DYNAMIC GEOTECHNICAL TESTING II

Ronald J. Ebelhar
Vincent P. Drnevich
Bruce L. Kutter
editors

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Foreword

This publication, *Dynamic Geotechnical Testing II,* contains papers presented at the symposium of the same name, held in San Francisco, CA on 27–28 June 1994. The symposium was sponsored by ASTM Committee D-18 on Soil and Rock and Subcommittee D18.09 on Cyclic and Dynamic Properties of Soils. Ronald J. Ebelhar of RUST E&I in Cincinnati, OH; Vincent P. Drnevich of Purdue University in West Lafayette, IN; and Bruce L. Kutter of the University of California, Davis presided as symposium chairmen and are editors of the resulting publication.

Overview

The first ASTM Symposium on Dynamic Geotechnical Testing was held in Denver, CO in June of 1977. In the intervening 16 years, there has been steady progress in cyclic and dynamic testing of soils for geotechnical engineering purposes and centrifuge testing has emerged as a new tool for understanding soil behavior and dynamic soil-structure interaction.

The Dynamic Geotechnical Testing II symposium was held in San Francisco in Jan. 1994 and was co-sponsored by ASTM Committee D18 on Soil and Rock for Engineering Purposes and ASTM Subcommittee D18.09 on Cyclic and Dynamic Properties of Soils.

As stated in the Call for Papers:

> The primary goal for the symposium is to identify both established and innovative tests for determining cyclic and dynamic properties of soils which are candidates for standardization. A secondary goal is to provide a forum for a discussion of testing which has been conducted using standard methods. This will provide insight into considerations for modifying or extending existing standards.

With these goals in mind, authors were requested to consider presenting the following information in their papers:

(1) description of the facilities, apparatus, and instrumentation used;
(2) theoretical analyses of apparatus and instrumentation, or both;
(3) results of experimental research;
(4) analysis of experimental results; and
(5) discussion of testing procedures, improvements, and guidelines.

The Symposium consisted of four one-half day sessions. The first three sessions had specific themes: Field Testing, Laboratory Methods, and Centrifuge Testing. The fourth session was a general panel discussion. Each of the first three sessions featured an invited presentation by a topic overview speaker and their papers are included in this special technical publication (STP). Each topic overview paper includes a general review of existing and new test methodologies and provides a review of the papers presented in that session. Some of the papers were presented at each of the sessions and others were presented at poster sessions that followed each of the sessions. The purpose of the general panel discussion was to integrate the salient points of the three sessions to obtain an improved understanding of geotechnical behavior under dynamic loading conditions.

This STP should provide an excellent reference document on current testing practice, emerging technologies, and additional information on measurement of soil properties under cyclic and dynamic loading conditions.

The decision on paper acceptance was difficult in that over 90 abstracts were submitted and space was only available for about 30 papers. Each accepted paper was reviewed by a minimum of three peer reviewers. Following revision by the authors, the manuscripts were re-reviewed by the editors and the ASTM staff. The Symposium co-chairmen express their appreciation to all authors who prepared manuscripts for this symposium. The reviewers also deserve thanks for assuring the quality of the papers.

The symposium co-chairmen express their appreciation to the topic overview speakers: Richard G. Campanella (University of British Columbia), Richard D. Woods (University of Michigan), and Ronald F. Scott (California Institute of Technology). The co-chairmen also wish to express their gratitude to the members of the Symposium Steering Committee who assisted with the Call for Papers, identifying reviewers, and completing reviews. The members of the Steering Committee were: Pedro De Alba, Roman Hryciw, Paul Knodel, Hon-Yim Ko, Derek Morris, Shamsher Prakash, Adel Saada, Raymond Seed, Marshall Silver, Scott Steedman, Mladen Vucetic, and Les Youd. Finally, the co-chairmen are most appreciative of the support provided by Committee D-18, Richard S. Ladd Chairman, and the ASTM staff (Bob Morgan, Manager; Dorothy Savini, Symposia Manager; Kathy Dernoga, Manager, Acquisition and Review; and Therese Pravitz, Manuscript Coordinator; Acquisition and Review) in organizing this symposium and publishing this STP.

Ronald J. Ebelhar

RUST E&I
11785 Highway Drive, Cincinnati, OH 45241; symposium chairman and editor.

Vincent P. Drnevich

Purdue University
1284 Civil Engineering Building, West Lafayette, IN 47907; symposium co-chairman and editor.

Bruce L. Kutter

University of California
Department of Civil Engineering, Davis, CA 95616; symposium co-chairman and editor.

Contents

Field Methods

Richard (Dick) G. Campanella[1]

FIELD METHODS FOR DYNAMIC GEOTECHNICAL TESTING: AN OVERVIEW OF CAPABILITIES AND NEEDS

REFERENCE: Campanella, R. G., **"Field Methods for Dynamic Geotechnical Testing: An Overview of Capabilities and Needs,"** Dynamic Geotechnical Testing II, ASTM STP 1213, Ronald J. Ebelhar, Vincent P. Drnevich, and Bruce L. Kutter, Eds., American Society for Testing and Materials, Philadelphia, 1994.

ABSTRACT: This overview is presented from a user's point of view and will consider the practical aspects, nature of the problem to be studied, information requirements, their applications and costs involved. The discussion also reviews the perceived advantages and limitations of various methodologies with suggestions and needs for future developments. Contributions to this symposium are also discussed within the above framework. The comments given are those of the writer and are based on reported research, and personal experiences and perceptions.

Conclusions suggest that most field seismic tests are quite capable to measure the low strain, shear wave velocity profile. However, the testing must rely on other tests to provide ground truthing and identify stratigraphy, except for the downhole seismic cone penetration test where the seismic sensor was added to a tool primarily used for stratigraphic logging. It is recommended that since the downhole seismic method for the cone has evolved into a simple, reliable, cost effective tool, it be added to the ASTM Standard D 3441-86 for cone penetration tests in soil which is currently being revised.

Also, most current field dynamic test methods do not routinely measure the important parameter, material damping. A preliminary procedure for damping measurements with the seismic cone is outlined in this symposium. It is suggested that researchers focus their efforts to measure damping in-situ, compare and scrutinize their results in order to establish an acceptable standard procedure.

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[1]Professor, Department of Civil Engineering, The University of British Columbia, 2324 Main Mall, Vancouver, B.C., Canada, V6T 1Z4.

It is also apparent that little progress has been made in the in-situ measurement of shear modulus and damping as a function of strain, even though it is generally accepted that such properties are necessary to predict dynamic response of high energy events like earthquakes and should be a high priority for future R and D. It currently appears that the self-boring pressuremeter, a downhole impulse test and a proposed tool reported in this symposium have the best chance of providing such information.

KEY WORDS: Geotechnical, Field, Seismic, Dynamic, Site investigation, Applications, Shear wave velocity, Strain level, Damping

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INTRODUCTION

This paper presents an overview of field methods in dynamic geotechnical testing from the point of view of the current capabilities we have when considering the properties needed to solve specific dynamic geotechnical problems. The papers in this session mainly address very specific details relating to research and development issues in dynamic testing.

The desired aim of any ASTM specialty symposium should be for evaluation of existing and proposed methodologies for potential revision or new inclusion as standards for practicing engineers and scientists. The review presented in this paper shows that considerable advances have been made in many areas of dynamic site characterization over the past few years but one tool and method has been in use for over 10 years, is commercially available (both contractors and manufacturers) and needs standardization; namely, the seismic aspects of the cone penetration test (SCPTU). Other advances, also worthy of consideration, must be evaluated in the context of repeatability of data and the range of problems, that can be solved with confidence once the data is obtained. Hopefully, this review paper will be of assistance in suggesting where areas of confidence exist, where much more refinement would be required prior to general acceptance for solving complex problems and where further research and development might be focused.

Field methods in dynamic geotechnical testing are performed to either determine stratigraphic details of a site or to determine site specific soil properties for a specific engineering design or both. Woods, 1991, recently presented a very comprehensive, state-of-the-art review of field and laboratory methods of determining dynamic properties of soil at the Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics at St. Louis, Missouri. The reader is referred to this excellent paper for a comprehensive review and list of references including a recent list of meetings, conferences and symposia having associated proceedings on the topic.

DYNAMIC PROPERTIES AND TESTS

The geotechnical engineer is primarily interested in determining the properties of surficial soils and rock at specific sites for engineering design for specific problems which are often dynamic in nature. The specific dynamic problems may be related to earthquakes (liquefaction, ground response and slope stability), characteristics of vibrating machinery, pile dynamics, dynamic compaction and other ground improvement techniques, shock and/or blast loading and wind, wave and ice loading. The geophysicist, on the other hand, is primarily interested in a qualitative or generalized site characterization and the delineation of gross changes in stratigraphy from a regional perspective. The engineer has tended to concentrate on seismic methods to measure soil properties while the geophysicist makes use of all earth exploration methodologies; for example, electrical resistivity, electro-magnetic, induced polarization, gravimetric, radar, nuclear, thermal, etc., as well as seismic. Engineers are beginning to realize the value and application of many of these geophysical methods, especially for groundwater contamination problems.

SYMPOSIUM PAPERS

Of the 8 papers in this session on field testing methods, 6 papers deal with low strain seismic, one with resistivity and one with large strain in-situ testing. All papers deal with details of testing, specific aspects of dynamic site characterization and property determination. The most commonly used field test in current practice is, however, not represented, namely, the SPT (Standard Penetration Test).

Figure 1 attempts to categorize the various approaches to measuring dynamic geotechnical properties. It starts by indicating the obvious advantage of field or in-situ measurements over laboratory testing where field testing minimizes disturbance, preserves the effects of fabric and aging on the measured properties and tests the soil at its natural in-situ stress, whatever it happens to be. Laboratory dynamic test methods are covered in another session of this symposium. Under "field" there is the major category of "seismic" which divides into site characterization and low strain and can include variable strain. Under seismic we have both compression or pressure waves (P-waves) and shear waves (S-waves). Both P- and S-waves are used for Tomography, but S-waves are used mainly to measure shear wave velocity, (V_S), where low strain methods dominate. P-waves are shown here for completeness as their use in geotechnical design is often limited to unsaturated soils. Shear waves travel through the soil structure and are used to determine the low strain or elastic shear modulus by multiplying the soil mass density by the square of shear wave velocity. In addition, material damping, (D_S), is required to assess dynamic response, but until recently its in-situ measurement and evaluation have not received much attention. The methods under resistivity and other geophysical methods are not dynamic tests but provide information and properties that are used to analyze dynamic problems and events. Under variable strain, the self-boring pressuremeter is identified with other in-situ tests. Finally, the shaded zones indicate a direct measure of shear velocity without requiring a soil model (constitutive relation), thus increasing reliability considerably.

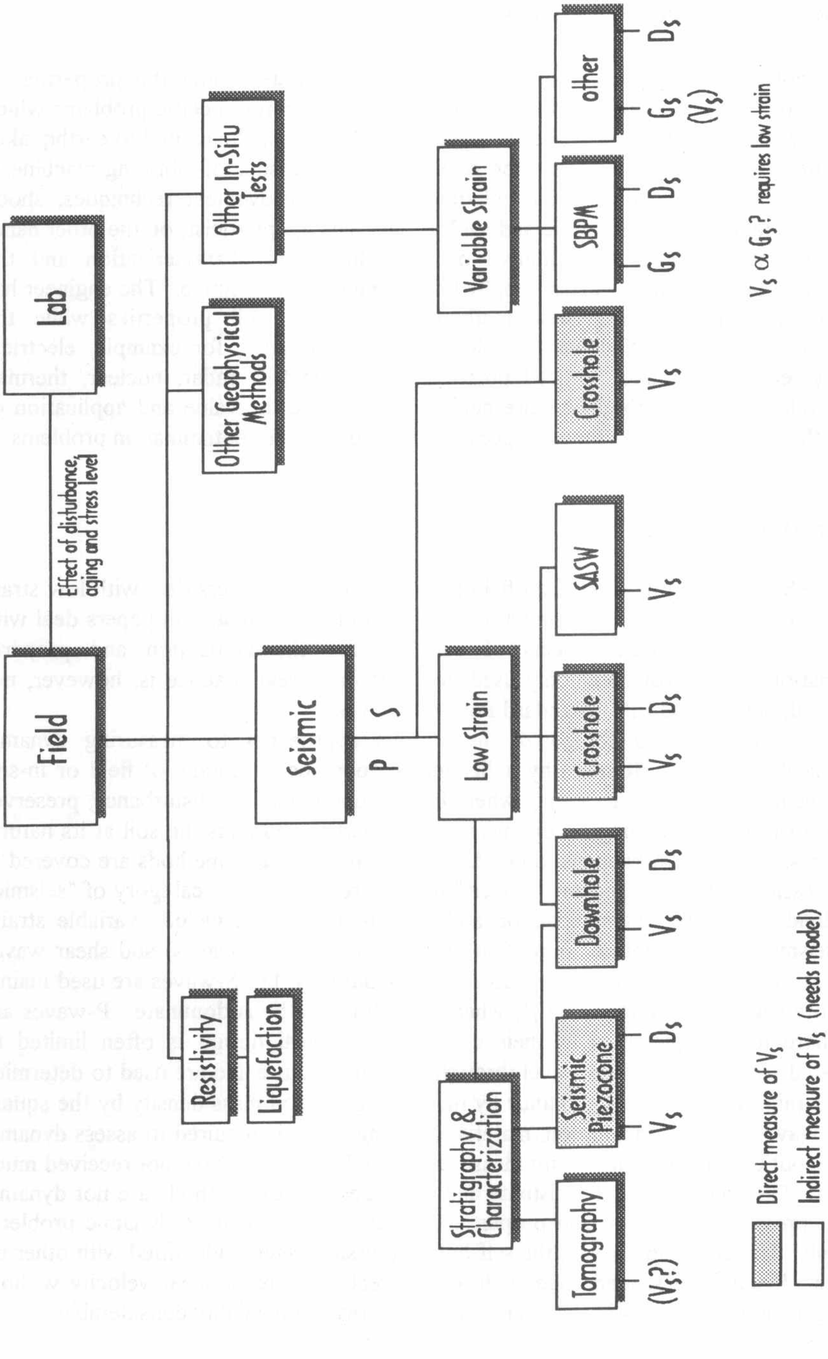

Fig. 1. -- Field Approaches to Measuring Dynamic Geotechnical Properties

Following is a brief review of the 8 papers to this session with reference to Fig. 1 and their relative advantages and limitations.

1. Arulmoli and Arulanandan re-introduce the concept of using a push-in thin wall tube to measure bulk soil resistivity (or conductivity) in the vertical and horizontal direction and correlate it through anisotropic Formation Factor to estimate liquefaction susceptibility and shear modulus (Arumoli et al, 1985). This is one of the two papers in this session which is not a dynamic test but addresses a dynamics problem. This method of determining material state is conceptually more fundamental in assessing soil dilatancy characteristics than are empirical relationships with dynamic penetration devices, but its application can be more complex and controversial. The technique requires pore fluid sampling for normalizing bulk conductivity, is slow and costly, and the tool is not very robust. Unfortunately, because of the nature of the tool (insertion disturbance and small test volume of non-horizontal and vertical conduction paths), the correlations to predict liquefaction and modulus are empirical, require extensive site specific data and are only good for the given tool geometry.

2. Rix on Tomographic Inversion using Artificial Neural Networks. This paper introduces the concept of tomographic imagery and the use of artificial neural nets to substantially reduce computation requirements. This is a highly specialized method, but potentially will be a very useful 2 and 3-D stratigraphic technique. Rix summarizes the basics, but also shows how an artificial neural network can fail to delineate certain local anomalies; anomalies that may be critical from an engineering perspective. Tomography is a valuable analytical tool for site characterization and its continued development should be encouraged. It is not usually used to obtain dynamic geotechnical properties like V_S and it requires the manipulation of very large data bases which are usually costly to obtain and process.

3. Stokoe et al. on repeated measurements with permanently embedded geophones. This paper summarizes the manner in which cross-anisotropic geological media can have their elastic properties determined and monitored at relatively reasonable cost. While this type of system is too limiting for site characterization efforts it does represent a simple approach using an installed array for specific seismic monitoring where geophones are used as both sources and receivers over close distances.

4. Wright et al. on SASW at sites overlain by water. The use of the Spectral Analysis of Surface Waves (SASW) technique on sites overlain by water is an excellent application of this non-intrusive technique and the authors clearly show how this method may be used. Unfortunately, as in all SASW applications, the determination of a shear velocity profile with depth is determined from non-standardized inversion methods which have the possibility of providing an infinite number of plausible solutions. Thus, operator experience plays an important role that, as yet, does not allow the SASW to be used beyond that of a screening technique requiring verification by other means at this stage of its development.

5. Nazarian et al. on recent developments in automating SASW analyses. As noted for Wright et al., there is still considerable difficulty by many users with SASW due to the complexities and non-uniqueness in achieving solutions. This paper demonstrates the involved procedures required. However, this paper does show that automation of these involved procedures is possible but the robustness that is attributed to the method must be

prefaced with the non ground-truthing nature of the method which requires it be used with other tools. Unfortunately, the comparison to "truth" is demonstrated in this paper with the SPT, which itself is highly unreliable and only loosely empirically related to shear velocity. A seismic cone profile would have provided the detailed stratigraphy and direct measure of shear velocity as required and could have been used to check the needed assumption of uniform horizontal layering.

6. Roblee et al. on crosshole SH wave measurements in rock and soil. The authors provide a simple yet effective methodology and describe the design elements of two borehole sources to accomplish SH-wave measurements.

7. Roblee et al. on feasibility of an in-situ tool to measure modulus and damping in clay over a wide strain range. The authors present a convincing argument to show the importance of assessing the modulus degradation and damping amplification with increased shear strain in earthquake site response analysis. The authors discuss many possible ways of inducing strains and discuss advantages and disadvantages of each. They are rightly concerned with insertion disturbance and envisage a self boring tool. A free-standing torsional shear test in the bottom of a borehole is ranked first in a comparison with four other types of tools. Unfortunately, all tools of this nature suffer from the fact that appropriate constitutive relationships and strain fields must be assigned to represent the real soil being tests which is often non-linear. This is further complicated in sands where volume changes must also be considered. The authors feel that the need is to test clays in-situ where amplification during earthquakes is of concern, and where sampling disturbance and stress release precludes the use of laboratory testing to determine these dynamic properties needed in site response analyses. In fact, the writer has just the opposite experience with laboratory testing of clays (Zavoral and Campanella, 1994, in this symposium and Stewart and Campanella, 1993) where resonant column tests and cyclic torsional tests on an undisturbed sensitive clay gave the same low strain modulus and damping values as those measured in-situ with the seismic cone.

The writer also shares the concerns of the authors about needing an in-situ tool to measure modulus degradation and damping amplification with strain, but is concentrating on saturated sands, and has been working with the development of the self-boring pressuremeter (SBPM) to minimize disturbance. Here the soil modeling is equally difficult, but can handle volume changes in sand in a closed form solution for cylindrical cavity expansion. Much of the research on insertion procedures, disturbance assessment criteria and analytical procedures will be published in the next year. The writer looks forward to seeing the results of the new tool being developed by Roblee and co-researchers and eventually comparing it to those from the SBPM.

8. Campanella et al. on the use of the downhole seismic piezocone (SCPTU) to measure low strain shear modulus and damping of soils. The authors present a detailed description of the straight forward test procedures used to carry out downhole shear wave velocity measurements while the piezocone is used to determine stratigraphy and estimate soil properties, hence the SCPTU can occupy two locations in Fig. 1, stratigraphy and low strain downhole. In addition, they present a detailed procedure and analysis to measure material damping provided one has an appropriate receiver and repeatable shear source. A detailed case history demonstrates the procedures and interpretations at a site underlain by