Abridgment

Increasing Communication Between Bridge and Geotechnical Engineers

PHILIP KEENE AND JOSEPH J. BULBA

Geotechnical engineering is a new field compared with bridge engineering. During the early stages of the former, various methods were developed to implement geotechnical applications to bridge foundation design and construction. Several reviews have been conducted of the organizational structure in the state transportation agencies and district federal offices of the Federal Highway Administration (FHWA). The interaction of the many disciplines within these offices needs further improvement. Geotechnical engineers have not always been able to incorporate new methodology into current bridge foundation design practices. The reasons for this are reviewed to improve communication between these units and top management. The conclusion reached is that cooperation between independent geotechnical, bridge design, and construction units, best serves the interest of the agencies.

Treated as a science since the days of Leonardo da Vinci, bridge engineering is an old discipline, dating back to early civilizations. It has been taught in universities for several centuries. Geotechnical engineering, on the other hand, is a relatively new discipline; its scientific form may be said to date back to Terzaghi, Casagrande, and other pioneers early in the present century. In 1940 only a handful of engineering schools taught soil mechanics; after World War II the number increased rapidly, and today there are many excellent geotechnical engineering programs offered in the United States and elsewhere. Its wide appeal is reflected, for example, in the membership of the American Society of Civil Engineers, where it ranks second to structural engineering in popularity.

Bridge engineering has developed rapidly; recent innovations in design concepts and materials include prestressed concrete, orthotropic superstructures, integral abutments, weathering steel, cantilevered end spans, jointless decks on multispan superstructures, and so on. The bridge engineer's growing confidence in superstructure design has also been abetted by the more sophisticated analyses of soil condition available. The more adventurous bridge engineers will design with anticipated settlements, total and differential, into their structures.

Various methods of analyses of soil and rock behavior have been developed in geotechnical engineering and the field has advanced from the use of a basically theoretical approach to supplementary field observations and instrumentation that modify or confirm the theoretical. For some situations, long-term monitoring is important. Thus, the geotechnical engineer is developing a more solid base for his recommendations. In addition, as geotechnical engineering has become recognized as a separate entity in the field of civil engineering, it has also become accepted in highway engineering.

P. Keene, 34 Home Ave., Middletown, Conn. 06457. J. J. Bulba, Storch Engineers, 161 Main St., Wethersfield, Conn. 06109.

CURRENT ORGANIZATIONAL STUDIES

In 1976 the FHWA conducted a nationwide management survey of the organizational position and functions of the geotechnical groups in each state transportation department *(1)*. From 1977 to 1981, the FHWA conducted a study of foundation engineering practices in state transportation agencies and FHWA district offices. The study entitled *Foundation Engineering Management Reviews (2)*, was published along with *Foundation Engineering Improvement Program FY 1983–1987 (3)* in 1983. The principal objectives of the study were to

1. Determine current agency procedures related to the design and construction of structural foundations;
2. Assess the effectiveness of these procedures in constructing safe, economical, and environmentally acceptable facilities;
3. Document innovative foundation practices that could be transferred to other agencies; and
4. Establish needs necessary to improve the foundation engineering capabilities of the agencies by providing follow-up technical assistance and training.

Among the state and federal departments, consulting engineers, and others involved in highways and railroads, the organization of the bridge and geotechnical groups and their relationship vary widely, for a number of reasons. The bridge group is usually a separate division in the agency. The geotechnical group may be a separate division, part of the materials laboratory, or divided between the bridge and roadway divisions and the materials division. In some cases, the agency may rely solely on consultant services.

The earlier FHWA report *(1)* was based on a nationwide study conducted by officials of FHWA and each state. Originally requested by some states, the study was expanded and made a part of a foundation engineering improvement program *(3)* initiated by the U.S. Secretary of Transportation. After the reviews were completed, a draft report, prepared from the reviews, was forwarded to each state and FHWA regional office for comment. The final report to the states was well received. The findings indicated that nine years ago, six states had a separate geotechnical division in the central office and five more were considering one. In six additional states geotechnical work was divided between the bridge division and the materials laboratory. In the remainder of the states geotechnical work was done in the materials laboratory. Currently, workshops are being held by FHWA to improve the geotechnical organizational setups, as well as certain technical engineering practices *(4)*.

According to the FHWA, the current organizational location of the foundation design units in state agencies is as follows: a few units (10 percent) are involved in all phases of subsurface investigation, design, and construction. Some are separated from the subsurface investigation entirely (10 percent), and 68 percent are included only in the subsurface investigation and design phases *(2, 3)*. These percentages were extracted from questionnaires in which multiple responses were permitted.

Geotechnical engineering is primarily a specialized technical function that serves planning, bridge design, roadway design, construction, and maintenance. As shown in the FHWA management studies *(1)* and *Foundation Engineering Management Reviews (2)* it serves not for testing or quality control but as an engineering function for subsurface investigation, design, construction, or combinations of the three.

In the executive summary of *Foundation Engineering Management Reviews (2)*, the FHWA states that "foundations for all civil engineering facilities are significantly less expensive when designed by a rational and scientific approach than when they are determined solely by rules of thumb and past experience." Unfortunately, the current practices of many of the agencies reviewed do not reflect modern state-of-the-art technology, nor do they resemble the practices of most of the private sector. In such agencies, it is the duty of top management (commissioner, chief engineer, etc.) to correct this situation, which is often the result of a lack of communication between the bridge and geotechnical engineers.

Although the reasons for this technological lag are undoubtedly many, several became obvious during the reviews: *(a)* low salary level, *(b)* insufficient technical personnel, *(c)* physical separation between geotechnical and bridge design facilities, *(d)* poor communication between design and construction personnel, *(e)* increased use of consultants, *(f)* lack of incentives for promotion of cost-effective designs, and *(g)* insufficient opportunities for technical training.

In addition to the foregoing list, it must be added that bridge design units are often under pressure to produce designs as rapidly as possible with limited manpower. This may result in costly overdesign of bridge foundations, as well as over design of the entire structure, but the excessive cost is buried in the construction cost. The public may believe that it is getting state-of-the-art design in its new construction, but this is often an illusion.

It is perhaps the direct and highly visible counting of personnel and funds that prevents the establishment of a separate geotechnical unit. Heads and dollars in a transportation agency budget cannot be hidden, but the cost of construction inefficiencies can. Despite the obvious reasons for technological lag and delay in the establishment of a more specialized approach to foundation design, probably the most frustrating aspect is the maintenance of the status quo in the system, which may inhibit the use of new methodologies. As already stated, top management has the opportunity to step in and bring the organizational structure up to date.

The FHWA recommendation can be summarized as follows:

> The need for continual geotechnical engineering involvement throughout all activities of foundation design and construction is absolutely necessary for a cost-effective end product.... This concept of project involvement from beginning to end is primarily related to the fact that soils are not man-made as are other construction materials such as concrete and steel; therefore, no matter how many borings are performed for a project, there will be a considerable amount of engineering judgement in the design which makes it likely that some modifications and adjustments will be necessary during the final structure design and construction.

Another deterrent to the proper use of geotechnical engineering in bridge foundations is the reluctance of many bridge engineers to accept modern and proven foundation design practices. This resistance is probably due chiefly to inertia and to well-intentioned conservatism. Other possible reasons are suggested by Keene *(5)*. For example, according to Wahls *(6)*, "recent surveys by FHWA indicate that in many states spread footings rarely are used for support of highway bridges. In some states, spread footings are not considered unless they can be founded on rock." In the words of the late O. J. Porter in 1953 *(7)*, "While we have had many mistakes due to inadequate foundations, we have also had many buried treasures of money due to using an expensive pile foundation where spread footings could be safely used." Often this situation can be corrected only through the intervention of top management, for example, the chief engineer.

Examples of savings realized where spread footings were used—even though piles would have been the "safe" choice—are given by Keene *(5)* and Wahls *(6)*. Part of this conservatism may also result from geotechnical engineers' involvement in public sector projects. As stated by Wahls *(6)*, in the private sector building foundation designs are typically more realistic and less costly, even though buildings are more delicate structurally than highway bridges. Most buildings are constructed with private funds, and unnecessarily costly design and construction would not be tolerated. Another example of the reluctance to change bridge design is the antiquated specification used in interpreting pile load test results *(8)*. One example indicates that the allowable load, from the test on a pile, should be 50 percent of the gross load, which results in a net settlement of ¼ in. This was specified in the original manual of the American Association of State Highway Officials (AASHO), Committee on Bridges and Structures published in 1931; it has not been changed in the 53 years of the manual's existence. Today, however, some agencies are ignoring this specification.

MODERN FOUNDATION DESIGN PROCEDURES

A separate soils and foundations unit was established in Connecticut in 1940, thus initiating a scientific approach to foundation analyses for roadways and structures. At the direction of the highway commissioner, this unit gave special attention to bridge foundations because of the number of bridges in the state. A list of items to be covered in foundation design was developed that included the geotechnical engineer's recommendations. This list, with discussion of items, is given by Keene *(9–11)*. A shorter list without discussion is given in the *Manual on Foundation Investigations (12)*. A good working relationship developed because the bridge designer was relieved of responsibility in an area where most bridge engineers had only limited knowledge. Piled foundations no longer needed to be used in the conservative approach to a majority of foundations, nor was a too-liberal approach needed for others. Inventive substructures could be designed with assurance that

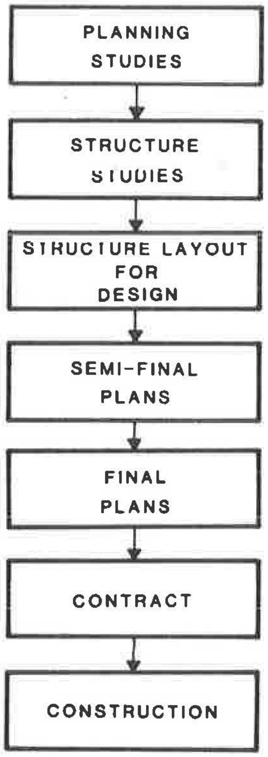

FIGURE 1 Communication procedures used to aid project design.

the developing soils science would be able to furnish the proper subsurface design information.

A procedure gradually evolved whereby a PD (Preliminary Layout and Design) Sheet was developed for each structure by the bridge designer. The degree of input varied in proportion to the number of divisions reviewing the plans. With the initiation of the Interstate program in the mid-1950s, the Connecticut Highway Department engaged the services of consulting firms to provide support to its engineers. Communication became a necessity for an orderly design process because so many projects were being designed (Figure 1). Later, a structure studies format was developed. Only structures showing promise for the site were to be studied, thereby keeping most studies to only two or three configurations. These structure studies were distributed to all sections concerned within the department as well as to agencies concerned for their review, and an acceptable type was selected, with modifications as required.

This review process has worked well, especially because there have been fewer reasons for delay due to unforeseen complications or omissions. During this process, a strong bond developed between the geotechnical engineers and the bridge engineers. Each serves in a unique sphere of expertise and recognizes his impact on the other.

CONCLUSIONS

Cooperation among the geotechnical engineer, the bridge and highway engineers, and all the interested participants in the design and construction process means that the public obtains the best structure for the location. This usually results in the most economical structure at the beginning, and invariably, to the end of its useful life.

It is recognized that each agency has a different and unique organization, suited to those who deal with it. Yet there is a growing belief in the profession that the geotechnical unit, with its own soils laboratory, test boring crews, and so on, cooperating with the bridge design and construction units located nearby will provide a more effective solution to the problem. Having the geotechnical functions combined into one unit is beneficial because it provides for a unified control and continuation of personnel, equipment, and experience involved with the same basic geotechnical problems. It also improves guidelines established for continuity of communication and project flow between the various engineering groups and the geotechnical group that serves them.

Many states have sizable areas where conditions are similar, where enormous sums of money can be saved easily merely by the application of current geotechnical analyses and evaluation, and by implementation of these findings by bridge design. As noted earlier, speed of design is not justifable on the basis of design, construction, and cost. However, the logistics of time for travel to construction sites and design offices must be acknowledged, as well as other factors in organizational implementation. These problems are real, but they can be accommodated. There is no one best answer, but there is an acceptable one.

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