

Construction Of and On Compacted Fills

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Preface

This book is in the Wiley Series of Practical Construction Guides. It deals with compacted fills and is written principally to be helpful to the construction contractor. In order to serve that purpose, however, it is necessary to provide practical and useful information to *all* nonspecialists who traditionally are involved with or affect the planning, plans, specifications, and execution of earthwork construction. Such nonspecialists include the architect, the structural engineer, and the fill inspector, whose activities have a strong impact on the contractor's performance and profits.

Recent spectacular failures of man-made earthen structures have been extremely costly in terms of both dollars and lives. On June 5, 1976, the 305-ft Teton Dam in Idaho collapsed. Seventeen months later, on Sunday, November 6, 1977, at approximately 1:30 A.M., the Kelly Barnes Dam near Toccoa, Georgia, failed. The resulting flood took 39 lives. As a direct result of the Toccoa Dam disaster, a national dam inspection program was initiated.

The principal cause of both failures has been judged by geotechnical experts to have been piping, a progressive interior deterioration of the earth structure associated with seepage forces of sufficient magnitude to dislodge and slowly transmit particles along with flowing water.

As imposing as the losses associated with these nationally reported disasters are, I am convinced that these losses pale in comparison to damage caused by the countless thousands of defective earth structures—or fills—that are constructed annually. The number of cracked sidewalks, pavements, floor slabs, walls and columns, and basement walls must be prodigious. Improperly backfilled trenches resulting in traffic hazards and damaged utilities can be both costly and dangerous. The costs escalate significantly when litigation becomes a factor, especially where personal injury or deaths are involved.

A peculiarity of earthwork construction is that many nonspecialists who are routinely involved frequently do not consult with geotechnical specialists for advice regarding filling operations. I believe the reasons for this are (1) a belief that filling operations are simple and straightforward and do

x *Preface*

not require the attention (and expense) of specialists and (2) a preoccupation with the (eventual) visible aspects of the structure such as architectural considerations and structural design.

The principal reasons for this undesirable situation are (1) the neglect of the topics of soil compaction and fill control in *required* undergraduate courses in civil engineering and civil engineering technology and (2) that little information seems to be available to *nonspecialists* involved in earthwork aspects of engineered construction.

I hope that this book will correct or at least alleviate the foregoing problems.

EDWARD J. MONAHAN

Bloomfield, New Jersey
March 1986

Acknowledgments

I would like to acknowledge the contributions of many former students at the Newark College of Engineering to the work in this book. Because of the short time of my association with each of them in the academic setting, it was generally not possible to bring to a satisfactory conclusion most of the projects that were initiated. But it was the constant stimulation they provided that was responsible for my broad study of compacted fill technology, represented especially by the content of Chapter 5. Many of these former students are now in professional practice "simulating field conditions" instead of getting sick of hearing the phrase; my best to them.

I also cite the valued contributions of Harvey Feldman, Chief of Laboratory; Tippetts, Abbott, McCarthy, and Stratton, New York, for his thorough and professional review of the manuscript, executed in a very timely and helpful fashion. Certain additions and modifications were made as a direct result of his comments, and the book was, I think, markedly improved as a result. The chapter glossaries, for example, were added because of his perception that too many terms were left unexplained in the manuscript copy he reviewed, particularly since the book was directed (mostly) to nonspecialists. He also suggested a short description of dynamic compaction.

Thanks to Tom Bellatty, early professional colleague, former MVAP (most valuable adjunct professor), and erstwhile square root student, for his insights regarding the role of "observers" in the implementation and enforcement of specifications. Ed Dauenheimer's comments and help in obtaining information with respect to "professional liability loss control" (Section 9.2) are also appreciated.

The assistance of Dan Morris, consulting editor for the Wiley Series of Practical Construction Guides, was invaluable, but most of all his attitude with respect to allowing "me to be me" (within reason) is most appreciated.

Finally, I am indebted to Mrs. Pearl Gordon, who typed the manuscript with much skill and patience and with great good judgment. She was always "there" when various deadlines were imposed along the way.

E. J. M.

Series Preface

The construction industry in the United States and other advanced nations continues to grow at a phenomenal rate. In the United States alone construction in the near future will approach two hundred billion dollars a year. With the population explosion and continued demand for new building of all kinds, the need will be for more professional practitioners.

In the past, before science and technology seriously affected the concepts, approaches, methods, and financing of structures, most practitioners developed their know-how by direct experience in the field. Now that the construction industry has become more complex there is a clear need for a more professional approach to new tools for learning and practice.

This series is intended to provide the construction practitioner with up-to-date guides which cover theory, design, and practice to help him approach his problems with more confidence. These books should be useful to all people working in construction: engineers, architects, specification experts, materials and equipment manufacturers, project superintendents, and all who contribute to the construction or engineering firm's success.

Although these books will offer a fuller explanation of the practical problems which face the construction industry, they will also serve the professional educator and student.

M. D. MORRIS, P.E.

Contents

1. Introduction, 1

- 1.1 Purpose and Scope, 1*
- 1.2 Importance and Nature of Earthwork, 2*
- 1.3 Important Definitions, 3*
- 1.4 The Role of Index and Engineering Properties, 8*
- 1.5 Glossary, 11*

2. Avoiding Costly Blunders, 13

- 2.1 The Practical Value of Knowledge of the Historical Development of Soil Compaction, 13*
- 2.2 Early Empirical Approaches, 13*
- 2.3 Rational Approach, 14*
- 2.4 Standard Proctor Density, 14*
- 2.5 Modified Proctor Density, 15*
- 2.6 Load-Bearing Fills Building Codes, 16*
- 2.7 Summary, 16*

3. Basics of Soil Compaction Curves: Laboratory Procedures, 18

- 3.1 Compaction Defined, 18*
- 3.2 Spectrum of Soil Types, 20*
- 3.3 Curve Locations and Shapes and Their Practical Meaning: Moisture and Energy Effects, 22*
- 3.4 ASTM Compaction Requirements, 23*
- 3.5 Summary, 26*
- 3.6 Glossary, 26*

4. Major Problems in Compacted Fill Technology: Proposed Solutions, 28

- 4.1 Standard-Modified Ignorance, 28*
- 4.2 The 95 Percent Fixation, 31*

- 4.3 *Changing Borrow*, 39
- 4.4 *Problems Evolving from Traditional Practice*, 42
- 4.5 *Cost and Time Pressures: A Summary*, 44
- 4.6 *Glossary*, 45
- 5. *Applied Research and Development*, 46**
 - 5.1 *Effects of Specific Index Property Variations*, 46
 - 5.2 *Waste Materials as Fills*, 52
 - 5.3 *Artificial Fills*, 53
 - 5.4 *Effects of Mechanical Laboratory Compactors*, 66
 - 5.5 *Density Gradients*, 67
 - 5.6 *Geostick Correlations*, 67
 - 5.7 *Percent Compaction Specifications for Clay Fills*, 68
 - 5.8 *Summary*, 69
 - 5.9 *Glossary*, 69
- 6. *Fills and Fill Compaction*, 71**
 - 6.1 *Strength, Stability, and Imperviousness: Contrasting Requirements*, 71
 - 6.2 *Potential Problems with Earth Structures*, 72
 - 6.3 *Controlled and Uncontrolled Fills*, 86
 - 6.4 *Nonstandard and Special Fills*, 86
 - 6.5 *Compactors and Lift Thicknesses*, 88
 - 6.6 *Energy and Moisture Control*, 96
 - 6.7 *Glossary*, 97
- 7. *Compaction Specifications*, 99**
 - 7.1 *Typical Specifications*, 100
 - 7.2 *Implementation and Enforcement*, 111
 - 7.3 *Nontechnical Aspects of Specifications*, 114
 - 7.4 *Specification and Project Evaluation*, 115
 - 7.5 *Glossary*, 118
- 8. *Fill Control Procedures—Inspection*, 119**
 - 8.1 *Field-Density Testing*, 119
 - 8.2 *The Compleat Field Man*, 141
 - 8.3 *Case Histories*, 151
 - 8.4 *Glossary*, 175

9. *Techonomics, 176*

9.1 *Engineering Design, 176*

9.2 *Legal Costs, 177*

10. *Update at Press Time, 181*

10.1 *Weight-Credit Update, 181*

10.2 *Very Large Jobs, 184*

10.3 *Annotated References for Self-Study, 186*

10.4 *Additional Seminars, 190*

References, 190

Index, 193

1

Introduction

1.1 Purpose and Scope

The purpose of this book is to present helpful information on soil compaction and fill control to nonspecialists. The information should also be useful to academic colleagues, and especially so if I am successful in convincing them of the importance of a greater emphasis in their courses, especially those which are heavily attended by nonspecialists. Because of the focus noted, established on the basis of 26 years of observations in both the classroom and in consulting practice, I assume no prior knowledge of soil compaction, or for that matter, soil mechanics. A careful study of Chapters 1, 2, and 3 is recommended for a better appreciation and understanding of that which follows.

Chapter 4 presents the major problems in fill control, and solutions are proposed for each problem. Some are strictly technical in nature, while others deal with much more sensitive matters ranging from professional ethics to human relations. Observations made about the latter are bound to be controversial. However, I am convinced that what is said needs to be said, openly and forthrightly, in order to have any chance of correcting certain practices detrimental to good engineered construction.

In order to provide credibility and validation to the assertions made regarding major problems, case studies are used. In all cases, names, locales, and other possibly embarrassing details are omitted.

Chapter 5 describes some of my unpublished research results and suggests further research efforts. I believe investigations can be pursued at many levels—funded research, undergraduate and graduate laboratory courses, and undergraduate and graduate projects and theses. I hope that geotechnical consultants adopt some of the suggestions and improve and extend certain procedures to augment their recommendations for, and su-

2 Introduction

pervision of, filling operations. In some cases, for example, the suggestions regarding a compaction data book (for dealing with the problems of *changing borrow*), their ability to accumulate large amounts of data makes it feasible to develop, refine, and validate methods rapidly.

Chapter 6, "Fills and Fill Compaction," deals in detail with the technological aspects of all types of compacted fills, and includes a section on potential problems with earth structures, with an emphasis on earthen dams. The intent is to provide information helpful to those involved with the National Dam Inspection Program, thus serving the dual purpose of improving capabilities in the inspection and remediation of completed earth structures and in the full range of activities needed for design, inspection, and construction of new earthworks. Chapter 7 complements Chapter 6 with a description of all details relating to compaction specifications.

Chapter 8 (plus some aspects of Chapter 7, notably Specification Evaluation, Section 7.4) is intended to serve as a manual for fill control procedures: it is written expressly for the typical inexperienced young geotechnical engineer or engineering technologist.

The book closes with two short chapters: "Technomics" and "Update at Press Time." The former is a coined term relating to the important link between technical and economic decisions in design and construction. The last chapter includes some material that evolved, was discovered, or just "seemed to be sensible additions" during the latter stages of completion of the manuscript.

As a departure from typical format, chapter glossaries are provided at the end of each chapter, to explain certain terms used in the chapter, which it was judged could not be explained fully within the text without adversely affecting readability. Terms are listed in order of appearance in the chapter. I suggest that the reader review each chapter's glossary before reading the chapter of interest.

1.2 Importance and Nature of Earthwork

The importance of soil compaction and fill control can be emphasized by one simple declaration: that almost no significant engineered construction occurs without the movement of soil from one place to another. Furthermore, it should be the nature of good engineered construction that parties become involved in earthwork operations in the following sequence: the geotechnical engineer, the architect and structural engineer, the fill inspector, and the construction contractor. A most important nonspecialist is, of course, the owner or client. Unfortunately, as noted in the preface, the geotechnical engineer is too often left out of the sequence. All too often, he is called in (late) to correct a bad situation or to act as an expert witness when it is already too late for correction.

In the ideal sequence, the geotechnical engineer explores and evaluates

the subsurface conditions through a logical process of analyzing soil (or rock) *index properties*, and then, as judgment dictates, determines appropriate *engineering properties* through laboratory and/or field testing. With a knowledge of the loading conditions that are to be imposed by the proposed structure, the engineer prepares recommendations for foundation type, methods of foundation construction, and allowable bearing capacities at particular foundation levels. Such recommendations are broadly based upon determining safe loading intensities on foundation elements (e.g., footings) of various sizes that will not result in either a *bearing capacity failure* or *unacceptable settlements*. More often than not, the recommendations will entail excavation and filling operations, requiring recommendations for *quality* (texture) and *condition* (compacted density) of the fill. Assuming compliance with specifications, the fill is then judged to have a certain allowable bearing capacity.

The structural engineer is one of the primary recipients of the geotechnical engineer's report. In addition to the obvious responsibility of structural design, it is his typical responsibility to prepare working drawings, including foundation drawings. The preparation of construction specifications becomes a natural extension of this work, typically as notes on the drawings and (for large projects) separate, additional documents. In the usual situation, the structural engineer will need to consult architectural drawings and geotechnical reports in the conduct of his work and communicate with the architect and geotechnical engineer when questions develop requiring their attention and expertise.

Construction engineers and contractors are, of course, the "doers." They bring to fruition the studies, concepts, designs, drawings, and specifications of the architect, the geotechnical engineer, and the structural engineer, thus completing the sequence of operations of engineered construction.

1.3 Important Definitions

Soil Compaction (Field). The reduction of void spaces (densification) of lifts of fill by the direct application of load, impact, and/or vibration, usually with a suitable type of compaction equipment. Lift thicknesses vary from several inches (for clays and silts) to perhaps 2 ft for free-draining fills (sands and gravels). [Note: One should not confuse soil compaction with consolidation, the long-term reduction of void ratio of a natural soil, usually saturated, thick deposits of soft clays or silts beneath the water table. This is usually accomplished by the application of static surface loading (called surcharges), resulting in the slow drainage of porewater from the subsurface stratum. Thus, one principal difference is that compaction is direct and immediate.]

Soil Compaction (Laboratory). The compaction of a small but representative soil sample, obtained from the field, in a steel mold of standard

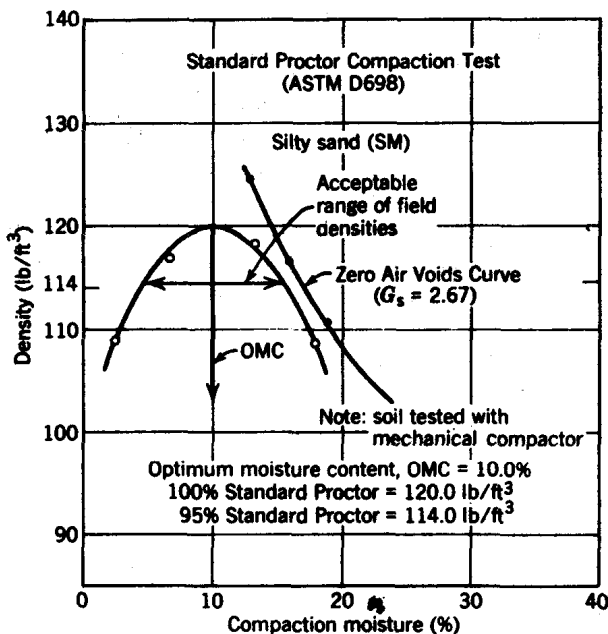


FIGURE 1.1 A typical compaction curve.

size. The soil is compacted usually in layers, commonly by dropping a hammer of specified weight through a specified distance a specified number of times. The energy of such compaction is chosen to simulate that of field compaction with rollers. The moisture content is varied for a series of filled molds, thus generating a *compaction curve* for the soil. A typical curve is shown in Figure 1.1.

Granular, Cohesionless Soils. Gravels, sands, and “clean” silts (those possessing no plasticity).

Cohesive, Plastic Soils. Clays, clay-silt mixtures, organic soils.

Drainage Quality Designations.

1. *Free-draining* soils—gravels, coarser sands, and mixtures thereof.
2. *Marginally draining* soils—finer sands, clean silts, and mixtures thereof.
3. *Impervious* soils—clays, clay-silt mixtures. (Note that no soil is impervious, so the term is used in a relative rather than absolute sense.)

Gemicoss. James Kilpatrick, one of my favorite columnists and lingophiles, suggests that if there is a legitimate need for a new word, invent one. Here-with, *gemicoss*.

It is defined as any soil that is a combination of soil types in such pro-

portions as to raise questions pertaining to contrasting engineering properties, for example, cohesionless vis-à-vis cohesive, plastic vis-à-vis nonplastic, free-draining vis-à-vis marginally draining. It may also be helpful to tell you how I invented the word: As a child, I learned that all (most?) English words required one or more vowels. Thus G is for gravel, C is for clay, SS is for sand and silt. E, O, and I, of course, are needed vowels. I might also represent inorganics, the soil minerals. In the Unified Soil Classification System, O is used to represent organics, and M to indicate silts. EM also stands for Ed Monahan.

There are many examples illustrating the need for the concept of the gemicoss. Often a chart or a formula has a principal limitation of being applicable to a certain soil type, that is, sand or clay. Blow counts, for example, are used for determining allowable bearing capacities *for sands*. For clays, one often uses the unconfined compressive strength. But what does one "do" with a sand-clay mixture? Or a sand-silt-clay mixture? There is no simple answer, other than to say that good engineering judgment must be employed.

Essentially Granular (or Cohesive) Soils. Texture that predominates in the context of dictating the overall behavior of the soil. This terminology is a natural extension of the notion of a gemicoss. After carefully evaluating the texture (sizes *and* plasticity) of the soil, one may be forced to decide whether it is essentially granular or essentially cohesive in order to justify the use of a particular design chart or formula.

For example, if a soil is composed of 60% highly plastic clay (by weight), with 40% sand and gravel, the soil would be an ECS, an essentially cohesive soil, since the sand and gravel particles are, for all practical purposes, merely isolated or "suspended" in a clay matrix, and their presence is essentially irrelevant to the overall engineering behavior of the soil. Note that this example does not fit the classification of a gemicoss, because the conclusion (ECS) is fairly evident. A gemicoss might be 40% medium plastic clay, 60% sand and gravel. Such a mixture raises questions pertaining to contrasting engineering properties.

As a contrasting example, if a soil is 75% gravel and sand, with 25% clay of high plasticity, it would be rated an essentially granular soil (EGS), inasmuch as it is reasonable to assume that the preponderance of granular particles are in contact. The significant percentage of highly plastic clay would act as "binder."

Thus, in summary, the simple auxilliary classification system that I propose includes five categories: granular, cohesionless soils; essentially granular soils; essentially cohesive soils; cohesive (plastic) soils; and the gemicoss.

Fill. The soil that is selected for use at the site. It may be from a site excavation or "imported" from elsewhere. In the latter case, the fill is termed *borrow*.

Fill Quality Indices. Texture: grain sizes and grain size distribution of cohesionless soils, or plasticity (usually plasticity index, or PI) of cohesive soils.

Fill Condition. Density (pounds per cubic foot, pcf) or relative density (percent), a measure of potential settlement. For clay soils, potential *expansion* is often an important additional condition to consider.

Permanent Stability. A concept referring to the fundamental question of whether the fill (or any soil) will remain stable under present *and future* conditions that may reasonably be expected to be imposed during the economic life of the structure. Thus, a very dense, free-draining soil, which is to be permanently contained (*laterally*), is the most "permanently stable" soil, for it cannot settle significantly; it is not susceptible to seepage pressures, nor will it expand when wetted. Conversely, a cohesive (clay) soil can settle unacceptably if not compacted sufficiently but can expand detrimentally upon (future) wetting if overcompacted. The pressures associated with such expansion can be substantial, causing damage to highway pavements and even heavy structures. Clays and silts are also susceptible to disturbance by seepage pressures (piping, uplift) because of their relative imperviousness. Silts are also susceptible to frost action.

Simulation of Field Conditions. This is an important concept concerning the rationale that should be used for all decisions relating to laboratory testing. Thus, what one does to the soil sample in the laboratory should, in all practical respects, simulate what will be done to the soil in the field. As one of the more obvious examples, the method and energy of compaction in the laboratory compaction test should approximate that of construction rollers used in the field.

Index Properties. Indicates the general nature of the subsurface problems that must be confronted. Such index properties are (or can be) obtained routinely and at modest expense in a typical subsurface investigation. Figure 1.2 shows, in simple flowchart form, how index properties should be used. Note that large jobs, requiring the expenditure of larger amounts of money, would justify the expenditure of larger amounts for field or laboratory testing to determine engineering properties needed for design. Engineering properties are defined as those measuring stress, strain, and strain rate on representative soil samples that enable computation of specific numerical values of bearing capacity and settlement. Thus, path ABC provides a design that is more "reliable" than path AC, but at considerably more cost. Path AC, for small jobs, where extensive testing is not economically justified, utilizes index properties directly for design purposes, usually by entering a chart to select allowable bearing capacities, rather than the more expensive ABC route. Of considerable practical importance, moreover, is the fact that

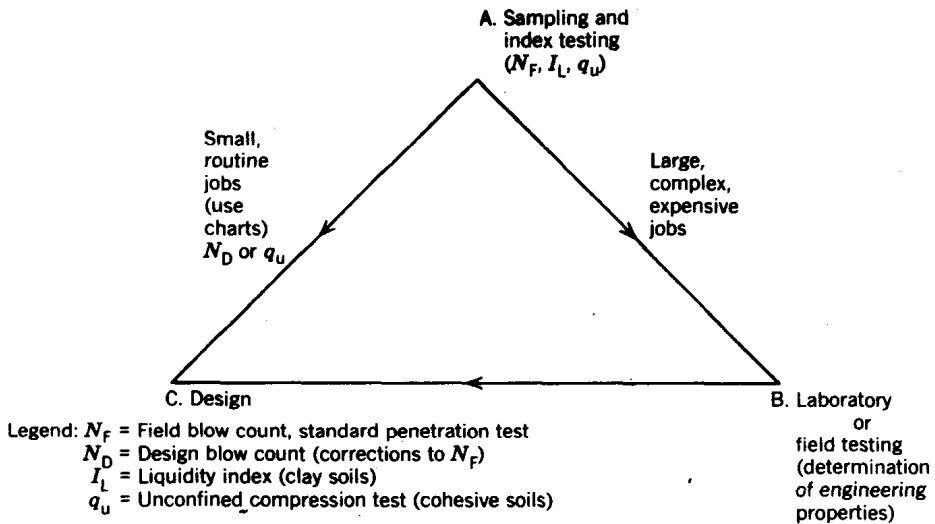


FIGURE 1.2 Design flowchart.

index properties, if obtained and properly evaluated, serve as the basis for a rational testing program (step B). In summary, index properties serve a twofold purpose and are indispensable tools in geotechnical engineering.

Blow Count, Density, and Relative Density. Illustrative of the foregoing description of index and engineering properties are the definitions of blow count, density, and relative density, particularly as related to compaction and fill control and the stability and bearing capacity of granular, or essentially granular, soils.

When a driller is sampling a soil that is expected to be an essentially granular soil, a sampling device is driven into the soil and a blow count, N (blows per foot) is obtained. Clearly, the blow count (with any appropriate corrections) is an indicator of density; the higher the blow count, the higher the density.

Relative density, a laboratory-determined *engineering property*, is a percentage of the practically obtainable maximum density for the particular soil. Thus, a soil of 100% relative density would have a negligible potential for future settlement. Furthermore, given the thickness of the soil, a knowledge of the relative density would allow for the computation of a specific, numerical settlement estimate. A judgment could then be made as to whether the computed settlement would be tolerable.

In this example, the blow count is an indicator (or index property) signifying the *general condition* of the soil (e.g., very loose, loose, medium-dense, dense, very dense), whereas the relative density (involving the added expense of laboratory testing) is an engineering property.

With respect to fills, knowledge of the relative density and the compacted