No. Z-29 REPORT ON A JOINT MEETING OF THE COMMITTEE ON FOUNDATIONS AND SOIL MECHANICS OF THE SOCIETY FOR THE PROMOTION OF ENGINEERING EDUCATION, AND OF THE COMMITTEE ON THE STANDARDIZATION OF SYMBOLS AND CONVENTIONS

The meeting was called to order on June 27, 1936, at 9.15 A.M. by Professor A. Casagrande, Chairman of both committees. There were about 25 members of the Conference present, of whom 16 participated in the lively discussion which lasted until the meeting adjourned at 12.45 P.M.

Considerable controversy developed on the question whether soil mechanics should be taught to undergraduates. It was suggested by several members that a summer school on soil mechanics should be held by prominent men of this field to permit engineering teachers to receive satisfactory instruction. Also, the need for a text book on soil mechanics was repeatedly stressed.

The members were urgently requested to submit their discussions in written form. Unfortunately only 8 members responded. The following discussions appear in the same order in which they were presented at the meeting:

No. Z-29a OPENING DISCUSSION

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One year ago the Executive Council of the Civil Engineering Division of the Society for the Promotion of Engineering Education established several committees in the various field of civil engineering. I accepted the chairmanship of the committee on Foundations and Soil Mechanics with the understanding that during the first year of its existence the committee would devote its efforts to preparations for this Conference. I am glad to report that members of the Committee have actively supported the Conference by the preparation of contributions and by stimulating interest among practicing engineers.

With the conclusion of the Conference begins a new period for us in which the large amount of material contained in the Proceedings will have to be carefully studied and evaluated. It is in connection with this work that the S.P.E.E. committee and the new committee on Symbols and Conventions should be of real service.

Instruction in Soil Mechanics. The most serious handicap which is confronting teachers of soil mechanics is the appalling lack of sufficiently detailed publications on important recent developments in this field. While our Conference has undoubtedly filled this need to a large extent, there are still great gaps which demand an answer to the question of how to teach this subject if the latest information is not readily available.

It seems to me that for an introduction into soil mechanics it is not essential that all the latest advances be included. Also, it is too much to expect that an instructor who, in addition to a heavy teaching load, is shouldering voluntarily the task of teaching an elementary course on soil mechanics, should possess an up-to-date knowledge of this subject. However, it is absolutely necessary that he should realize how incompletely this field is developed, and that tomorrow some discovery may throw overboard something which he is inclined to consider an established "fact". He must realize that this subject requires a different method of presentation than, e.g., statics and structures which are so well advanced that the instructor can or should be able to answer the questions which come up in class. In soil mechanics it is not only undesirable, but actually detrimental, to convey to the student the impression that the knowledge which is imparted to him, is definitely established. If the subject is correctly taught, pointing out weaknesses in our theories, errors influencing our soil tests, discussing various possibilities of approach to each problem, stressing the necessity of further investigations, and warning the student that the worst mistake one can make in soil mechanics is to generalize on the basis of a relationship derived from tests on a few types of soil; any intelligent student will have dozens of questions to ask which will go beyond our present knowledge. It is only by such an approach that the student can develop independence in thinking and the critical attitude and resourcefulness, which are more essential for the practical application of soil mechanics than what he learns of the subject matter itself.

I believe that in many ways soil mechanics lends itself splendidly to the correct training of the minds of engineers-to-be. It lifts them to a level from where they can see the subjects of mechanics, theory of elasticity, and properties of materials in their true and very interesting relationships. Especially the nature of "stress and strain" in its full meaning can be more fully understood from the study of materials with so wide a range of possible combinations, as is the case with soils.

I wish to take this opportunity to reply to an objection which has been repeatedly raised against my ideas on instruction in soil mechanics. Some of my colleagues maintain that soil mechanics should not be taught as I am recommending it, because it creates too much confusion in the mind of the student; that the student must believe the things which the instructor presents in class; and finally, that there can be no serious harm even if later developments should prove that some of the conceptions, methods and formulae are wrong, since the pioneers in this field had believed it themselves at one time without hurting their ability and initiative for progressing further. This argument sounds very convincing. However, there is a fundamental difference in the mental attitude of a "pioneer" and of a

student toward his subject. The man who is actively engaged in research has a background of experience which has taught him again and again that what he believe today he may discover to be wrong tomorrow. He is, therefore, ready and willing to abandon his beliefs, and sometimes waiting for the moment when a new discovery will force him to change his ideas. How very different from this is the attitude of a student, especially when he likes his teacher. This can be noticed particularly after the student has left school. A feeling of loyalty to their teachers and to their Alma Mater misleads even very open-minded men, many years after leaving college, to defend stubbornly the ideas which their teachers have imparted to them. Should it be a coincidence that so many outstanding engineers and scientists have won their fame in a field remote from the subjects on which they spent their greatest efforts in college? And in those cases where they remained in the field of their study one can trace it almost invariably to a teacher who really taught his students to think and to question every thought offered them from outside.

It is unfortunately very little realized how difficult it is for a student to free himself of fundamental ideas which he has learned in school from teachers who had not the faculty to train their students to critical, independent thinking. Such ideas are then dragging through his life like invisible chains, hampering his professional progress.

Thus, the question of how to teach soil mechanics really boils down to the question of how to instruct the teachers themselves. There is no doubt that at the present state of development this is a very difficult undertaking and I hesitate to offer any suggestions. There is one point, however, which I do wish to bring out. I know of no better guide for anyone who desires to learn the right mental attidude toward soil mechanics than by carefully studying Professor Terzaghi's masterly exposition of the development of this science in his opening address of the Conference. (Printed in this volume.) I, myself, have read this address a number of times and I am so deeply impressed by it that I shall make it compulsory for my students to analyze and interpret each chapter of soil mechanics, after it has been presented, in the light of the contents of Terzaghi's paper. I believe that its significance goes far beyond our subject, since it contains in exceptionally clear language an analysis of research in engineering that embraces all engineering sciences.

(Note: The following remarks were not made at the meeting but are added at this place, in consideration of their bearing on the question of instruction and self-education in soil mechanics.)

Since publication of the first two volumes of the Proceedings I have been subject to critical remarks from different sources in which it is maintained that a number of contributions to the Proceedings are valueless and that their publication will only result in confusion. While I must admit that some of the papers would have better remained unpublished, I cannot share the view that they will cause serious confusion. To understand why they were accepted at all, it should be remembered, that the time which the Editorial Board had available for examination and editing of the contributions was extremely short so that a fair evaluation of each individual paper was not possible. Besides, any impartial observer will agree that the percentage of papers of doubtful contents is not very large, particularly if compared with most technical publications.

Some of these critics, as well as others, have suggested that Professor Terzaghi or I should work up a summary of the material contained in the Proceedings with a certain emphasis on the merit of the contributions, to permit a rapid orientation. Teachers, particularly, seem to be anxious for such a manual. However, the value of such a guide for teachers is very questionable in my mind. I believe that a thorough study of the entire Proceedings, with all its controversal view points, should stimulate the development of a critical attitude and of sound independent judgment which is an absolute necessity for anyone who desires to teach this subject. If one or the other should object that his teaching load is so heavy that he cannot find the time for such studies, then I can only reply that for the sake of his students he either must find the time, or else not teach the subject at all.

Symbols and Definitions. There is no doubt that a considerable amount of confusion which exists at present in the literature on soil mechanics, is the result of indiscriminate use of the same names or symbols for different meanings. This situation is particularly harmful from the standpoint of instruction in soil mechanics. Therefore, the question of standardization of symbols is also of special interest to the S.P.E.E. committee on Foundations and Soil Mechanics. And beyond this, co-operation on this question should and must be made possible to anyone interested therein, regardless of his membership on special committees. For this reason I wish to propose that every one interested in this question should notify me for the purpose of creating a mailing list of all to whom progress reports of this committee will be sent and whose criticisms and suggestions will be invited.

It may be well to point out now, that in a field which is developing so rapidly, we cannot expect to reach perfect agreement on all, or even the greater majority of points of disagreement. It is always possible for a small group of men to agree and create a set of standards, but it will not be possible to force others to use such standards. The creation of a standard only too often represents a compromise which may be essentially new, thus adding to several existing symbols or terms a new one.

Frequently, attempts at standardization give no consideration to the fact that certain aspects must be left open to further development and should not be standardized. Therefore, the first question which must be studied in each individual case is whether standardization is really desirable.

In general, it seems to me that those who strongly recommend standardization, are going far beyond the desirable goal. From their standpoint the work of a committee like ours would be considered a failure, unless it results in the publication of a booklet which contains a complete set of standards for symbols and terms, and preferably also for all soil tests. Such a development would represent a

strait jacket for soil mechanics. After all, standardization cannot and should not be considered a goal in itself. In my opinion the purpose of a committee like ours, is to clarify the technical language used in our field, to eliminate ambiguities and the use of such words which have no definite meaning. Even if this committee after hard work should not be able to agree on any standards, its work would not be in vain, because the educational value of a thorough investigation of the meaning of all terms used in soil mechanics, and the accumulation of data on the use of symbols, will be inestimable. Such work alone will suffice to induce gradually the workers in this field to abandon confusing or actually detrimental usage of certain words and symbols, and inspire clearer thinking and the use of more careful definitions than has been customary so far. In other words it would promote the use of a language which readers can understand without the necessity of guessing at the meaning, if any.

I should like to illustrate the foregoing by one example. The names "sand", "silt", and "clay", as they appear in engineering literature, have anything but a well-defined meaning. Quite frequently I find within the same publication the terms silt or clay used with two entirely different meanings, without the author himself seeming to be aware of this peculiar fact. The term "clay" may refer to a fine-grained soil which is plastic within a certain range of water contents, regardless of its grain size distribution, or it may refer to a specific grain size fraction, regardless of its physical properties. In the latter case "clay" may represent all soil particles smaller than 0.005 mm in diameter according to the Bureau of Soils classification which is widely used in this country, or it may mean the fraction smaller than 0.002 according to the "International Classification" (adopted in 1927 by the First International Soil Congress in Washington, D.C.) which is used in Europe and in a few prominent soil mechanics laboratories in this country. In recent years several changes in these most important existing classifications have been proposed. There is no doubt that the meaning of these terms, instead of being standardized, is becoming more and more confused.

Why not, then, follow the advice of the great number who strongly advocate adoption of a uniform standard for the sand, silt and clay fractions? If all we are interested in is the creation of a standard, we should probably be able to do it. However, it is our first and principal duty to study the question whether standardization is advisable. In the course of such an investigation we would find that these terms are more often used with reference to the general character and the physical properties of the material than the size fractions. Then the question would have to be decided first for which of the two meanings should these names be reserved. I cannot predict the conclusions and recommendations of the committee. I can only offer my personal opinion, which is that the names should be used for soils possessing certain properties, and not for size fractions. I find that if one gets used to the graphical presentation of the grain size distribution of soils, one can work with such curves to greater advantage than with a few fractions. If tabulated results are preferred, they can always be prepared by stating the limiting sizes of the individual fractions without a name, or by using only a letter. This would not complicate the presentation by fractions, but only simplify it, since today the names of the fractions are not sufficient to identify clearly what sizes are meant.

Hence, it is entirely feasible that the studies of the committee would not lead to a standardization of the grain size limits for silt and clay, but to the recommendation that these names should not be used for this purpose. Possibly these names will be replaced by letters, the A-fraction (gravel), B-fraction (sand) C-fraction (silt), and the D-fraction (clay), with further sub-divisions as e.g., C1 and C2. Or perhaps it will be decided to retain the names gravel and sand for the respective fractions, since their meaning coincides fairly well with the properties of these fractions, and to subdivide the fine-grained fraction by letters into several classes. Whatever the recommendation will be, resulting from a careful study of this question, it will have to eliminate the present confusion including such possibilities that a very fine rock flour or ground quartz, possessing no plasticity, is classified as 100% clay.

Standardization of Soil Tests. Closely related to the foregoing discussion is the question of standardization of soil tests. Again, we should ask ourselves in every instance as the first and principal question: is standardization necessary, or is it probable that in the near future developments may take place which will render such a standard valueless, in which case standardization may actually impede progress.

If we analyze from this standpoint our principal soil tests, we find that standardization is advisable for those tests whose results do not yield a single and well-defined physical constant, but in which several physical properties are active to a degree and in such intricate relationships that they defy accurate theoretical interpretation. Tests of this kind, as for example the Atterberg limit tests, are mainly used for general classification purposes. For these reasons it is not only advisable but necessary to standardize such tests so as to permit comparative studies between the investigations from different laboratories. At the same time one should always keep in mind that the use of such tests is only forced upon us by our lack of understanding of the interrelationship of the physical properties of soils and by our lack of scientifically correct methods for measuring such properties. It must always be our aim to replace such "classification tests", also known as "routine" or "simplified" tests, by tests in which the action of individual physical properties is fairly well understood, permitting quantitative evaluation of the test results.

The other and more important group of soil tests is represented by those tests which inform us quantitatively about the fundamental physical properties of the soil, usually expressed by constants, which are needed in connection with analyses of settlements and of stability. Among others, the shearing test, compressive strength test, and consolidation test belong in this group. Since these physical

constants enter directly into our computations, as e.g. the tensile strength of steel enters into the design of a bridge, our primary concern is to know the value of these constants as accurately as possible, and the question of whether or not a fellow worker in another laboratory can duplicate our test results is of but little import. Unfortunately, our apparatus and technique of testing has not yet developed to a point where accurate results can be expected. Almost every one of our testing methods is affected by errors, some of which are so important that they defeat the purpose of our tests. These errors are being studied and apparatus and technique of testing are constantly improving.

Under these circumstances standardization of such tests would be unwise, to say the least. I realize that lack of standards has many disadvantages, particularly since every publication must contain a detailed description of how tests were made. I see no way in which this can be eliminated. However, it is in connection with the publication of investigations that standardization could be of assistance. We could standardize the form in which reports on soil tests should be presented. In a carefully arranged small table or graph one can include a large amount of information and make certain that the presentation of any necessary data cannot be overlooked. Such standardized forms would not only insure that all pertinent information is included in published accounts, but will also permit that such information can easily be studied and compared with similar information from other sources, and further, that the space required for publication is small enough so that it will not be a serious handicap to publication. In this manner better co-operation and more rapid progress in our understanding of the mechanics of soils could be made possible.

No. Z-29b DISCUSSION ON INSTRUCTION IN SOIL MECHANICS

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During the last 25 years soil mechanics has developed from a state of tentative, haphazard experimentation into an independent branch of engineering science with outstanding practical and economic importance. Therefore adequate instruction in soil mechanics becomes a vital part of any course in Civil Engineering. The most up-to-date review of present knowledge in this field is contained in the Proceedings of our Conference. The rapid advance revealed by their contents automatically involves the fact that many of our present views and methods are still in a state of flux, which makes a dogmatic method of instruction impossible.

In order to illustrate the nature and the consequences of these changes I wish to cite a case from my own experience. Seven years ago I published a paper entitled "Mechanics of Shear Failures on Clay Slopes and the Creep of Retaining Walls," (Public Roads, December, 1929). This paper experienced a rather wide circulation, because it contained a summary of what we knew or believed we knew in 1929 about the subject. Comparing the contents of this paper with that of older publications, say prior to 1920, we realize that it was full of new and vital information of lasting value. It contained the well-documented records of the Swedish Geotechnical Commission concerning the shape and position of sliding surfaces in cohesive soils. It introduced the reader to the principles of an approximate method for computing the stability of slopes in cohesive earth. This method, which also originated in Sweden, has stood the test of time and its field of application still increases. The paper disclosed the serious error which was committed in an attempt to replace the approximate method by a more scientific one. It contained information on the important effect of the load history on the shearing resistance of clays. This effect was unknown to other investigators and subsequent investigations have merely helped to emphasize its importance. The paper also presented for the first time reliable data on the gradual outward movement of retaining walls under unaltered external conditions. I explained this phenomenon by seasonal variations of the intensity of the lateral pressure. These permanent additions to our knowledge, achieved within less than ten years, exceed in scope and in practical importance everything which had been accomplished in this line during the preceding century.

On the other hand, ten years are by far too short a period to eliminate <u>all</u> the prejudices which were inherited from past generations. Since progress has continued at its initial rate ever since the paper was published in 1929 it is not surprising that it contains a number of statements which today, in 1936, must be considered superseded. One of them is represented by the equation (1), $t = c + n \tan \varphi$ which is known as Coulomb's equation of the shearing resistance, t, of cohesive soils under a normal pressure n. In 1929 I, myself, and everybody else, still believed that the coefficient of shearing resistance, $\tan \varphi$, in this formula is independent of the rate at which the shearing force is applied. We also believed, in accordance with statements to be found in any elementary textbook on applied mechanics, that the angle between the planes of shear is equal to $90 - \varphi$. Since 1929 we have realized that both assumptions are far from being accurate enough, even for practical purposes. Furthermore, in 1929, I knew only <u>one</u> of the several causes of the periodic changes of the lateral pressure of fine-grained backfills existing under field conditions. In 1929 this represented progress, since in 1920 no one even suspected the existence of important pressure variations. Today, in 1936, I know a second cause which is still more important than the one mentioned in my paper. This second cause is described in the paper No. J-4 of the Proceedings of our Conference. I also wrote in my paper of 1929, that "we are not sure as to the extent to which hydrostatic uplift acts within a mass of plastic clay." Today this is well known, as a result of experiments described in an article in Eng. News-Record, June 18, 1936.

There is an obvious reason for the shortcomings of the paper. Since research dealing with cohe-

sive soils requires an appalling amount of time and labor, we had to satisfy ourselves with the revision of some of the older conceptions. The balance of the work had to be postponed for a later period. A similar situation necessarily exists in every branch of a rapidly advancing science.

It cannot be denied that the continuous change increases the difficulties of keeping one's knowledge up-to-date. The method of teaching such a science must be governed by the intention to educate the student for successful participation in the struggle towards improvement. The first requirement for accomplishing this purpose is an emphatic discrimination between what we really know and what we merely suspect or believe. Classifying the contents of our knowledge in the field of soil mechanics according to its nature and practical importance, we recognize the following categories: (a) knowledge acquired by observations in the field and by direct measurement of forces and of movements. (b) Knowledge of the physical properties of the soil obtained by laboratory investigations and (c) the theories which are used for the purpose of estimating forces or settlements by methods other than analogy.

(a) Knowledge Acquired by Observation. Whatever we learn by conscientious and complete observation in the field represents a permanent asset, subject to no further modifications. To acquire knowledge of this kind requires merely good will and patience. Fifty years ago, conscientious observation would have disclosed the absurdity of many of the rules which are still being used in the design of important and expensive structures. The scantiness of pertinent knowledge is inexcusable and merely due to inertia and short-sightedness.

(b) Soil Testing. To be of any use, our observations in the field must be supplemented by information which permits the identification of soils in different localities. Pertinent research soon disclosed the fact that the traditional methods of sampling alter some of the vital soil properties to a point beyond any recognition. Therefore it became necessary to develop methods for securing and testing undisturbed samples. The soil tests can be divided into two groups. The tests of the first group, the so-called simplified soil-tests merely serve the purpose of a preliminary soil classification. These tests do not furnish any of the data which are needed in connection with stability or settlement computations. Due to the more or less arbitrary character of the tests of this group it was necessary and possible to standardize them from the very outset. The tests of the second group, or the final soil tests, provide us with quantitative information on the compressibility, permeability and other soil properties with a well-defined physical meaning and with a known and direct bearing on engineering problems. The laboratory procedures for evaluating some of these are not yet satisfactory. The tests for determining the shearing resistance of cohesive soils and for securing information on the average compressibility of thick, natural beds of sand may be mentioned as examples. The attention of the student should be called to the transitory character of such testing methods.

(c) Theories. In order to prepare an intelligent program for the investigation of soil conditions we need at least a general knowledge of the mechanics of the interaction between the soil and our structures. Pertinent information can only be obtained from theories, subject to verification and modification by purely empirical methods.

Every theory, without exception, applies only to ideal materials. If such a theory is based on the laws of mechanics it must be considered strictly correct within the limits determined by the assumptions and there is no possibility of a subsequent discovery of errors. Future research can only modify our knowledge of the difference between the ideal material to which the theory applies and the real substance in which we are interested. For artificial building materials such as steel and concrete experience has shown that the difference between the ideal and the real substance is practically negligible. In the case of soil on the other hand, we know from experience that their properties are always more or less radically at variance with any ideal material which is simple enough for theoretical treatment. One of the chief sources of uncertainty, strife and disagreement in the field of soil mechanics resides in the general failure to recognize this fundamental fact. In the Proceedings, this uncritical and unwarranted attitude is disclosed by titles such as "Stresses in a Two Dimensional and Isotropic Earth Mass" or by papers whose authors do not hesitate to generalize the conclusions derived from pure theory or from small-scale tests on materials with very little if any resemblance to real soils. One of the principal goals of instruction in soil mechanics should be to discourage this prevailing tendency to unwarranted generalization.

There is no complete theory of the settlement of foundations or of the lateral pressure of earth and there never will be. We have only theories which inform us by crude approximation on one or more aspects of the real soil phenomena and the degree of approximation can only be ascertained by field and construction experience. A brief summary of the theories pertaining to settlement and bearing capacity is contained in the general discussion of section F. This discussion also contains a demonstration of the utter futility of the attempts to discover any single-valued relation between the results of small-scale loading tests and of the settlement of large foundations on stratified soils. A summary of the theories of earth pressure will be found in paper No. J-9.

The first and foremost function of these theories consists in guiding us in the preparation of records of settlements and of earth pressure phenomena. Prior to the advent of soil mechanics, records of this type were practically worthless because the description of the soils to which the records referred was too incomplete to permit reliable identification. Furthermore, most of the settlement observations were fragmentary and failed to inform us on vital facts such as the time rate of settlement or the distribution of the settlement over the loaded area. If complete records of precedents are

available, reliable estimates can be based on analogy. The practical value of this method cannot possibly be overemphasized, because it points the way for eliminating a high percentage of the hazards which are still connected with foundations. An instructive example of the type of observations which should be made is contained in the papers No. C-1, D-1, E-1 and F-1, Vol I. If observations of this type are made in any city over a period of five years of active construction, a knowledge of the collected data would suffice to exclude for most sections of the city the danger of settlements in excess of estimates based on the existing records. The preliminary investigations would be limited to the test borings and to routine tests.

A second important function of theory consists in revealing the factors and the soil properties which determine the intensity of the earth pressure, the amount and the time rate of settlement and other phenomena of practical interest. It would be a waste of time and labor to determine in every case all the properties of the soil samples regardless of the purpose of the investigation. On the other hand no vital soil properties can be ignored without invalidating the results of the investigation. Without a systematic investigation of the mechanics of the processes involved it would have been difficult to discover the influence of the permeability of compressible soil strata on the time rate of settlement of a superimposed structure, the influence of the elastic properties of the earth on the intensity and the distribution of the earth pressure on the timbering of cuts and the influence of the pressure in the pore water on the stability of slopes. The existence and the importance of these influences is demonstrated by the results of the observations described in the papers No. F-9, J-3, D-7, Vol I, and many others. Our knowledge of the mechanics of the different processes makes it possible to secure in every practical case the vital information concerning the properties of the soil with a minimum amount of laboratory work.

A third application of theory is to provide a method for a prediction of the pressure exerted by the earth or the settlement of a foundation from the results of soil tests alone. The application of this method is necessary in all those cases which are not covered by our knowledge of adequately recorded precedents. Outstanding examples of this function of theory are contained in paper No. N-3, Vol I. In order to utilize our theories for this special purpose we need, above all, a knowledge of the importance of those soil properties which do not enter our equations. Owing to the difference between the ideal materials to which the theories apply and the real soils, it is obvious that a computed result represents at the very best a crude approximation. In the field of reinforced concrete the errors due to the approximations are negligible. On the other hand, in soil mechanics, they can be intolerably important, in which case the theory must be supplemented by purely empirical correction factors. In order to find out whether such a correction is needed and to accomplish the correction we must proceed as follows:

We first determine in the laboratory the value of the constants which appear in the equations, and by means of these equations, we predict the behaviour of the full-sized structure. The forecast thus obtained is then compared with actual observation. The difference between forecast and reality may be due to the deficiency of the method of testing, to the alteration of the properties of the soil during the operations of sampling or to one or more properties of the soil in an untouched stated, neglected in the theory. In order to discriminate between these three sources of inaccuracy of our forecasts a systematic investigation of all the factors is needed which are likely to influence the test results. An outstanding example of such an investigation is contained in paper No. D-11, Vol II.

Future developments of a fundamental character will be limited to the use of theories for the purpose of predicting phenomena from the results of soil tests. In this field we stand at the very beginning of a laborious process of research. The degree of approximation which we shall ultimately achieve cannot yet be predicted. It would be unfair and deceiving to judge the value of soil mechanics exclusively from past progress in this special and highly advanced field of application. Therefore it should be emphasized that at present the principal function of soil mechanics is to record adequately and digest construction experience, and to utilize this experience by means of identification tests. For these important and promising activities we are amply equipped.

Once a teacher has grasped this situation he should have no difficulty in discriminating between positive knowledge and tentative conclusions. By representing tentative conclusions as certainties he discloses his own ignorance and produces in the mind of the student the opposite of what the course should accomplish. The student should emerge from the course with a keen desire to employ his trained faculties for the purpose of broadening our scanty knowledge by observations of his own, and with a clear perception of the practical significance of his potential contributions. If he leaves the course with the impression of having learned a set of hard and fast rules to be applied without considering the radical approximations involved, the course can be considered a failure. What the profession needs is not a new generation of blind believers, but a generation of pioneers who do not ignore the uncertainties which they are going out to face.

This method requires a fundamental departure from the method of teaching the theory of structures. It requires a mature mind and practical experience on the part of the teacher and in my opinion it excludes the subject from undergraduate courses.

Eleven years ago, when I published my first book on the subject of soil mechanics after seven years of careful preparation, my own ideas about the boundaries between certainty and tentative conclusions were still rather vague and I would not have hesitated to teach the subject to undergraduates. But since that time I have come to the conclusion that we should not initiate the student into our troubles until he has gained strength from a thorough knowledge of those fields in which the troubles have already been eliminated.

No. Z-29c DISCUSSION

Herbert Ensz, Associate Professor of Civil Eng., Armour Institute of Technology, Chicago, Ill.

I am grateful to Dr. Terzaghi for reviewing his article in the December, 1929, issue of Public Roads. I feel as though the review was made for my special benefit, since I have asked so many questions concerning its content.

In regard to teaching soil mechanics, I have taught the subject without having been previously instructed. My attendance during the past semester at Harvard University has given me additional knowledge and confidence so necessary for all teachers of this new science.

The many warnings given by Dr. Terzaghi and Dr. Casagrande that whatever they say in regard to soil mechanics is subject to change and should not be considered as a definite fact is probably very true. Nevertheless, it is hard to disbelieve them when they present the subject in such a convincing manner.

Personally I agree with them that we must caution the student that present knowledge of the subject will be supplemented and very likely changes made as progress in research continues. Thus the subject should be a post-graduate study and given to the undergraduate only in a limited way.

No. Z-29d DISCUSSION

E. E. Bauer, Asst. Professor of Civil Eng., University of Illinois, Urbana, Illinois

Interest in the new field of soil mechanics is developing rapidly among civil engineering educators, who have in mind the teaching of the subject to their students. How shall these teachers prepare themselves? Will they be properly qualified before meeting their first class? If they are to study the subject themselves first, what methods are available? There is no doubt in my mind but that the average teacher is willing to make the necessary preparation, but certain circumstances may interfere. Most college budgets are not elastic enough to permit at least one staff member to take time off for a year with salary to permit him to go to a school where the science is taught. In some instances teachers are attempting to learn the subject as they conduct classes in it, in addition to a regular teaching load.

For several years I attempted the latter program. Some progress was made each year to be sure, but the rate was too slow. Dr. Terzaghi's coming to Harvard suggested the idea of a semester's leave of absence and I have been here the past semester. It is of course impossible to become an expert in such a short interval of time, but I have got a picture of the whole subject presented in an orderly manner. I have seen how it is taught by some one who has spent considerable thought on the subject. The one semester is equivalent to many years of effort which I might have put forth at home. I think it is entirely fitting and proper that this committee emphasize in an early report the necessity of adequate preparation by the men who are to teach the subject.

If leaves of absence are not going to be available to any except a very few teachers, it may be necessary for some school which has established courses to repeat each summer a portion of their instruction for the special benefit of teachers. This thought was expressed to me during the Conference and I mention it because it does offer a solution to the problem.

Another possibility of assistance to the beginning teacher would be short courses. This type of activity is not new to S.P.E.E. as it has been done on several occasions in the past. At these meetings I would like to emphasize the necessity of beginning at the beginning of the subject, for the special benefit of the newcomers.

As just pointed out many teachers and engineers are attempting to study the published literature and are finding it exceedingly difficult. I would like to point out some of the things that are troublesome, which I have observed and which have been mentioned to me by others.

1. What should be read and in what order? The amount of material which has been published is voluminous and the beginner is at a loss to know which is important. In some instances later articles furnish factual evidence proving earlier theories in error. It should be possible for this committee to prepare and publish a suggested list of readings, which would begin at the beginning and take the reader through in a logical order. Some articles are in publications not generally available and many in those publications not read regularly by the average person.

2. Most of the articles are reports of special investigations, either analytical or experimental, and these reports begin where the other investigators left off. The reader does not get the full significance of the article without reading many other articles and reports. Oftentimes also these scientific reports are prepared primarily for other scientists who readily grasp their meaning, but there are many who attempt to read these reports who are entirely lost. I do not see what the committee can do about this situation, but it is something which needs some thought and attention.

3. Many of the articles and books written in the field of soil mechanics are written in other languages than English. Very few American engineers have any occasion to use other than English and as a result less emphasis is being placed on it in our engineering schools. Because of non-use in his daily routine the average person soon forgets any foreign language he may have studied in school.

Since it will not be possible to entice any but a very few into learning any other language than English, it seems to me that this committee could render a fine service to American teachers and engineers by arranging for the preparation and publication of reviews in English of the outstanding con-

tributions written in other languages. As an example, many references are made in the American publications to Terzaghi's theory of consolidation, but always the reference given is Erdbaumechanik, which is written in German. An examination of any list of references at the end of practically any article on soil mechanics will show that a large percentage of the contributions are in languages not understood by the average American.

4. The use of the metric system of weights and measures in practically all the publications concerning soil mechanics is a decided handicap to the average American. Except for the use of the metric system when weighing with an analytical balance the English system is used in all our class work. While this committee cannot dictate to others what they shall do, it can point out the desirability to those controlling the publication of most of the American articles that these articles will mean much more to their readers if the English system of weights and measures is used. The American Association of State Highway Officials has been using for several years the English system in the specifications and methods of testing they publish.

5. Immediately following this meeting the Committee on Standardization of Symbols and Conventions will meet and I wish to mention a complaint which I have heard frequently. The extensive use of the Greek alphabet in literature pertaining to soil mechanics is a handicap to the average American reader and I am hoping that the use of Greek letters for symbols will be kept at a minimum.

6. The adoption of a set of uniform definitions for the various terms in soil mechanics will be another aid in the presentation of reports and articles and this committee should co-operate with other interested groups in the preparation of those definitions and then promote their use.

I should like to mention also something concerning the value of a laboratory in connection with instruction in soil mechanics. It seems to me that every school offering courses in this field should have a laboratory in which the student may do some testing himself, or if that is not possible where he can see the equipment and how it is used. This laboratory should be equipped to perform such routine tests as specific gravity, particle size, liquid limit, plastic limit, shrinkage limit, and flocculation, and then those tests which use the fundamental properties such as consolidation, shear, compression and permeability. The laboratory should have available samples of the various type of soil, which the student can handle and test. The laboratory is essentially part of the soil mechanics set-up, it seems to me.

No. Z-29e DISCUSSION

W. P. Kimball, Asst. Professor of Civil Eng., Thayer School, Dartmouth College, Hanover, N.H.

Regarding teaching methods. In order to avoid asking questions on written examinations which would tend to suggest to the students that a definite answer should be given, I have used oral examinations to cover those parts of the course where there can be no definite, incontrovertible answer. The written examination questions are confined to those fundamental principles which it is desired to impress on the students as infallible. The method has worked well.

Regarding a training course for teachers. I suggested that I should like to see the S.P.E.E. committee go on record as recommending that the S.P.E.E. sponsor a one-week course to be given next summer.

Regarding standardization of symbols. I suggested that a mimeographed questionnaire be sent to all interested parties asking them to fill in the symbols which they use. These questionnaires should be returned to the Committee who should then tabulate the results and, giving due weight to the sources and the parties using the notations, should select a system of notation which should be representative of the best and most common usage. If engineers are given an opportunity to express their opinions and these opinions are honestly considered in establishing standards, engineers will generally be more willing to adopt the system proposed by the committee than if the system were more or less arbitrarily established by one or two individuals.

No. Z-29f DISCUSSION

Frederick J. Converse, Professor of Civil Eng., California Institute of Technology, Pasadena, Calif.

1. From several different sources within the past six months the statement has reached me that all literature relative to soil mechanics published prior to 1933 is wrong. This statement has come by way of Harvard trained men and has been reiterated here this week by Dr. Casagrande and Dr. Terzaghi. I am sure that neither Dr. Terzaghi nor Dr. Casagrande mean that such statements should be taken too literally. Such an interpretation by certain students and some engineers has had a definitely detrimental effect on their attitude toward modern soil science. There is a great body of experimental and theoretical literature of an older date that is exceedingly valuable. The fact that many of the theories were (and still are) incomplete or inaccurate does not decrease their value as stepping stones to progress. After all, we are only interested in the theories as they explain the facts, and we should recognize that our present theories are scarcely out of the hypothesis stage, and that we may expect change for many years to come. It would be better for us to teach our students that all soil mechanics

is in a growing state, and that any equations or theory used for practical purposes must be carefully studied in the light of the assumptions and the experiments on which they are based, and used with great caution for other conditions. By so doing we will avoid such unpleasant and incorrect conclusions that all ideas prior to any date were wrong, and the further usual assumption that anything since that date is correct.

2. I would like to suggest that this Committee recommend to the S.P.E.E. that a list of colleges and research laboratories, together with their personnel and the main research problems on which they are working, be published once a year.

One of the most valuable things which has eminated from this Conference has been the opportunity of contact with men in the same field. This can be kept up and extended by correspondence if a live list of kindred spirits is at hand, to the great advantage of each of us and of the science which we are struggling to develop.

3. The National Engineering Societies have adopted a preferred list of symbols which it seems desirable for us to use as far as possible. Where new symbols are necessary I am in favor of adopting those most generally used in present day literature, even though they be largely of European origin.

No. Z-29g DISCUSSION

D. Krynine, Research Associate in Soil Mechanics, Yale University, New Haven, Connecticut

1. I have been teaching soil mechanics to graduate students at Yale for six years and have always followed the critical attitude to the subject as advised by both Dr. Terzaghi and Dr. Casagrande. I explain to the students that the probability of the accuracy of a statement depends on the author of the statement and may range within very wide limits without reaching 100% even in the case of the most advanced research leaders. This is the reason why views in soil mechanics are being changed rapidly in accord with the results of new investigations. It is much more difficult to teach soil mechanics to undergraduates than to graduates, especially if the former group has already studied highways and foundation engineering under another teacher. The best policy would be to teach soil mechanics in the senior year simultaneously with other subjects requiring its knowledge. Geology should precede soil mechanics and not be taught after the course in foundations has been taken as is the custom in some institutions.

2. I think that the use of Greek letters as formula symbols should be continued in soil mechanics. So far as Latin letters are concerned, I should like to propose that terms or conceptions be designated by their initial letters in English, for instance "F" should stand for "force"; "LL" for "liquid limit", etc. In ambiguous cases, brackets could be used, for instance if "s" designates "settlement", [s] could designate "stress"; [sh] "shear", etc.

No. Z-29h DISCUSSION

Robert G. Hennes, Instructor in Civil Engineering, University of Washington at Seattle

I believe that the interchange of information suggested by the previous speakers might well be extended to include information relative to the content of the soil mechanics courses at the various institutions concerned. Such co-operation would be helpful to the instructor in deciding what to teach in this unstandardized field.

While admitting the danger that exists in teaching soil mechanics to undergraduates while the science remains in its present state of flux, it must also be conceded that there is another side to the matter. One of the speakers at the Conference estimated that $200,000,000 of construction in progress constituted a direct application of the principles of soil mechanics, in addition to similar sums expended for highways where subsoil studies played an important part in design. When a branch of engineering achieves a position of such importance in the construction industry it becomes an obligation of the technical school to see that the student of engineering is acquainted with the fundamental principles involved.

The participants in the International Soils Conference have been classified by one speaker into three groups: engineers, field men, and research men. To my mind the function of the undergraduate course in soil mechanics is not to produce specialists in research, but to provide the average engineer with a sufficient grasp of the subject to read the literature intelligently, to become acquainted with routine field and laboratory tests, and to obtain the necessary background for co-operation with the soils or foundation expert. I believe that the undergraduate course can accomplish these ends by emphasizing the fundamental principles upon which we are on the whole agreed, without indoctrinating our students with controversial theories that demand the more mature judgment of the graduate student.

At the University of Washington we have been trying to accomplish that in our soils courses for the past two years. Our students are accustomed to the problem method of teaching, and the efficient presentation of this wholly new type of material requires a transition period in which the student can make an adjustment from the old to the new classroom technique. We use the quarter system, and in the fall quarter the emphasis is placed on mechanics, dealing with the application of soil mechanics to such engineering problems as stability of slopes, settlement and bearing capacity of foundations,

earth dams, and retaining walls. In the winter quarter the properties of soil are studied, and the student performs the usual tests of grain size, Atterberg limits, permeability, consolidation, and shear. In the spring quarter the interested student has opportunity for further study in a more restricted field of his own choice. This arrangement of subject matter has proved to be more successful than my former method of teaching soil physics before its applications; the latter is perhaps the more logical approach, but one that left the student wondering where it was all leading. Our present method is far more productive of student interest, and while it cannot be acclaimed as the model for undergraduate courses, it has been satisfactory under local conditions. This summary has been presented in the hope that it may be of interest to those of you who are faced with similar problems.

No. Z-29i DISCUSSION

THE PLACE OF AN INTRODUCTORY COURSE IN SOIL MECHANICS IN THE ENGINEERING CURRICULUM

Donald M. Burmister, Instructor in Civil Engineering, Columbia University, New York City

The International Conference on Soil Mechanics and Foundations at Harvard has done one very important thing, namely, it has served to focus attention on the necessity of giving graduate work in Soil Mechanics in the Engineering Schools. We believe at Columbia that the time has come to take a further important step and give an introductory course in Soil Mechanics to the undergraduate which will supply a similar basic and scientific approach to Foundation Engineering and Earth Structures in the Engineering curriculum as that long occupied by the fundamental course in mechanics of materials and hydraulics with respect to Structural Design and Hydraulic Engineering.

As developed in our Columbia program this course is intended to give the student an introduction to the physical characteristics and physical properties of soils early in his engineering work. The subject matter discussed in "Soil Mechanics" is closely coordinated with the courses in Highway Engineering, Elementary Reinforced Concrete Design, etc. We can no longer discuss subgrade and drainage problems in Highway Engineering and the design of footings and retaining walls in Structural Design in general terms with purely arbitrary assumptions as to soil conditions and soil behavior, even if a completely rational basis for such design is not at present possible.

It is, of course, true that a wide gap still remains to be bridged between our still somewhat limited knowledge of soil physics and soil mechanics and the use and application of such data as is available in the practical design of foundations and earth structures. Although much of our existing data on soil characteristics and behavior is of qualitative rather than quantitative value, the time has arrived when we can no longer ignore the value of this qualitative information. We are today in the midst of a rationalizing movement in this field. If we are to be progressive and forward-looking in our educational viewpoint, we should prepare the student of today, who, by the way, will not be an engineer until some four or five years hence, to know, evaluate, use and contribute to the development of this newer technique in foundation and soil design which is surely on the way. The first step in such a course in Soil Mechanics is to call the student's attention to the Existence of Soil Problems - to encourage him to recognize soil problems and their implications.

The teaching problem, from the standpoint of effectiveness, seems to be that of conducting the course so that laboratory work closely parallels the class discussion. Knowledge and experience comes only from the actual handling and testing of soil samples and from familiarity with laboratory practice. It must be recognized that soil tests are absolutely indispensable to the solution of soil problems. The student becomes somewhat familiar with the technique of soil testing and with the methods of analysis and interpretation of results.

The laboratory work serves another very important purpose in that the student has the opportunity to develop early in his engineering work habits of (a) close and careful observation of the character, physical properties and behavior of soils, (b) of making correct interpretations of physical phenomena, and (c) of making accurate conclusions supported by physical facts.

Probably more than in any other course in engineering, the class demonstration is the most effective method of presenting to the class and illustrating the fundamental principles and concepts of Soil Mechanics. From a simple demonstration of physical phenomena or of soil behavior the student grasps the ideas more quickly, and they make a more lasting impression.

Finally experience has shown that in the study of Soil Mechanics, as in many other branches of applied mechanics, mastery of the subject cannot be attained without familiarizing oneself with computation methods. The problems must, however, of necessity be quite simple in this course, but whatever assumptions that are made or limitations that are imposed on the problem, they must be clearly stated and their significance made clear in limiting the possible practical applications. The problems will serve their purpose best if they are of the practical problem type and selected from actual practice where the experience with the behavior of the structure is known.

At Columbia we have found it desirable to combine our treatment of soils with the fundamentals of both structural and highway foundation work, thus preparing the student for his future work in structural design and in highway engineering. Earth structures are treated in subsequent courses. The sequence of the course may be briefly outlined as follows:-

1. Historical background.

2. Discussions of the origins of soils.

3. Soil Physics - discussion of the physical character of soil.

4. Applications - particularly with respect to Highway Engineering.

5. Soil Mechanics - consideration of the physical and elastic properties of the soil and of its behavior as an engineering material.

6. Engineering applications of the principles of Soil Mechanics.

7. Discussion of practical construction methods of getting down to suitable bearing materials.

No. Z-30 DISCUSSION OF PAPER Z-4 (By Letter)

O. Godskesen, Geo-technical Engineer of Danish State Railways, Copenhagen

For better penetration in firm soil the drill point is usually twisted as shown herewith instead of straight as in Fig. 1 of Paper Z-4.