

Table of Contents

List of Figures.....	ii
List of Tables.....	iii
Introduction	1
Seepage through Soil.....	1
Darcy's Law	1
Heads, Pore Water Pressures, and Hydraulic Gradients	2
Erosion and Piping	3
Heave.....	5
Creep Ratios	5
Bligh's Creep Ratio	5
Lane's Weighted Creep Ratio	6
Use of Creep Ratios.....	7
Methods of Analyzing Seepage.....	8
Flow Nets	8
Blanket Theory.....	10
Finite Element Method	11
Rational Methods of Evaluating Safety Against Erosion and Piping.....	15
Seepage Severity.....	15
Seepage Severity Example.....	16
Vertical Seepage – Effective Stress.....	17
Vertical Seepage – Total Stress.....	17
Method 1.....	19
Method 2.....	20
Vertical Seepage Examples.....	21

Seepage Out of a Slope – Effective Stress	23
Factor of Safety Against Heave	25
Schmertmann’s Method for Analysis of Piping	25
Conclusions.....	26
References.....	27
Appendix A.....	29
Appendix B.....	35

List of Figures

Figure 1. Pressure head, elevation head, and hydraulic gradient.....	2
Figure 2. Flow net for pervious levee on impervious foundation showing near-horizontal exit flow.....	3
Figure 3. Flow net drawn for impervious levee on pervious foundation showing near-vertical exit flow.....	4
Figure 4. Example piping paths	4
Figure 5. Line of creep for Bligh’s creep ratio	6
Figure 6. Flow net for a clay levee on a sand foundation.....	9
Figure 7. Basic geometry accommodated by blanket theory (from DIVR 1110-1-400, 1998).....	11
Figure 8. Example for evaluation of exit gradients (not to scale).	12
Figure 9. Effective stress and total stress analyses of erosion due to vertical seepage	18
Figure 10. Seepage out of a slope, and initiation of erosion as surface instability	23
Figure A1. Slide results – 1 element per foot using six-node triangular elements	29
Figure A2. Slide results – 2 elements per foot using six-node triangular elements.....	30
Figure A3. Slide results – 4 elements per foot using six-node triangular elements.....	31
Figure A4. SEEP/W results – 1 element per foot using six-node triangular elements	32

Figure A5. SEEP/W results – 2 elements per foot using six-node triangular elements	33
Figure A6. SEEP/W results – 4 elements per foot using six-node triangular elements	34
Figure B1. Blanket theory equations for impervious blanket (from USACE 1956)	35
Figure B2. Blanket theory equations for Semi-pervious blanket (from USACE 1956)	36

List of Tables

Table 1. Minimum safe creep ratio factors (after Lane 1934)	7
Table 2. Effect of mesh density on point values of vertical hydraulic gradient for the Figure 8 example	13
Table 3. Effect of mesh density on average values of vertical hydraulic gradient for one foot distance below A for the Figure 8 example	13
Table 4. Proposed categories of seepage severity	15
Table 5. Results of seepage severity example	16