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Geotechnical Challenges of the Interstate Highway System

The First 50 Years and a Look Ahead

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Foreword

The year 2006 marked the 50th Anniversary of the Eisenhower Interstate Highway System (hereafter referred to as the System). During the design and construction of the System, geotechnical engineers faced many challenges to construct a highway system that would facilitate the movement of traffic, specifically military traffic. The Cold War was at its height 50 years ago. Reliable transportation was needed from the east–west and the north–south borders of the United States as quickly and efficiently as possible. This required the design and construction of a highway system through many different geologic formations, several different climates, and many different soil depositions. Karl Terzaghi's 1925 *Erdbau Mechanic* was barely 30 years old. Many of the challenges first had to be recognized and defined before they could be understood and solved. To accomplish the task, many new and innovative geotechnical engineering technologies were developed, along with enhancements to the traditional designs. The product of these efforts was an enviable transportation system that met military requirements and became a pillar to support previously unparalleled economic growth of the country. Maintaining and upgrading this system to meet continuing and new needs left more than one challenge for the future.

At the 2006 Annual Meeting of the Transportation Research Board, in a session sponsored by the Soil Mechanics Section (AFS00) of the TRB Design and Construction Group, titled 50 Years of the Interstate Highway System: Geotechnical Engineering Challenges That Lie Ahead, four nationally recognized geotechnical engineers provided their views on what was learned, and they also highlighted what they saw as the challenges. Three of the participants were directly involved in the design and construction of the System, and presented their thoughts from that perspective. They were

- Reynolds Watkins, Professor Emeritus, Utah State University;
- Verne McGuffey, retired from the New York State Department of Transportation (NYSDOT), Geotechnical Engineering Bureau; and
- Richard Cheney, retired from the NYSDOT Geotechnical Engineering Bureau, and FHWA;

The fourth presenter, Robert Burnett, currently employed by NYSDOT's Geotechnical Engineering Bureau, presented the perspective of a geotechnical engineer currently involved with continuing maintenance of the New York State portion of the System.

The presenters didn't just focus on the System, but addressed the general challenges that geotechnical engineers will be facing in the future.

This circular is a summary of the four presentations. The information is taken in part or in whole from the presentations; the section by Reynolds Watkins is summarized from an unpublished paper submitted for the session. In some cases, the preparer of the circular has expanded on comments or points made by the presenters.

The circular is sponsored by the Soil Mechanics Section, which also provided the peer review of the contents of the document. Geology and Properties of Earth Materials Section also participated in the peer review of the document. The key points made by each of the presenters have been highlighted. The circular has also been reviewed by the presenters for accuracy of their key ideas.

—L. David Suits
Chair, Design and Construction Executive Board
Former Chair, Soil Mechanics Section

Contents

Our Interstate Highway System
From Conception to Birth

REYNOLD WATKINS
Utah State University

When can-do is impregnated with know-how, something remarkable could be conceived and born. The Interstate Highway System (the System) was one such remarkable birth. In the backwash of World War II, highway transportation was a maze of local roads (state, county, and town) at the time of desperate need for interstate transportation that had been neglected during two simultaneous wars—one across the Atlantic and one across the Pacific. On June 29, 1956, President Dwight D. Eisenhower signed the Federal-Aid Highway Act. The Federal Interstate Highway Program was born. The plan was to construct 42,000 mi of interconnected, limited-access, parallel twin highways throughout the country.

The concept started in the backwash of World War I, in July 1919, when an army company departed from Washington, D.C., in a cross-country automobile caravan. The objective was to evaluate army transportation by automobile as the inevitable replacement of horse and wagon transportation of World War I. A young officer in the company was Captain Dwight D. Eisenhower. He noted that the wagon roads were the most serious deterrent to automobile transportation. It took 62 days to reach San Francisco.

At the end of World War II, General Eisenhower surveyed the damage in Germany caused by the Allied bombing. He noted that a railway was out of service by a single bomb. But the German Autobahn was durable. A single bomb could not knock it out of service. The Autobahn was limited-access, twin highways with no speed limit. One could cross Germany in 2 days.

In 1953, President Eisenhower remembered the 62 days on rough wagon roads across America and the 2-day Autobahn speedway across Germany. He got onto the case for an "American Autobahn," realizing the importance of highways—not only for rapid deployment of troops and equipment and emergency evacuation routes, but urgent civilian transportation and commerce. It took 2 years, but a can-do Congress responded.

Incredibly, President Eisenhower was not beholden to big oil, big auto, or big construction companies. He was not angling for reelection. He prioritized needs of the U.S. troops above politics and favoritism. The President was supported by a trained and disciplined nation, the Greatest Generation, just emerging from the war. It was an eager, and able can-do. And the know-how was available. Highway technology had been progressing innocuously.

Before World War I, Anson Marston was coerced, as his professional responsibility, to become the first Dean of Engineering at Iowa State College (Figure 1). He accepted reluctantly, "but only for 2 years, mind you." Anyway, why is engineering needed in an agricultural college in corn and hog country? Marston found out why. Each spring, Iowa farmers were bogged down in roads that were quagmires of mud (Figure 2). Marston responded with a call for action to "get Iowa out of the mud." He had support from the farmers who helped him put pressure on the state government. The farm votes were impressive. The road project was launched.

Marston realized that to get Iowa out of the mud, they had to get the water out of the roads. And that, he declared, could be accomplished by drain pipes and culverts. Marston led by deriving a formula for earth load on buried pipes. Then it became the responsibility of pipe manufacturers to make pipe that could support his Marston load (Figure 3). The D-Load test for

FIGURE 1 Anson Marston, first Dean of Engineering at Iowa State College.

FIGURE 2 Iowa roads in the 1920s.

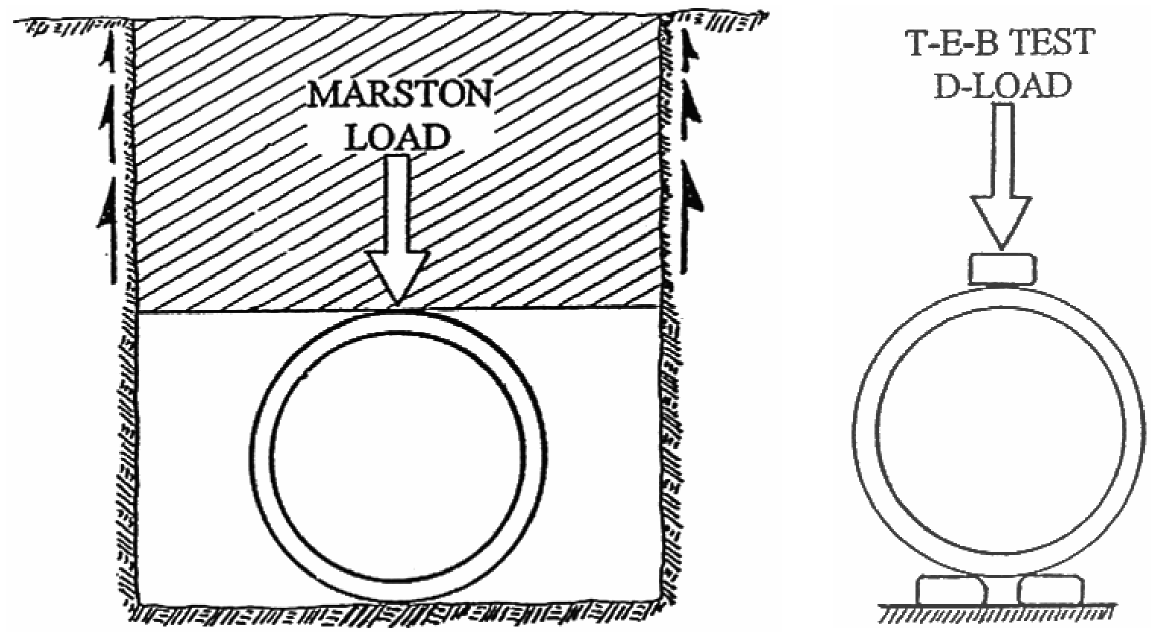

FIGURE 3 Marston load on rigid pipe (left) is the weight of backfill (cross-hatched) reduced by friction of the trench walls; and three-edge-bearing test (right) for D-Load strength at failure of pipe.

pipes became a performance specification—not another controversial set of procedural specifications. The concept of performance specification was a significant innovation in the evolution of highway technology.

The Iowa road drainage project was a success. The nation took notice. Pipe manufacturers were pleased. They could utilize their own expertise in making pipe that could meet the D-Load test, unencumbered by volumes of procedural specifications. State highway departments took notice. Iowa was not the only state bogged down in muddy roads. The federal government established the Highway Research Board (HRB) with Anson Marston as its first Chairman of the Executive Committee. Highway drain pipes were part of a remarkable development of buried pipes—for highway culverts and drains—but also for transmission of water, gas, power, and oil, and for disposal of sewage and storm water. Buried pipes were becoming arteries of communal life—the guts of civilization's infrastructure.

Evolution of pipes in communities started from antiquity: terra cotta water pipes in ancient Greece; bamboo pipes in the Orient; rock-lined, fresh-water *khanats* from the mountains to the cities in Persia. Then later there appeared lead pipes in Rome and underground brick-lined sewers in Paris and London. Development of pipes was empirical, labor-intensive, and fraught with failures. Who knows how many Persian lives were lost in underground tunnel collapses while excavating tunnels ahead of the rock lining? How could the Romans know that their acid water in lead pipes would cause lead poisoning and infertility of the elite and mental retardation of their children like imbecile emperors Caligula and Nero who "fiddled while Rome burned."

But in the 20th century, buried pipe technology exploded, ignited by Marston.

The Marston load was applied to rigid pipes—concrete and clay. Then came Armco with flexible, corrugated, steel pipe. From tests in the Armco yard in Ohio, corrugated steel pipes performed well as buried culverts, but they could not survive the standardized D-load test. Flexible pipes collapsed under the D-load. So why did flexible pipes perform so well as culverts under traffic? The dean assigned the flexible pipe question to a young instructor, M. G. Spangler (Figure 4). That was in the late 1930s. Spangler discovered the effectiveness of horizontal soil support at the sides of a flexible pipe. It became clear that buried pipe performance is pipe–soil interaction. And soil is a major component of the conduit. Spangler derived his Iowa formula for ring deflection (percent increase in horizontal diameter of a buried flexible pipe) as a function of pipe ring stiffness and horizontal soil support. Spangler demonstrated that good soil embedment is the basic structure, and that flexible pipe is a liner and a form for construction of a soil conduit.

During World War II, the know-how of mechanized equipment developed phenomenally. The Germans invaded neighboring nations with *blitzkrieg* (lightning strike) mechanized artillery. Horse-drawn field artillery was suddenly obsolete. Steam engines were replaced by diesels. The old steam shovel was replaced by the backhoe. Horse-drawn scrapers, slushers, and fresnos were replaced by internal combustion-powered graders, bulldozers, and carry-all loaders.

R. G. LeTourneau's remarkable inventions were part of the know-how. Legend has it that LeTourneau sought inspiration from "on high" in his conference room where a large table was surrounded by 12 empty chairs with pad of paper and pencil at each place. Into this sanctuary came the revelations, as LeTourneau paced around the table. When a revelation descended, he would drop onto the nearest chair and make notes. From his autobiography, *Mover of Men and Mountains,* comes the following notes on some inventions pertinent to highway construction.

> In 1885, Benjamin Holt built his first tractor in Stockton, CA. It had large steel driver wheels with cleats on them. Steam powered at first, then gasoline powered, these monsters could do the work of 100 mules. But in poor soil, the wheels would spin and dig down under the heavy weight. In a rain-soaked field, Holt was watching one of his tractors when the wheels started to spin and quickly dig down to the axles. In a flash of inspiration, he remembered the treadmills on which a

FIGURE 4 M. G. Spangler, professor of Civil Engineering, Iowa State College.

> horse would plod to turn the gears that ground the corn. Why couldn't a tractor, riding on a treadmill, spread the weight of the tractor on soggy ground? The result was the new, 1905 version of a tractor-on-a-track that crawled along over mud like a "caterpillar." The future was obvious. A major manufacturer of caterpillars was created. And competition was created.
>
> Then came World War I. The British Ministry, remembering the "caterpillar," armor plated tractors and mounted cannons on them. The monster was called a "tank." It wallowed through water-filled shell holes, and crashed over sand bags to straddle German trenches. It knocked down stone walls and trees, crushed machine gun nests, and blew up ammunition dumps. It left little doubt as to the possibilities for tracked vehicles.
>
> The Fresno was invented by a blacksmith, Abijah McCall of Fresno, CA. It was simply a mule powered scoop shovel three feet wide for a two-mule team, and five feet wide for a four-mule team. The operator manipulated the handle of the scoop shovel by raising it to cut and load, and by lowering it to haul (drag) the load. The operation was risky. Mule skinners had colorful descriptions of accidents caused by the handle jerking sideward, or flipping the operator up over the load when the fresno hit a rock. The fateful handle was eliminated in 1915 by T. G. Schmeiser of Fresno, who patented a scraper with a blade that could be raised and lowered by compressed air cylinders controlled by an operator riding on the scraper. And the scraper was pulled by a tractor controlled by a tractor operator. Coordination of the two operators was troublesome. LeTourneau introduced electric motors to replace compressed air for raising and lowering the blade. Compressed air was terribly "bouncy." The electricity was generated by diesel engines. The invention eliminated the need for an operator on the scraper. The tractor operator could control his scraper by simply "pushing buttons."
>
> Then LeTourneau expanded the scoop-shovel into a bucket with sides that could handle larger quantities of soil. He powered tractor wheels with electric motors for uniform traction.

The need for moving large quantities of earth resulted in bigger scrapers, and faster, for hauling the soil; and a front panel that could be dropped into place to prevent soil from sloughing out of the bucket during hauling. Speed was increased by lifting the bucket after it was loaded so it was not dragging, and by replacing tracks with rubber tires. This became the first Tournapull in 1937 (Figure 5). By 1941 this carry-all was improved and widely used to "move mountains." Of interest was the intense bombing of Hickam Field during the attack on Pearl Harbor. The intent was to destroy U.S. air power in the Pacific. LeTourneau recalled:

> Yet minutes after the attack, out lumbered a weird assortment of earth-moving machines, neglected by the enemy as a worthless target…scrapers powered by Tournapulls filled in the bomb craters on the runways and aprons, packing and spreading the dirt so swiftly that the planes that had gone into the air to challenge the attackers were able to return to their own base.

During World War II, earth-moving equipment was important in the construction of the Burma Road and the Alcan Highway. And since then, modern earth-moving equipment has revolutionized construction of roads, and airfields, worldwide—and mines, and dams, and railways, etc.

FIGURE 5 LeTourneau's Tournapull.

LeTourneau invented the carry-all-loader. He master-minded development of gargantuan earth movers with electric wheels to move enormous quantities of soil. He devised procedures for handling soil efficiently. He expanded "know-how"—and, also, some significant "can-do."

President Eisenhower's original Highway Project of 1956 became feasible by culvert and drainage know-how, by earth-handling know-how; and by many ancillary know-hows. Returning servicemen and American citizens of the Greatest Generation, provided a disciplined, well-trained, can-do, work force. The System was born.

Highway drainage and earth moving were only two of the phenomenal innovations in President Eisenhower's Interstate Highway Program. Computers came online for complex analyses including traffic flow, highway design, and maintenance requirements.

The highway program generated ancillary know-how projects: road surface, base material, costs, maintenance, traffic facilitation, speeds, service life, routes, right-of-ways, etc. Know-how technology established test facilities, AASHO in Illinois, and WASHO in Idaho. These were circular test roads, like race tracks, with heavy truck loads running around them. Road damage, service life, maintenance, and the effect of speed were investigated. The integrated result was a significant contribution to the Interstate System.

CONCLUSION

Research on alternate fuels for transportation is lagging even though fossil fuels are disappearing with wanton waste. What happened to the know-how for alternate modes of transportation? The future may, or may not, need another Interstate System, but how about alternatives: railways and subways and buried pipes? The cost of transportation decreases from airways, to highways, to railways, to ships, and into pipes; and even further by a reduction in demand for "people movers" made possible by our remarkable know-how in communications. The opportunities for innovation are unlimited if know-how is not subverted or expropriated.

We can grasp the future about as far ahead as our memory of the past. Before the memory dims, let us remember the Interstate Highway Project of 1956 and the power of know-how and can-do.

Geotechnical Research

Where We Have Been and Where We Are Going

VERNE MCGUFFEY
New York State Department of Transportation (retired)

Learning is accomplished through many different avenues. Some are formal settings such as planned deliberate research unrelated to any specific design and construction project. Others are what can be referred to as semi-formal. That is a design and/or construction problem for which there may not be a ready, economical, solution, leading to efforts to solve the problem. This is research, but not in the strict sense. Then there is learning through sharing of information and experiences, through making mistakes, etc. Theses are illustrated by McGuffey in the opening remarks of his presentation. They are as follows.

Learning in the early years

- Used old standards;
- Many mistakes (learning opportunities);
- Needed instant answers (for new projects);
- Used the Transportation Research Board (TRB; formerly HRB) as information exchange;
- Set up specialty networking contacts;
- Did lots of "informal" research; and
- Made changes to design before the research was complete.

Old standards may not have been applicable to the design and construction of the System, thus new methods had to be developed, many times as the design and construction were progressing. Many new methods are the results of mistakes made. Changes had to be made in order to avoid the same problems and mistakes in the future. As has been said, many times "on the fly" answers had to be found to avoid project delays.

Figure 1 illustrates one reason for research. Many times conditions change after design and construction which cause major geotechnical problems requiring in-depth study and research.

There are many other reasons for research, including:

- Evolving technologies—equipment, theories, models, computers, materials.
- Evolving user needs—heavy trucks, more cars, year-round service.
- Some indirect items had important impacts on research and development:
  - Political changes,
  - Professionals were added to agencies,
  - Extensive borrowing was allowed to advance projects, and
  - Education was lagging, but major efforts were expended.

Great strides were made during the early years of the design and construction of the System. To list a few generalities:

FIGURE 1 Recurring landslide on Colorado State Highway 133 at McClure Pass, west of Aspen, in spring 1993—a good reason for research.

- AASHO Road Test,
- Nuclear density gauge,
- AASHTO drill guides,
- Lab certification,
- FHWA National Highway Institute (NHI) training,
- FHWA manuals, and
- Lots more.

Specifically in the design, construction, and maintenance arenas, as well as in training, advancements took place in the following areas:

- Terrain reconnaissance (read the land),
- Subsurface explorations (standards, new tools),
- Geophysical methods (seismic, resistivity),
- Surveying tools,
- Sampling, testing methods, and tools,
- Modeling methods and computerized models,
- Instrumentation,
- Compaction control,
- Equipment and lift thickness,
- Alternate materials,
- Environmental issues,

- Real time monitoring,
- Rideability,
- Drainage,
- Snow and ice effects,
- Slope slides,
- Long-term performance,
- FHWA courses,
- NHI courses,
- Manuals,
- TRB publications,
- Computerized training, and
- Expert systems.

But with these advances came challenges for the future. Due to the development of new technologies the persons involved in the design and construction activities were able to see things that they were not able to earlier. This meant that problems couldn't, and still can't be ignored or overlooked because we don't know about them. Thus in the future it is expected that geotechnical engineers will provide:

- Better characterization of ground and water;
- More geophysical [ground-penetrating radar (GPR), electrical, sonic] data;
- Topographic characterization of subsurface conditions;
- Positioning through Global Positioning Systems (GPS);
- Photography (down hole and surface);
- Character recognition (material size, landslide identification, drainage, etc.);
- Improved field testing and instruments; and
- Long-term monitoring.

In addition they need to provide

- Combined surface and subsurface terrain models;
- New design models;
- Reliability-based design;
- Interactive expert systems; and
- Real time changes to design model in construction.

Theses abilities lead to two major questions:

- How to apply Interstate technologies to new programs (information technology towers, high-speed toll booths, high-occupancy vehicle lanes, and mode interconnects)?
- How to approach "microprojects"?

Introduction of sophisticated methods can enhance knowledge, but can also distance engineers, especially the less experienced, from understanding the geotechnics of a design problem. As experienced engineers retire, several issues become of increasing concern. These include:

- Loss of "corporate knowledge";
- Loss of intuition based on experience;
- Dependency on consultants, who may not have local "corporate knowledge";
- Training processes and subjects not up to date;
- May become too dependent on old guides; and
- Who will guide focused research?

For many different reasons transportation agencies have or are experiencing the loss of corporate knowledge through retirements, or movements into different careers. The loss is occurring as a result of gaps in hiring or replacement of personnel. The new geotechnical engineers must develop their own intuitions instead of being able to build on those that have been developed through experience by their predecessors. This has resulted in a dependency on design consultants, in a large part because of the loss of experienced personnel. This loss also shows up in the inability to do adequate design reviews and revisions. This is made worse due to short time schedules, short staff, and the workload of the staff.

One cannot rest on the laurels of the past, but we must continue to research new and innovative methodologies and materials. What are some of these areas of research for tomorrow?

- Tomography of construction sites;
- Soil characterizations related to geophysical tests;
- Tie slope models to weather patterns (rainfall cycles) (with delays);
- Settlement performance based on geologic history;
- Construction control (and payment) from geophysical testing;
- High-quality long-term monitoring (GPS, geographic information systems, design, construction and maintenance in one place);
- Maintenance decision process tied to geophysical testing; and
- More use of satellite mapping for disaster management and recovery.

Each of these areas has the potential of providing time sensitive, more detailed, and economic solutions to geotechnical problems of the future.

How does one proceed in order to accomplish the above and continue to push the knowledge barriers further and further out?

- Continue research and refocus.
  - Remember the lessons of prior research and make this information readily available to the new practitioners.
  - One must ensure that current research is not just continued, but brought to a logical and useful conclusion.
  - One cannot be bound by the traditional areas of research. We must move into the new technologies, and find ways to apply them to geotechnical engineering.
  - To do this one must continue to emphasize the importance of research monies being made available to fund such works.

  - One should encourage personnel to continue to look for and investigate “new ways of doing business.”
- Merge with other disciplines (pavement, structures, maintenance).
  - The geotechnical community can’t wait for the other disciplines to come to us. It has to go to them, and be persistent in its efforts.
- Refocus training (both staff and consultants).
  - Just because new methods are available, that doesn’t mean that everyone understands them, or accepts them. Continual training and refreshing is an essential. Misuse of research products leads to disaster.
- Push for permanent professional staffing to develop and maintain corporate knowledge.
  - While the ideal scenario is not to have gaps in staffing, that is not always possible, or within our control. What is in one’s control is to ensure that corporate knowledge is continually and deliberately passed on to younger staff. Look for ways to preserve the knowledge despite these gaps. Possible place for use of expert systems.
- Shift life-cycle thinking for geotechnical works—100 to 1,000 years.
  - Remember when 20 to 25 years was considered the life cycle of a system? Well, it isn’t too far out of line, with the new materials and technologies, to consider life cycles out to 100 years or more. A little scary, but realistic.

Quality Assurance in Geotechnical Explorations and Laboratory Testing

RICHARD CHENEY
New York State Department of Transportation and Federal Highway Administration (retired); Parsons Brinckerhoff

The following statement is as true today as during and preceding the Interstate design and construction period. “Subsurface drilling, sampling and laboratory testing provided the basis for geotechnical design and construction of transportation projects.” Speaking from the perspective of working for the New York State Department of Transportation (NYSDOT), during the pre-Interstate system days, the NYSDOT Soil Mechanics Bureau (now known as the Geotechnical Engineering Bureau) had a staff of highly knowledgeable and experienced drilling and laboratory personnel. During the Interstate system period workloads and schedules exceeded the resources of the department. To meet these needs we began to see the advent of outsourcing of geotechnical work, either in the form of low bidder drilling contracts or consultant design contracts that included all geotechnical engineering work. See Figure 1.

Initially the outsourcing of geotechnical work was modest, the capability of the in-state firms engaged to do the work were well known to the agency, and acceptable results were achieved with modest levels of review and inspection by the Soils Bureau. The quality of results decreased as the demand for outsourcing increased and more contracts were awarded to a wide range of firms based on low bid. The need for new inspectors outstripped the number of trained inspectors in the Soils Bureau. Numerous detailed “war stories” could be re-counted as a result

FIGURE 1 Getting the samples.

of this outsourcing and the lack of in-house inspection. A range of problems was identified, including the following.

- Soil samples obtained by improper methods and from other than the project site.
- Improper “undisturbed” samples with the soil hand packed into the Shelby tubes.
- Improper handling, packaging, and shipping of samples. (Compare Figure 2, a sample that has voids caused by improper sealing and shipping with Figure 3, a quality sample.)
- Improper storage of Shelby tube samples.
- Testing of dried-out samples as a result of the improper storage from above.

More important than the actual stories are the lessons which were learned as a result. In regard to drilling they included the following:

- Inspect all outsourced boring work; preferably with in-house personnel.
- Require all non-DOT drilling inspectors to be trained and certified by the highway agency.
- Maintain an in-house staff of drillers and drilling equipment.
- Provide yearly training to in-house drillers, including briefings by geotechnical designers to emphasize dependence of design on quality drilling results.

In regard to sampling, particularly undisturbed sampling, they included the following:

- Provide a trained inspector for each boring.
- Require all non-DOT drilling inspectors to be trained and certified in sampling, packaging, and transport procedures by the agency.
- Record the quality of undisturbed samples by physical examination or preferably x-ray (Figures 2 and 3).

In regard to laboratory testing they included the following:

- Require all laboratories to be certified by AASHTO Materials Reference Laboratory. See www.amrl.net.
- Maintain in-house basic soil testing capability and a core group of certified in-house laboratory technicians.
- Brief in-house laboratory technicians on expected geotechnical design issues before testing begins on major geotechnical projects.
- Inspect contract laboratory facilities prior to contract award and periodically thereafter.

Included in the lessons learned which is appropriate to both the field and laboratory work is the use of proper standardized test methods. Methods such as found in AASHTO and ASTM International. Examples of these methods are listed in Table 1.

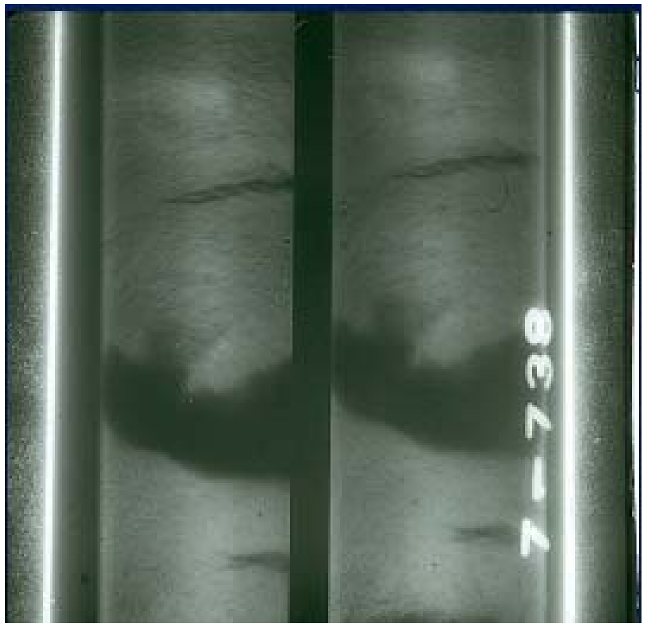

FIGURE 2 X-ray of a disturbed Shelby tube "undisturbed" sample (ASTM D4452).

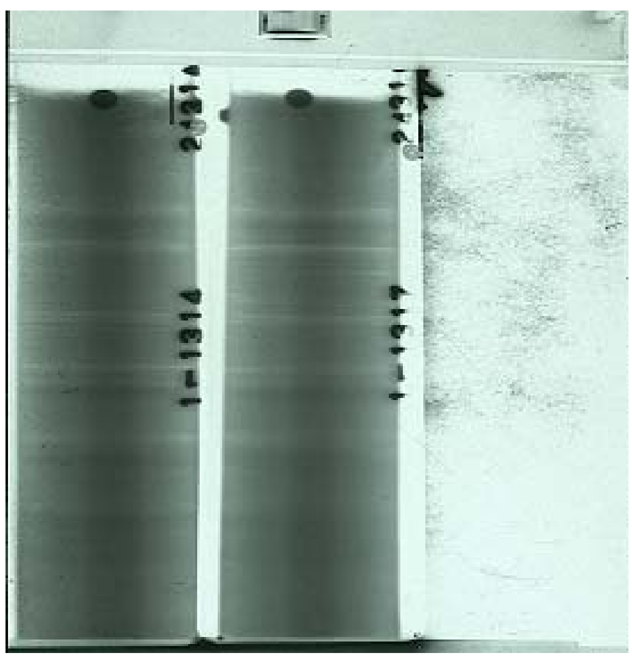

FIGURE 3 X-ray of a good quality undisturbed Shelby tube sample (ASTM D4452).

TABLE 1 Appropriate Geotechnical Field and Laboratory Tests

Test Method	AASHTO No.	ASTM No.
Field Sampling/Test Methods		
Standard penetration	T-206	D1586
Undisturbed sampling	T-207	D1587
Preserving/transport of samples		D4220
Hollow stem auger		D6651
Logging soil/rock		D5434
Vane shear		D2573
Cone penetrometer		D3441
Diamond core drilling		D2113
Preserving/transport of rock cores		D5079
Laboratory Tests		
Grain size analysis	T88	D422
Moisture content	T93	D2216
Atterberg limits	T89,90	D423, 424
Specific gravity	T100	D854
Sample preparation	T87, 146	D421, 2217
Unconfined compression	T208	D2166
Triaxial shear	E17	D2850
Consolidation	E15, 16	D2435

Even when laboratory tests are performed correctly, the designer must routinely evaluate the overall quality of the test results. This is particularly true for strength and consolidation testing results, since sample disturbance is not always detected prior to testing and can strongly influence results. Simple evaluation of the shape of the consolidation test curves, or correlations of moisture content versus shear strength results can provide a basic degree of reliability. More sophisticated techniques can be used to develop a reliability score for the test data. Determination of design values of geotechnical properties should include reliability of individual test results.

The bottom line-lesson learned is that "there is no substitute for proper, reliable collection of subsurface data."

With these things being said, what are the current and future challenges facing the geotechnical engineer? They include the following:

- Accelerated construction.
  - With more and more traffic, along with the need not to tie up traffic for long periods of time, accelerated construction schedules are unavoidable. This includes night construction, and faster construction methods.
  - Requires high degree of confidence in subsurface profile and soil properties as innovative geotechnical techniques are frequently substituted for standard structural support.
- Innovative contracting.
  - Aimed at accelerated construction schedules.
  - Requires an accurate, in-depth assessment of subsurface conditions.

- Load and resistance factor design for geotechnical design.
  - Resistance factors replace allowable stress design methods.
  - The reliability of everyday basic soils and rock sampling and testing does not lend itself to routine statistical analysis. A minimum level of reliability must be insured by application of standardized sampling and testing procedures and inspection of any outsourcing of those procedures. A reliability score should be determined for each strength and consolidation test result.
- Consider impact of nonstandard laboratory tests.
  - There needs to be an understanding of how these relate to the methods we are accustomed to.
  - May require new equipment, thus additional monies needed.
  - Need time for development of these methods.
  - Must consider the benefits of such methods.

Geotechnical Engineering at Midpoint of the Interstate Century

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Most geotechnical engineers remember when

- Heavy equipment was cable operated;
- Survey equipment was merely optical;
- Hard hats were completely optional;
- Smoking was “cool” and cars were “hot”;
- Land was cheap and avoiding poor soils was easy;
- Digging out swamps was not a problem; and
- Transportation engineers were actually perceived as “forces of nature.”

These remind us that the System is “old enough to have a history, yet young enough to have a future” and there was an impression that “engineers could build anything.” However, since that time, changes in philosophy and concerns for the impact on the environment have changed our thinking and approaches to geotechnical engineering. As a result,

- We protect, instead of excavate, wetlands (formerly known as swamps and bogs).
- We build over the poor soils in the valleys, rather than bulldoze the mountains.
- We bridge sensitive areas, using ever more sophisticated foundation methods.
- We need clever geotechnical engineering solutions to solve more restrictive problems.

Because of the above new approaches, we developed more tools. Some examples are

- Lightweight fills;
- Drilled-in deep foundations;
- Internally reinforced soils;
- Deep soil drains;
- Stabilized fine-grained soils;
- Geosynthetics; and
- Faster analysis by computer.

The use of these “new tools” has speeded construction by shortening design processes and time, shortening or eliminating waiting periods during construction, as well as improving ease of installation of some features.

With regard to change, one needs to note that

- Fashion and style change very rapidly.
- Entertainment and amusement change quickly.
- Lifestyle and existence move with the times.

- Teachings and beliefs are followed more carefully.
- Establishments and bureaucracies change last.
- Science learns quickly but accepts gradually.

The last two bullet points have a major impact on the way we do business. A good example is Einstein's Theory of Relativity, which was formulated in 1905 but its application had to wait four more decades.

Moving from the past and present into the future, one should note the following points:

- If one is to predict about science, stay away from the fashionable and look at the reasonable.
- The strongest trends we see today are in information management.
- Gathering data, transmitting data, and analyzing data are all changing rapidly.
- Data have always been the weakest link in geotechnical engineering.

In reference to the last bullet point, the following characteristics of geotechnical engineers have and continue to guide the gathering of data for use in design, which have to change in order to meet the demands of the future:

- We really like to drill holes.
- Sometimes, we'll just poke and probe.
- Our trust in remote sensing is not as strong.

How will this happen? By developing and trusting in the following:

- Automated logging of drillhole information (replacing paper with PDAs, direct sensing, etc.).
- Capturing electronically generated information (cones, GPR, tomography, etc.) immediately.
- Location information combined with the captured data right at the field location.
- Information beamed by wireless technology back to the geotechnical engineer in the office.
- For analysis, digital terrain modeling could be developed from satellite imagery with a bit more detail.
- Laser imaging of more critical sites or those with extreme vertical relief.
- Discovery of obscured surface anomalies which are indicative of subsurface discontinuities.
- Computer manipulation of surface data to develop critical cross-sections

What will these lead to?

- More possibilities can be analyzed in less time.
- Instant communication with distant laboratories means shake tables, centrifuges, and other rare means of analysis can be brought to bear.

- Can do finite element if data are worthy and problem warrants such a detailed analysis.
- Analysis beyond the quality of the data will still be the primary issue of concern.
- Plans developed and sent straight to the field, without committing them to paper.
- Grading done electronically without stakes or a grade foreman wondering “English or metric?”
- Compaction monitored by the compactor and confirmed by a “point and shoot” device.
- All systems become so interoperable that robots take over building roads.

Some of the newer techniques already in practice include

- Deep soil mixing,
- Pile-supported embankments,
- Expanded polystyrene (Geofoam),
- Rammed aggregate columns (Geopier),
- Plastic lagging and reinforcements,
- Geotextile-encased columns,
- Launched soil nails, and
- Bioengineering.

In the current, fast, ever-changing world, the possibilities for even more innovative technologies and tools for the geotechnical engineer’s use are becoming seemingly boundless. Some examples are

- Real-time remote monitoring of problem slopes using digital sensors and wireless reporting; and
- Several applications that gather up information about the surface of the earth into one huge, searchable database—the same could be applied to the gathering of subsurface information.

It is important for geotechnical engineers to ensure that they are not left behind in this ever-changing technological world.

Epilogue

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On the 50th anniversary of the establishment of the System it is appropriate that we stop and take a brief look back at the advances that were made in technologies and methodologies as a result of the challenges that appeared during the design and construction of the System. Of equal or greater importance, is the need to look ahead at future challenges that geotechnical engineers will need to face as a result of past decisions made to bring the System online.

What are some of the challenges for the future? Probably first and foremost is that geotechnical engineers have to overcome any reluctance or hesitancy to use and trust electronic, instantaneous data and subsurface information collection. They must also learn when to trust and how to interpret output. Real-time monitoring presents engineers an opportunity to develop a picture of what is happening to their projects during and after construction. It is already possible to electronically gather data and transmit data to an office via cell phones or other wireless technologies. Tomography can generate an electronic three dimensional picture of what is under the surface of project sites, complementing, or in some cases replacing traditional methods of site investigation. In other words, subsurface exploration is taking on a different look than we have been accustomed to in the past. One of the real challenges for the future geotechnical engineer is not to totally abandon the customary methods and techniques. One still needs to get their hands dirty. But combining some of the traditionally used techniques with the new age ones will enable more confidence in final designs and construction of future projects.

To go along with the electronic data collection, computer-based design techniques have had a growing presence over the last 15 to 20 years. Don't assume the program knows what you want. One has to develop an understanding of how the program works, what input is required, and what output is generally expected. If simple checks on validity of input and output are not conducted, the design answer may not be the most appropriate or in the worst case, it might be incorrect. Incorporation of uncertainty and variability into routine geotechnical tasks increasingly is being treated with a probabilistic approach. Load and resistance factor design techniques for geotechnical components are being developed and will be widely used in the near future. Factor of Safety approaches will give way to acceptable deformation approaches as quantitative expressions of uncertainty and variability can be incorporated into design considerations.

Public agencies have experienced reduced in-house staffing for several years, although work loads have not changed and time schedules have tightened. As a result, outsourcing of various components of public projects has and will continue to grow. The challenge here is to maintain the quality and integrity of the outsourced work from soil sample retrieval, to testing, to design, and finally, to construction. Quality control of geotechnical work must not be outsourced, but assigned to experienced in-house staff. This means that an agency must still maintain an active in-house training program in all geotechnical aspects of the projects it is responsible for. There has to be a well developed quality control and quality assurance program for the agency engineer to use.

Communication is often one of the stumbling blocks in any organization. There must be clear and concise communications within units within any specific organization, and between all organizations involved in a project. "Just because you know what you mean or want, don't assume someone else does.” With shorter planning, design, and construction schedules, one has to really work to ensure proper and complete communications take place.

Politics are an inevitable consequence of serving the public. So one needs to develop an understanding of the politics involved and learn to work within the political framework present to produce and maintain a quality transportation product for the public.

All of the past advances in techniques, equipment, design, and construction protocols, along with continuing research and development, the geotechnical engineer has the opportunity to provide the most accurate, detailed geotechnical designs than ever before. Geotechnical engineers should not be afraid to use all the devices currently available, and they should not rest on the laurels of the past. There is still room for improvement, and this comes through research and the implementation and use of research results, motivated by the insistence by engineers for creative solutions to meet the professional challenges of today and tomorrow.

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