P_2$	=	the derivation of the elliptic curve;
P_r	=	confining pressure;
P_s	=	shear meridian;
P_t	=	tensile meridian;
q_i	=	body force, Eq. (3.32);
R	=	radius of cylinder;
R_r^{ik}	=	spring force between the nodal points i & k in direction r ;
R_t^{ik}	=	spring force between the nodal points i & k in direction t ;
S	=	slip modulus;
T_i	=	surface traction;
$T'_{ij}(P, Q)$	=	traction in direction i at the point P due to a unite load in direction j at the point Q , Eq. (A.3);
$U_{ij}(P, Q)$	=	displacement in direction i at the point P due to a unit load in direction j at the point Q , Eq. (A.3);
v_{ci}	=	shear stress on crack surfaces;

w	=	crack width;
$x_{ij}, \varphi_{ij}, \psi_{ij}$	=	geometry, traction and displacement variation according to interpolation functions respectively, Eq. (A.20);
x_i, t_j , and u_j	=	the nodal values of the element, Eq. (A.20);
α	=	an angle between bond force & surface of reinforcing bar;
α_{sb}	=	related rib area;
θ	=	angle, see Fig. (4.10);
λ	=	function in failure criterion, Eqs. (4.11) and (4.12);
μ	=	coefficient of friction between normal and tangential tractions, Eq.(A.11);
μ_i	=	initial friction coefficient, Eq. (A.13);
μ_m	=	limit friction coefficient, Eq. (A.13);
ξ	=	$(1/\sqrt{3}) I_1$; invariant, see Fig. (4.10);
ρ	=	$(2J_2)^{1/2}$; invariant, see Fig. (4.10);
ρ_c , and ρ_t	=	stress component perpendicular to the hydrostatic axis at $\theta = 0^\circ$, and $\theta = 60^\circ$, respectively in Eq. (4.16);
Γ	=	the curve of body, Eq. (A.1);
Γ^A	=	cylinder surface body A, Eq. (A.9);
Γ^B	=	cylinder surface body B, Eq. (A.9);
Γ_c	=	contact zone, see Fig. (A.2) and Eq. (A.9);
β	=	plasticity index, Eq. (5.2);
Δ_r	=	radial displacement;
Δ_r^{ik}	=	relative nodal displacement of the nodal points i & k in radial direction;
Δ_s	=	the bar contraction;
Δ_t	=	axial displacement;
Δ_t^{ik}	=	relative nodal displacement of the nodal points i & k in axial direction;
$\Delta_2^{\theta, n}$	=	residual tangential traction, see Fig. (A.4) and Eq. (A.16);
Δ_2^n	=	the incremental in tangential traction, see Fig. (A.4) and Eq.(A.17);
δ	=	slip between reinforcing bar and concrete;

δ_{ui}	=	virtual displacement increments, Eq. (3.32);
δ_x	=	the slip between steel and concrete at section x;
$\delta_{\epsilon_{ij}}$	=	virtual strain increment, Eq. (3.32);
$\epsilon_1, \epsilon_2, \epsilon_3$	=	principal strains ($\epsilon_1 \geq \epsilon_2 \geq \epsilon_3$, elongation positive);
ϵ_c	=	strain at uniaxial compressive failure;
n	=	shear retention factor, Eq. (5.15);
(ρ, θ)	=	polar coordinates;
σ_0	=	yield stress, see Fig. (4.24) and Eq. (4.19);
σ'_{bc}	=	biaxial compressive strength;
σ_{ij}	=	stress tensor, tensile stress positive;
$\sigma_1, \sigma_2, \sigma_3$	=	principal stresses;
σ_c	=	uniaxial compressive cylinder strength;
σ_m	=	the mean stress;
σ_t	=	uniaxial tensile strength;
σ_{oct}	=	octahedral normal stress;
τ_b	=	bond stress at section x;
τ_{br}	=	radial bond stress;
τ_k	=	shear bond component;
τ_{oct}	=	octahedral shear stress;
τ_{max}	=	maximum bond stress;
v_e	=	the effective slip, Eq. (A.13);
v_f	=	secant value of Poisson's ratio at failure, Eq. (5.9);
v_i	=	initial Poisson's ratio, Eq. (5.9);
v_s	=	secant value of Poisson's ratio, Eq. (5.9);
Φ	=	diameter of steel bar;
ψ	=	theoretical or experimental constant;
ϕ	=	theoretical or experimental constant;
Ω	=	linear elastic body, Eq. (A.1);
Ω^A	=	linear elastic body A, Eq. (A.9);
Ω^B	=	linear elastic body B, Eq. (A.9);
$[B]$	=	the strain-displacement matrix in Eq. (3.40);

$[C]$	=	elastic constitutive matrix;
$[D]$	=	material stiffness matrix for a linear isotropic material, in an axisymmetric stress state;
$[K]$	=	the structural stiffness matrix in Eq. (3.45);
$[L]$	=	differential operator matrix, Eq. (3.41);
$[N]$	=	matrix of the displacement interpolation function;
$[T]$	=	transformation matrix;
$[\epsilon]$	=	element strain matrix;
$[\sigma]$	=	element stress matrix;
$^{m+1}\{F\}$	=	equivalent force of stress acting on the nodal points, Eq. (3.49);
$\{R\}$	=	equivalent external force acting on the nodal points, Eq. (3.43);
$\{u\}$	=	vector for displacement;
$\{U\}$	=	displacement vector for nodal points;
$\{\epsilon\}$	=	vector for strain;
$\{\sigma\}$	=	vector for stress;
$\{\Delta R\}$	=	the load increment;
$\{\Delta U\}$	=	the displacement increment;
$\{\Delta \epsilon\}$	=	strain increment; and
$\{\Delta \sigma\}$	=	stress increment.

TERMINOLOGY

Anchorage	: Anchorage at the end of reinforcing bars makes it possible that they can be taken into consideration as tensile or a compressive member in the reinforced concrete structure.
Anchorage device	: Mechanical devices, usually used at the end of reinforcing bars or prestressed tendons to anchor them over a very short length.
Anchorage length	: Anchorage length measured from the butt end of the reinforcing bar necessary to transfer a given force from the bar to the concrete.
Beam test	: A testing method proposed by Rilem to checkk the bond characteristics of deformed reinforcement.
Bond	: Interaction between reinforcement and surrounding concrete.
Bond forces	: Forces between reinforcement and surrounding bars.
Confining effects	: Effects - transversal compression or transverse reinforcement - which influence the resistance of the concrete to bursting or splitting forces.
Internal bond cracks	: Internal bond cracks, that develop in the surrounding concrete starting from the top of the ribs surface of the bar.