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The Role of the Consulting Engineer in the Application of New Technology

by

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SUMMARY. The role of the consulting engineer in the application of new technology is examined. Importance is placed on the ability of the professional engineer to convert research into acceptable practice. The paper illustrates the premise with actual case history examples.

1 INTRODUCTION

The consulting geotechnical engineer is being increasingly called upon to assume the role of extending the developments of others into the realm of accepted practice. There are several reasons for this role. More difficult site conditions and more complex projects can both separately and combined require extension of techniques and practices to allow their development. Increasing concern for environmental protection can also require that answers be provided for questions that were not raised before.

Completed research work undertaken by universities and research organizations in the geotechnical field often cannot be directly applied to real engineering problems. There are several reasons for this. The first is a direct consequence of the research environment where progress is judged by completion of a project or topic. This results in the idealization and simplification of problems to enable completion and publication of results and conclusions. The second is the tendency to focus detailed attention on small facets of the problem.

In contrast, the consulting geotechnical engineer must work with the full complexity of a real problem and provide an adequate but not overly conservative solution often within strict time limits. Theoretical research developments can appear to represent conditions somewhat analogous to a problem with a current project and may be applied with some modifications. It is also possible that a problem may possess special characteristics that require the direct help of specialists in the research field. In these cases the consulting engineer must work with the research group to develop the special techniques.

The separate areas of the researcher and the practicing engineer are both necessary for the advancement of the profession. What is needed is more direct interaction between the two groups. Awareness of this need for inter-relationship is gradually being recognized more widely. Dr. Charles N. Thiel (Ref. 1), Manager of Earthquake Engineering of the United States National Science Foundation recently stated "Professionals have expertise to forge research into viable operating procedures."

The consulting engineer must formulate his problem in as complete a way as possible commensurate with the ability to obtain a solution. The

first requirement, however, is to identify the nature of the problem or even to determine if a potential problem exists. In research the simplification of the problem to a form that is amenable to solution is often necessary. This simplification is not always detrimental. It can be desirable if understanding of the principles involved is increased. The geotechnical engineer, on the other hand, cannot simplify his problem and is usually interested in simplifying the solution. This could perhaps be achieved by showing that a simple upper bound approach provides an adequate solution. An example of this would be by showing slopes remain stable even with unquestionably conservative shear strength assumptions.

The importance of obtaining an adequate answer rather than a complete or correct answer is perhaps the major philosophical difference between the practicing engineer and the research engineer. In the examples that follow demonstrating the extensions of research developments into viable operating procedures the first is devoted to the concept of a simple adequate answer. Also included among the examples is one where special developmental assistance in research was required.

2 SETTLEMENT

An estimate of the total settlement expected is often required as part of a preliminary site evaluation study. For such an evaluation the modulus approach suggested by Janbu (Ref. 2) has been found to be especially useful. Janbu classifies settlement computations into three categories to cover over-consolidated clays, sands, and normally consolidated clays. While the procedures have been found to work well on all three soil types only the modulus method for normally consolidated clays is considered here. Janbu suggested that the modulus number m is dependent only on the moisture content for a wide range of naturally occurring clays. For plastic clays the Janbu modulus number m is equivalent to the natural logarithm of 10 divided by m_v the coefficient of compressibility or:

$$m = \frac{2.3}{m_v} \quad (1)$$

Modulus numbers were computed from consolidation test data performed during many projects. These data were plotted against initial moisture content as shown in Figure 1. The good correlation between moisture content and modulus number is readily apparent.

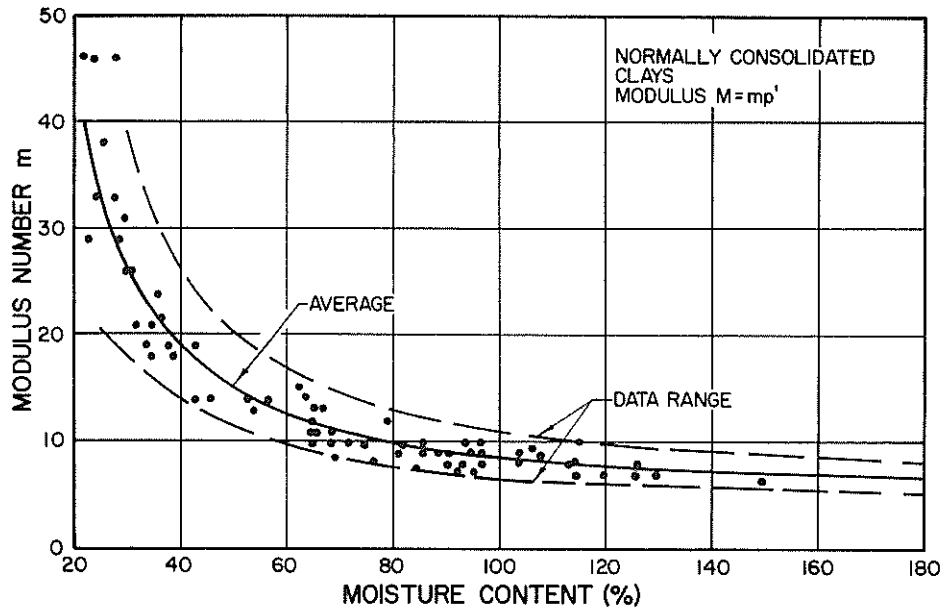


Fig. 1 Modulus Numbers for Normally Consolidated Clays

The value of this approach can be most easily shown by considering an example. A molasses storage tank of 150 feet diameter was being planned for construction in an area with soft normally consolidated clay. This clay had a moisture content of 50 percent and a wet density of approximately 110 pounds per cubic foot. The tank height was 32 feet but it was not expected to be loaded to more than 24 feet except for very short periods of time at infrequent intervals. The total settlement at the center of the tank was estimated using the Janbu generalized modulus number in the following way. By Janbu's definition the material modulus for plastic clays is defined as:

$$M = mp' \quad (2)$$

where p' is the existing effective confining pressure. The strain within a layer would then be defined as:

$$\epsilon = \frac{\int dp'}{M} \quad (3)$$

This expression can be integrated either in a closed form or numerically for different simple loading conditions. If a load ratio term N is defined in one of the following ways:

$$N = \frac{q}{\gamma H} \quad (4)$$

$$N = \frac{q}{\gamma B} \quad (5)$$

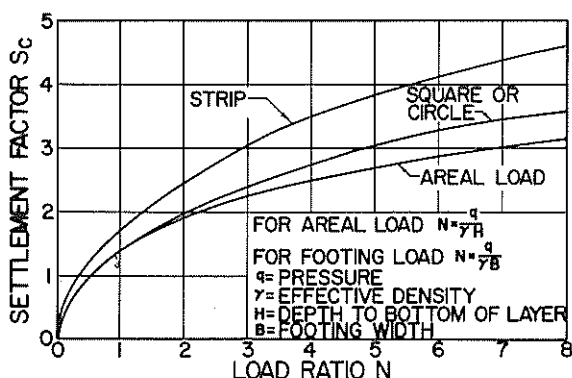


Fig. 2 Settlement Numbers for Surface Loads

for a uniform areal surface load of q , a buoyant density of γ , and either a layer thickness of H , or a surface footing width of B . Simple charts can be prepared and used for finding the average strain or settlement factor S_C . An example of these charts for normally consolidated clays is shown on Figure 2. For the example considered the value of N obtained is 0.31 (molasses has a specific gravity of 1.5) and from Figure 2 the value of S_C for a square or round footing is 0.7. The modulus number may be read from Figure 1 as 15 and the total settlement computed as:

$$\sigma = S_C \frac{B}{M} = 0.7 \frac{150}{15} = 7 \text{ feet} \quad (6)$$

Consolidation tests and a detailed settlement analysis were subsequently performed for this project. The detailed analysis which included the reduced settlement of small layers of sand in the profile and the direct laboratory test data gave a settlement estimate of 6 feet. It is possible therefore to make preliminary settlement estimates on the basis of simple classification tests. Detailed testing and analysis can still be carried out if desired or if the facility being designed is particularly sensitive to settlements.

3 SEISMIC RISK

Interest in probabilistic procedures and their application in civil engineering has increased in recent years. Although the concept of return periods for flood control design is widely used applications in other areas have been developed more slowly. A proper balance between possible losses which may be caused by an event and the costs of protecting against these losses is the desired aim. For seismic considerations public safety and the economic effects on the total community must also be considered. Some seismic design coees, such as that of Canada (Ref. 3), are being expressed in terms of risk parameters.

Probabilistic methods based on extreme value theory have been developed for use in estimating the exposure of sites and structures to earthquakes. (Ref. 4). Although complex in form the analytic techniques developed in the literature can be readily programmed for use in a digital computer. This was done but when attempts were made to apply

the procedure to real sites it was found that the results were sometimes inconsistent with pragmatic judgment. As the analytical techniques and the basic assumptions were sound the sensitivity of the major input parameters had to be examined. Some parameters were found to be especially sensitive. Fortunately, as the results of studies of worldwide seismicity, some parameters can be defined within fairly narrow bands. Other sensitive parameters were found to be quite inadequately and inconsistently defined within the literature. The attenuation of motion with distance was one of these. Published attenuation relationships were examined and compared. They showed a wide variation in values and led to the conclusion that most of them showed inconsistencies in either the short or long distance range.

The 1971 San Fernando earthquake provided the first large sample of strong motion records from one event. This data set was compiled and compared with representative attenuation relationships (Ref. 5). Figure 3, which is taken from that reference, shows that the variation between the attenuation relationships is much greater than the scatter of the individual data values. The relationships showing closest agreement are those which have used the San Fernando data in their development. Each major seismic event provides some additional understanding of seismic behavior to incorporation in new projects.

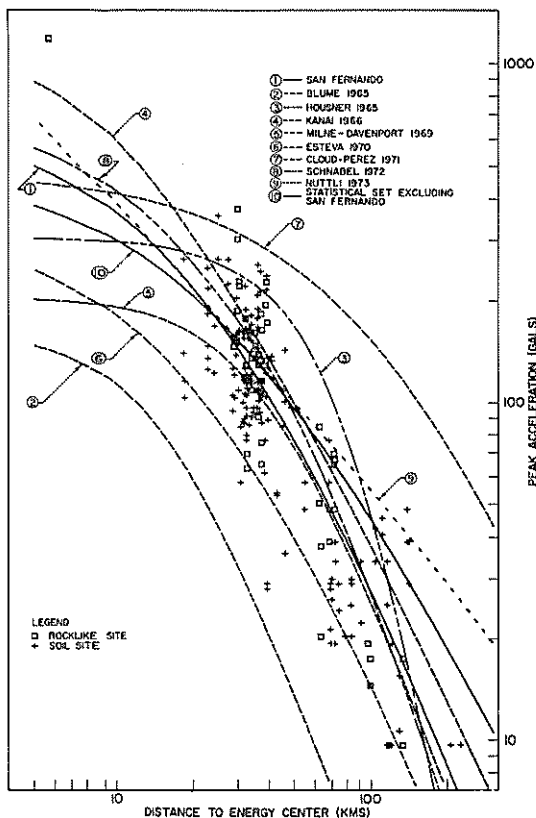


Fig. 3 Comparison of Attenuation Equations With 1971 San Fernando Strong Motion Data

From extensive studies of the individual parameters during their application to a wide variety of projects, the basic numerical results of the research have been converted into a viable operating procedure. Estimates of exposure to seismic risk using these procedures can be incorporated into the decision making process for the choice of

design level earthquakes for structural analysis and site response studies. An example of the type of results obtained from a study are shown in Figure 4. These results are from a study for a site in South Africa.

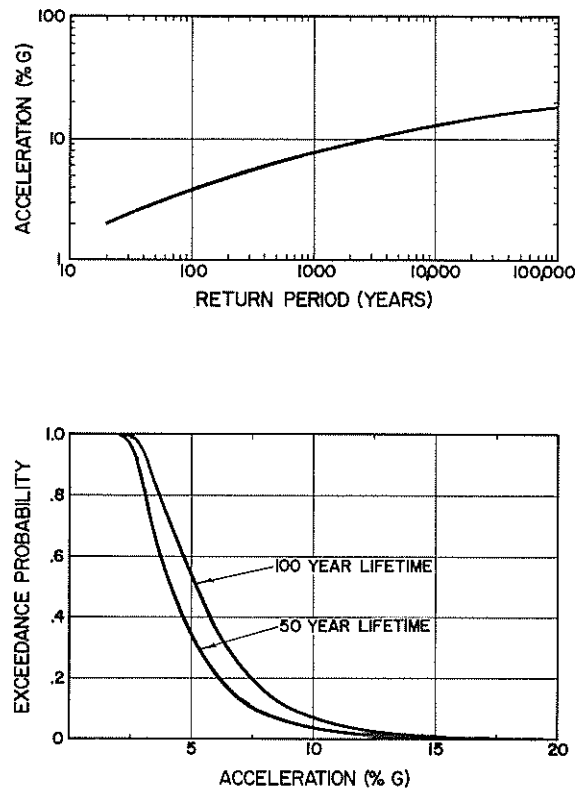


Fig. 4 Peak Acceleration Return Periods and Probabilities

4 SEISMIC LIQUEFACTION

The Trans Alaska pipeline traverses 800 miles of Alaska, from the Arctic Ocean to the ice-free port of Valdez on the Gulf of Alaska. The pipeline traverses a wide range of topography and climatic zones as it crosses some highly seismic areas. In the cold environment few clays are formed, so most of the soil types consist of silts, sands, and gravels. The thermal disturbance produced during construction will cause some degradation of permafrost. These newly thawed areas and areas where permafrost does not exist may be subject to liquefaction in the event of an earthquake. Techniques have been developed to evaluate the potential of soils for liquefaction (Ref. 6, Ref. 7). Faced with the wide variety of soil types and changing seismic zones, it was necessary to develop a procedure which could be used on a routine basis for analysis. One of the more common procedures uses the results of vertical wave propagation and shear stress time histories, preferably for more than one input time history. These procedures were too time consuming for the amount of analysis required. Some generalized representation of potential seismic stresses was necessary. A statistical study of observed strong motion records showed that a stochastic procedure could be developed to represent the cyclic stresses within a layer and used within a digital computer program to evaluate the liquefaction potential. The basic procedure of analysis has been published elsewhere (Ref. 8).

To accommodate the variety of soil types and the wide range of relative densities encountered, relevant test data from the literature and

laboratory test data were compiled and reviewed. To expedite the engineering studies it was necessary to represent these assembled data in a generalized way. This data was used in numerical form within the computer program. The graphical representation of the data from which the numerical basis was prepared is shown on Figure 5. This stylized data representation, when considered alone, can be criticized as an incomplete representation of test observations. The total analytical method including the test data representation, was successfully checked against 34 known case histories of liquefaction before application to routine analyses of soils along the pipeline route. The direct checking procedure is an adequate empirical answer to possible criticism of the simplified data representation.

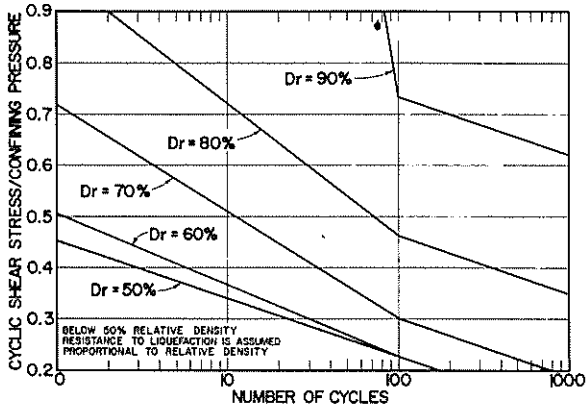


Fig. 5 Liquefaction Criteria

This case represents a much more complex example of how a consulting geotechnical engineer must combine research from different disciplines to produce a useful analytical procedure. In this case, results from the fields of seismology, earthquake engineering and soil dynamics had to be combined to produce the comprehensive technique.

5 THAWED SOIL ANALYSIS

In some cases a problem may develop which requires special extension of the available technology. A situation such as this will require the consulting engineer to interact directly with a research group, to use their expertise in providing a solution. An example of such a situation arose during analyses for the Trans Alaska pipeline.

Hot oil flowing through a pipe which is buried in permafrost will develop a thawed zone with time. This thawed zone or thaw bulb, as it is called because of its cross sectional shape, will increase in size with time. Concern was expressed for the seismic stability of this thaw bulb, especially in the longitudinal direction. Available finite element procedures could be used only in the plane normal to the pipeline. Stresses induced by motion in this plane were inconsequential. What was needed was a method which would analyze the serious shaking in the longitudinal direction. No methods had been developed to analyze such a model.

Structural dynamics experts at the University of California were contacted about this problem and after some discussion a procedure was devised where the two conjugate pairs of shear stresses, such as shown on Figure 6, could be incorporated into the analysis of a two-dimensional model (Ref. 9). This revised computer code was used to

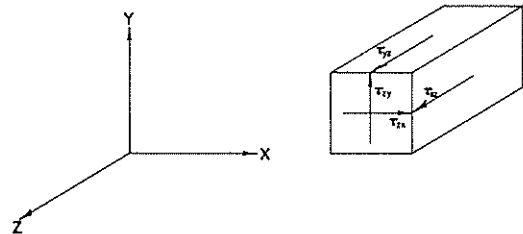


Fig. 6 Shear Stress Coordinate System

analyze the performance of several stages of development of the thawed zone. A typical section showing the finite element mesh used is shown on Figure 7. The acceleration time history was input to the nodal points around the permafrost boundary in a direction normal to the plane of the elements. The accelerations and displacements of the system were computed for each nodal point using a step by step procedure. From the relative displacements between nodal points the time history of stress in each element was computed. A typical computed

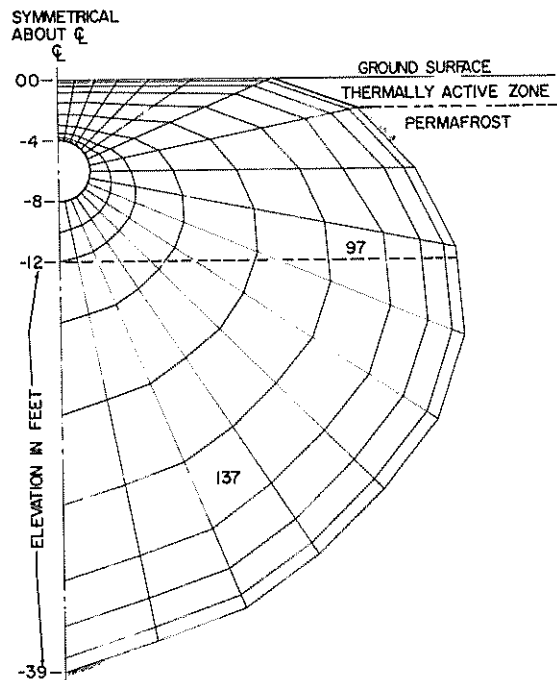


Fig. 7 Finite Element Mesh

shear stress time history is shown on Figure 8. This is the shear stress in the xz direction with in element 137. Peak shear stresses across the

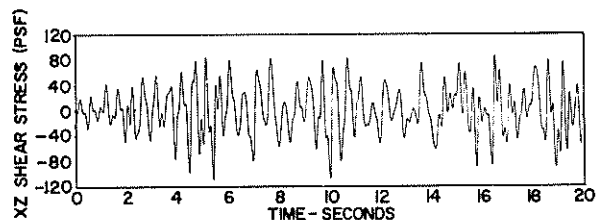


Fig. 8 Shear Stress in Element 137

section at Elevation -12 are shown on the upper part of Figure 9. In the lower part of Figure 9 the 20 cycle average shear stress across the same section is compared with the uniform cyclic shear stress required to cause liquefaction in 20 cycles for the assumed soil conditions when the ground water table is at the ground surface and at a

depth of 8 feet. It is readily apparent that the safety against liquefaction would be closely controlled by the depth of the water table.

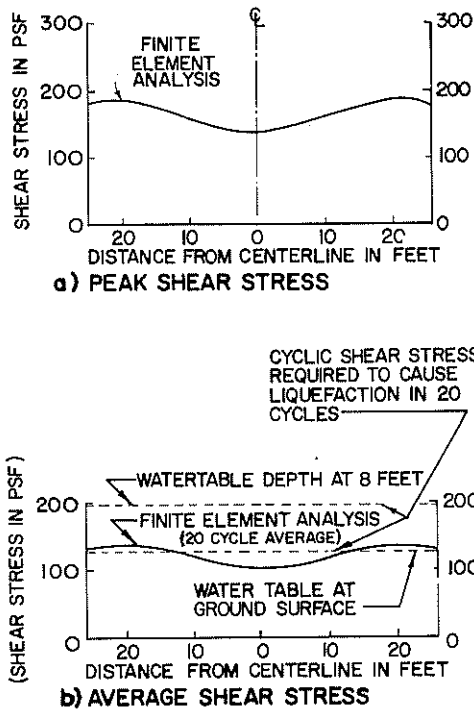


Fig. 9 Shear Stresses Across Section at Elev. -12

The design scheme for the Trans Alaska pipeline was eventually changed so that in all permafrost areas with fine granular soils the pipe would be supported above ground on piers. The analysis still serves as an excellent example of the way technical progress can be achieved by the interaction between the practicing professional engineer and those engaged in research within universities and research organizations.

6 CONCLUSIONS

Consulting geotechnical engineers are being required to design and analyze increasingly complex projects. This often requires the use of new techniques based on adaptation of research results which are not directly applicable. This paper describes with some simple examples the basic principles involved and demonstrates the need for interaction between the research oriented engineer and the practicing consulting engineer. Each is essential to the other. One method by

which this interaction is being achieved is by having practicing engineers serve on advisory boards which meet to review progress of major research projects.

7 REFERENCES

1. THIEL, C.N. A Pill to Cure an Earthquake. Proceedings 43rd Annual Convention, Struct. Engrs. Assoc. of California, Nevada, 1974.
2. JANBU, N. Settlement Calculations Based on the Tangent Modulus Concept. Bulletin, Technical University of Norway, Trondheim, Norway, 1967.
3. MILNE, W.G. and DAVENPORT, A.G. Distribution of Earthquake Risk in Canada Bulletin of the Seismological Society of America, Vol. 59, 1969, pp. 754-799.
4. CORNELL, C.A. and VANMARCKE, E.H. The Major Influences of Seismic Risk, Proceedings of the Fourth World Conference on Earthquake Engineering, Santiago, Chile, Vol. 1, 1969, pp. 69-83.
5. DONOVAN, N.C. A Statistical Evaluation of Strong Motion Data, Including the February 9, 1971 San Fernando Earthquake Proceedings of the Fifth World Conference on Earthquake Engineering, Rome, Italy, Vol. 1, 1973, pp. 1252-1261.
6. LEE, K.L. and SEED, H.B. Cyclic Stress Conditions Causing Liquefaction of Sand Journal of the Soil Mechanics and Foundation Division, A.S.C.E., Vol. 93, 1967, pp. 47-70.
7. SEED, H.B. and PEACOCK, W.H. Applicability of Laboratory Tests Procedures for Measuring Soil Liquefaction Characteristics under Cyclic Loading Earthquake Engineering Research Center Report, EERC 70-8, University of California, Berkeley, 1970.
8. DONOVAN, N.C. A Stochastic Approach to the Seismic Liquefaction Problem Proceedings of the First International Conference on Applications of Statistics and Probability to Soil and Structural Engineering, Hong Kong, 1971, pp. 514-535.
9. RUKOS, E. Earthquake Analysis of Interactive Ground-Structure Systems University of California Report, UCSESM 71-9, May, 1971.