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History of Embankment Construction

William G. Weber, Jr.*
Pasco, Washington

Primitive civilizations used soil to construct earth structures and embankments for dwellings, religious worship, burials, canals, roads, and fortifications. Simple trial-and-error procedures led to progress in the use of soil as a construction material, and this knowledge, initially passed on from generation to generation by word of mouth, later became part of the written record. One of the earliest of these is in the *Dschou-Li,* a book on the customs of the Dschou Dynasty, written about 3000 B.C. in China. It contains, among other things, instructions for the construction of roads and bridges (Speck 1950). According to AASHTO (1950), the oldest road in the world, "The Royal Road" across southwest Asia and Asia Minor, was used by wheeled wagons in about 3000 B.C. One of the oldest technical records of construction using soils is found in the Ten Books on Architecture compiled during the first century B.C. by the Roman engineer Vitruvius (Granger 1934).

In the mid-1600s, France undertook an extensive public works program, including construction of highways, canals, and fortification systems for the country's borders. The first engineering school in Europe, Ecole des Ponts et Chaussées, was established in Paris in 1747, and here engineers were educated in the principles of physics, mathematics, and mechanics as known at the time for the construction of highways, bridges, harbors, canals, and retaining structures. The founding of this engineering school had an important influence on the scientific development of civil engineering.

In the early 1800s in England, Thomas Telford and John MacAdam were constructing roads based partly on scientific principles. One principle was to raise the foundation above the surrounding ground so that water would not soften the subgrade. The embankments were seldom

* Deceased.

more than 10 ft high with maximum side slopes of about 3H:1V. Most of the roads followed the contours in hilly country, resulting in partial fill and cut; drainage blankets were common in these situations.

With the construction of railroads beginning in the 1830s, new problems developed because of the flat grades and long radius curves required and the higher loadings imposed on the subgrades. It was soon realized that moisture in the soil played an important role in compaction of fills. When the soil was too wet, construction equipment bogged down and failures occurred. When the soil was too dry, unanticipated settlements would occur during periods of rain.

A simple test was soon devised by construction personnel to gauge the proper moisture content in the soil. The soil was formed by hand into a compact ball; then a person would spit on the soil. If the moisture soaked into the soil, it was too dry; if the moisture balled on the soil, it was too wet. If the moisture slowly soaked into the soil ball, it had the proper moisture content. Although this test was crude and unscientific, it was quite effective as a method of moisture control, and ultimately it led to the development of the field moisture equivalent test.

After several disastrous landslides in Sweden, a Royal Commission of the Swedish State Railways was appointed in 1913 to develop procedures to avoid future disasters. The report of the Commission in 1922 was an important milestone in the understanding of soil properties and geotechnical analyses. Among the most important developments were the well-known and still commonly used Swedish Circular Arc method for determining slope stability, undisturbed soil sampling, and laboratory shear testing. The problems of embankment stability were now on their way to engineering solutions.

In 1925, in his book *Erdbaumechanik*, Terzaghi demonstrated the importance of the water phase in the long-term settlements that occurred under loadings on clay and developed the theory of consolidation. He also presented a new view of soils as materials with widely varying properties.

Expansion of the highway system in the United States during the 1920s and the construction of increasingly higher earth dams demanded improved compaction procedures. The California Division of Highways (Stanton 1928) used the first soil compaction test to determine the optimum moisture and maximum density before construction and relative density during construction. The Bureau of Water Works and Supply of the city of Los Angeles conducted an extensive study of the effects of soil compaction on the shear strength and permeability of compacted soils in earth dams. The results of this study were reported by Proctor (1933). About the same time and apparently independently of Proctor, Kelso (1934–1935) was performing experiments on the soil moisture–unit weight relationships during the construction of Silvan Dam in Australia.

The relationships between density, moisture, strength, compressibility, and other soil properties were fairly well established by the mid-1930s, and these factors were intensely studied for various soil types during the next 30 years.

Construction equipment used in the hauling and placing of earth for embankments has also undergone a similar development. In ancient times, soil was hauled by humans and animals. With the advent of wheeled vehicles, soil was hauled by animal-drawn carts. Animals were used to pull the Fresno scraper, which could load itself, and for compaction. A patent was issued to M. Louis Lemoine of Bordeaux, France, in 1859 for a steamroller. With the development of the gasoline engine in the early 1900s, gasoline-driven trucks, loaded with the use of a steam shovel, came into common use, and in 1906, a patent was issued for a horse-drawn sheepsfoot roller. Compaction was commonly limited to the surface of embankments, because the general feeling was that the fill would settle anyway.

Expansion of the highway system during the 1920s resulted in rapid development of heavier hauling and compaction equipment. During the 1930s, an extensive public works program was undertaken. Tractor-drawn scrapers came into common use, and new and heavier compaction equipment was developed. The requirement that fills be compacted from the ground to the surface became generally accepted by engineers. Embankments as high as 50 ft were common in mountainous areas.

In the 1950s when the Interstate highway system was begun, flat grades and long radius curves, previously encountered only in railroad construction, became standard. Whereas railroads often had used trestles to cross valleys, highways used embankments, and Interstate highway embankments often exceeded 100 ft in height. Zoned embankments, where specified materials were employed in different portions of the embankment, came into common use. As the pressures on culverts increased, their design required greater consideration, and foundation soils often were also of serious concern.

Construction of the Interstate highway system caused many changes for both engineers and contractors. The movement of large quantities of soil resulted in rapid advances in construction equipment. The use of self-propelled, rubber-tired scrapers capable of carrying 20 to 30 yd^3 of soil at high speeds became common, and larger tractors and blades were developed. Although the Interstate system is now essentially complete, many problems remain. Portions of the system are now carrying more traffic than they were ever designed for. Upgrading will require adding more lanes, which will mean widening existing embankments. Also, other means may be required to increase capacity. Many of the roads feeding traffic to or receiving traffic from the Interstate will need to be upgraded or rebuilt. Safety improvements will also be required, and, of course, never-ending maintenance will present new challenges.

Environmental factors have become of increasing concern to engineers. Previously, potential embankment erosion was considered a maintenance problem; today it must be considered in design. Construction of sound barriers has become common in urban areas. Retaining walls are often required where limited right-of-way exists in reconstruction areas. Frequently, reconstruction will alter drainage patterns and cause other problems. Imaginative solutions are required, although the basic engineering principles will remain substantially the same.

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ABBREVIATION

AASHTO American Association of State Highway and Transportation Officials

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