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.

UNDER THE SUPERVISON OF

Prof. Dr. Eng. J. Eibl
Karlsruhe University

Prof. Dr. Eng. M. Nassef
Cairo University

Prof. Dr. A. K. Abdel Khalik
Suez Canal University

Dr. Eng. M. El. Ghazouly
Suez Canal University

Faculty of Egineering
Suez Canal University
(1995)

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.

UNDER THE SUPERVISON OF

Prof. Dr. Eng. J. Eibl
Karlsruhe University

Prof. Dr. Eng. M. Nassef
Cairo University

Prof. Dr. A. K. Abdel Khalik
Suez Canal University

Dr. Eng. M. El. Ghazouly
Suez Canal University

Faculty of Egineering
Suez Canal University
(1995)

بسم الله الرحمن الرحيم

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.

أ . د . محمود السيد نصر – كلية الهندسة – جامعة القاهرة

أ . د . حسن محمد حسنى – كلية الهندسة – جامعة حلوان

أ . د . محمد العدوى ناصف – كلية الهندسة – جامعة القاهرة

أ . د . أحمد كمال عبد الخالق – كلية الهندسة – جامعة قناة السويس

Acknowledgement

First, I would like to forward my thanks to Allah Almighty for His great help and guidance to get this work done, determination, and strength needed to complete my doctorate degree.

*I would like to express my thanks and sincere gratitude to **Prof. Dr. Eng. Mohammed El-Adawy Nassef** who in spite of his limited time, kindly supervised this thesis. I am particulary thanking him for having listened to all my ideas and analysis.*

*I thank from my heart **Prof. Dr. Eng. Josef Eibl** for having corrected and reoriented me at the right time. I am thanking him for his supervision of this thesis at his Institute in Germany, he completely helped me all the time. I am deeply indebted to him for his planning as well as for his encouragement and constructive criticism through out the compilation of this thesis.*

*I would like also to acknowledge the considerable contributions by **Prof. Dr. Eng. Ahmed Kamal Abdel Khalik** for his valuable suggestions during working on my thesis at Cairo. I wish to express my sincere gratitude to **Dr. Eng. Mohammed El-Ghazouly** for his encouragement and contribution.*

Finally, I would like to express my unlimited gratidude to my parents who raised me on the basic principals of morality and goodness, and my wife for her support, patience, and perseverance during my study in Germany.

CONTENTS

Chapter 3 NUMERICAL APPROACH OF BOND MODELLING

Chapter 4 GENERAL CONSTITUTIVE MODELS FOR CONCRETE AND STEEL

Chapter 7 RESULTS AND DISSCUSION

Chapter 8 SUMMARY AND CONCLUSION

PART III APPENDICES

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);
$E_c = \sigma_c/\varepsilon_c$	=	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 infailure 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 cylider;
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}, φ_{ij}, ψ_{ij}	=	geometry, traction and displacement variation according to interpolation functions respectively, Eq. (A.20);
x_j, 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 $\theta = 0°$, and $\theta = 60°$, 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;
$\Delta_2^{0,n}$	=	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;
$\delta_{\varepsilon ij}$	=	virtual strain increment, Eq. (3.32);
$\varepsilon_1, \varepsilon_2, \varepsilon_3$	=	principal strains ($\varepsilon_1 \geq \varepsilon_2 \geq \varepsilon_3$, 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 streses;
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;
υ_e	=	the effective slip, Eq. (A.13);
υ_f	=	secant value of Poisson's ratio at failure, Eq. (5.9);
υ_i	=	initial Poisson's ratio, Eq. (5.9);
υ_s	=	secant value of Poisson's ratio, Eq. (5.9);
Φ	=	diameter of steel bar;
ψ	=	theoretical or experimental constant;
φ	=	theoretiacl 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;
[ε]	=	element strain matrix;
[σ]	=	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;
{ε}	=	vector for strain;
{σ}	=	vector for dtress;
{ΔR}	=	the load increment;
{ΔU}	=	the displacement increment;
{$\Delta\varepsilon$}	=	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 derformed 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 develope in the surrounding concrete starting from the top of the ribs surface of the bar.