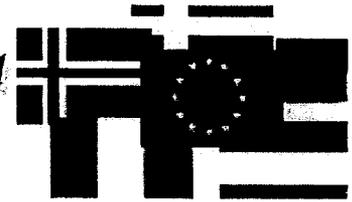


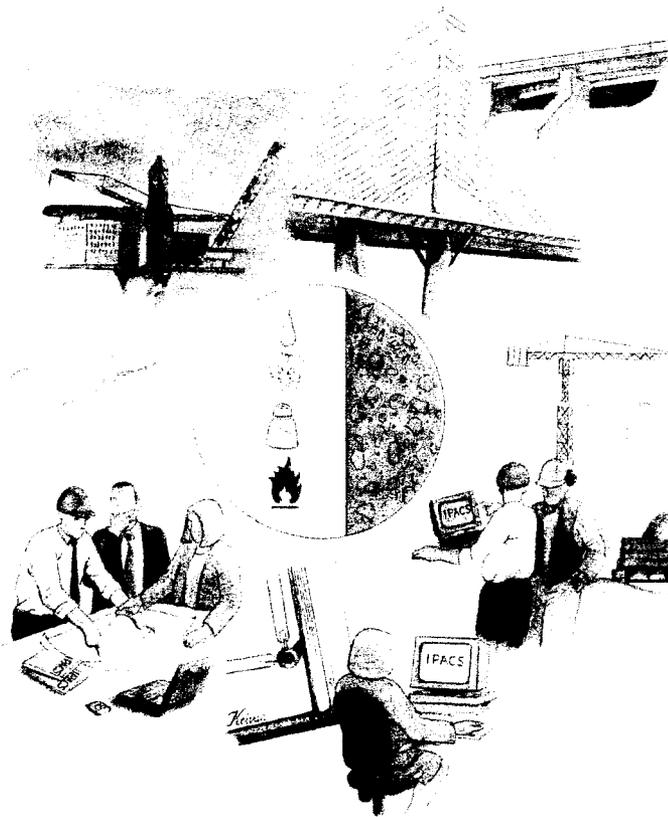


*Improved Production of Advanced
Concrete Structures -IPACS*



REPORT BE96-3843/2001:59-1

Engineering Models for the Assessment of Restraint of Slabs by Soil and Piles During Early Age of Concrete



*Ferdinand S. Rostásy¹
Alexander-W. Gutsch³*

Matias Krauß²

*1,2,3
Institut für Baustoffe, Massivbau und Brandschutz,
Technische Universität Braunschweig*

Published by
Department of Civil & Mining Engineering
Division of Structural Engineering

ISBN 91 - 89580 - 59 - 1 • 2001:59-1 • SE



CONTENTS

PREFACE	1
1 INTRODUCTION	2
1.1 PARAMETERS OF RESTRAINT AND STIFFNESS.....	2
1.2 FREE DEFORMATIONS AND RESTRAINT	2
1.3 BASIC APPROACHES FOR THE DESCRIPTION OF INTERACTION.....	3
2 GEOMETRY OF SLAB ON SOIL AND FREE DEFORMATIONS	5
3 MECHANICAL BEHAVIOUR OF SOIL WITH RESPECT TO INTERACTION	6
3.1 PROBLEM AND INTENTIONS	6
3.2 SHEAR BEHAVIOUR OF SOILS	6
3.3 MODEL OF SHEAR-FRICTION INTERACTION FOR NON-COHESIVE SOIL.....	9
3.4 MODEL OF SHEAR FRICTION INTERACTION FOR COHESIVE SOIL.....	11
3.5 MODELS OF ELASTIC BEDDING OF SLAB ON SOIL	12
4 ENGINEERING MODELS FOR AXIAL RESTRAINT.....	17
4.1 INTENTIONS AND MODELS	17
4.2 DISTRIBUTION OF SHEAR STRESS, DISPLACEMENT AND NORMAL FORCE.....	17
4.3 MAGNITUDE OF MEAN FREE STRAIN.....	19
4.4 AXIAL RESTRAINT OF SLAB DUE TO ELASTIC INTERACTION WITH SOIL IN HALF SPACE....	21
4.4.1 <i>Three layer model - TLM</i>	21
4.4.2 <i>Restraint forces and restraint factor</i>	22
4.5 DETERMINATION OF LENGTH ℓ_E AND ℓ_F	24
4.6 DEPENDENCE OF RESTRAINT FORCE ON FREE STRAIN AND LOCATION.....	28
4.7 MITIGATION OF RESTRAINT BY SLIDING LAYERS	29
4.8 SUMMARY	30
5 ENGINEERING MODELS FOR BENDING AND COMBINED RESTRAINT.....	32
5.1 PROBLEM AND INTENTIONS	32
5.2 THREE-LAYER MODEL OF AXIAL AND BENDING RESTRAINT TLM	33
5.2.1 <i>Assumptions</i>	33
5.2.2 <i>Stiffness of Equivalent Soil Layer</i>	34
5.2.3 <i>Assessment of Restraint Actions</i>	35
5.2.4 <i>Degrees of Restraint</i>	37
5.2.5 <i>Influence of Age of Concrete and Time under Stress on Restraint Actions</i>	39

5.2.5.1	Age dependence of degrees of restraint	39
5.2.5.2	Age-adjusted effective modulus and relaxation	40
5.2.5.3	Influence of age of concrete and time under stress on axial restraint	41
5.2.5.4	Influence of age of concrete and time under stress on bending restraint	43
5.3	FINITE STRIP METHOD WITH AGING AND VISCO-ELASTIC CONCRETE	44
5.3.1	<i>Introductory remarks</i>	44
5.3.2	<i>Mean free deformations ϵ_{0m} and κ_0</i>	45
5.3.3	<i>Compatibility and equilibrium within slab</i>	48
5.3.4	<i>Interaction with soil</i>	50
5.4	ASSESSMENT OF THERMAL RESTRAINT WITH THE SUBGRADE REACTION MODULUS METHOD	
	51	
5.4.1	<i>Introductory remarks</i>	51
5.4.2	<i>Elastic length</i>	51
5.4.3	<i>Degree of bending restraint</i>	52
5.4.4	<i>Restraint caused by friction moment</i>	54
5.4.5	<i>Consideration of age and relaxation of concrete in the SRMM</i>	55
5.5	COMPARISON BETWEEN TLM AND SRMM	56
5.6	DEGREES OF RESTRAINT OF JSCE AND COMPARISON WITH TLM.....	57
5.7	SUMMARY	61
6	NUMERICAL STUDY.....	62
6.1	SCOPE	62
6.2	TEMPERATURE IN SLABS	62
6.2.1	<i>Distributions and maximum values</i>	62
6.2.2	<i>Temperature differences</i>	64
6.3	DEGREES OF RESTRAINT, MECHANICAL PROPERTIES AND FREE THERMAL DEFORMATIONS	
	65	
6.3.1	<i>Degrees of restraint acc. TLM</i>	65
6.3.2	<i>Comparison of degrees of restraint for different approaches</i>	66
6.3.3	<i>Some mechanical properties</i>	67
6.3.4	<i>Free Thermal Deformations</i>	67
6.4	STRESSES	68
6.4.1	<i>Dependence of stress on age and elevation</i>	68
6.4.2	<i>Magnitude of stresses dependent on material model</i>	69
6.4.3	<i>Influence of season of cast and slab thickness</i>	70
6.5	RESTRAINT ACTIONS	70
6.5.1	<i>Influence of material model</i>	70

6.5.2	<i>Influence of thickness of slab</i>	72
6.5.3	<i>Influence of heat liberation</i>	72
6.6	NON-LINEAR STRESSES VS. STRESSES ACC. TO BEAM THEORY AND CRACK RISK.....	73
6.6.1	<i>Comparison of stresses</i>	73
6.6.2	<i>Crack Ratio</i>	74
6.7	SUMMARY	75
7	RESTRAINT OF SLABS BY PILES	76
7.1	PROBLEM AND SCOPE	76
7.2	DEFORMATIONS AT PILE'S HEAD	76
7.2.1	<i>Horizontal subgrade reaction modulus</i>	76
7.2.2	<i>Relationships of Displacement and Rotation</i>	78
7.3	RESTRAINT CAUSED BY A GROUP OF PILES.....	81
7.3.1	<i>Axial restraint force (example)</i>	81
7.3.2	<i>End moment of fixed pile</i>	82
7.3.3	<i>Influences on restraint by piles</i>	83
7.3.4	<i>Parameters of restraint and degree of restraint</i>	83
7.3.5	<i>Combined restraint by piles and shear-friction</i>	86
7.3.6	<i>Additional restraint effects</i>	87
7.4	ASSESSMENT OF FORCE-DISPLACEMENT RESPONSE BY IN-SITU PILE TESTS-CASE STUDY	89
7.5	SUMMARY	91
8	CONCLUSIONS AND RECOMMENDATIONS	93
9	LITERATURE	95
	APPENDICES	98
A	DERIVATION OF RELATIONSHIPS FOR THE METHOD OF IBMB	98
A.1	EFFECTIVE CENTER OF CROSS-SECTION	98
A.2	FREE MEAN STRAIN	99
A.3	FREE CURVATURE.....	99
B	MATERIAL MODELS	102
B.1	EQUIVALENT CONCRETE AGE	102
B.2	DEGREE OF HYDRATION	102
B.3	DEVELOPMENT OF AXIAL TENSILE STRENGTH, COMPRESSIVE STRENGTH, MODULUS OF ELASTICITY	102
B.4	STRESS-STRAIN-LINE UNDER TENSION	103

B.4.1	<i>Basic model</i>	103
B.4.2	<i>Stress-strain line for the concrete in the structure</i>	105
B.4.3	<i>Tensile failure criterion</i>	107
B.4.4	<i>Stress-strain-line under compression</i>	108
B.4.5	<i>De- and reloading under tension and compression</i>	108
B.4.6	<i>Creep and relaxation</i>	109
B.4.6.1	Creep function	109
B.4.6.2	Relaxation function	109
B.4.6.3	Data and parameters	109
C	DATA FOR COMPUTATIONS AND EXAMPLES	110
C.1	CONCRETES.....	110
C.2	GEOMETRY	110
C.3	FIELDS OF TEMPERATURE.....	111
C.4	FIELDS OF STRESS AND RESTRAINT ACTIONS	112
C.4.1	<i>Stress fields</i>	112
C.4.2	<i>Numerical Examples</i>	112
C.4.2.1	CO1, 1 m, Spring/Fall ($T_{c0} = 15^{\circ}\text{C}$)	113
C.4.2.2	CO1, 1 m, Summer ($T_{c0} = 25^{\circ}\text{C}$)	117
C.4.2.3	CO1, 1 m, Winter ($T_{c0} = 10^{\circ}\text{C}$)	121
C.4.2.4	CO1, 2 m, Spring/Fall ($T_{c0} = 15^{\circ}\text{C}$)	124
C.4.2.5	CO1, 3 m, Spring/Fall ($T = 15^{\circ}\text{C}$).....	127
C.4.2.6	CO23, 1 m, Spring/Fall ($T = 15^{\circ}\text{C}$).....	130
C.4.2.7	Comparisons	133