



Herausgeber:  
Professor Dr.-Ing. H.-G. Kempfert

---

**Lateral spreading  
in basal reinforced embankments  
supported by pile-like elements**

**Gourge Samir Fahmi Farag**

---

**Heft 20**

März 2008

---

**Table of contents**

<b>1 Introduction .....</b>	<b>1</b>
1.1 Statement of the problem.....	1
1.2 Objectives and methodology .....	2
<b>2 State of the art .....</b>	<b>5</b>
2.1 General.....	5
2.2 Lateral forces in embankments .....	5
2.3 Spreading stresses at the embankment base.....	7
2.3.1 Magnitude and distribution of shear stresses due to spreading.....	7
2.3.2 Horizontal deformations due to shear stresses at the embankment base .....	8
2.4 Spreading stresses in the reinforcement.....	10
2.4.1 Embankment with pile-like elements .....	10
2.4.2 Embankment without pile-like elements .....	19
2.5 Pile elements .....	21
2.5.1 General.....	21
2.5.2 Stresses and displacements of piles .....	21
2.6 summary.....	23
<b>3 Conception and results of model tests .....</b>	<b>25</b>
3.1 General.....	25
3.2 Model theory and basics of the own model tests .....	25
3.3 Test materials .....	26
3.3.1 Bearing elements.....	26
3.3.2 Model sand.....	27
3.3.3 Geosynthetics reinforcement .....	28
3.3.4 Soft layer.....	31
3.4 Measuring procedures.....	31
3.4.1 General.....	31
3.4.2 Horizontal force measurement.....	31
3.4.3 Strain in geosynthetics (Strain gauges, DMS) .....	32
3.4.4 Stress measurement.....	33
3.4.5 Displacement measurement .....	34
3.5 Model test variations and extent .....	34
3.6 Model preparation and dimensions.....	36
3.6.1 Model building and external loading .....	36
3.6.2 Model dimensions.....	38
3.7 Representation and illustration of the test results .....	39

3.7.1 Evaluation of shear stresses due to own weight at the base of homogeneous sand embankment under slope variations.....	39
3.7.2 Stress and deformations in the reference test MT1, homogeneous sand embankment .....	42
3.7.3 Effect of soft underground without geogrid reinforcement .....	44
3.7.4 Comparing the test results of the unreinforced Embankment.....	47
3.7.5 Effect of soft underground with geogrid reinforcement .....	47
3.8 Summary .....	54
<b>4 Verification of the model test-results.....</b>	<b>57</b>
4.1 General .....	57
4.2 Material parameters and constitutive relations .....	57
4.2.1 Constitutive relations of the embankment sand layer .....	57
4.2.2 Constitutive relations for the soft underground .....	60
4.2.3 Numerical formulation of soil/reinforcement interface .....	60
4.2.4 Constitutive relation for the pile-like elements.....	60
4.3 FE-Model geometry and boundary conditions .....	61
4.4 Verification of the reference test results with homogeneous sand MT1 .....	62
4.5 Verification of the model test results MT2, unreinforced embankment on soft underground .....	65
4.6 Verification of the model test results MT3, reinforced embankment on soft underground .....	66
4.6.1 Investigation of some in-situ strain results .....	67
4.7 Verification of the model test results MT4, unreinforced embankment on soft underground supported by pile-like elements.....	68
4.8 Verification of the model test results MT5, reinforced embankment on soft underground supported by pile-like elements.....	69
4.9 Evaluation of the results .....	71
<b>5 Parameter study .....</b>	<b>73</b>
5.1 Objectives and fundamentals of the parameter study .....	73
5.2 Pre-calculation steps .....	74
5.2.1 Studying the interface soil/reinforcement.....	74
5.3 Material properties .....	75
5.3.1 General.....	75
5.3.2 Geogrid reinforcement .....	75
5.3.3 Embankment fill .....	76
5.3.4 Underground layer .....	76
5.3.5 Pile-like supporting elements.....	77
5.4 External load.....	78

5.5 Pre-calculation steps for the numerical analysis .....	78
5.5.1 General .....	78
5.5.2 Steps to build a membrane model by FEM .....	79
5.2.3 Steps to determine the force due to spreading effect by FEM .....	80
5.6 Model dimension and variation matrix .....	81
5.7 Results of the numerical parameter study .....	84
5.7.1 General .....	84
5.7.2 Results of tensile forces under variation of the embankment height .....	85
5.7.3 Results of tensile forces under variation of the underground stiffness .....	90
5.7.4 Results of tensile forces under variation of the embankment slope .....	94
5.7.5 Results of tensile forces under variation of the geogrid reinforcement layers .....	97
5.8 Summary and evaluation of the numerical parameter study .....	102
5.9 Comparing the FEM-results with some available analytical methods .....	103
5.9.1 Objectives .....	103
5.9.2 Determination of the membrane forces in reinforcement due to arching effect .....	104
5.9.3 Analytical methods to determine the total forces applied in reinforcement .....	105
5.10 Summary of the analytical calculation .....	110
<b>6 Development of a modified analytical method .....</b>	<b>111</b>
6.1 General .....	111
6.2 Empirical modification of the sliding soil wedge and the spreading force .....	112
6.2.1 Horizontal active earth pressure force due to own weight, $E_{agh}$ .....	113
6.2.2 Horizontal active earth pressure force due to external load $E_{aph}$ .....	114
6.2.3 Determination of the tensile force in reinforcement and estimation of a reference parameter-model .....	115
6.3 Determination of the earth pressure forces in the case of piled embankment .....	116
6.3.1 Determination of the angle $\theta$ according to the results of the parameter study .....	116
6.3.2 Derivation of the factors $f_{Es}$ and $f_{\beta}$ .....	118
6.4 Comparison of the modified analytical spreading forces with FEM-results and <i>EBGEO (2007)</i> .....	121
6.4.1 Spreading forces under variation of the underground stiffness .....	122
6.4.2 Spreading forces under variation of the embankment slope .....	124
6.5 Comparison of the modified analytical total forces with FEM-results and <i>EBGEO (2007)</i> .....	126
6.5.1 Determination of the membrane force .....	126
6.5.2 Total tensile force in reinforcement under variation of the underground stiffness .....	127
6.5.3 Total tensile force in reinforcement under variation of the embankment slope .....	130
6.5.4 Spreading effect on the pile elements .....	132

6.6 Summary to the modified method .....	133
<b>7 Summary .....</b>	<b>135</b>
<b>Zusammenfassung.....</b>	<b>140</b>
<b>8 References .....</b>	<b>147</b>

**Appendices**

Appendix A: Earth pressure forces

Appendix B: Model test results

Appendix C: Verification of the model test-results

Appendix D: Parameter study

Appendix E: List of frequently used symbols and expressions