An 5930890



# Design of Shallow Foundations

Samuel E. French, Ph.D., P.E.



1801 Alexander Bell Drive Reston, Virginia 20191–4400

# CONTENTS

## PREFACE

TABLE OF CONVERSION FACTORS	1
PART I TYPES OF LOADS AND TYPES OF SOILS	
Chapter 1 Applications	
Shallow Foundations in Modern Construction	5
Common Types and Configurations of Buildings	
Common Types and Configurations of Foundations	
Common Soil Pressures and Settlements	
Standard Test Specifications	12
Useful Approximations	12
Chapter 2 Gravity Loads on Foundations	
General Categories of Loads on Structures	
Allowable Footing Pressures for Gravity Loads	15
Gravity Loads	16
Distribution of Gravity Loads to Foundations	20
Example Calculations of Gravity Loads on Footings	23
Combinations of Gravity Loads	26
Summary of Gravity Loads on Footings	
Review Questions	
Chapter 3 Lateral Loads on Foundations	
Types of Lateral Loads	21
Ctability and a Combined Loading	31
Stability under Combined Loading	
Wind Velocities and Stagnation Pressures	
Shape Factors for Wind Loads	37
Calculation of Base Shear due to Wind	39
Overturning Moment due to Wind	39
Earthquake Loads on Structures	
Seismic Risk Zones and Zone Factors	
Seismic Response of Building Systems	
Soil Profile Type for a Building Site	
Seismic Coefficient for a Structure	45
Calculation of Base Shear due to Earthquake	
Overturning Moment due to Earthquake	
Effect of Lateral Load on Footings of Rigid Frames	
Restoring Moment and Frictional Shear Resistance	54

Drift in a Rigid Frame	
Summary of Foundation Loads on a Rigid Frame	
Effect of Lateral Load on Foundations of Braced Frames	58
Drift in a Braced Frame	
Restoring Moment and Frictional Shear Resistance	59
Allowable Soil Pressures for a Braced Frame	
Summary of Foundation Loads for a Braced Frame	
Load Combinations for Final Design	65
Applications in Determination of Design Loads	66
Review Questions	
Chapter 4 Classifications and Properties of Soils	
Broad Soil Groupings	75
Response of a Soil to Foundation Loads	76
Geologic Origins of Soil	78
Soil Profiles and Soil Horizons	79
Grain Size and Distribution	Q1
Plasticity and Atterberg Limits	
Consistency and Textural Classification of Soils	04
Engineering Classification of Soils	
Index Properties of Soils	00
Review Questions	93
Chapter 5 Strength and Pressure Dispersion in Soils	
Democability Defeating Comments of the Solis	
Permeability, Effective Stress and Submergence	neni)
Vieasurement of the Shear Strength of Clave	105
Management of the Character of Clays	105
Measurement of the Shear Strength of Sands	105
Measurement of the Shear Strength of Sands The Coulomb Equation for the Strength of Soils	105
Measurement of the Shear Strength of Sands  The Coulomb Equation for the Strength of Soils  Dispersion of Load into a Soil Mass	105 108 113 122
Measurement of the Shear Strength of Sands The Coulomb Equation for the Strength of Soils Dispersion of Load into a Soil Mass Approximate Dispersion of Load into a Soil Mass	105 108 113 122 122
Measurement of the Shear Strength of Sands  The Coulomb Equation for the Strength of Soils  Dispersion of Load into a Soil Mass  Approximate Dispersion of Load into a Soil Mass  Pressure Dispersion through Underlying Strata.	
Measurement of the Shear Strength of Sands  The Coulomb Equation for the Strength of Soils  Dispersion of Load into a Soil Mass  Approximate Dispersion of Load into a Soil Mass  Pressure Dispersion through Underlying Strata  At-Rest Pressures in a Soil Mass	
Measurement of the Shear Strength of Sands  The Coulomb Equation for the Strength of Soils  Dispersion of Load into a Soil Mass  Approximate Dispersion of Load into a Soil Mass  Pressure Dispersion through Underlying Strata  At-Rest Pressures in a Soil Mass  In Situ Properties of Soils	
Measurement of the Shear Strength of Sands  The Coulomb Equation for the Strength of Soils  Dispersion of Load into a Soil Mass  Approximate Dispersion of Load into a Soil Mass  Pressure Dispersion through Underlying Strata  At-Rest Pressures in a Soil Mass	
Measurement of the Shear Strength of Sands The Coulomb Equation for the Strength of Soils Dispersion of Load into a Soil Mass Approximate Dispersion of Load into a Soil Mass Pressure Dispersion through Underlying Strata At-Rest Pressures in a Soil Mass In Situ Properties of Soils Review Questions  Chapter 6 Calculation of Allowable Pressures	
Measurement of the Shear Strength of Sands  The Coulomb Equation for the Strength of Soils  Dispersion of Load into a Soil Mass  Approximate Dispersion of Load into a Soil Mass  Pressure Dispersion through Underlying Strata  At-Rest Pressures in a Soil Mass  In Situ Properties of Soils  Review Questions  Chapter 6 Calculation of Allowable Pressures  Levels of Accuracy of the Failure Analysis	
Measurement of the Shear Strength of Sands The Coulomb Equation for the Strength of Soils Dispersion of Load into a Soil Mass Approximate Dispersion of Load into a Soil Mass Pressure Dispersion through Underlying Strata At-Rest Pressures in a Soil Mass In Situ Properties of Soils Review Questions  Chapter 6 Calculation of Allowable Pressures Levels of Accuracy of the Failure Analysis Ultimate Shear Failure in a Soil Mass	
Measurement of the Shear Strength of Sands The Coulomb Equation for the Strength of Soils Dispersion of Load into a Soil Mass Approximate Dispersion of Load into a Soil Mass Pressure Dispersion through Underlying Strata At-Rest Pressures in a Soil Mass In Situ Properties of Soils Review Questions  Chapter 6 Calculation of Allowable Pressures Levels of Accuracy of the Failure Analysis Ultimate Shear Failure in a Soil Mass Allowable Bearing Strength of a Soil Mass	
Measurement of the Shear Strength of Sands The Coulomb Equation for the Strength of Soils Dispersion of Load into a Soil Mass Approximate Dispersion of Load into a Soil Mass Pressure Dispersion through Underlying Strata At-Rest Pressures in a Soil Mass In Situ Properties of Soils Review Questions  Chapter 6 Calculation of Allowable Pressures Levels of Accuracy of the Failure Analysis Ultimate Shear Failure in a Soil Mass Allowable Bearing Strength of a Soil Mass Corrections for Shape of Footings	
Measurement of the Shear Strength of Sands The Coulomb Equation for the Strength of Soils Dispersion of Load into a Soil Mass Approximate Dispersion of Load into a Soil Mass Pressure Dispersion through Underlying Strata At-Rest Pressures in a Soil Mass In Situ Properties of Soils Review Questions  Chapter 6 Calculation of Allowable Pressures Levels of Accuracy of the Failure Analysis Ultimate Shear Failure in a Soil Mass	

		161
	Corrections for Lateral Loads	161
	Common Factors of Safety in Soils	
	Use of a Reference Footing in Strength Calculations	
	Applications in Calculating Bearing Capacity	
	Review Questions	173
(	Chapter 7 Settlement of Foundations in a Soil Mass	
	Consolidation and Settlement in Clays	181
	Degree of Consolidation	183
	Overconsolidated Clay	186
	The Consolidation Test for Clay Soils	188
	Comparative Time-Consolidation Relationships	193
	Fragmentation and Settlement in Sands	201
	Review Questions	203
(	Chapter 8 Calculation of Settlements	
	Differential Settlements	207
	Reliability of Settlement Calculations	207
	Use of a Reference Footing in Settlement Calculations	
	Settlement Calculations in Normally Consolidated Clays	213
	Settlement Calculations in Overconsolidated Clays	223
	Settlement Calculations in Sands	234
	Modulus of Subgrade Reaction	
	Comparison of Response of Clays and Sands to Load	240
	Review Questions	
PAR	ET III DESIGN OF SHALLOW FOUNDATIONS ON A SOIL MAS	
		S
	Chapter 9 Effects of Soil-Structure Interaction	
	Chapter 9 Effects of Soil-Structure Interaction Summary of Allowable Soil Pressures	251
	Chapter 9 Effects of Soil-Structure Interaction  Summary of Allowable Soil Pressures  Estimated Pressure-Settlement Relationships	251
	Chapter 9 Effects of Soil-Structure Interaction  Summary of Allowable Soil Pressures  Estimated Pressure-Settlement Relationships  Effects of Structural Design on Foundation Design	251 254
	Chapter 9 Effects of Soil-Structure Interaction  Summary of Allowable Soil Pressures  Estimated Pressure-Settlement Relationships  Effects of Structural Design on Foundation Design  Footings with Vertical Load Only	251 254 256
	Chapter 9 Effects of Soil-Structure Interaction  Summary of Allowable Soil Pressures	251 254 256 256
	Chapter 9 Effects of Soil-Structure Interaction  Summary of Allowable Soil Pressures	251 254 256 256
	Chapter 9 Effects of Soil-Structure Interaction  Summary of Allowable Soil Pressures  Estimated Pressure-Settlement Relationships  Effects of Structural Design on Foundation Design  Footings with Vertical Load Only	251 254 256 257 259
	Chapter 9 Effects of Soil-Structure Interaction  Summary of Allowable Soil Pressures	251 254 256 257 259 263
	Chapter 9 Effects of Soil-Structure Interaction  Summary of Allowable Soil Pressures  Estimated Pressure-Settlement Relationships  Effects of Structural Design on Foundation Design  Footings with Vertical Load Only  Effects of Column Moments on Footing Rotations  Effects of Footing Rotations on Soil Pressure  Generalization of Effects of Rotations  Attachment of Columns to Footings	251 254 256 257 259 263
	Chapter 9 Effects of Soil-Structure Interaction  Summary of Allowable Soil Pressures	251 254 256 257 259 263 266
	Summary of Allowable Soil Pressures	251 254 256 257 263 266 268 268
	Summary of Allowable Soil Pressures	251 254 256 257 269 268 268 269

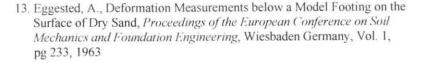
...269

..277 ..279 ...281

Chapter 10 Comparative Selection of Footing Sizes	
Interaction within a Group of Footings	.285
Relative Settlements between Footings	.286
Applications in Selecting Footing Sizes	.287
Effects of Close Proximity	.293
Effects of Unequal Loads	.296
Effects of Intermixed Footing Types	.298
Effects of Adjacent Excavations	
Review Questions	
PART IV RELATED TOPICS IN FOUNDATION SYSTEMS	
Chapter 11 Other Topics in Foundation Design	
Special Design Conditions	
Combined Footings	
Lateral Friction Loads on Footings	.319
Foundations for Stucco or Decorative Masonry	
Unreinforced Foundations	
Rubble or Masonry Foundations	
Treated Timber Foundations	
Foundations on Expansive Clays	
Review Questions	. 332
Chapter 12 Field Tests and the Soils Report	
Initiation of a Soils Investigation	335
Preliminary Assessment of Site	
Scope of the Site Investigation	
Field Sampling and Testing	348
Field Load-Settlement Tests	354
Common Laboratory Tests	.357
The Soils Report.	.358
Review Questions	. 360
References	.365
Index	.369

## REFERENCES

- Atterberg, A., Die Plastizat der Tone, Internationale Mitteilungen fur Bodenkunde, Vol.I (1911), pp. 10-43
- 2. ACI Committee 318-89, Building Code Requirements for Reinforced Concrete, American Concrete Institute, Detroit, Mich., 1989
- American Society of Civil Engineers, Subsurface Investigation for Design and Construction of Buildings, ASCE manual of Engineering Practice 56, ASCE, New York, 1962
- American Society of Civil Engineers Standard 7-93, Minimum Design loads for Buildings and other Structures, ASCE, New York, 1994
- 5. Bazaraa, A., Use of the Standard Penetration Test for Estimating Settlements of Shallow Foundations on Sand, Ph.D. Thesis, University of Illinois, 1967
- 6. Boussinesq, M. J., Application des Potentiels, a l'Etude de l'Equilibre et du mouvement des Solides Elastiques, Gauthier-Villars, Paris, 1885
- Brinch Hansen, J., A General Formula for Bearing Capacity, Bulletin No. 11, Danish Geotechnical Institute, Copenhagen, 1961
- 8. Brinch Hansen, J., A revised and Extended Formula for Bearing Capacity, Bulletin No. 28, Danish Geotechnical Institute, Copenhagen, 1970
- Casagrande, A., Determination of the Preconsolidation Load and its Practical Significance, Proceedings, First International conference on Soil Mechanics and Foundation Engineering, Cambridge, Mass., Vol.3 (1936), pp.60-64
- 10. Casagrande, A., Classification and Identification of Soils, *Transactions of the American Society of Civil Engineers*, (1948), pp. 901-902
- 11. Chen, W. F., Limit Analysis and Soil Plasticity, Elsevier, Amsterdam, 1975
- Das, B.M., Principles of Foundation Engineering, 3rd ed., PWS Publishing Company, Boston, Mass, 1995



- Fang, Hsai-Yang, (Ed.), Foundation Engineering Handbook, Van Nostrand Reinhold, New York, 1991
- French, S.E., Fundamentals of Structural Analysis, West Publishing Company, St. Paul, Minn., 1995
- 16. General Services Administration, Structural Engineering, in *GSA Handbook*, PBS-P-3475.1B, GSA, Washington, D.C.
- Hvorslev, M.J., Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes, Waterways Experiment Station, Vicksburg, Mississippi, 1949
- Hough, B. K., Basic Soils Engineering, 2nd ed., Ronald Press, New York, 1957
- Holtz, Robert D., Pressure Distribution and Settlement of Shallow Foundations, in *Foundation Engineering Handbook*, Winterkorn, H.F., and H.Y. Fang, Eds., Van Nostrand Reinhold, New York, 1975, Chapter 3.
- Huntington, W.C., and Mickadeit, R.E., Building Construction Materials and Types of of Construction, 5th ed., John Wiley, New York, 1981
- 21. International Conference of Building Officials, *Uniform Building Code*, ICBO, Whittier, Calif., 1994
- 22. Ingra, T.S., and Beacher, G.B., Uncertainty in Bearing Capacity of Sands, ASCE Journal of Geotechnical Engineering, 109, No. 7, pp. 899-914, 1983
- 23. Merritt, F. S. (ed.), Building Design and Construction Handbook, 5th ed., McGraw Hill, New York, 1994
- Meyerhof, G. G., The Ultimate Bearing Capacity of Foundations, Geotechnique, 2, No. 4, pp. 301-332, 1951
- Meyerhof, G. G., The Bearing Capacity of Foundations under Eccentric and Inclined Loads, Proceedings, 3rd International Conference on Soil mechanics and Foundation Engineering, Zurich, Vol I, 1953
- 26. Meyerhof, G.G., Some Recent Research on the Bearing Capacity of Foundations, Canadian Geotechnical Journal, 1., No. 1, pp. 16-26, 1963

- Meyerhof, G. G., Safety Factors and Limit States Analysis in Geotechnical Engineering, Geotechnique, 21, pp. 1-7, 1984
- Meyerhof, G. G., and Fellenius, B. H. (eds.), Canadian Foundation Engineering Manual, 2nd ed., Canadian Geotechnical Society, 1985
- Mississippi State Highway Department, A Study of Active Clays as Related to Highway Design, MSHD, Jackson, Miss., 1972
- National Forest Products Association, All-Weather Wood Foundation System: Design, Fabrication, Installation Manual, NFPA, Washington, D.C. 1982
- 31. Peck, R. B., Hansen, W.E., and Thornburn, T. H., Foundation Engineering, 2nd ed., Wiley, New York, 1974
- Schmertmann, J.H., Static Cone to Compute Static Settlement over Sand, *Journal of the Soil Mechanics and Foundation Division*, American Society of Civil Engineers, Vol. 96, SM3, 1970, pp. 1011-1043
- Schmertmann, J.H., and Hartman, J.P., Improved Strain Influence Factor Diagrams, *Journal of the Geotechnical Engineering Division*, American Society of Civil Engineers, Vol. 104, GT8, 1978, pp. 1131-1135
- 34. Skempton, A. W., Notes on the Compressibility of Clays, *Quarterly Journal of Geological Society*, London, Vol. C (1944), pp. 119-135
- 35. Southern Building Code Congress International, *Standard Building Code*, SBCCI, Birmingham, Alabama, 1994
- Sowers, G.F., Introductory Soil Mechanics and Foundations: Geotechnical Engineering, 4th ed., Macmillan, New York, 1979
- Teng, T.C., and Clisby, M.B., Experimental work for Active Clays in Mississippi, *Transportation Engineering Journal, ASCE, Proceedings*, Vol. 101 No. TE1, 1975
- Terzaghi, K., and Peck, R. B., Soil Mechanics in Engineering Practice, Wiley, New York, 1967
- U.S. Department of the Navy, Design Manual—Soil Mechanics, Foundations and Earth Structures, NAVFAC DM-7, U.S. Government Printing Office, Washington, D.C., 1971
- U.S. Department of the Navy, Soil Mechanics, NAVFAC DM 7.1,
   U.S. Government Printing Office, Washington, D.C., 1982



### INDEX

A

AASHTO, 12 ACI, 12 ACI approximate method, 20 accuracy of failure analysis, 143 of settlement calculations, 207 A-line (Activity Line), 87 active clays, 11, 87, 328 allowable bearing pressures for braced frames, 15, 33, 62 from classifications, 88 gravity plus lateral, 33, 252 presumptive, 277 for rigid frames, 33, 56 summary of, 252 allowable bearing strength, 143, 148 computation of, 33, 152, 252 derivation of, 144 angle of internal friction, 115 approximations of constants, 12 of pressure bulbs, 127 size-settlement ratios, 128, 208 of shear failure mode, 148 applications and calculations selecting footing sizes, 269, 287 ASTM, 12, 80, 357 at-rest pressures, 132 attachments, columns to footings, 266 typical designs, 266 Atterberg limits, 84 augers, 349

#### 3

base shear distribution of, 32, 39, 49 earthquake, 32, 49 example calculations, 40, 50 wind, 32, 40 bearing capacity calculation of, 153, 168, 252 corrections for, 156 factors, 141, Table 6-1 at failure, 148 Boussinesq pressure bulb, 122 abbreviated, 124 approximate, 127 overlapping, 129, 293, 296 building codes, 31, 34, 37, 43, 48 buildings, types, 5 building systems, 45 buoyancy, effects of, 105, 160

braced frames
allowable soil pressures, 15, 33, 62
defined, 5
drift in, 58
effects of lateral loads on, 58
footing loads in, 58
reference footing for, 166
selection of footings for, 273
summary of foundation loads, 63

C cantilever footing, 318 Casagrande plasticity chart, 87 casing, of test hole, 350 center of lateral forces inertia, 32, 50 wind, 32, 40 classification of soils unified system, 88 consistency and textural, 87 clays activity in, 11 appearance, 75, 181 cohesion in, 75, 108, 111, 122, 135 consolidation in, 181, 188, 192 defined, 81, 87 desiccation in, 187, 328 expansive, 11, 87, 328 failure angle in, 109, 145 flocculent layup, 182 as group classification, 75, 90 honeycomb layup, 182 lightly consolidated, 227, 229 normally consolidated, 183, 213 overconsolidated, 186, 223 porewater in, 183 sensitive, 182, 188 coefficients of curvature, 84 of uniformity, 84 seismic, 47 cohesion, 75, 111 combined footings 295, 314 combined loads, 32, 56, 63, 65 comparative sizing, 166, 286 compression index, 214, 226 compression tests, 108 consolidated quick, 112 consolidated slow, 112 triaxial, 109 unconfined, 110 unconsolidated quick, 111

41. U.S. Department of the Navy, Structural Engineering, NAVFAC DM-2, U.S. Government Printing Office, Washington, D.C., 1983

43. Vesic, A.S., Bearing Capacity of Shallow Foundations, Foundation

Engineers, Vol. 99, No. SM1, pp. 45-73, 1973

Chapter 3, Van Nostrand Reinhold, New York, 1975

42. Vesic, A.S., Analysis of Ultimate Loads of Shallow Foundations, Journal of

the Soil Mechanics and Foundations Division, American Society of Civil

Engineering Handbook, 1st ed. H. F. Winterkorn and H. Y. Fang (eds.),