An Annotated Bibliography

SOIL DYNAMICS AND SOIL RHEOLOGY

by

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PREFACE

A thorough search of the literature has provided an annotated bibliography on Soil Dynamics and Soil Rheology. This work was performed to explore methods of determining dynamic load-deformation and damping properties of soils and to obtain the useful data that are now available. This information has been collected for Research Project No. 2-5-62-33 entitled "Piling Behavior". The broad objective of this project is to fully develop the computer solution of the wave equation for determining pile driving stresses and predicting pile load bearing capacity. The wave equation program uses rheological models to simulate the soil resistance on the pile during driving. Soil spring constants and damping properties are needed to simulate the behavior of the pile-soil system.

In this bibliography the papers are classified into two parts: (1) Soil Dynamics and (2) Soil Rheology. They are listed alphabetically by author. If, in a given category, more than one paper by a particular author appears, the papers are listed chronologically. The papers are numbered consecutively from 1 to 90.

ABBREVIATIONS OF PUBLICATIONS APPEARING IN BIBLIOGRAPHY

AIMME - American Institute of Mining and Metallurgical Engineers.

Ann. Ponts Chauss - Annales des Ponts et Chausses, Paris, France.

ASCE - American Society of Civil Engineers.

ASTM - American Society for Testing Materials.

Bull. Earthquake Res. Inst. Japan - Bulletin of the Earthquake Research Institute, Tokyo University, Japan.

HRB - Highway Research Board.

ICSMFE - International Conference of Soil Mechanics and Foundation Engineering.

IUTAM - International Union of Theoretical and Applied Mechanics.

JSCE - Japan Society of Civil Engineers.

Japan Nat. Cong. Appl. Mech. - Japan National Congress of Applied Mechanics.

Journ. Appl. Math. Mech. - Journal of Applied Mathematics and Mechanics (Translation of the Soviet Journal, Priklanaia Matematika i Meckhanika).

Soil Sci. Soc. Am. Proc. - Soil Science Society of America Proceedings.

SOIL DYNAMICS

1. ASTM Spec. Tech. Publ. No. 156. "Syposium on Dynamic Testing of Soils," Philadelphia, Pa., 1953.

   Contents:

   (1) Introduction (R. K. Bernhard)

   (2) The Elastic Theory of Soil Dynamics (P. M. Quinlan)

   (3) Vibrations in Semi-Infinite Solids due to Periodic Surface Loading (T. Y. Sung)

   (4) A Discontinuous Model for the Problems of Soil Dynamics (J. J. Slade, Jr.)

   (5) Macromeritic Liquids (H. F. Winterkorn)

   (6) Elasticity and Damping Effects of Oscillating Bodies on Soil (H. Lorenz)

   (7) Loose Sands - Their Compaction by Vibroflotation (E. D' Appolonia)

   (8) Performance Records of Engine Foundations (G. P. Tschebotarioff)

   (9) Vibration Research on Road Constructions (C. van der Poel)

   (10) The Pressures Generated in Soil by Compaction Equipment (A. C. Whiffin)

   (11) Pilot Studies of Soil Dynamics (R. K. Bernhard and J. Finelli)

   (12) Bibliography of Publication on Soil Dynamics (Prepared by Subcommittee R-9 on Dynamic Properties of Soils, R. K. Bernhard, Chairman)

2. ASTM Spec. Tech. Publ. No. 305, "Syposium on Soil Dynamics," ASTM, Philadelphia, Pa., 1961.

   Contents:

   (1) Introduction (R. K. Bernhard)

   (2) Biaxial Stress Fields in Noncohesive Soils Subjected to Vibratory Loads (R. K. Bernhard)

(5) Facilities for Dynamic Testing of Soils (G. K. Sinnamon and N. M. Newmark)

(6) The Damping Capacity of Some Granular Soils (G. F. Weissmann and R. R. Hart)

(7) Testing Procedures for Model footings and presentation of TRADEX Site Data (J. A. Alai)

(8) Dynamic Loading Machine and Results of Preliminary Small-Scale Footing Tests (R. W. Cunny and R. C. Sloan)

(9) Bearing Capacities of Dynamically Loaded Footings (S. Shenkman and K. E. McKee)

3. Baskan, D. D., "Dynamics of Bases and Foundations," Translated by L. Drashevska, McGraw-Hill Book Co., Inc., New York, New York, 1962.

This book is divided into three parts, namely (1) elastic and vibratory properties of soils, (2) the theory and design of foundation under dynamic loads, and (3) propagation of elastic waves in soil.

4. Bendel, L., "The Dynamic Triaxial Trials," Proc. 2nd ICSMFE, Vol. 3, Rotterdam, Netherlands, 1948.

A dynamic triaxial apparatus has been developed and experiments have been conducted on cohesive and noncohesive soils under various combinations of vertical and horizontal pressures for both static and dynamic loading. Stress-strain relations, influence of moisture content, frequency and amplitude, and elastic-plastic relations are considered. Static and dynamic penetration of pile like objects are also considered.

5. Bendel, L., "Dynamic Investigations," Proc. 2nd ICSMFE Vol. 3, 1948.

6. Bernhard, R. K., "Geophysical Study of Soil Dynamics," AIMME - Tech. Publ. No. 834, Rotterdam, Netherlands, 1948.

Outline of new geophysical method of dynamic soil tests with application of artificial vibration excited by centrifugal forces resulting from eccentrically supported rotating masses. Results of tests indicate that method opens new field for investigating soil, foundation, dams, and structures.

7. Bernhard, R. K., "Shear Stress Measurements in-situ of Soils Subjected to Vibratory Loads," Exptl. Mech. Vol. 3, No. 4, New York, New York, 1963.

Sinusoidal vertical load at 23 cps was applied to surface of of large mass of coarse sand. At a depth of 6 in., normal and shear stresses were measured with cells incorporating differential transformers. Shear cell consisted of parallel serrated plates connected by leaf springs; dead load calibrations were reproducible with 2%. Readings were made on galvanometer oscillograph with cells oriented each 10 degrees, these were analyzed biaxially. Stresses computed from three measured values were compared with a curve through all measured values; standard deviation was only 5%.

8. Burmister, D. M., "Strain-Rate Behavior of Clay and Organic Soils," ASTM Spec. Tech. Publ. No. 254, Philadelphia, Pa., 1959.

9. Calif. Inst. Tech., "Vibration Compaction of Sand," Pasadena, California, 1952.

10. Calif. Inst. Tech., "Vibration Compaction of Cohesive Soils," Pasadena, California, 1954.

11. Carroll, W. F., "Vertical Displacements of Spread Footings on Clay: Static and Impulsive Loadings," Ph. D. Disser., Univ. of Illinois, Urbana, Illinois, 1964.

12. Casagrande, A., and W. L. Shannon, "Research on Stress Deformation and Strength Characteristics of Soils and Soft Rock Under Transient Loading," Soil Mechanics Series No. 31, Harvard University, Cambridge, Mass., 1948.

A review of past investigations of the mechanical properties of different materials under transient loading, including the description and operation of different test apparatus. Measurements and specimens and the effect of time loading on the strength and deformation of the soils are discussed.

13. Casagrande, A. and W. L. Shannon, "Stress Deformation and Strength Characteristics of Soils Under Dynamic Loads," Proc. 2nd ICSMFE, Vol. 5, Rotterdam, Netherlands, 1948.

This paper describes apparatus developed and results of tests performed to investigate the stress deformation and strength characteristics of soils under dynamic loads. This is in connection with studies of stability of slope under the effect of loading.

14. Casagrande, A. and W. L. Shannon, "Strength of Soil Under Dynamic Loads" Trans. ASCE Vol. 114, New York, New York, 1949.

This paper describes apparatus developed and the results of tests performed to investigate the strength characteristics of soils and soft rocks under dynamic loads.

15. Casagrande, A. and S. D. Wilson, "Effect of Rate of Loading on the Strength of Clays and Shales at Constant Water Content," Geotechnique Vol. 3, London, England, 1951.

Two types of tests were used to study the effect of longtime loading on the compressive strength of soil, (1) creep strength tests and (2) long-time compression tests. This paper describes apparatus developed and results of tests performed to investigate the effect of rate of loading on strength. The entire range of time from 0.001 sec to 1 year. Within this range the strength ratio varies from about 2.0 for the fastest times of loading to about 0.25 for the slowest.

16. Converse, F. J., "Compaction of Sand at Resonant Frequency," ASTM Spec. Tech. Publ. No. 156, ASTM, Philadelphia, Pa., 1953.

The effects on the density of sand due to operating a surface vibratory at the resonant frequency of the vibratory-soil system are described. Experiments with a Lazan oscillator on a sand pit 10 ft square by 6 ft deep are outlined, and an empirical formula for predicting resonance, showing the effects of various parameters, is presented. The results of check tests on beach sand at three sites with different sizes of oscillators are given.

The increases in density due to the operation of both large and small oscillators show that densities of from 90 to 95 per cent of a modified AASHO maximum density may be obtained in a few seconds to depths of twice the width of the oscillator.

17. Converse, F. J., "Stress - Deformation Relations for Soft Saturated Silt Under Low Frequency Oscillating Direct-Shear Forces," ASTM Spec. Tech. Publ. No. 305, ASTM, Philadelphia, Pa., 1961.

Undisturbed samples of soft saturated mud were subjected to oscillating direct shearing forces in order to establish the modulus of rigidity and the energy loss per cycle under conditions occurring during strong earthquakes. The samples were cylinders 2.41 in. in diameter and approximately 1 in. in unconfined height between shear planes. The amplitudes of the diameters were limited to a few thousandths of an inch, and the frequencies were less than 3 cps. The most important factor affecting the modulus of rigidity was the amplitude of deformation. Variations of frequency within the range of 0.5 to 3.0 cps had very little effect on the modulus, but the creep effect became important in very slow oscillations. Amplitude was also the most important factor in the amount of energy loss per cycle.

18. Crawford, C. B., "The Influence of Rate of Strain on Effective Stresses in a Sensitive Clay," ASTM Spec. Tech. Publ. No. 254, ASTM, Philadelphia, Pa., 1959.

19. Davin, M., "Study of the Dynamic Behavior of Stratified Soils," Ann. Ponts. Chauss. Vol. 128, Paris, France, 1958.

Stratified soil homogeneous in the horizontal plane and heterogeneous vertically are subjected to moving loads to produce a sine variation of load intensity. This load becomes a source of wave propagation which for certain velocity functions and with the assumptions of isotropy for modulus of elasticity, Poisson's ratio, celerity yields mathematical expressions for stress and strain. Operational mathematics is used throughout. The method and results are basis for research in the behavior of subgrade under heavy moving loads.

20. Davydov, S. S., "Vibrations in Hetergogeneous Soil in Elastic-Plastic Stage Under Shock Loads," Proc. 5th ICSMFE Vol. 1, Paris, France, 1960.

The paper is aimed at improving the theory of designing underground structures with due regard for dynamic loads applied simultaneously over a considerable area of soil.

A "column" of soil is taken as a design unit; the top of the column is subjected to a shock load which increases (either for a certain period of time or instantaneously), up to its maximum and decreases therefore for a definite period down to zero.

By using the method of characteristics, it is possible to solve the problem for soil with constant and variable moduli of elasticity.

The general conclusion is that sandy and clayey soils should be regarded as heterogeneous, and rock as homogeneous. Since the characteristics in undisturbed soil mass can be determined only with relative accuracy approximate design methods are fully justified for practical use.

21. Durelli, A. J. and W. F. Wiley, "Performance of Embedded Pressure Gages Under Static and Dynamic Loadings," ASTM Spec. Tech. Publ. No. 305, ASTM, Philadelphia, Pa., 1961.

A laboratory program was conducted to study the performancy of small diaphragm and barium titanate pressure gages. The gages were embedded in cylinders in urethan rubber and of clay and were subjected to both static and dynamic loadings. The static loads were applied by means of a ballistic pendulum system.

The results of the investigation show that both types of gages have a higher response to a given applied stress when they are embedded than when they are in air. The embedded gage response of a diaphragm type gage to a dynamic compressive stress is higher than the embedded gage response to an equivalent static compressive stress. The per cent increased in response depends on the gage type and the material properties of the medium in which it is embedded. It was also established in the program that embedded gages respond only to the normal component of stress acting on their sensitive face.

22. Edelman, T. and J. C. Schonfeld, "Statics and Dynamics of Soil," Proc. 5th ICSMFE Vol. 1, Paris, France, 1960.

This paper deals with the plane state of stress and the plane state of strain in a granular material without a liquid phase. It is shown, that the stress pattern in any state of equilibrium differs from the stress-pattern during motion. In general, it is impossible to derive the shape of a rupture-line from an investigation of an equilibrium state of stress, since a rupture-line belongs to a dynamic state of soil.

The pattern of rupture-lines has to be derived from kinematical considerations. It seems to be irrational to carry out stability investigations with the aid of elements belonging to a state of motion.

23. Goto, S., "Measurements of the Elastic Modulus of Clay by Vibration Experiments," Proc. 1st Japan Nat. Cong. Appl Mech., Tokyp, Japan, 1955.

24. Goto, S., "On the Basic Concepts of Soil Dynamics," Journ. Appl. Math. Mech. Vol. 24, New York, New York, 1960.

26. Grigorian, S. S., "On Some Simplifications in the Description of the Motion of a Soft Soil," Stress Waves in Anelastic Solids IUTAM Syposium, Providence, R. I., 1963.

The author discusses different methods in order to simplify the system of equations which were presented in his earlier paper. The simplification of the equations is based upon different cases as follows: (1) when motions are purely elastic case, (2) motions are accompanied by small elastic-plastic strains, (3) the motions with large elastic-plastic deformations but moderate stresses, (4) the motions with large elastic-plastic deformations as well as the stresses are large, and (5) the motion is accompanied by very large stresses.

27. Grigorian, S. S., and F. L. Chernous, "The Piston Problem for the Equations of Soil Dynamics," Jour. Appl. Math. Mech. Vol. 25, New York, New York, 1961.

Writers have studied the problem of wave motion in soil by alternately moving a piston into the soil and withdrawing it, with constant velocity. The function which characterizes the soil material is not explicitly specified, so the results are of a general nature. Starting from the equations established in earlier publications, writers describe the conditions for compression and rarefaction waves, both in the regions of elastic shear and plastic shear.

In the second chapter the shock surface is studied as well as the velocity of small perturbations. In the third chapter these studies are applied to the piston problem.

28. Hardin, B. O., "Study of Elastic Wave Propagation and Damping in Granular Materials," Ph. D. Disser., Univ. of Florida, Florida, 1961.

29. Hardin, B. O., "The Nature of Damping in Sands," Journal of Soil Mech. and Foundation ASCE, 1965.

The problem of determining soil properties in the dynamic range of loading, in which inertia forces must be taken into account, is considered. Analytical solutions for two models, representing closely some of the systems that have been used to study the dynamic properties of solids, are presented. In the solutions, the Kelvin-Voight model has been assumed to represent the material. Although sand is a very complex material and no simple model will completely describe its behavior under all loading conditions. The Kelvin-Voight model can be a useful tool for describing the behavior of dry sand subjected to small amplitude sinusoidal vibration, over a large frequency range. Experimental results are obtained from steady state and free vibration and static torsion tests. The tests show that for shear strain amplitudes in the order of 10^{-6} to 10^{-4}, for confining pressure between 50 psf and 3,000 psf and for frequencies less than 600 cps, the viscosity should be assumed to decrease with frequency such that the ratio, viscosity time frequency divided by shear modulus, is a constant with frequency in order to use this model. Values of this ratio for dry sand are given.

30. Hardin, B. O. and F. E. Richart, Jr., "Elastic Wave Velocities in Granular Soils," Journ. Soil Mech. and Foundation, ASCE, 1963.

Laboratory tests, using the resonant column method, were conducted to evaluate the longitudinal and shear wave velocities in specimens of Ottawa sand, crushed quartz sand, and quartz silt. The variables considered were the confining pressure, and the moisture content, void ratio, and grain characteristics of the materials. The wave velocities for the sand varied with approximately the 1/4 power of the confining pressure, it was found that the void ratio was most significant variable; the wave velocity varied almost linearly with void ratio. The effects of relative density, grain size, and gradation entered only through their effects on void ratio. The wave velocities in the quartz silts were found to be greatly dependent on time.

31. Heierli, W., "One-dimensional Inelastic Wave Propagation in Soils: Experimental and Theoretical Investigations," Stress Waves in Anelastic Solids IUTAM Syposium, Providence, R. I., 1963.

Plane waves in one-dimensional inelastic bodies of soil are investigated. The dynamic stress-strain diagram of two types of soil, sand and gravel, is determined in an oedometer operated dynamically. A theory is developed for the calculation of plane waves in any kind of nonlinear inelastic material with heterogenities and any type of reflective surfaces. Examples show that great influence of inelasticity on the propagation and attenuation of stress waves. Wave propagation experiments were conducted, and the results are compared to the theoretical findings.

32. Hejazi, H., "The Influence of Forced Longitudinal Vibrations on Rods Penetrating Soils," Ph. D. Disser., The Ohio State Univ., Columbus, Ohio, 1963.

This paper was concerned with theoretical analyses of penetration of rods into soils under the influence of forced longitudinal vibrations.

First, the rod was considered as a rigid body and the soil was treated as a linear spring in one case and nonlinear soft spring in another. The soil resistance was replaced by an equivalent viscous damping. The linear vibration theory was applied in the case of small amplitudes. The nonlinear vibration theory was applied in the case of large displacements, and the equation of motion was solved by the perturbation and iteration methods.

33. Housel, W. S., "Dynamic and Static Resistance of Cohesive Soil 1946-1958," ASTM Spec. Tech. Publ. No. 254, ASTM, Philadelphia, Pa., 1959.

34. Iida, K., "Relation Between Normal - Tangential Viscosity Ratio in Soils," Bull. Earthquake Res. Inst. Vol. 14, Tokyo, Japan, 1936.

35. Ishimoto, M. and K. Iida, "Determination of Elastic Constants of Soils by Vibration Methods," Bull. Earthquake Res. Inst. Vol. 14 and Vol. 15, Tokyo, Japan, 1936-37.

36. Jacobsen, L. S., "Motion of Soil Subjected to a Simple Harmonic Ground Vibration," Bull. Seismo. Soc. Am. Vol. 20, Baltimore, Maryland.

37. Johnson, R. W., "Physical Characteristics of Sand-Soil Mixture Under Repeated Dynamic Loads," Ph. D. Disser. Purdue Univ., Indiana, 1961.

38. Jones, R., "In-Situ Measurement of the Dynamic Properties of Soil by Vibration Method," Geotechnique Vol. 8, London, England, 1958.

Application of vibration methods to determine in-situ soil properties is described in two parts of the paper. Part I describes determination of soil properties from measurement of phase velocity of surface vibration within the frequency range of 35 to 400 cps. Using known theory, average values for dynamic shear modulus from resonant frequency of a mass vibrating perpendicular to the soil surface.

Both methods are based on existing theory and show good correlation for the soil type tested.

39. Koehler, A. M., "Stress-strain Properties of Soil - Aggregate Subjected to Rapid Loading," Ph. D. Disser., Texas A&M Univ., College Station, Texas 1964.

This research is concerned with an investigation of the shape of the dynamically deformed soil-aggregate specimen and relates qualitatively and quantitatively the effect of the lateral deformations upon the stress-strain characteristics of the material.

The partial differential equations of motion were developed for a cylinder using polar coordinates and the boundary conditions for the cylinderical problem were discussed.

A review of methods of measuring lateral displacement were discussed together with the development of a lateral deformation transducer used to measure dynamic lateral movements of a cylindrical specimen subjected to repetitive loadings.

40. Kondner, R. L., "The Static and Dynamic Phenomenological Macrorheology of Cohesive Soils," Dr. Engr. Disser., The John Hopkins Univ., Baltimore, Maryland, 1961.

The phenomenological macrorheology of a cohesive soil is described with viscoelastic parameters determined by stress relaxation, creep, and dynamic testing methods. The creep and stress relaxation studies were conducted in uniaxial compression and the dynamic studies were conducted in vibratory uniaxial compression and vibratory simple shear. The dynamic variables considered include the frequency of vibration, ratio of vibratory stress amplitude to static stress, amplitude of strain, specimen size, damping, and strain-rate effects. The use of rheological models as an aid to the understanding of the material response is used. The methods of dimensional analysis in conjunction with small-scale model as the tool to study the rheologic models.

41. Kondner, R. L., and R. J. Edwards, "The Static and Vibratory Cutting and Penetration of Soils," Proc. HRB, Washington D. C., 1960.

42. Lara, M., "Research on the Time-Dependent Deformation of Clay Soils Under Shear Stress," Ph. D. Disser., The Ohio State Univ., Columbus, Ohio, 1961.

43. Lorenz, H., "Dynamics of Foundations," (in German) Springer-verlag, Germany, 1960.

It is devoted to analysis of soil and soil-supported structures under influence of forced vibrations. After the introduction in the first chapter, the second chapter gives an analysis of harmonic vibrations of elastically supported plannar bodies and non-damped and damped vibrations of systems of bodies, as they appear in machine foundation design. Third chapter deals with dynamics of framed structures. It repeats results by Hohenemser - Prager "Dynamik der Stabwerke" (1933).

Fourth chapter is devoted to soil dynamics and gives results of long lasting experiments of Hertwig, Lorenz and others, which were begun about 1930 in Berlin in Degebo Society. Starting from analysis of vibrating point on elastic half-space, there is analyzed a dynamic investigation of soil properties, further vibratory compaction of soil, and finally vibratory driving of piles and sheet piles.

44. Mass. Inst. Tech., "The Behavior of Soils Under Dynamic Loadings." Mass. Inst. Tech., Cambridge, Mass.

Report 1. Hydraulic Machine for Dynamic Compression Tests, 1952.

Report 2. The Interim Report on Wave Propagation and Strain Rate Effect, 1952.

Report 3. Final Report on Laboratory Studies, 1954.

45. Mass. Inst. Tech., "The Response of Soils to Dynamic Loadings." Mass. Inst. Tech., Cambridge, Mass.

Report 1. Scope of Test Program and Equipment Specifications, 1957.

Report 2. Test Equipment for High Speed Triaxial Tests, 1959.

Report 3. First Interim Report on Dynamic Soil Tests, 1959.

Report 4. One Dimensional Compression and Wave Velocity Tests, 1960.

Report 5. Pore Pressure Measurement During Transient Loadings, 1960.

Report 6. Effects of Rate-of-Strain on Stress-Strain Behavior of Saturated Soils, 1961.

Report 7. Adaption and Use of the Boyton Device for Rapid One-Dimensional Compression Tests, 1961.

Report 8. Laboratory Measurement of Dilational Wave Propagation Velocity, 1961.

Report 9. Shearing Resistance of Sands During Loading, 1962.

Report 10. Strength of Saturated Fat Clay, 1962.
Report 11. Triaxial Tests upon Saturated fine Silty Sand, 1962.
Report 12. Static Tests Upon Thin Domes Buried in Sand, 1962.
Report 13. The Dependence of Dilation in Sand on Rate of Shear Strain, 1962.
Report 14. Propagation Velocity of Ultrasonic Waves Through Sand, 1963.
Report 12. Undrained Strength of Saturated Clayey Silt, 1963.

46. Mass. Inst. Tech., "The Behavior of Soil Dynamic Loadings", Summer Program, Cambridge, Massachusetts, 1962.

Contents:

(1) Introductory and Review Material
  (i) Introduction to Soil Dynamics (R. V. Whitman)
  (ii) Dynamical Principles (S. H. Crandall)
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  (xvii) Experiments and Applications concerning One-Dimensional
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(4) Foundation Vibrations and Pavement Deflections
  (xix) Resilience Characteristics of Subgrade Soils and Their Relation to Fatigue Failures in Asphalt Pavement (H. B. Seed, C. K. Lee and C. E. Lee)

(xx) Foundation Vibrations (F. E. Richart, Jr.)

47. Mogami, T. and K. Kubo, "The Behavior of Soil During Vibration," Proc. 3rd ICSMFE Vol. 1, Zurich, Switzerland, 1953.

Some experiments on the behavior of sand and loam when subjected to vertical harmonic vibration are described and results are given. The shearing strength of the tested materials diminishes considerably with increasing acceleration of vibration. This effect, called "Liquefaction" by the authors, may explain the weak soil as observed during earthquakes. Further change in the density of the material during vibration is considered.

48. Mogami, T., H. Yamaguchi, and A. Nakase, "The Dynamical Properties of Soils," 1st Report Univ. of Tokyo, Tokyo, Japan, 1954.

The direct shear tests were performed on the statical and dynamical resistance of so-called Kanto-Loam.

The results of these studies may be summarized as follows:

(1) The shearing resistance of both undistrubed and disturbed clay are influenced by the shearing speed.

(2) The lowering of yield value by vibration, in case of disturbed clay, may depend on the acceleration of vibration.

(3) The empirical formula which represents the relationship between shearing load and shearing deformation was obtained.

49. Mogami, T., H. Yamaguchi, and A. Nakase, "The Dynamical Properties of Soils," 2nd Report Univ. of Tokyo, Tokyo, Japan, 1955.

50. Murayama, S., and T. Sibata, "On the Dynamic Consolidation of Clay," Trans. JSCE Vol. 62, Paper No. 9, Tokyo, Japan, 1959.

This is a report of theoretical and experimental research on the dynamic consideration of clay. Assuming that the clay constitution has the Burger's rheological model. A fundamental formula concerning the dynamic consolidation is derived, and the experimental results are analyzed in order to give some quantitative characteristics of dynamic consolidation of clay.

51. Parkin, B. B., "Theory compared with Experiments of Sand Columns," Trans. ASCE Vol. 127, Part 1, New York, New York, 1962.

A phenomenological theory is developed in order to study the propagation of unidimensional compression wave in columns of sand. The medium of the theory is treated as an elastic-plastic continuum. It is assumed that each element of the substance exhibits a strain-rate effect such that, at a given strain, the plastic strain-rate is proportional to the difference between the compressive stress on the particle and the stress which would act on the element under static conditions. Published experimental results on the propagation of stress waves in sand are used as a basis of comparison between experiment and theory. The present theory gives satisfactory agreement with experiments on stress propagation in two dry sands.

52. Parkin, B. B., "Impact Waves in Sands--Implications of an Elementary Theory," Trans. ASCE Vol. 127, Part 1, New York, New York, 1962.

Some implications of an elastic-plastic theory for the propagation of uni-dimensional compression waves in dry Ottawa sand are examined. The theory, which contains an explicit strain rate effect, has previously been found to give good agreement with experiment. Results from it are compared with elastic and plastic theories of wave propagation in soils. Problems associated with the use and experimental determination of "dynamic" stress-strain curves are considered. Laws of similitude required by the present theory are examined. Tentative design data on the response of impact pressure gages are developed.

53. Pauw, A., "A Rational Design Procedure for Machine Foundations," Ph. D. Disser. Calif. Inst. Tech., Pasadena, California, 1952.

54. Pauw, A., "A Dynamic Analogy for Foundation-Soil Systems," ASTM Spec. Tech. Publ. No. 156, Philadelphia, Pa., 1953.

This paper presents a procedure whereby the dynamic soil constants required for the accurate prediction of the natural frequencies of a foundation-soil system may be determined. The foundation-soil system is treated by considering the foundation mass to be supported by a truncated pyramid of "soil springs." By the use of this analogy, the effect on the spring constants of the size and shape of the contact area and the effect of increasing soil modulus with depth may be evaluated. The analogy further permits the computation of the effective or apparent mass of soil moving with the foundation.

Analytical expressions are derived for the dynamic soil constants and are presented in graphical form to permit rapid calculation. The equations of motion for a block foundation are next discussed and sample calculations for determined the natural frequency of a typical foundation are shown. In conclusion the accuracy of the procedure is demonstrated by comparing computed frequencies with the frequencies observed on experimental foundations.

55. Perloff, Jr., W. H., "The Effect of Stress History and Strain-Rate on the Undrained Shear Strength of Cohesive Soils," Ph. D. Disser., Northwestern Univ., Chicago, Ill., 1962.

56. Peters, John D., "A Gage for Measuring Pore Water Pressures in Soils Under Dynamic Loads," Ph. D. Disser., Univ. of Illinois, Urbana, Ill., 1963.

57. Richardson, Jr., A. M., and R. V. Whitman, "Effect of Strain-Rate Upon Undrained Shear Resistance of a Saturated Remolded Fat Clay," *Geotechnique*, Vol. '3, London, England, 1963.

Normally consolidated specimens were tested in triaxial compression using two strain rates: 1% strain in 1 minute and 1% strain in 500 minutes. In some tests, the rate-of-strain was changed during shear. Pore pressures were measured at the center of the specimen, and the possible effects of internal mositure migration were studied.

The peak shear resistnace increased about 10% in passing from the slow to the fast strain-rate; at small strains, the resistance increased as much as 100%. The increase in resistance with increase in strain-rate resulted: (1) at small strains, from increased strength in terms of effective stress, and (2) at large strains, from decrease excess pore pressure.

Results from tests upon heavily over-consolidated specimens are also included. Internal moisture redistribution controlled the behavior of these specimens.

58. Seed, H. B., and R. Lungren, "Investigation of the Effect of Transient Loading on the Strength and deformation Characteristics of Saturated Sands," *Proc ASTM* Vol. 54, Philadelphia, Pa., 1954.

This paper describes the investigation of the effect of transient loading on the strength and deformation by triaxial compression tests, of the drained and undrained types, on specimens of fine and coarse sand at different rates of loading. The main conclusions resulting from the tests performed may be summarized as follows:

(1) The strength increase caused by dilatancy and lack of drainage, deformation of a dense sand at a rate of 40 in. per sec causes an increase in strength of about 15 to 20% over the strength for normal rates of loading; a rate of deformation of 6 in. per minute has no measurable effect on the strength for normal rates of loading.

(2) Laboratory tests on dense, saturated specimens of coarse and fine sand using a confining pressure of 2 kg per sq cm show that if no drainage can occur dilatancy effects will cause the strength to increase.

(3) The effects of rate of loading and dilatancy on the strength of a saturated sand decrease as the void increases.

(4) For strains up to 2%, the modulus of deformation determined by a rapid transient test on a specimen of saturated fine sand is about 30% greater than that determined by a static test on similar specimen of equal void ratio.

59. Shannon, W., G. Yamane, and R. J. Dietrich, "Dynamic Triaxial Tests on Sand," 1st Pan Am. Conf. Soil Mech. and Foundation Engineering, Mexico City, Mexico, 1960.

This paper presents an investigation of the dynamic modulus of elasticity of sand including the effect of stress condition on the modulus. A comparison is presented between the dynamic modulus and static modulus with the effect of creep removed. Tests have been limited to standard Ottawa sand in the dry condition with minor principal stress ranging from 5 to 100 psi.

60. Sinnamon, G. K. and N. M. Newmark, "Facilities for Dynamic Testing of Soils," <u>ASTM Spec. Tech. Publ.</u> No. 305, Philadelphia, Pa., 1961.

The authors describe some testing facilities which have been develope at the University of Illinois. These testing facilities are of pneumatic type. Equipment is available which will apply a concentrated load of 60 kips to a loading pad in as short a time as 2 milliseconds or apply a uniform pressure of 500 psi to the top of a soil specimen 2 ft in diameter and 2 ft deep in as short a time as 6 milliseconds. Additional facilities currently in the design stage will be built which will be able to supply a uniform pressure up to 800 psi in as short a time as 3 milliseconds.

61. Sung, T. Y., "Vibrations in Semi-Infinite Solids due to Periodic Surface Loading," <u>ASTM Spec. Tech. Publ.</u> No. 156, Philadelphia, Pa. 1954.

This paper is an analytical study of the behavior of an elastic foundation that is subjected to a periodic loading on a portion of its top surface.

The foundation is regarded as an elastic, isotropic and homogeneous semi-infinite solid, or half-space. The periodic pressure forces, distributed axial symmetrically over a circular region of the surface, represent the action of a mechanical oscillator which rests on the foundation.

The study is essentially an extension of a previous analysis by E. Reissen, but the additional complication arising from a change in pressur distribution at the oscillator base is also considered. Three assumptions were made which defined the distributions of pressure as (a) uniform, (b) parabolic and (c) that produced by a rigid base in the static case, at the surface of the foundation.

The resonant frequency, the amplitude of oscillation and the input power requirement were shown to depend on the pressure distribution as well as upon the characteristics of the oscillator-foundation system. These characteristics are determined as functions of the radius of the foundation, and the radius of load area, the static weight of the oscillator, the material constants of the foundation, and the radius of rotation as well as the rotating mass. The effects of these variables are shown by a series of curves.

By use of these curves, it is possible to evaluate the elastic constants of a given foundation by means of suitable tests. These elastic constants may then be used as a basis for computing the critical frequency, the amplitude of oscillation, and the power requirement for a wide range of oscillator-foundation combinations.

62. Taylor, P. W., and B. K. Menzies, "The Damping Characteristics of Dynamically Stressed Clay," 4th Aus. -N. Z. CSMFE, Melbourne, Australia, 1963.

Damping characteristics of soils were investigated. The apparatus used embodies the cell of a triaxial compression machine. Cell pressure oscillatory load is applied axially. The motion is sinusoidal, of constant amplitude. Strain gage transducers are used to measure deformation and axial load. Outputs from the strain gage bridges, suitably amplified are fed to the horizontal and vertical plates giving the stress-strain hysteresis loop. Photographs of the image, together with the direct measurements of peak values, enable results to be evaluated quantitatively.

63. Tschebotanoff, G. P., "Effects of Vibrations on Bearing Properties of Soils," Proc. HRB, Vol. 24, Washington, D. C. 1944.

64. Tsien, H. S., "On the Basic Equations of Soil Dynamics," Problems of Continuum Mechanics, Contributions to N. I. Muskhelishvili, Soc. Indust. Appl Math., Philadelphia, Pa., 1961.

On the basis of the equations of N. M. Gersevanov, the author derived his basic equations by introducting T. K. Tan's concept on soil skeleton. The basic equations include: (1) stress-strain equations, (2) equations of motion for the solid phase, (3) equations of motion for the liquid phase, and (4) equation of continuity.

65. Whitman, R. V., "The Behavior of Soils Under Transient Loading," Proc. 4th ICSMFE Vol. 1, London, England, 1957.

A hydraulic apparatus and special instrumentation were constructed to test triaxial soil samples. Failure was achieved in times as short as 0.001 sec. Curves of compressive strength verses strain-rate were determined for cohesive soils, dry sands, and saturated sands. Transient pore-water pressure was recorded during tests on saturated sands. Another apparatus was constructed to study wave propagation. Soil samples, 2 in. in diameter and 32 in. long, were struck at one end by a ram. Results for a dry sand were compared with theoretical solutions for the wave propagation problem. Other tests were devised to study creep and relaxation phenomena in dry sands, and to study the permeability of saturated sands to pressure gradients applied suddenly.

66. Whitman, R. V., "Testing Soils with Transient Loads," ASTM Spec. Tech. Publ. No. 232, Mexico City, Mexico, 1957.

This paper presents a brief discussion on the present state of knowledge concerning the strain-rate effect in dry and saturated sands, and in cohesive soils. Techniques for the performance of strain-rate tests are discussed. Conclusions drawn from the paper lead to suggestions for the guidance of future research.

67. Whitman, R. V. and K. E. Healy, "Shearing Resistance of Sands During Rapid Loadings, Trans. ASCE Vol. 127, Part 1, New York, New York, 1963.

Triaxial tests with times-to-failure ranging from 5 minutes to 5 milliseconds have been used to investigate the effect of strain-rate on the strength of dry and saturated sands. New techniques were developed for applying strains rapidly, and for measuring the resultant stresses and pore pressures. It was necessary to give careful attention to the possible influence of testing errors, of inertia forces, and of the membrane effect.

The peak friction angles of the sands that were tested were substantially independent of failure-time. However, the excess pore pressures generated within saturated loose sands did, for certain conditions, vary with failure-time, and for these conditions the compressive strengths were correspondently time-dependent. A tentative hypothesis has been advanced to explain this behavior. One loose saturated sand exhibited a pronounced yield point stress decreased as the rapidity of load application increased.

68. Winterkorn, H. F., "Macromeritic Liquids," ASTM Spec. Tech. Publ. No. 156, Philadelphia, Pa., 1953.

In the theoretical study of the response of a soil system to dynamic loading, one usually makes the assumption that the soil system represents essentially a perfect elastic, isotropic medium, introducing later adjustments and corrections to take care of the nonideal behavior of actual soils. However, if one tests the general validity of a formula by applying it first to extreme conditions, in qualitative thinkings, which should precede every quantitative formulation, it is justified and often very profitably to start with extreme concepts. For the case under condition, one extreme concept is to consider the soil as a perfectly elastic, isotropic medium; the other extreme is to consider as an actual or potential macromeritic liquid. The latter approach has been employed in this exploratory paper for this case of sand assembles.

69. Bedesem, W. B., "A Continuum Theory of Soil-Structure Interaction in Granular Media," Ph. D. Disser., Univ. of Illinois, Urbana, Ill., 1964.

70. Bucknam, R. E., "A Rheological Investigation of Kaolinite Slurries in Terms of Effective Stresses," Ph. D. Disser., Univ. of Illinois, Urbana, Ill., 1964.

The shearing strength characteristics of clay soils below the liquid limit have been investigated in the laboratory by use of the triaxial shear spparatus.

The object of this investigation was to develop a type of shear apparatus which would afford observations of the shearing behavior at large strains of soils with water contents at and above the liquid limit in terms of effective stresses. It was also desired to observe the effects of variations in water content sample pH and shear strain-rate on pore pressure strain phenomena.

71. Christensen, R. W., "Analysis of Clay Deformation by Rate Process Theory," Ph. D. Disser., Michigan State Univ., Ann Arbor, Mich., 1964.

The deformational characteristics of clays are analyzed from the point-of-view of the particle structure utilizing rate process theory. The deformations at the particle bond as a rate process. Theoretical considerations concerning the nature of the particle structure, and the physical aspects of deformation processes are presented. A schematic model is used to represent the behavior of the particle structure under load.

Creep and relaxation data obtained from specimens prepared in the laboratory and undisturbed specimens are presented.

72. Christensen, R. W. and T. H. Wu, "Analysis of Clay Deformation as a Rate Process," Jour. Soil Mech. and Foundation ASCE, Vol. 90, 1964.

73. Hecbtl, Hans-Christian, "Impact Tests on Soils and Their Significance for Trafficability," Ph. D. Disser., Princeton Univ., Princeton, New Jersey, 1964.

74. Geuze, E. C. W. A., and T. K. Tan, "The Mechanical Behavior of Clays," Proc. 2nd Intern. Cong. on Rheology, Oxford, England, 1953.

75. Klansner, Y., "The Mechanical Behavior of Soils," Princeton Univ., Princeton, New Jersey, 1959.

The formulation of the mechanical behavior of soils in this paper is based on the new theoretical approach. This is basically a rheological conception of the behavior of materials which was extended to soils.

A distinction between volumetric and shear stress-strain relationship has been made and each has been formulated separately in the form of rheological equations which are considered by the author to be the fundamental equations in soil rheology.

76. Klausner, Y., "Volume Rheology of a Two-Phase System," Princeton Univ., Princeton, New Jersey, 1959.

The general volumetric stress-strain relationship of a two-phase system is formulated here in such a way to allow for elastic, viscous (creep) and retarded deformation, and it includes the effects of a plastic restraint. It is represented by a degenerated model of three Kelvin elements in series, coupled in parallel with an infinite series of St. Venant elements.

It is believed that this stress-strain relationship holds for most materials, which may be considered as two-phase systems.

77. Krizek, R. J., "Investigation of the Stress-Strain-Time Response Spectra," Ph. D. Disser., Northwestern Univ., Chicago, Ill., 1963.

This study investigates the one-dimensional stress-strain-time behavior of a remolded plastic clay. The concept of a compliance function is employed to represent soil behavior over approximately nine decades of the time spectrum. Experimental data within this time range obtained from both transient and steady state testing techniques and formulated in terms of the Gaussian Error Integral. This integral permits the unified presentation of observed material response by a coherent phenomenological expression and from quasi-static response characteristics.

The method of analysis illustrated a possible technique for the rational development of a more comprehensive relation. The approach is based on the principle of continuum mechanics, and the theory of linear viscoelasticity is found to be very advantageous as a qualitative aid in describing complicated soil behavior. In particular, the analysis of a quasi-descriptive linear rheological system over the time spectrum considered provides valuable insight into the anticipated behavior of a nonlinear material, such as soil, as in soil mechanics. However, the quantitiative constitutive equation of this study originates in the observed, experimental measurements and is not based on mathematical analysis alone or the assumption of a combination of Hookean and Newtonian elements.

78. McMurdie, J. L., "Some Characteristics of the Soil Deformation Process," Soil Sci. Soc. Am. Proc. Vol. 27, 1963.

Existing deformation theories--infinitesimal and finite deformation elasticity theory, plasticity theory, and linear viscoelasticity--were discussed on their applicability to soils. Analysis of data obtained on a Yolo Loam utilizing triaxial compression equipment showed that compression is nonlinear, finite, irreversible, that the component ratios such as Young's modulus and Poisson's ratio were not constant during the deformation process, and therefore elasticity is not generally applicable. Plasticity theory was found to be unsatisfactory as a general theory because of its assumption of a region of Hookean behavior or of yield after only small deformations, neither of which condition holds for soils. Performance of creep tests showed that the basic assumption of viscoelasticity theory, the time-independence of the relationship between stress and strain states, is valid for soils. It is concluded that viscoelasticity offers the best hope for deformation theory for soils.

79. Goldstein, M. N., V. Misumsky, and L. S. Lapidus, "The Theory of Probability and Statics in Relation to the Rheology of Soils," Proc. 5th ICSMFE Vol. 1, Paris, France, 1960.

The authors discuss the application of the theories of probability and statics to soil mechanics. Now results of rheological investigations undertaken by the authors are described, and experimental equations of elastic deformation, and viscous flow of soils are given. A theoretical method of determining the rate of mining subsidence is put forward, taking creep into account and a comparison with field measurement.

80. Murayama, S. and T. Shibata, "Rheological Properties of Clays," Proc. 5th ICSMFE Vol. 1, Paris, France, 1960.

The viscosity of clay is assumed to be a structural viscosity derived from statistical mechanics and based on the frequency of the mutual exchange of position between each water molecule and its void in a bond material containing soil, particles. A mechanical model of clay is constructed by introducing the structural viscosity. The authors have developed a formula relating deformation and strength of clay with this model.

81. Reiner, M., "Lectures on Theoretical Rheology," North-Holland Publ. Co., Amsterdam, Netherlands, 1959.

82. Saada, A. S., "A Rheological Investigation into Shear Behavior of Saturated Clay Soils," Ph.D. Disser., Princeton Univ., Princeton, New Jersey, 1961.

83. Schiffman, R. L., "The Use of Visco-Elasticity Stress-Strain Laws in Soil Testing," ASTM Spec. Tech. Publ. No. 254, Philadelphia, Pa., 1959.

84. Tan, T. K., "Investigations on the Rheological Properties of Clays," (in Dutch with English Summary) Dr. Ing. Disser., Technische Hogeschool Te Delft, Holland, 1954.

85. Tan, T. K., "Structure Mechanics of Clays," Soil Mech. Lab., Harbin, China, 1957.

This paper presents the study of the rheological properties of clays of tests which have been carried out with the help of torsion plastometers. It is found that the internal stresses decrease with the time, when a clay is subjected to a constant deformation. A tentative analysis of the structure mechanics of clay is presented. The author is inclined to believe that bound water only plays a secondary role as compared with the bonding forces between mutually connected plate-shape clay particles. It is shown that the structure mechanics of clays quite well can be based on the concept that the clay particles should form a network.

86. Terzaghi, K., "The Rigidity of Plastic Clays," Journ. of Rheology, Vol. 2, Philadelphia, Pa., 1931.

87. Vialov, S. S. and A. M. Skibitsky, "Problems of the Rheology of Soils,: Proc. 5th ICSMFE Vol. 1, Paris, France, 1960.

The initial rheological relationships are concerned with the rheological phenomena applicable to a compound stress condition. Principles for calculating creep and continuous strength of soils are given. The peculiarities of creep in dense clays are considered. These are explained on a rheological model, and a law of variation of viscosity is established.

88. Waldron, L. J., "Soil Visoelasticity: Superposition Tests," Soil Sci. Soc. Am. Proc. Vol. 28, Madison, Wisconsin, 1964.

Viscoelasticity is a linear deformation theory in which time-dependent of stress-strain ratios conforms to the Boltamann superposition principle. These types of superposition tests were made on briquets of Yolo silt loam subjected to torsional deformation. The principle was found to be valid when stress, stress duration, and soil water content were kept below certain limits were exceeded first as non-Newtonian flow rather than as Non-Hookean (instantaneous) elastic response. Where the principle applies, there is a structural stability under deformation which makes viscoelasticity promising for relating mechanical behavior to soil-water structure.

89. Waldron, L. J., "Viscoelastic Functions for Soil," Soil Sci. Soc. Am. Proc. Vol. 28, Madison, Wisconsin, 1964.

Three viscoelastic functions which describe the stress-strain and time relations for two types of loading were obtained when the soil was in equilibrium with humidities ranging from 15 to 90% at 70°F. Three functions were the shear creep, compliance, the distribution of relaxation times, and the complex shear compliance. The functions were very sensitive to small changes in water content. Equal time shear creep compliances were exponential functions of water content. Increasing temperature from 40° to 100° F apparently did not change the rates of deformation process uniformly since temperature coefficients of equal-time compliances reversed sign as the stress duration passed from 1 to 7200 sec. The functions are discussed in terms of a two phase concept.

90. Yalcin, A., "The Rheology of Clays and Thixotropic Phenomena," Ph. D. Disser., Univ. of Toronto, Ontario, Canada, 1961.