Transportation Earthworks

KEVIN G. SUTTERER, *Rose-Hulman Institute of Technology*

Since the invention of the wheel, inventors and innovators have sought to develop land-based vehicles and transportation systems that travel faster and carry more goods or passengers with greater comfort. A critical though unpublicized barrier to achieving this goal has been providing the energy required to overcome gravity when traveling from one elevation to another. Railroads, roadways, tunnels, and canals are constructed across a region only if earthwork can efficiently and cost-effectively provide the necessary grade for the vehicles and the surfaces on which they will travel. Earthwork will remain an essential factor in the cost and efficiency of transportation systems until air travel becomes controllable, simple, and cheap enough for daily routine commuting. Since this scenario is unlikely in the coming decades, earthwork will remain as significant to transportation for at least the first half of the coming century as it has been to date.

Geotechnical engineers are concerned with all matters related to the design and construction of earthwork, including compaction, the behavior and stability of earth and rock embankments and their foundations, soil improvement techniques, natural and constructed earth slopes, bases, and ballast courses. The scope of earthwork design and construction includes laboratory and field investigations in these areas, as well as the methods required for cost-effective construction and satisfactory performance of transportation earthworks.

The research challenges in transportation earthworks include chemical and mechanical ground improvement for undesirable soil conditions, improved construction processes, behavior modeling, and use of synthetic or recycled materials. The challenges to design and construction will continue to be reduced cost, efficient construction, improved quality control, enhanced performance, and minimal maintenance. Research must be focused on both long-term improvements in transportation and more immediate design and construction challenges. A recent survey of transportation engineers, conducted under the auspices of TRB's Committee on Transportation Earthworks, was aimed at assessing the importance to clients and merit for research of 31 topics in transportation earthworks. Each topic was rated on a scale of 0 to 5, with 5 denoting high importance or merit. The findings for the 20 highest-rated topics are summarized in Table 1.

Table 1 provides some insight into the perceived research needs and transportation industry concerns related to earthworks. It should be noted that the merit of research may not be apparent to practitioners or even the investigator until years after the work has been completed. It is also the nature of successful research that as engineers gain confidence in the work, its perceived merit and importance decrease. These characteristics of some of the research topics shown in Table 1 are likely reflected in the survey findings.

A successful engineering research initiative pursues understanding and solutions by means of interrelated techniques, including study of the state of the art and reliable existing data, incorporation of fundamental physical principles, model development, laboratory studies, field verification, and observation of performance. Research involving all of these elements is needed in three key areas related to earthworks: improved design, modeling, and construction processes; mechanical and chemical ground improvement; and use of recycled or synthetic materials.

IMPROVED DESIGN, MODELING, AND CONSTRUCTION PROCESSES

Improvements in a number of areas related to both routine and sophisticated design and construction affect the economic success of transportation earthworks. These areas include modeling of the behavior of embankments and earth foundations, design of earthworks, preparation and quality control of pavement subgrade, methods of increasing the rate of construction of structural fill, and earthwork quality control methods and procedures. Understanding of many of the fundamental concepts that control behavior in each of these areas is lacking. For example, considerable work is required in prediction of the consolidation of soft clay deposits when preloading and wick drains are employed. Similarly, there is a great need for methods to increase the rate of fill placement in urban areas where road closures and detours have a costly impact on the economy.

Another area in which advances are needed is construction of the soil subgrade for pavements. Failures of subgrade designed and constructed to state-of-the-art standards still occur. Improvements in this area could have a tremendous impact on pavement maintenance costs. Simple evaluation of compaction technologies and quality control techniques and better correlation of behavior with parameters used to control compaction would be highly beneficial to many projects. Recent developments in this area include use of resilient modulus as a means of characterizing subgrade behavior. Future work on resilient modulus testing could lead to improvements in laboratory specimen strain measurement, incorporation of effective stress and partial saturation effects into interpreted behavior, and closer coupling of observed laboratory behavior with expected field subgrade performance.

MECHANICAL AND CHEMICAL GROUND IMPROVEMENT

Ground improvement is crucial to making marginal or unacceptable sites suitable for construction. In transportation, ground conditions that frequently lead engineers to consider mechanical or chemical ground improvement include soils susceptible to liquefaction, weak or highly compressible soils, and landfilled materials. The simplest mechanical method of ground improvement is earth compaction, while the simplest chemical method is lime modification. Mechanical and chemical ground improvement technologies continue to advance even as engineers' growing confidence in these technologies leads them to undertake more difficult challenges. Technologies considered leading edge two decades ago are now considered routine.

Ground improvement research is needed on two fronts: development and verification of new technologies and improvement of existing technologies to reduce cost and increase accessibility. Fortunately, this is a field that is usually driven by economics, as ground improvement techniques are generally employed at sites where ground conditions are very poor but construction must proceed. Thus clients are willing to pay a high price while accepting a greater risk of failure than might otherwise be the case. Construction methods can evolve rapidly under such conditions if the local economy is good. Even so, considerable basic research on ground improvement is needed, since the construction technology is developed to meet performance criteria, and the fundamental basis of success remains undetermined.

USE OF RECYCLED OR SYNTHETIC MATERIALS

Composite materials continue to revolutionize many areas of engineering. Composites may be defined as consisting of at least two dissimilar materials with complementary properties, combined for improved performance or reduced cost. Tieback systems and soil nailing are examples of composite systems in earthworks that have been highly useful. Another example is the use, which increased dramatically in the 1980s and 1990s, of composites consisting of geosynthetics and soil. Potential applications of geosynthetics include the functions of separation, filtration, reinforcement, drainage, and formation of barriers to fluid or gas flow. Notable examples in transportation earthworks include pavement subgrade separation, subgrade drainage, reinforced slopes and walls, and reinforced embankments. Exceptional work is being done in the development of these materials.

As transportation systems expand, they are more likely to be supported by less desirable foundation soils, such as highly compressible deposits. The mass of the earthwork for such systems can cause unacceptable long-term settlement or even shear failure of these deposits. Ground improvement techniques may not be effective in stabilizing such soils. Although not a composite, geofoam provides a very lightweight manufactured fill for embankments on such materials. The development of lightweight fill has led to engineering of fills consisting of soil-like particulate materials that are lighter than soil, not prohibitively expensive, and environmentally safe. Sawdust and shredded tire chips are excellent examples of such materials.

The use of sawdust and shredded tire chips exemplifies an important emerging area of transportation earthworks—the use of materials in construction that would otherwise be considered waste products. Examples of the use of waste in earth embankments are thermoplastic materials (e.g., shredded and chipped tires), ashes (e.g., municipal sludge, sewage sludge, coal), slags (e.g., from steel and blast furnace), by-products (e.g., from flue gas desulphurization, papermills), iron-rich residues, mine tailings, quarry fines, demolition debris, recycled concrete, waste foundry sand, fibers (e.g., carpet), and crushed glass. Issues facing engineers who use such materials in embankments either as a component of a composite system or as the entire earthwork include characterizing and modeling immediate mechanical and conductive behavior, assessing environmental impacts, predicting long-term performance, developing placement methods, performing quality assurance and quality control, and monitoring performance.

Knowledge of soil mechanics and current geotechnical models are inadequate for confidently predicting the behavior of particulate masses composed of particles that may be compressible, transient, or unstable over the long term. Although use of some wastes is already under way, there have been and will continue to be failures due to inadequate knowledge of the material being used. The field of waste geomechanics is less developed and subject to greater risk in application than was soil mechanics at the start of the 20th century.

There are substantial economic and environmental benefits to be gained from using waste materials in transportation earthworks. Those benefits justify a serious commitment to research in this area at all levels—from basic, fundamental research to applied studies. Among the critical needs are development of a unified system for classification of waste materials, guidelines for characterization, means of measuring and predicting behavior, and informed policies for use of these materials. Geotechnical engineers are well positioned to lead these efforts, applying their unique knowledge of particulate behavior, their well-developed intuition regarding how materials behave in the ground, and their empirical observations.

LOOKING TO THE FUTURE

The design, construction, economics, and management of earthworks are often a major component of transportation projects. There are many critical needs in earthwork research, all of which merit attention. Continued pursuit of better predictive methods, composite systems, and ground improvement technologies is certain and should be encouraged. In addition, it may be hoped that the economic impact of research in areas such as pavement subgrade design and construction, slope stability, and quality assurance/quality control will not be overlooked, as improvements in these areas could have tremendous economic impact on transportation projects and long-term maintenance costs. A balanced research approach in the field of transportation earthworks should include efforts involving both high early payoff/low technology and low early payoff/high technology. In some cases, a high-technology effort will have a high early payoff.

Looking beyond the need to continue ongoing efforts in earthworks research, many of which were discussed above, there is a great need for work in characterizing the short- and long-term mechanical behavior of nonsoil materials in the ground. Such materials are already being used regularly. The quality of work done thus far in the development of manufactured materials, such as geofoam and geosynthetics, and in the use of waste materials, such as shredded tires, should provide motivation for similar efforts with other materials, both manufactured and waste.

The role of organizations such as the Transportation Research Board should be to provide a forum for discussion, an opportunity for brainstorming, and a conscience for the research under way. The goal should be to support researchers working in areas with at least some potential for either short- or long-term benefits, and to achieve thorough dissemination of the findings of the work, successful or otherwise, to the transportation industry.

TABLE 1 Average Rating of 20 Highest-Rated Earthworks Topics

Topic	Importance to Clients (Overall Avg. = 2.5)	Merit As Research Need (Overall Avg. = 3.0)
Innovative uses of waste in earthworks	4.2	4.1
Rapid embankment construction	4.6	3.5
Synthetic modification of soil for enhanced performance	3.8	4.2
Construction of fills comprised of or overlying materials with undesirable properties	4.3	3.6
Lightweight fill	4.3	3.5
Seismic stability of embankments comprised of mixed soils	3.9	3.5
Steeper slopes for increased roadway capacity	4.0	3.3
Fill construction to minimize wetland impact	4.3	2.9
Quality assurance/quality control for earthwork operations in modern construction	4.2	2.7
Earthwork for urban construction	3.8	2.9
Slope stability	4.0	2.5
Rock slope stability	3.8	2.6
Flowable fill (trench backfill)	3.9	2.5
Unconventional fill, both synthetic and waste	3.5	2.8
Instrumentation of earthwork operations	3.5	2.7
Erosion control	3.5	2.8
Earthwork construction in difficult environments	3.5	2.7
Blending of materials for improved fill properties	3.7	2.3
Biological modification of soil for enhanced performance	2.5	3.5
Liquefaction assessment and mitigation	2.9	3.0