Theoretical Foundation Engineering

Braja M. Das

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To
My wife Janice
and
daughter Valerie

PREFACE

Theoretical Foundation Engineering is divided into five major chapters: Lateral Earth Pressure, Sheet Pile Walls, Bearing Capacity of Anchor Slabs and Helical Anchors, Ultimate Bearing Capacity of Shallow Foundations and Slope Stability. Many foundation engineering books now in print cover the above-mentioned topics which are directed toward providing a hands-on type of approach to design engineers. The goal of this book is somewhat different, in that it provides a state-of-the-art review of the advances made in understanding the behavior of earth-retaining and earth-supported structures. Most of the material is drawn from open literature, and a list of references is given at the end of each chapter. The text is liberally illustrated. To demonstrate the application of theoretical derivations, several worked-out problems are given in each chapter. In some instances, the final solutions to the problems under consideration are given, and detailed mathematical treatment has been deleted to keep the text within its scope and space limitations. It is my hope that this text will be useful to students, researchers, and practicing geotechnical engineers.

I am grateful to my wife Janice for typing the entire manuscript in camera-ready form. Several others have been extremely helpful during the preparation of the manuscript. Dr. Samuel P. Clemence, Professor and Chairman of the Department of Civil Engineering at Syracuse

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— **Braja M. Das**

El Paso, Texas

March, 1987

CONTENTS

Preface vii

CHAPTER 1 LATERAL EARTH PRESSURE 1

1.1 Introduction 1
1.2 At-Rest Earth Pressure 3
1.3 At-Rest Force and Resultant 7
1.4 Rankine Active Pressure (Rotation about Bottom of Wall) 13
1.5 Active Pressure with Wall Friction--Coulomb's Active Pressure Theory 23
1.6 Graphical Solutions for Coulomb's Active Force 29
1.7 Graphical Procedure for Coulomb's Active Force for a c-ϕ Soil Backfill 33
1.8 Active Earth Pressure for Backfill with Vertical Drain 35
1.9 Wall Rotation Required for Active Earth Pressure Condition 37
1.10 Active Force on Wall with Rotation about Top 38

1.10.1 Dubrova's Solution 40
1.10.2 Terzaghi's General Wedge Theory 43
1.10.3 Empirical Pressure Diagrams for Design of Braced Cuts 49

1.11 Active Earth Pressure for Lateral Translation of Wall 50
1.12 Rankine Passive Pressure (Rotation about the Bottom of the Wall) 56

	1.13	Passive Pressure with Wall Friction (Coulomb's Passive Pressure)	63
	1.14	Passive Pressure by Using Curved Failure Surface	65
	1.15	Other Solutions for Passive Pressure (Rotation about the Bottom)	70
	1.16	Dubrova's Method for Calculation of Passive Pressure Distribution	76
	1.17	Experimental Results for Passive Pressure	78
	1.18	Wall Rotation Required for Passive Earth Pressure Condition	80
	1.19	Stability of Slurry Trench Cuts in Saturated Clay	81
	1.20	Stability of Unsupported Axisymmetric Excavations in Saturated Clay	84
	1.21	Lateral Earth Pressure on Linings of Circular Shafts in Sand	86
	1.22	Lateral Earth Pressure on Linings of Circular Shafts in Saturated Clay	96
	References		100
CHAPTER 2	SHEET PILE WALLS		103
	2.1	Introduction	103
	2.2	Types of Sheet Pile Walls	104
	2.3	Anchors in Sheet Pile Wall Design	108
	2.4	Construction Methods for Sheet Pile Walls	109
	2.5	Lateral Earth Pressure--General Considerations	111
	2.6	Cantilever Sheet Pile Walls Penetrating into Sand	114
	2.7	Cantilever Sheet Pile Walls Penetrating into Clay Layer	126
	2.8	Anchored Sheet Pile Wall Penetrating into Sand--Free Earth Support Method	131
	2.9	Lateral Earth Pressure Due to Strip Load Near a Wall	133
	2.10	Rowe's Moment Reduction Method	135
	2.11	Anchored Sheet Pile Wall with Sloping Dredge Line	140
	2.12	Computational Pressure Diagram Method	141

2.13 Anchored Sheet Pile Wall Penetrating into Clay--Free Earth Support Method 146
2.14 Fixed Earth Support Method for Anchored Sheet Pile Walls 150
2.15 Other Observations on Anchored Sheet Pile Wall Design 156
References 158

CHAPTER 3 HOLDING CAPACITY OF ANCHOR SLABS AND HELICAL ANCHORS 160
3.1 Introduction 160
3.2 Ultimate Holding Capacity of Shallow Vertical Anchor Slabs in Sand 160
3.2.1 Teng's Procedure for Shallow Anchors 162
3.2.2 Ovesen and Stromann's Procedure for Shallow Anchors 164
3.2.3 Analysis of Shallow Anchors by Biarez, Boucraut, and Negre 170
3.2.4 Meyerhof's Theory 171
3.2.5 Neeley, Stuart, and Graham's Method 172
3.2.6 Load-Displacment Relationship for Shallow Vertical Anchors in Sand 174
3.2.7 Deep Vertical Anchors in Sand 177
3.2.8 Soil Friction Angle for Estimation of the Ultimate Anchor Capacity 179
3.3 Vertical Anchor Slabs in Clay 180
3.4 Uplift Capacity of Horizontal Anchors in Sand 183
3.5 Uplift Capacity of Horizontal Group Anchors 192
3.6 Uplift Capacity of Horizontal Group Anchors in Clay 194
3.7 Uplift Capacity of Helical Anchors 200
References 205

CHAPTER 4 ULTIMATE BEARING CAPACITY OF SHALLOW FOUNDATIONS 206

4.1 Introduction 206
4.2 Types of Bearing Capacity Failure 206
4.3 Terzaghi's Bearing Capacity Theory 210
4.4 Some Observations on Terzaghi's Bearing Capacity Theory 221
4.5 Meyerhof's Bearing Capacity Theory 224
4.6 General Bearing Capacity Equation 237
4.7 Other Solutions for Bearing Capacity Factors 241
4.8 Effect of Water Table 248
4.9 Bearing Capacity of Foundations on Anisotropic Soil Extending to a Great Depth 249
4.10 Ultimate Bearing Capacity Due to Vertical Eccentric Load 260
4.11 Foundations Supported by a Soil with a Rigid Rough Base at a Limited Depth 277
4.12 Bearing Capacity of Foundations on Slopes 283
4.13 Bearing Capacity of Foundations on Layered Soil 286
4.14 Continuous Foundation on Weak Clay with a Granular Trench 317
4.15 Shallow Foundation Above Voids 322
4.16 Interference of Shallow Continuous Foundation in Granular Soil 325
4.17 Foundation Settlement 330
References 339

CHAPTER 5 SLOPE STABILITY 342

5.1 Introduction 342
5.2 Factor of Safety--Definition 344
5.3 Stability of Finite Slopes (c-ϕ Soil)--Plane Failure Surface 346
5.4 Stability of Clay Slopes (ϕ=0 Condition) 350
5.5 Clay Slopes with Aniostropic Strength Properties (ϕ=0 Condition) 356
5.6 Stability of Slopes in Clay (ϕ=0 Condition) with c_u Increasing with Depth 361
5.7 Stability of Finite Slopes with c-ϕ Soils--Mass Procedure 365

5.7.1 Taylor's Friction Circle Method 366
5.7.2 Cousins' Stability Analysis (c-ϕ Soil) 375

5.8 Method of Slices 385
5.8.1 Ordinary Method of Slices 386
5.8.2 Bishop's Simplified Method of Slices 390
5.8.3 Bishop and Morgenstern's Method of Slices 391
5.8.4 Morgenstern's Method of Slices for Rapid Drawdown Condition 398
5.8.5 Spencer's Method of Slices 399

5.9 Limit Analysis Solutions for Slopes 413
5.10 Estimation of Ditch Safety by Using a Cycloidal Failure Surface 416
5.10.1 Calculation of the Side Slopes for Ditch with Deeper Cuts 422

References 424

APPENDIX A THE POLE METHOD FOR FINDING STRESSES FROM MOHR'S CIRCLE 426

APPENDIX B PROPERTIES OF LOGARITHMIC SPIRALS AND LOGARITHMIC SPIRAL SECTORS 429

APPENDIX C HELICAL ANCHORS 434

INDEX 436

CHAPTER 1
Lateral Earth Pressure

1.1 INTRODUCTION

In the construction and design of many structures, a thorough knowledge of the earth pressure to which these structures will be subjected is required. Important among these structures are retaining walls, sheet pile bulkheads, temporary sheathings for supporting vertical or near-vertical cuts in soils, and earth anchors. The earth pressure to which the above types of retaining structures are subjected is commonly referred to as *lateral earth pressure*. The lateral earth pressure on an earth-retaining structure can generally be divided into three major categories. They are

1. Earth pressure at rest
2. Active earth pressure
3. Passive earth pressure

The above-stated earth pressure conditions can be explained by means of Fig. 1.1, in which *AB* is a retaining wall supporting soil at its left. The backfill soil has a horizontal ground surface. If the retaining wall does not yield at all from its original position, the horizontal lateral earth pressure at any depth to which the wall will be subjected is called the *lateral earth pressure at-rest*. The total force per unit length of the wall is equal to P_o. This type of condition is shown in Fig. 1.1a. However, if the wall tends to *yield away* from the soil sufficiently to create a plastic state of equilibrium in the soil mass located immediately behind it, the lateral earth pressure at any depth to which it will be subjected is called the *active earth pressure*. The conditions for development of active earth pressure are shown in Fig. 1.1b, c, and d. This can happen by *rotation of the wall* about its bottom or top, and also by lateral *translation* of the wall away from the

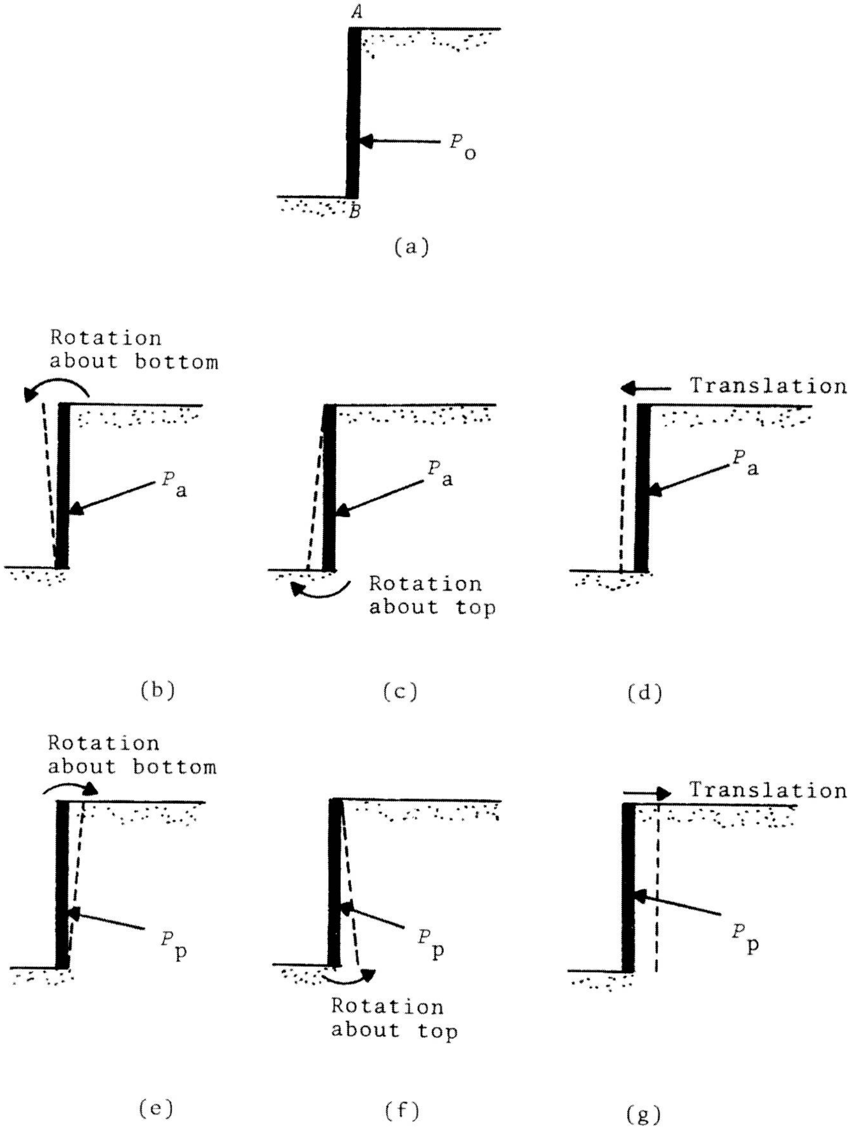

Figure 1.1. Definition of (a) Earth pressure at rest; (b), (c), and (d) Active earth pressure; (e), (f), and (g) Passive earth pressure.

backfill. The magnitude, direction, and the location of the resultant of the *active force* P_a per unit length of the wall will depend on several factors, such as the shear strength parameters of the backfill, profile of the top of the backfill, roughness of the wall and the mode of the wall movement.

Figure 1.1e, f, and g shows the condition where the wall yields into the soil mass located behind it by *rotation* about its bottom and top, and also by lateral *translation*. If the movement of the wall is sufficient to create a plastic state in the soil mass near it, failure will occur. This is referred to as the *passive state*. The lateral earth pressure on the wall at any given depth is called as the *passive earth pressure*. The magnitude, direction, and the location of the resultant of *passive force* will primarily depend on the same factors as listed above for the *active case*.

This chapter has been devoted to analyzing various lateral earth pressure theories presently available in literature. In all cases, it has been assumed that the shear strength of the soil can be defined by Mohr-Coulomb's failure criteria, or

$$s = p'\tan\phi + c \qquad (1.1)$$

where s = shear strength
p' = effective normal stress
ϕ = drained angle of friction
c = cohesion

AT-REST EARTH PRESSURE

1.2 AT-REST EARTH PRESSURE

As explained in the preceding section, the *at-rest* condition exists if a wall does not yield at all (that is, either away from the soil mass or toward the soil mass). Figure 1.2 shows a retaining wall with a horizontal backfill. At a depth z below the ground surface, the vertical and horizontal effective stresses are p_v' and p_h', respectively. The ratio of p_h' to p_v' is usually referred to as the *lateral earth pressure coefficient at-rest*, or

$$K_o = p_h'/p_v' \qquad (1.2)$$

where K_o = earth pressure coefficient at-rest

The most common and widely used relationship of K_o for design is that given by Jaky (1944), which is of the form

$$K_o = 1 \quad \sin\phi \qquad (1.3)$$

where ϕ = drained friction angle

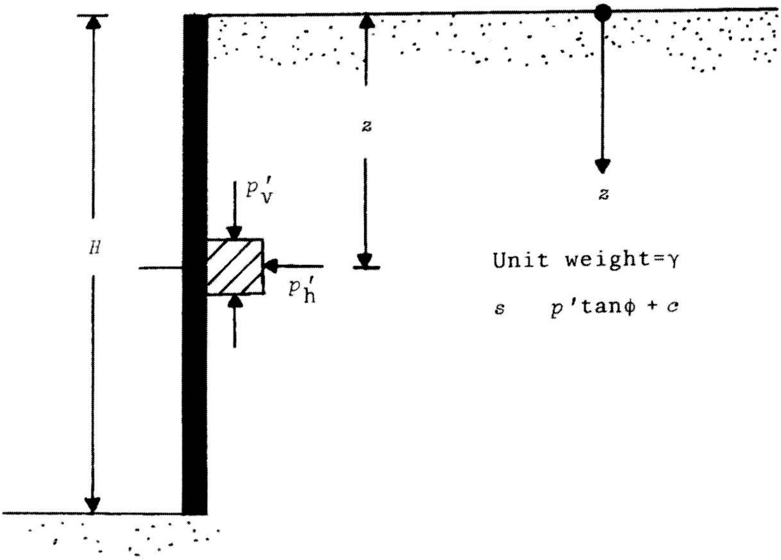

Figure 1.2. Definition of lateral earth pressure at-rest.

In recent times, it has been shown by several investigators that Eq. (1.3) is applicable only to normally consolidated loose soils. This fact can be explained by referring to Fig. 1.3, which shows a plot of p_h' against p_v'. Along the branch *OA* (initial loading), the soil is normally consolidated. Mayne and Kulhawy (1982) have analyzed the published results of about 121 soils. Based on their analysis they found that, for both sand and clayey soils, the best fit line from linear regressions analysis can be given as

$$K_{o(nc)} = 1 - 1.003\sin\phi \qquad (1.4)$$

where $K_{o(nc)}$ = at-rest earth pressure coefficient for normally consolidated soils

So it appears that the original Jaky equation is generally valid for all normally consolidated sands and clays. Brooker and Ireland (1965) have given the following relationships for normally consolidated clays

$$K_{o(nc)} \quad 0.4 + 0.007(PI) \quad \text{(for } PI \text{ between 0 and 40)} \qquad (1.5)$$

and

$$K_{o(nc)} \quad 0.64 + 0.001(PI) \quad \text{(for } PI \text{ between 40 and 80)} \qquad (1.6)$$