Discussion

By Robert F. Ogilvy*

In April 1957, about half a year before Dr. Terzaghi read his paper "Consultants, Clients, and Contractors" at a meeting of the Boston Society of Civil Engineers, I was asked to talk at a luncheon meeting of the Montreal Soils Group on the topic "What the Structural Engineer Expects from the Soils Consultant". This talk was repeated in Ottawa in early October. My remarks on this subject supplement in many respects the statements contained in Dr. Terzaghi's paper. Therefore, Dr. Terzaghi has suggested that I submit the following abstract of my talk to the Montreal Soils Group as a contribution to the discussion of his paper. Although my talk dealt essentially with the relationship between the soils consultant and the structural engineer, in many instances the structural engineer may represent the owners, or act as an intermediary between the soils engineer and the owners, and as such may assume the position of client as far as the soils consultant is concerned. The soils consultant and the structural engineer should be mutually and equally concerned with the contractor's performance, and determined that the work shall be carried out to conform to the basis of the design specifications.

The work of the soils consultant and of the structural engineer lies quite largely within the field of general construction work. Possibly a brief review of design and construction practices in North America will provide some background for more detailed observations later. On one of the first warm days of the spring of 1927, several engineers, engaged on the construction of the Gatineau mill for Canadian International Paper Company, were sitting in a quiet alcove on the sunny side of the grinder building during noon hour discussing the construction work which was just drawing to a close. An Australian engineer expressed great surprise in comparing his previous experience with what he considered the strange practices which had been involved in the construction of Gatineau Works. He described the procedure in Australia based on practice in Great Britain, which required that all drawings for the entire project should be completed and checked and approved before any construction work was started. This was in very direct contrast to the procedure followed at Gatineau

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and which is being followed throughout North America to a very large extent today. I had joined the C. I. P. staff at Gatineau, 1st February 1926, on the morning on which the concrete spread foundations for the digester building had been blasted out to make way for pile foundations. The entire plant had been designed to rest on spread footings, but investigation during the previous three months of the loaded spread footings and loaded concrete and timber piles had shown that the very fine grey silty clay on the east bank of the Ottawa River required the use of pile foundations. As a result, all the concrete foundations designed already as spread footings had to be redesigned to rest on Raymond cast-in-place concrete piles. Although this did add considerable unexpected burden on the paper company's designing staff in New York, it did not altogether explain the fact that drawings came into Gatineau on the morning mail and, in some instances, were being used for actual construction a few hours later. This is only an extreme example of the accepted practice in North America which encourages construction work to be started in the very minimum time after the decision to proceed has been made at the highest level, with the result that design drawings are used for construction purposes as soon as they become available for part of the project. As design progresses for other sections of the undertaking, it may become necessary to revise or adjust the parts for which design was completed first, and this may even involve changes in the field if construction has progressed far enough to require this. It is not uncommon to have buildings under construction before certified prints are received from manufacturers of equipment to be housed in the buildings, and the final information contained on these prints of equipment may show that adjustments have to be made to drawings of buildings and foundations, which in turn may or may not require adjustments in the field to structures already completed.

The owners represented by the company directors are anxious to bring into production as soon as possible any enterprise which has received approval. Management is eager to further construction with the least time delay, and engineers themselves are ambitious to accomplish the maximum in the shortest time. Everyone involved directly or indirectly in a construction undertaking must be aware of, and recognize honestly, the universal desire on this continent to complete the job as soon as possible. This may be universal all round the world, but there are varying interpretations of what is "possible", and correspondingly varying degrees of pressure and differences in method; with the North American viewpoint being one extreme.

When any structure is to be built today, the first question certainly is "What are foundation conditions? On what will this structure rest?" To an increasing extent in the past twenty years, this consideration has gained recognition as the first essential for structural design, and certainly is the first proper question today. The correct answer to this question should avoid the observed damage to some structures built many years ago without such consideration. The structural engineer must start by roughing out a very general picture of the structure itself. Before he can proceed to proper design, he must know what the ground conditions are and what bearing pressure the soil will take. Variations of this requirement apply to dams, to wharves, and to practically every other type of structure in addition to the more common demand for information needed for building sites.

Although organizations or companies may be involved in structural design and soil investigation, it will be easier to consider these groups as represented by individuals in the person of the structural engineer and the soils consultant. The structural engineer normally is responsible for layout and design of a structure, and for final design decisions on matters on which the soil consultant's advice has been obtained. The soil consultant normally is responsible for investigating the site and providing advice and recommendations concerning:

1. Suitability of soil conditions for safe support of the proposed structure.
2. Specific Limitations which soil conditions will impose upon design, construction, and operation of the proposed structure. These are qualifications which may govern not only the type of foundation but also the type of structure which can be used with normal safety.
3. Prediction of physical behaviour of the foundation soil under the given applied conditions, and the effects of this behaviour on the structure and its intended use. Specifically, (a) what settlement is expected—what magnitude and during what time period; (b) what is the sheer strength of the soil in relation to stresses applied; and (c) for dams and other hydraulic structures, what is the estimated seepage and hydrostatic pressure.

The proper relation of these two persons involves almost complete integration. The structural engineer and the soil consultant must work together—not in parallel with a distance between them, but in full cooperation with close interchange of thoughts to provide continuity and consistency in the work, and avoid either a gap in thinking or a misinterpretation of intent. This comes in several stages:

(a) Preliminary. The structural engineer briefs the soil consultant on the preliminary planning and layout for the project and provides some basic data essential to a preliminary analysis of the foundation problem such as the type and use of the structure contemplated. The soil consultant should be prepared to make preliminary recommendations as to the type and extent of the investigation program.

(b) Work in the Field. The soil consultant plans and directs field investigation and laboratory analyses and tests. That work should be carried out competently and expeditiously.

(c) Report Submitted. The soil consultant submits an interim report or a final report, which normally includes an outline and appraisal of the general soil conditions with general recommendations pertinent to the design of the foundation structure. This work allows the final choice of a site if there are several alternatives, or confirms the practical suitability of a specific site. This provides the opportunity for an exchange of thought, and for a detailed discussion of individual design problems. The structural engineer may want more detailed interpretation of some item in the report, or further explanation of soil conditions. At this time the soil consultant should be given information as to the final site selected and details of the type and loading of individual structures, and he should review these and submit specific recommendations concerning foundations for individual structures or special cases.

(d) Review of Final Design. In order to be sure that exchange of information has been thorough and without misunderstanding, the soil consultant should review the final foundation design. For instance, at Kitimat, we were prepared at one time to provide more cover against frost protection than was necessary for foundations on that particular type of thoroughly consolidated sand and gravel backfill. Our soil consultant was informed of our thinking, and furnished further information on that one point.

(e) Review of Site Conditions During Construction. The soil consultant's report is an interpretation of the probable soil conditions over the entire site, based on soil borings which actually represent only an infinitesimal cross-section of the total site. In many cases it is advisable to check the validity of the interpretation when field conditions are revealed in volume during construction, so that any variations from the original interpretation may be brought to light and corrections applied to the design made by the structural engineer.

The work involved in a complete foundation analysis by a soil consultant breaks down into five natural steps. All or part of these may apply to an individual project depending upon its size, the degree of complexity of the soil problem, and the terms of reference of the consultant.

(a) Subsoil Investigation. Reconnaissance of site, supervision of drilling, sampling, and special field testing. This may or may not include contract drilling by the consultant's force. There may be some advantage in having the consultants carry out all work, although some of the consultants prefer to devote their energies to engineering supervision of the gathering of field data rather than being involved as both soils consultant and drilling contractor. This relationship can be debated at considerable length as each arrangement has its advantages and disadvantages. We have had satisfactory experiences with both arrangements.

(b) Laboratory Testing. A laboratory testing program has to be planned and executed with the specific purpose of investigating the properties of the soil pertinent to the individual problem. The program is carried out in two phases. The first consists of visual examination of the samples, together with elementary classification tests, to obtain an indication of the soil types present and of the degree of variation or uniformity of the soil profile. The second consists of physical tests to determine settlement, shear strength, or permeability characteristics, which can be used in a quantitative analysis of the foundation behaviour. The first tests are routine whereas the second tests are specifically aimed at particular soil conditions indicated by the first tests.

Care should be taken to give particular attention to the second group of tests as these results should be tailored to the intended use of the soil and the soil type itself. In certain instances, the standardized procedure has not yielded information pertinent to the problem, because the problem itself had not been sufficiently explained to the soil consultant, whereas the person using the data for design purposes may not understand the limitations of its use. The soil consultant should exercise great care to establish definitely that the data is understood and is applied properly to the problem under consideration. This further emphasizes the absolute necessity of close contact between the soils engineer and the structural engineer. It is essential that the soil consultant is absolutely sure that the test data obtained from laboratory work does apply specifically to the structural engineer's problem.

(c) Compilation of Data. This phase consists of assembly and compilation of field and laboratory data covering the drill logs and test results, and the presentation of this data in a concise and probably graphical form, in which it can be studied and digested. This is drafting room work. It is essential that the vast mass of data obtained on a large project should be summarized concisely in order that it may be very much to the point and easily understandable by an engineer not fully coversant with soil problems.

(d) Engineering Analysis and Report. This phase consists of study and analysis of the data in relation to the engineering problem by fully qualified professional personnel. This is the step in which the closest liaison with the structural engineer is required.

(e) Inspection and Supervision of Construction. This phase includes review of actual field conditions in comparison to the assumed conditions, field control testing to assure compliance with specifications in the case of earth construction, and provision of field soils engineers as advisors to the construction engineering staff, when such assistance is warranted. This is the final follow-up which is particularly valuable in generating confidence in the owners as represented by the structural engineering staff.

At the risk of repetition, it may be wise to run over in further brief detail the factors which affect the close co-operation between the structural engineer and the soil consultant. The basic problem of the soil consultant is:

(a) To determine from the structural engineer what conditions, present and future, will be imposed upon the foundation soil by the proposed structure.

(b) To determine the soil conditions at the site by subsoil investigation.

(c) To analyze the behaviour of the particular foundation soil under the imposed conditions and to interpret the behaviour in terms of the effects it may have on design and construction aspects.

To enable the soil consultant to resolve this problem, the structural engineer must provide the following information:

(a) Plan area and average net loading applied over the plan area of the structure, because the magnitude of settlement is related directly to these. This includes building loads both live and dead, and anticipated fill loads.

(b) Sensitivity of the structure and its enclosed plant to settlement effects, in order to assess the safe settlement tolerances of the structure. The rigidity of the building frame, the type of interior finish, and the sensitivity of machinery are pertinent points of interest.

(c) Special features of the structure which might affect or be affected by the foundation. Such items as vibrating loads, deep excavations, adjacent fill or storage loads, probability of future extensions to the structure, nature of foundations of existing adjacent buildings, etc., may have a critical bearing on the foundation behaviour.

Particular aspects of the general problem considered by the soil consultant include the following details applied to specific types of structures:

A. Building Foundations, Bridges, Wharf Structures, Retaining Walls, Bulkheads, etc.

1. Aspects Related to Design Considerations

   i. Review of types of foundation support suited to soil conditions.

   ii. Analysis of magnitudes of total and differential settlements and of time-rate of settlement.

   iii. Analysis of shear strength of foundation soil.

   iv. Analysis of effects of vibrations and earthquakes on foundation soil.

   v. Consideration of effects of future expansion of structure on foundation of existing and future buildings.

   vi. Analysis of lateral earth pressure to be resisted by retaining structures.

2. Aspects Related to Construction Considerations
   - i. Effects of weather and season of year on behaviour of soil relative to working conditions and access on site during construction. Protective measures which might be necessary at various periods of year to prevent damage to soil foundation such as shrinkage due to drying, swelling due to wetting, expansion due to freezing.
   - ii. Unwatering—extent of problem and whether or not special methods required.
   - iii. Pile Foundations—analysis of problems of driving piles, recommendation of criteria for establishing adequate penetration resistance to meet design requirements, review of suitable types of driving equipment, review of special precautions to be taken to prevent interference with driven piles during driving of subsequent piles.

B. Embankments and Fills for Building Foundations, Roadways, Dykes, also Dams and their Foundations

1. Aspects Related to Design Considerations
   - i. Analysis of settlement of foundation and fill.
   - ii. Analysis of shear strength of foundation soil and stability of slopes of fill section.
   - iii. Analysis of permeability, seepage and hydrostatic pressure conditions within fill and foundation, for dykes and dams.
   - iv. Recommendations concerning dimensions, slopes and cross-section of fill dictated by fill and foundation soils.
   - v. Evaluation of borrow materials.
   - vi. Specifications for selection of borrow materials and placement of fill materials.
2. Aspects Related to Construction Considerations
   - i. Review of most suitable types of equipment and construction procedures in relation to soil conditions, prevailing weather conditions and specification requirements.

A variety of construction jobs comes to mind, in which the demands on the soil consultant differed greatly in application. The basic requirement on all jobs, however, is to earn the customer's confidence. The structural engineer must be confident that the advice and guidance he is receiving is well founded. The second requirement on practically every job in North America today is speed—test results and the consequent recommendations are required urgently in no time at all!! Nothing shakes the client's confidence as much as being given a series of unfulfilled promises on delivery of data and advice.

The third factor is the extent of responsibility the soil consultant displays. Does he make a quick trip to the site, submit a report, and then vanish? Or does he continue to appear at intervals during construction and keep his recommendations up-to-date and refreshed periodically? Perhaps the fee for the work won't permit this further attention, but in that case the soil consultant should do a better selling job for his services. Get confirmation of the advice given, and stay on the job until it is confirmed.

Some of the suggestions which have been outlined are based on very practical experience. On the Peribonka River, north of Lake St. John, the site for a concrete dam and powerhouse was established and the construction work started. As the scope of the site investigation was expanded, it became apparent that a hillside covered by overburden on the east bank of the river did not consist of country rock covered to the usual fairly shallow depth by earth and gravel but actually was an earth and gravel hillside with the country rock at some considerable depth. Investigation was required very promptly to determine just what design of concrete abutment would be necessary to fit into that hillside, and whether a core wall was necessary in the hillside. In order to give the designers some indication of site conditions in the very shortest time, a geophysical investigation was carried out from the surface to determine rapidly the depth of bedrock, and the results of this investigation were confirmed by diamond drilling which required several weeks' more time. This is one example of the work of the soils consultants being adapted to the time requirements of the particular job, which fairly definitely dictated how the investigation should be carried out. On this particular location, observation wells were placed in this hillside to permit seepage measurements to be taken at regular intervals to determine just how effective the structural engineer's design had been, and these seepage readings were discontinued only last April after a record of five years had shown that the conditions are entirely satisfactory.

At Kitimat the smelter plant is located in the Kitimat River valley and is built upon material laid down by the Kitimat River. Soft top soil has been stripped off to a depth varying from 1 foot to a maximum of somewhat more than 20 feet, and the stripped material has been replaced to the required grade by sand and gravel backfill. Compaction of this backfill material has been very good and practically no settlement takes place in this replaced layer. However, at a depth of approximately 40 feet, varying somewhat with the location, there is a horizontal strata of compressible gray silt which compacts under pressure and very appreciable settlement takes place as buildings loads are applied. Our soils consultants estimated these settlements five years ago, and estimated variations in the settlement according to the location. These predictions have been proven to be quite satisfactory although there have been some minor variations. However, actual settlements have been observed and measured very closely during the intervening years with the result that this experience has been sufficient to enable the soils consultants to prepare predictions with increasing accuracy, so that we believe that the predictions of settlement for Potline 8 will prove to be almost exactly what will be experienced during the next 5 years at that location.

The soils consultant must be persistent and must have self-confidence. On one job, we took exceptional care to consolidate the rock on which a concrete storage dam was being constructed. Every means was taken to ensure that the rock was sound and an extensive grout curtain was drilled and placed under the upstream face of the dam. There was the rewarding satisfaction derived from the comment by an experienced consultant in dam construction that he had never witnessed a dam built from which leakage had been cut to such an absolute minimum. However, our satisfaction with this accomplishment was tempered somewhat by the question from one of our own engineers as to whether such care was really justified or whether it would be better to take less pains and permit certain leakage. The soils engineer may be faced with a similar question as to whether a full investigation of soils conditions is actually necessary, or whether construction work can be carried out to somewhat less exacting standards. The soils consultant must have the answers to justify the work he is doing.

Of course, a very definite example of that justification was the experience with a timber pile wharf designed for the west coast. When this design was well under way and the type of construction definitely established, a soils consultant was asked to confirm the fact that this design was satisfactory for this particular location. This investigation very promptly showed that normal loading of this wharf would stress the piles at least 100% and any combination of added wind loads or wave action would very seriously overstress the piles. In this particular instance, the soils consultant had to convince the owners that his conclusions based on expert investigation were more reliable than the owner's own previous experience with timber wharf construction on the west coast but under somewhat different conditions.

The growth of soils engineering during the past 20 years has led to an appreciation of the value of this work. However, it is still necessary to increase this appreciation in some quarters and that is the responsibility of the soils engineer. The structural engineer expects from the soils consultant definite engineering advice presented with sufficient confidence that it will be approved by the owners.

For material for this discussion, I am very much indebted to personal contacts with the soils consultants in the Montreal district. The engineering staff of the Aluminum Company of Canada, Limited, has very kindly commented on specific details. Our soils consultant on the west coast has provided invaluable information through discussion on what may be expected from the soils consultants.

Discussion

By Ralph B. Peck*

Probably every consultant acquires a professional personality that reflects his own background and the fortunes of his professional life. No two consultants would have identical views about the relations among consultants, clients and contractors. Yet the publication and discussion of opinions and experiences concerning this subject may serve a most useful purpose, and we are fortunate that Dr. Terzaghi has ventured to open for debate a field with many controversial aspects.

The writer has by necessity given considerable attention to the special opportunities and problems of the professor-consultant. Soil mechanics experienced much of its early growth in academic surroundings and it is not surprising that many teachers and research workers developed consulting practices. Nevertheless, there are all shades of opinion regarding whether or how the professor-consultant

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