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Building a Better World

1852–2002: 150 YEARS OF CIVIL ENGINEERING IN THE UNITED STATES OF AMERICA

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ABSTRACT: On the 150th anniversary of the founding of the American Society of Civil Engineers it is important to review the growth of the profession and the country it serves. This paper introduces the major projects and people who changed the practice of civil engineering from almost an art form in the 1850s to the science that it is today. In the opinion of the writer, those included are the ones that had the greatest impact on the country. Others favoring other projects and people should prepare similar papers for the society.

INTRODUCTION

The American Society of Civil Engineers (ASCE) was founded in 1852 by a small group of engineers meeting in offices of the Croton Aqueduct, in New York City. Their goal was to form a national civil engineering society based upon the Institution of Civil Engineers, in London. They used the constitution of the Boston Society of Civil Engineers, founded four years earlier, as a framework. After approving a constitution and set of by-laws, they prepared a list of potential members who, from their personal knowledge, were practicing civil engineering in the United States. That list of 229 names was a "Who's Who" of American civil engineering. It included the Honorary Members of the Society: S. H. Long, Col. Albert, Prof. Bache, Henry Burden, Moncure Robinson, and Dennis Hart Mahan. In addition, 46 were listed as members. Railroad engineers predominated, as that was what most were practicing at the time. Most were from main cities along the eastern seaboard, and some from as far west as St. Louis. Listed (some with their current job titles) were civil engineers, mechanical engineers, and architects. Many of the men unknown to us went on to design and build the United States just prior to and after the Civil War.

UNITED STATES IN THE 1850s

The enlargement of the Erie Canal, which opened in 1825, was well underway. The Delaware and Hudson Canal and the Lehigh Coal Canal were delivering increasing amounts of anthracite coal to the cities of New York and Philadelphia. The canal-building mania of the earlier part of the century gave way to railroad-building mania in the middle part of the century. After over 25 years, by 1852, the Baltimore and Ohio Railroad made it to the Ohio River at Wheeling. The New York and Erie Railroad was completed to Lake Erie from the Hudson River at Piermont in 1851. The New York Central was being formed by combining many of the short lines that developed between the cities of the state to create a complete line from New York City to Buffalo. In the west, rail lines were laid westerly from Chicago to the Mississippi. By the end of the decade, rail service had spread throughout the land east of the Mississippi and reached as far west as St. Joseph, Missouri. Between 1840 and 1850 the number of railroad miles increased from 2,818 to 9,021 (320%); in the decade of the 1850s from 9,021 to 30,635 miles, or an increase of over 340%.

Bridge building, soon to be a major activity of civil engineers, was still in its infancy. Men like Squire Whipple, Wendell Bollman, and Albert Fink were building iron bridges for the B&O Railroad and the Erie Canal, but most bridges were still built of wood or stone. Charles Ellet built the Fairmount wire cable suspension bridge across the Schyulkill River in 1847. He followed this with his 1,010-foot bridge at Wheeling, in 1849, and had erected a small suspension bridge across the Niagara Gorge in the early 1850s. In Pittsburgh and on the Delaware and Hudson Canal, John A. Roebling built several short suspension bridges for carriages and canal boats. He was working on his double-deck railroad suspension bridge, the successor bridge to Ellet's, at Niagara. His major bridges, however, were still in the future. The early wooden-bridge builders like Palmer, Burr, Wernwag, Towne, and Howe were either dead or past their prime.

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Squire Whipple's book on bridge building was published in 1847, and Herman Haupt's in 1851, but the use of science and mathematics to design bridges more efficiently was still in its infancy.

As the railroad opened up more and more of the country, cities and towns grew rapidly. But the technology of designing and constructing buildings had changed little from ancient times; most buildings were wood-frame or masonry-bearing wall construction. In the larger cities of the east a high building would still be only around six stories.

Municipal water works developed as early as the late seventeenth century in Boston. Other cities followed throughout the eighteenth century. These waterworks, however, were suited only for small populations and were inadequate as cities grew. The Croton Aqueduct, the primary water supply for New York City, was opened in 1842 under the engineering genius of John B. Jervis. In the 1850s it was enlarged by some of the founders of ASCE, primarily A. W. Craven and George S. Greene. Boston opened its Chocituate Aqueduct in 1850 under the guidance of Ellis Chesbrough. Other large cities—Philadelphia, Albany, etc.—followed and provided their citizens with a clean, ample, untreated water supply. But disease and subsequent death plagued the major cities of the United States well into the twentieth century. In New Orleans, for example, almost 8,000 citizens died from yellow fever in 1853, while in 1854 in Chicago 1,424 died from cholera. Many cities were virtual ghost towns during the summer months, when these diseases struck fear into the population and caused mass migrations into the countryside.

The collection and treatment of sewage was in its infancy, and typhoid and cholera were common in many cities. It wasn't until 1858 that the same Ellis Chesbrough developed a plan to collect the sewage of Chicago and discharge it into Lake Michigan. This plan relied primarily on dilution as the solution to pollution. It can be said that the beginnings of what was to become the specialty of sanitary engineering began in Chicago and then spread throughout the cities of the United States.

The roadway system was virtually nonexistent, as roads built in the turnpike boom of the early part of the century were not maintained. The Cumberland (National) Road, from Washington to the Ohio River, was completed earlier but had also not been well maintained.

To meet the growing demand for trained engineers, more engineering schools were needed. Prior to 1845 only Rensselaer Polytechnic Institute in Troy, N.Y., and Union College, in Schenectady, N.Y., were offering degrees in civil engineering. The USMA at West Point had been training men moving into the profession for many years, based upon their knowledge of topographic engineering, drafting, and mathematics. For many years their professor had, and would be, Dennis Hart Mahan, one of the first Honorary Members of ASCE. Harvard and Yale established engineering branches in 1847. It wasn't until the passage of the Morrill Land Act, in 1862, that the number of engineering schools in the country began to increase significantly.

When the Boston Society of Engineers was formed in 1848, only three of its members had any formal education and only one of them, Eben Horsford, had a civil engineering degree (1838) from Rensselaer. Most practicing civil engineers were apprentices to men like Benjamin Wright, Charles Ellet, Benjamin LaTrobe, Strickland Kneass, and Stephen H. Long. Foreign emigration of trained engineers, including an influx from Germany in the late 1840s, helped to fill the need.

With a population in 1860 of over 31,000,000 (up over 8,300,000 from 1850) the country was growing rapidly and developing the lands of the Ohio and Mississippi Valleys. The gold rush in the late 1840s brought more people west, and after the Civil War that migration increased.

In 1852, when ASCE was founded, the country was growing rapidly. The railroad system was expanding but the roadway system was virtually nonexistent. The supply of trained civil engineers was limited and the collection and treatment of sewage was in its infancy.

PROJECTS THAT SHAPED THE GROWTH OF THE UNITED STATES

To properly describe the growth of civil engineering over this 150-year period requires difficult decisions as to what projects truly made a difference and who the men were behind them.

In 1955, ASCE named its *Seven Modern Wonders*. Later, in 1994, ASCE updated this list as follows:

1955

- Empire State Building
- Panama Canal
- Hoover Dam
- San Francisco-Oakland Bay Bridge
- Chicago Sewage Disposal System
- Colorado River Aqueduct
- Grand Coulee Dam/Columbia Basin Project

1994

- World Trade Center
- Panama Canal
- Hoover Dam
- Golden Gate Bridge
- Kennedy Space Flight Center
- Interstate Highway System
- Trans-Alaskan Pipeline

Later in 1998, an international committee named the Seven Modern Civil Engineering Wonders of the World. They were the following:

- Panama Canal
- Itaipu Dam in Brazil

- World Trade Center (New York City)
- Chunnel under the English Channel
- CN Tower (Toronto)
- Netherlands North Sea Protection Works
- Golden Gate Bridge

I have chosen the projects based upon my experience (primarily in the structures, transportation, and geotechnical areas) and the literature of the period. They are in approximately chronological order as follows:

- The Chicago Water and Sewage Treatment System 1858–1869
- The Transcontinental Railroad 1863–1869
- The Brooklyn Bridge 1869–1883
- New York City Interborough Rapid Transit (IRT) System 1900–1904
- The Panama Canal 1904–1914
- The Empire State Building 1930–1931
- The Golden Gate Bridge 1931–1936
- The Interstate Highway System 1956–1990

CHICAGO WATER AND SEWAGE TREATMENT SYSTEM, 1858–1869

It has been said that of all the accomplishments of civil engineers, its contribution to public health has saved more lives and contributed more to our standard of living than any other effort. A review of the number of deaths from cholera in Chicago in the years between 1850 and 1854 indicates that almost 3,000 people died. In 1854, the worst year, there were 1,424 deaths and a rate of 2,162 deaths per 100,000 inhabitants.

Contaminated drinking water and the decomposition of human waste were the causes of many deaths not only from cholera and typhoid but also yellow fever. The actual link between typhoid and the decomposition of organic (and chiefly vegetable) substances was not discovered until the 1870s.

If Chicago was to continue to grow and prosper it was necessary that steps be taken to clean up the city. Ellis S. Chesbrough (Fig. 1), the man who would clean up Chicago, came to the city in 1855 as Chief Engineer to the newly formed Chicago Sewerage Commission. When he arrived the city disposed of its sewage directly into the Chicago River, which flowed slowly into Lake Michigan. The residents relied on wells for most drinking water and those wells were near the river. The proximity of the two resulted in the pollution of the wells and in the periods of disease noted. Before coming to Chicago, Chesbrough had experience as a railroad engineer and served as one of the Chief Engineers of the Cochituate Aqueduct in Boston, under the guidance of John B. Jervis. He remained in Chicago with the Commission for the next 24 years.

FIG. 1. Ellis S. Chesbrough

In 1856 one of the first acts of the Commission was to send Chesbrough to Europe to study and examine sewage disposal systems. In 1858 he published his findings in a *Report of the Results of Examination Made in Relation to Sewerage in Several European Cities in the Winter of 1856–57.* Based upon that experience he greatly modified the design he promoted prior to his trip abroad. His revised plan was the first comprehensive sewerage system in any U.S. city. It entailed raising the entire city so sewage could flow more rapidly into Lake Michigan through the Chicago River. The sewage outfall points close to the shore contaminated the water intake from the lake, requiring him to design a tunnel extending two miles into Lake Michigan to a water intake, therefore minimizing pollution of the drinking water. This project, started in 1864, opened to public acclaim in 1869, and for the first time Chicago had a source of clean water that could not be polluted by discharge of sewage into the lake. The 1866 outbreak of cholera was the last for Chicago since the city now had a water supply system and sewage collection and disposal system, both designed and built by the same man, that enabled the city to grow. Chesbrough was sought after as a consultant by many other cities to design or consult on their systems, and most major United States cities built their systems based upon that of Chicago. Between 1890 and 1900 the city reversed the flow of the Chicago River and dumped its sewage into the Des Plains River, using water from Lake Michigan to flush the river and it sewage downstream. Still later, in 1938, a major treatment program was implemented to minimize the negative effects downstream as far as St. Louis. It was this project that was named one of the Civil Engineering Wonders in 1955.

TRANSCONTINENTAL RAILROAD, 1863–1869

Railroading in the United States is said to have begun with the chartering of the Baltimore and Ohio Railroad and to a lesser degree with the Mohawk and Hudson Railroad. The number of miles spread rapidly between 1831 and the founding of ASCE. It would continue to grow rapidly until the Civil War. During the war, expansion of the system slowed, as most of the country's resources went to the war effort.

The nation had been debating the construction of a transcontinental railroad starting in 1853, when Congress authorized Jefferson Davis, then secretary of war, to make a survey of possible routes. Visionaries like Edwin Ferry Johnson and A. C. Whitney were promoting such a railroad as early as 1837, but it required action by the federal government to move the road from a dream to reality. Three lines were surveyed. The north route was primarily along the 49th parallel, the Buffalo route along the 38th to 39th parallels, and the south route along the 32nd to 35th parallels. By 1856 both the northern and southern states favored a Pacific railroad, but with tensions high over the issue of slavery and states rights, they couldn't agree on the route to select. In 1862, after the secession of the southern states and the beginning of the Civil War, Congress, with the support of President Lincoln, passed the Pacific Railroad Bill.

The war didn't stop Theodore Judah (Fig. 2) from thinking big. In 1854 he went west to design the first railroad in California, the Sacramento Valley Railroad. As early as 1856 he became so obsessed with the idea of a transcontinental railroad that he was frequently called "mad Judah" or "crazy Judah." In 1857 he published a pamphlet titled "A Practical Plan for Building the Pacific Railroad." For the next several years he promoted the idea in Congress and sought backing from California entrepreneurs. He finally convinced Collis Huntington, Leland Stanford, Charles Crocker, and Mark Hopkins, known in history as the "Big Four," to support his efforts and create the Central Pacific Railroad. In 1860 he surveyed the route over the Sierras, which proved his idea was feasible. It wouldn't be easy, but it was possible. In the east Thomas Durant and the Ames Brothers were forming the Union Pacific (UP) Railroad to match Judah's Central Pacific (CP) Railroad. In 1864 Congress passed the Pacific Railroad Act, amending the 1862 Act, which designated the Union Pacific and Central Pacific, both privately owned organizations, to build the transcontinental railroad, providing them with land grants and subsidies. The CP actually started east as early as October 1863, but tension was developing between Judah and the Big Four. Judah went east to find backers to buy out the Big Four in late 1863. He died in the same year from yellow fever contracted while crossing the Isthmus of Panama on the Panama Railroad, which could be called the first transcontinental railroad of the Americas.

The construction of the UP line began from the east with Peter Dey as chief engineer. He surveyed three routes, but the route along the North Fork of Platte River was an early favorite and would be the designated route. General Grenville Dodge (Fig. 3), then fighting in the Civil War, discovered a route through the mountains earlier. After the war Dodge became the UP's Chief Engineer and he and his surveyors laid out the route seeking the shortest, straightest line with the lowest grade. Moneymen like Durant, however, did not always agree with his routes and actually wanted the line to be longer than it had to be, as their subsidy was by the mile.

FIG. 2. Theodore Judah

FIG. 3. Grenville Dodge

The story of the building of the two converging lines continues to fascinate as new books are constantly printed describing the epic adventure. From an engineering, construction, and supply standpoint, the project marked the evolution from small eastern railroads near their points of supply and labor to remote regions with no natural resources, and little labor, water, or wood. In addition, the UP line had to contend with the Plains Indians, who generally did not want the "iron horse" coming across their lands.

All supplies for the UP were shipped from the east up the Mississippi and Missouri Rivers to Omaha. There they were shipped along the completed railroad to the end of the line. The CP shipped all supplies, such as rail and locomotives, by sea through the Isthmus of Panama on the Panama Railroad or around the Cape. This project required greater coordination of purchasing, shipping, and delivery to point of use than any project in the history of the world. An additional constraint was the fact that backers of both lines were frequently cash poor and relied on prompt payment of government subsidies to continue. These subsidies were not issued until each 20-mile increment of line was approved. Surveyors would be out in front staking the line. They were followed by the grading crews, who in turn were followed by the tracklayers. Add to all these constraints the long bitter winters, a shortage of laborers, and primitive labor-saving equipment. Consider what a great accomplishment it was to build the entire 1,776 miles. The CP relied primarily on Chinese to build its line over the Sierras by means of major tunnels, and thence across Nevada to Utah. The UP relied on veterans of the Civil War and Irish emigrants to cross the plains and the Wastach Mountains. The Union Pacific built 1,086 miles between late 1864 and May 1869, and the Central Pacific built 690 miles of line between January 1863 and May 1869. They connected at Promontory Point on May 10, 1869, with the driving of the Golden Spike.

The total number of miles (1,776) is an appropriate number as the line gave a new freedom of mobility that was lacking prior to the opening of the Railroad. The country would never be the same again. It was now possible to travel its length in seven days for $70. Previously the trip by land across the country could take as much as six months, by ship and the Panama Railroad upwards to three months, and seven months by sea around the cape. It was the Big Four of the CP, Thomas C. Durant, and Oakes and Oliver Ames of the UP who financed the project. Engineers like Peter Dey, Grenville Dodge, S. B. Reed of the UP, and Theodore Judah, James Strobridge, and Samuel Montague of the CP who made it happen. Dodge and Judah, in addition, were the main men involved in getting congressional and presidential approval of the railroad in the late 1850s and early 1860s. They created a railroad compared to which there was "nothing like it in the world."

BROOKLYN BRIDGE 1869–1883

In 1867 John A. Roebling was selected as chief engineer of the New York and Brooklyn Bridge, after a charter for the bridge was issued by the New York State Legislature. Roebling had been advocating a bridge at this site for almost a decade. What Roebling proposed was a suspension bridge with a span of almost 1,600 feet. This was almost 50% longer than his Cincinnati Bridge, which opened earlier that year. Between the founding of ASCE and 1867, suspension bridges had also been built across the Niagara, 821 feet by Roebling and 1,268 feet by Samuel Keefer. James Eads was ready to start his bridge across the Mississippi at St. Louis. Both Roebling and Eads were thinking about using steel instead of wrought iron and both faced difficult foundation problems.

Roebling knew his bridge would be something special as he told Bridge Directors, "the contemplated work, when constructed in accordance with my designs, will not only be the greatest bridge in existence, but it will be the great engineering work of the continent and of the age." His son Washington A. Roebling (Fig. 4), after graduating from Rensselaer in 1857, worked with his father on the Allegheny Bridge, in Pittsburgh, and the Ohio River Bridge. He enlisted as a private in the Civil War and was, after almost four years, discharged as a Major with a Brevet rank of Colonel.

After the war the Roeblings finished the Ohio River Bridge, and in 1867, as a wedding present from his father, Washington took his wife, Emily Warren, on a tour of Europe. On this trip, however, John wanted Washington to look into the latest engineering works on the continent, particularly the use of pneumatic caissons by the French. The elder Roebling knew that the success of his dream demanded a stable foundation for his towers. The borings indicated that bedrock was at 90 feet on the Brooklyn side and 76 feet on the New York side. On July 6, 1869, John Roebling injured his foot in a collision between a ferryboat and the pier on which he was standing while surveying for the Brooklyn Tower. In 16 days he died because of complications from lockjaw. Washington became Chief Engineer and for the next 14 years was dedicated to the fulfillment of his father's dream.

Pneumatic caissons were a new construction technique in the United States at that time. James Eads was sinking very deep foundations at St. Louis and William J. McAlpine sunk pneumatic caissons for the Dry Dock at the Brooklyn Navy Yard in the late 1840s. Roebling's caissons were much larger than either Eads' or McAlpine's

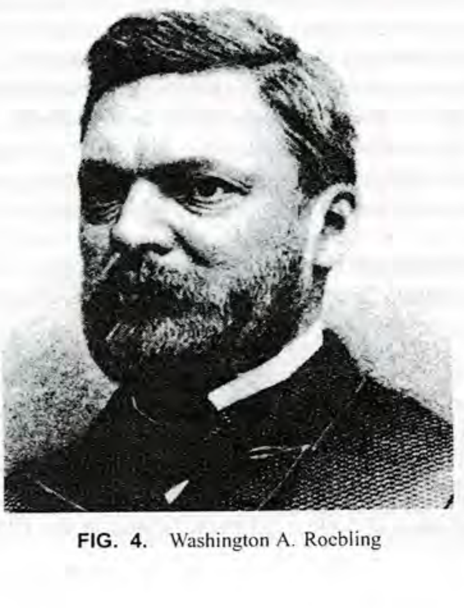

FIG. 4. Washington A. Roebling

and would carry a much larger loading. He sank his Brooklyn caisson to a depth of only 45 feet, resting it on a tight soil with boulders. He encountered many problems sinking the caisson, including a fire that badly damaged the wooden roof. He finished the caisson and, based upon his experience, greatly modified his design for the much larger New York caisson. The changes, along with sandy soil, greatly accelerated the sinking, but he was going to a much greater depth, and his men started to experience the same caisson disease that he himself suffered on the Brooklyn caisson. With the problem getting worse each foot the caisson sank, he decided to stop the caisson at 78 feet, resting it on the upper cusps of bedrock with dense sand filling the spaces between the rock outcroppings. Shortly thereafter Roebling became incapacitated from the effects of caisson disease and never visited the bridge site again during construction. He observed construction from his home on Brooklyn Heights and used reports from his assistant engineers and wife Emily to direct construction of the anchorages, spinning of the cables, and the hanging of the deck structure. He followed his father's plan in his use of steel wire to spin the cables and later built the entire suspended structure with steel rather than wrought iron.

Cable spinning began in 1876 and was completed in October 1878. It required almost five years to hang the decking and complete the approaches. On May 24, 1883, the bridge opened with a huge ceremony attended by all the local dignitaries as well as by the governer of New York and the president of the United States, Chester A. Arthur. The bridge, designed by John A. and Washington A. Roebling and built by Washington, became an icon of the City and to this day remains one of the most recognized and beloved bridges in the country. It became an example of the daring of the American civil engineer and would remain the longest bridge in the world until the Williamsburg Bridge opened 20 years later. Its majestic stone towers and lace-work of suspender cables and cable stays are perhaps the most photographed elements of any bridge in the country. Roebling's assistant engineers traveled across the country to build bridges of their own and became leaders of the engineering profession. The American engineer, based upon example of the Roeblings, became known around the world for this ability to accomplish the difficult, and even impossible, task. The Brooklyn Bridge has been called the Great Bridge and has fully lived up to the elder Roebling's dream.

NEW YORK CITY RAPID TRANSIT LINES, 1900–1904

New York City grew rapidly in the mid to late nineteenth century, and its necessary expansion to the north and east resulted in major transportation difficulties in moving its people from their homes to their places of work. The horse-drawn surface trolley system addressed the problem for a period, and the advent of the steam-powered train and elevated track helped in the 1880s and 1890s. Those locomotives were dirty and discharged ash and smoke, creating a further negative impact on surrounding dwellings. The elevated structures also created a sense of clutter and darkness in the streets below. The speed on the elevateds rarely exceeded 12 miles per hour and, while an improvement, still was not fast. There was insufficient room for the structure of elevated tracks and all the surface carriage, pedestrian, and wagon traffic on the streets. Proponents of a subsurface rapid transit system began their efforts to build a modern system.

The entrenched elevated companies had considerable political muscle, and they stymied the subway proponents for many years. A committee of the ASCE, chaired by Octave Chanute, recommended the elevated system over the subway in 1875. Its report cited six issues in support of its recommendations, including the problem of clearing tunnels of smoke generated by locomotives and the difficulty of building the subway with such large numbers of utilities buried in city streets.

In the late 1890s the electric motor was developed to power subway trains, thus solving the smoke problem—but the political problem remained. In 1897 the Tremont Street Subway was built in Boston and even though it was a short line, it gave American engineers experience in this type of construction. In 1900 the transportation problem worsened in New York City, and finally a plan was developed to build the IRT (Interborough Rapid Transit) subway. The financing plan, originally proposed by Abram Hewitt, son-in-law of well-known Peter Cooper, required the city to fund construction by a private organization that would build and operate the system, with ownership being retained by the city.

Construction began in March 1900 under Chief Engi-

FIG. 5. William B. Parsons

neer William Barclay Parsons (Fig. 5). Parsons was associated with the subway effort since 1886, when he was appointed engineer for the New York District Railway. The IRT would connect Manhattan, the Bronx, and Brooklyn. The project was to be cut-and-cover between City Hall and 34th Street, with tunneling required between 34th and 42nd Streets and under Central Park. Above 60th Street the contractor could select his own method as long as it did not interfere with street traffic. In cut-and-cover sections the contractor could not open more than 400 feet unless he covered this with a structure on which vehicles and pedestrians could ride or walk. The cut-and-cover method required meticulous planning to disconnect, relocate, and reconnect all buried utilities while maintaining surface and elevated traffic. It was also necessary to ensure that adjacent buildings were not undermined.

The tunnels under the Harlem, to the north, and East Rivers were major projects in themselves. The Harlem River Tunnel was built with twin 14-foot-diameter cast-iron tubes covered with 2 1/2 feet of concrete on the top and a minimum of 1 foot on the sides and bottom. The contractor built this tunnel in a uniquely designed wooden box consisting of wooden sheet piles for walls and a 40-inch-thick wooden top that was anchored to the walls. The water was then forced from the box by pneumatic pressure and the tunnel built under pressure to mid-river. The northerly half of the tunnel was built in a similar fashion with the exception that the top half consisted of cast-iron rings and the required concrete cover was cast off-site, floated to the site, and sunk onto the sheet piles forming the walls. This connection was sealed and the area under the roof dewatered by pneumatic pressure, and the bottom half of the tunnel was completed. The East River Tunnel went through rock on the Manhattan side and was advanced by standard tunneling techniques. The tunnel from Brooklyn, however, was through sand and required shields that were pushed through the sand. The space behind the shield was pressurized to permit soil to be removed and cast-iron rings to be placed. Concrete was then injected between the rings and the bored wall of the tunnel.

Parsons, working with the contractor, successfully implemented this project between March 24, 1900, and October 24, 1904, and the first paying customer rode on the line between City Hall and 125th Street. In his 1906 report Parsons concluded, "the years 1905 and 1906 may be regarded as an epoch in the history of rapid transit, looking to construction of future subways on so extensive a scale as to have been hardly conceivable a few years ago, or even contemplated within the past decade." It was said that it was "one of the great public 'improvements of the twentieth century, but also as an indispensable element in the life of America's largest city.' " Without it, and its extensions, the growth of New York City would have been severely limited. It was conceived in a time of great political instability and lack of direction by political leaders. Leaders like William B. Parsons, the engineer, and August Belmont, the financier, made it happen. Lessons learned on the IRT were helpful as many other cities grew and needed their own subway systems.

PANAMA CANAL, 1904–1914

The United States' interest in a canal connecting the Atlantic and Pacific Oceans started under President James Polk, who in 1846 signed the Bidlack Treaty with Columbia. This treaty stated that "the right of way or transit across the Isthmus of Panama, upon any modes of communication that now exist, or that may be hereafter constructed, shall be open and free to the government and citizens of the United States. . . ." The Panama Railroad was built by private enterprise across the Isthmus between 1850 and 1855. For a time this eliminated the pressure for building a canal across the Isthmus. In 1875 President Ulysses S. Grant authorized the survey of proposed routes starting very close to the South American continent and extending as far north as Mexico. The two routes that received the most attention were the Panama Route, which followed very closely the route of the railroad, and the Nicaragua Route, which made use of Lake Nicaragua. The latter route became the American Route while the French, under the guidance of Ferdinand DeLessups, in 1879 selected the Panama Route.

Using private monies, the French began preliminary work in early 1880 on a sea-level canal similar to that which DeLessups built at Suez in 1869. Many American and some French engineers expressed their opinions that a sea-level canal was not possible with the funding available and the time frame DeLessups proposed. They pointed out the difficulty of controlling the Chagres River during construction and operation and the problems of diseases like yellow fever and malaria rampant in that part of the world. By force of personality and his ability at Suez to do just what many engineers said couldn't be done, DeLessups was able to obtain large sums of money to progress with the work. But between 1880 and 1886 it became clear that he could not complete a sea-level canal. He then adopted the recommendation of Phillipe Bunau Varilla to build a temporary lock canal that would have ships lock up to an artificial lake at the summit level and then lock down to sea level. While the canal was in operation, constant excavation would continue at the summit, dropping the level until such time as a set of locks could be removed. This excavation would continue until they arrived at a sea-level canal. But by this time disease, lack of money, and a growing realization that he still did not have a plan to control the Chagres River resulted in the company passing into receivership. A new company fored to continue work to the extent needed to maintain the concession that the French received from Columbia in 1879.

In 1903 the United States agreed to buy all equipment on the Isthmus and the title to the work completed dependent upon the signing of a treaty with Columbia. This treaty would give the United States the right to build and run a canal on the route selected by the French. Columbia, at least in the eyes of President Theodore Roosevelt, was slowing down his effort to build the canal. After Columbia rejected the treaty, the citizens of Panama revolted and declared their independence from Columbia. A new treaty, much more in the interest of the United States, was signed in 1904 with the new country of Panama. John Findlay Wallace was appointed the first chief engineer and was effectively told to go and "make the earth fly." Arriving at Panama in 1904 and surveying the work completed by the French, he was very complimentary of their efforts. Between 1904 and 1905 it became clear that organization of the enterprise was unwieldy and resulted in very slow decision-making. At the same time yellow fever returned and killed many American workers. In addition, Wallace in his effort to make the dirt fly did not provide the housing and food required for his workers. All these factors resulted in a very poor start by the United States. Wallace resigned in 1905 after only one year on the largest construction job in the history of the world.

Roosevelt appointed John Stevens (Fig. 6), a leading railroad engineer, to take over the project. Stevens observed that the United States did not have a plan, and he knew that the success of its effort rested on making the Isthmus free of yellow fever and at least minimizing malaria. He saw that housing and food distribution needed to be upgraded to attract and keep the men necessary to dig the canal. He decided to stop most excavation and join with Col. William Gorgas to eliminate the disease-carrying mosquitoes and clean up the canal route. At the same time he devised a material-hauling system to move earth from the Culebra Cut to places where it could be used or successfully wasted. His knowledge of railroading enabled him to set up a very efficient system of steam shovels and dirt cars to keep the dirt/rock moving. He proposed the largest man-made lake in the world at an elevation of 85 feet above sea level to be fed by the Chagres River. This made the river his friend as contrasted to the problem it was for the French effort. He needed to build a large (Gatun) dam at the northerly end of the canal with smaller dams and locks at the southerly end to create this lake.

After a Commission of Engineers expressed the opinion that the United States should build a sea-level canal, Stevens convinced Roosevelt they were wrong. With Roosevelt's support the decision was made to continue with a lock canal. The plan had ships come from the Caribbean lock up to Lake Gatun through a series of three locks and then pass through Gatun Lake and the Culebra Cut (now the Gaillard Cut). They would then be locked down through another set of three locks to the Pacific Ocean. This required the construction of the largest earth fill dam in the world at the time, the Gatun Dam, and the largest excavation project in history.

FIG. 6. John Stevens

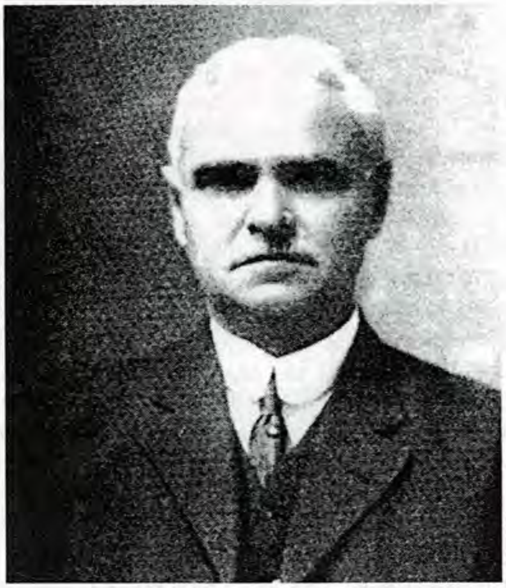

FIG. 7. George Goethals

After making all these decisions and initiating his earth-handling system, Stevens resigned in 1907, much to the consternation of Theodore Roosevelt. Roosevelt decided that he needed to send someone to the Isthmus who would not easily resign, so he appointed Col. George Goethals (Fig. 7) as chief engineer. Goethals came to this new position with almost dictatorial powers, as Roosevelt believed that everything on the Isthmus should be under the control of one man. Goethals was not only chief engineer but was also in charge of the Panama Railroad and the governance of Colon, Panama City, and all lands controlled by the United States along the route of the canal. He had other military men as assistants who would be at their posts as long as the president and Goethals required. While Stevens made most of the key decisions, Goethals made the system work in the most efficient way possible. He did this with Col. Gaillard assigned to the Culebra Cut and Col. Seibert to the Gatun Locks. For the next seven years Goethals and his "Army of Panama" fought huge earth slides (some as large as 3,000,000 cubic yards) in the Culebra Cut, poured more concrete for the locks than had ever been poured on a single project, built the largest earth-fill dam in the world, relocated the Panama Railroad, built port facilities at both ends of the canal, and placed into service a lock control system that was fail-safe and ensured the success of the canal's operation using the power of water dammed up in Gatun Lake. This water worked the locks and generated all the electricity needed to run the support facilities.

In 1914, after seven years of American effort and 34 years after DeLessups broke ground, the canal opened with little fanfare, due to the beginning of WWI. Slides continued to interrupt service years after completion. The United States indeed built the canal and that opened a path between the seas, bringing to a close the greatest project in the history of the young country since the completion of the Transcontinental Railroad in 1869. Ships could now pass between our east and west coasts much faster and carry goods at a much lower cost. Like the Suez Canal 45 years earlier, the Panama Canal changed the world.

EMPIRE STATE BUILDING, 1930–1931

The erection of tall structures can be traced back to the Pyramids of ancient Egypt (height 481 feet), the Pharos of Alexandria (lighthouse with a height of 350 feet) and the Colossus of Rhodes. Masonry church spires became the highest structures in most cities and villages and reached as high as 404 feet at the Salisbury Cathedral. The Washington Monument at a height of 555 feet was completed in masonry in 1884 and Gustave Eiffel built his famous tower in 1889 to a height of 1,000 feet. It wasn't until late in the 19th century that high structures were considered to house large numbers of people. Residential and commercial buildings were limited in height by the number of flights of stairs, usually six flights so that the occupants could reasonably be able to climb to apartments or offices. As elevators developed in the middle to later part of the century, the limiting factor shifted to the efficient height that masonry-bearing walls could be built without taking up excessive amounts of floor space. Exterior bearing walls became excessively wide as the height of the building increased, even when cast-iron columns were used for interior support of floor systems.

With the advent of inexpensive cast and wrought iron, and later steel, it became possible to design and build a steel frame that held up floors and wall-covering materials, thus making bearing walls unnecessary. In the 1870s iron—cast for columns and wrought for beams—framed buildings, one being the 10-story Western Union Building in New York City. In 1884 the first building built with a steel frame was Chicago's 10-story Home Insurance Building, designed by William Jenney. In 1902 in New York, the famous 20-story, 285-foot Flat Iron Building at Times Square was built with a steel frame and six elevators.

The construction of the Woolworth Building in 1913 began the rapid increase in height of what were called skyscrapers. It had a height of 792 feet and an average floor height of 12 feet for its 60 stories. It was the first truly tall building requiring new elevator systems and ways of moving people in a vertical direction. It was an instant success and retained the title of the tallest building in the world for almost 20 years. In the boom times of the late 1920s the Bank of Manhattan was built on Wall Street, a 71-story, 925-foot-high building with a very tall flagpole. Walter Chrysler, the automobile maker, planned his famous building. When the final height of the Bank building was set, he added its famous top, made up of the curving and overlapping metal plates that are so recognizable. It surpassed the Manhattan Bank by 105 feet and set a new record of 1,030 feet when it opened in 1930.

In the race to be the tallest, the Empire State Building was conceived. Officers of DuPont and General Motors were the prime movers behind this project to build a massive office tower on the former site of the Waldorf Astoria Hotel. They elected a former governor of New York and presidential candidate, Al Smith, as president of the board. The plan was to build the tallest structure in the world and to do it in the early part of the Great Depression. A steel frame was selected with a cladding of aluminum, stone, and stainless steel to speed up construction and cut down on weight. The contractor demolished the hotel in less than five months and had the foundation in place in another three. By late March 1930 the building was ready for the first steel. What followed was perhaps one of the greatest construction projects in United States history. They were constructing an 86-floor building in the middle of the busiest city in the world. The erection of the steel proceeded at an average rate of one story per day. In one week it actually grew by 14 stories. It took just 161 days to erect and rivet the entire steel frame. Like clockwork the other trades followed. Scheduling of material delivery was critical, as there was little room on site to store it. Elevator construction followed at an equally rapid pace. The building as erected was 1,050 feet above street level. With the installation of a 200-foot mooring mast (for dirigibles), the building topped out at an elevation of 1,250 feet. (Later, in 1951, it increased to 1,472 feet with the installation of a 222-foot TV antenna.) The building opened on May 1, 1931, ahead of schedule after a total construction time of 1 year and 45 days—20% below the original estimates.

The Empire State Building (Fig. 8), even though surpassed in height by many other buildings in the city and around the world, it is still one of the most recognized and visited. As an engineering achievement it makes every list of landmark structures.

GOLDEN GATE BRIDGE, 1931–1936

After the opening of the Brooklyn Bridge in 1883, the next key suspension bridge built was the Williamsburg Bridge by Leffert L. Buck in 1903. This bridge was

FIG. 8. Empire State Building

longer, wider, and carried a much higher load than the Brooklyn Bridge. It was the first to use steel for its towers in addition to cables and suspended structure. The next major design was the George Washington Bridge, built in 1931 by Othmar Amman, with its 3,500-foot span. Other major suspension bridges in that period were the Bear Mountain Bridge over the Hudson River, the Manhattan Bridge adjacent to the Brooklyn Bridge, and the Ambassador Bridge in Detroit, Michigan. Contemporary with the Golden Gate was the twin-span San Francisco–Oakland Bay Bridge that was noteworthy as a complete bridge project. It has not received the attention and accolades of its neighbor, partially because of its setting but also the fact that its central suspended spans are significantly shorter.

A bridge across the Golden Gate was the vision of Michael O'Shaughenessy, City Engineer of San Francisco, and Joseph B. Strauss (Fig. 9) as early as 1919. O'Shaughenessy saw the need to open up the Marina Peninsula north of the city to vehicular traffic with a bridge rather than the slow ferry system. He asked Strauss if he could build a bridge across the Gate and told him that other engineers had given him a price of $250 million. Strauss indicated that he thought he could build a bridge for $25 million. After borings were taken and a survey of the site completed, Strauss determined that the total length across the Golden Gate was over 6,700 feet and that foundations on rock at a depth of only 50 feet could be built with a central span of 4,000 feet. In 1921 Strauss submitted a plan that combined the suspension and cantilever bridge types. The suspended cable span was 2,640 feet and each cantilever arm 680 feet. Strauss believed that structurally the bridge was technically feasible and within his earlier cost estimate. O'Shaughenessy also asked Gustave Lindenthal and Robert McMath to submit proposals, but their estimated costs were far beyond the City's ability to finance. Strauss' design was, in reality, the only one seriously considered by O'Shaughenessy. In the eye of many observers it was ugly and not in keeping with the natural beauty of the Golden Gate.

FIG. 9. Joseph B. Strauss

Over the next eight years this was the bridge studied as O'Shaughenessy and Strauss tried to convince the voters that a bridge was possible and within their ability to pay. It wasn't until 1929, however, that a new suspension bridge was proposed with a 4,200-foot central span. This was possible by the addition of Charles Ellis to Strauss' staff and the assistance of Othmar Amman (then working on the George Washington Bridge), Charles Derleth, and Leon Moisseiff. Moisseiff developed a method of distributing wind load between the cables and stiffening trusses. Prior to this, trusses were assumed to carry the entire wind load. As a result, as span length increased, the trusses increased significantly in size. With Moissieff's analysis, the trusses and the look of the bridge could be much lighter as well as less expensive to build. Using the new theory, Ellis then designed the towers, anchorage, cables, and suspended spans.

The design was completed in 1930. It was recognized that, while Strauss had been the promoter of the bridge, the design was the work of Charles Ellis, using the theories of Moissieff. Strauss, however, was not a man who could share his project with others: he fired Ellis in late 1931. The design was completed, but Ellis continued on his own to work on the tower design over the next nine months. In the fall of 1932 he believed he had completely solved the problem to his satisfaction. He submitted his design to the other consulting engineers and went over Strauss' head to ask for an interview with the bridge's directors. Nothing came of this request and the bridge, as originally designed by Ellis, was ready for construction. Work started on the anchorages and piers in early 1933. The anchorages, although huge, created no major problems, nor did the northerly pier foundation that was close to shore. The southerly pier being well out into the Gate, created major problems in sinking the caisson because of the turbulent nature of the bay. After several major setbacks, the piers were placed and the steelwork was ready to begin.

In the midst of the Great Depression, men and materials were available at bargain prices. The towers, over 748 feet high, went up without problems. Then the John A. Roebling Company came in to spin the 36-in. diameter cables. Using new techniques, it spun faster than on any previous bridge and finished two months ahead of schedule. The suspended structure followed, and by April 1936 the last of the concrete was placed on the deck. The bridge opened officially on May 27, 1936, for pedestrians and on the following day for automobiles.

The bridge, with its central span of 4,200 feet, retained its status as the longest bridge in the world until the Verrazano Narrows bridge opened, in 1964, with its main span of 4,260 feet. It was designed by Othmar Amman, the consultant on the Golden Gate and designer of the George Washington Bridge. Even though the Japanese have recently completed a 6,527-foot bridge, the Golden Gate and the Brooklyn Bridge are perhaps the two most recognized bridges in the world. The Golden Gate Bridge, with its unique color and magnificent setting, is currently undergoing a renovation to increase its resistance to earthquake loading. It has been recognized not only for its beauty but for its contribution to the design and construction of suspension bridges around the world.

INTERSTATE HIGHWAY SYSTEM, 1956–1990

The United States highway system prior to WWII was incomplete and in poor condition. The rapid expansion in the number of automobiles and trucks placed great pressure on government, at all levels, to add to and improve the system. While steps had been taken, the expansion of the network was very slow, and few of what we would call modern highways had been built. The Pennsylvania Turnpike was an exception. When it opened in 1940 it was the most modern, divided, and controlled access road in the country. From Harrisburg to Pittsburgh, it covered over 160 miles. It was financed by bonds and an influx of money from the WPA. The coming of World War II set back highway construction and expansion for the next five to six years. After the war there was a rapid increase of automobiles and trucks on the inadequate network. Several turnpike authorities were created to build roads, as government at the state and federal levels could not find a way to finance the needed improvements. President Truman, with the pressures of the cold war, the financing of the Marshall plan, and the hot war in Korea, did not have the resources to commit to road building. His successor Dwight Eisenhower, however, was very interested in highways; he began the process that led to the passage of the Federal-Aid Highway Act of 1956 and created what is known as the Interstate and Defense Highway System.

The Federal-Aid Highway Act called for a system of 40,000 miles of multilane divided highways to connect most of the major cities in the United States as well as highways around and through those cities. Its $25 billion cost was to be expended over a 12-year period, and the system would be completed by 1972. It was to be financed through gasoline taxes that would go from 2 to 3 cents per gallon with all tax increase being placed in a Highway Trust Fund. The Federal Government would pay 90% of the cost, and the states 10%. The system was designed to carry the estimated traffic projected for 1972.

Once the project began it became clear that there would not be enough money generated by the gasoline tax to complete it in 12 years. President Eisenhower recommended that additional monies be appropriated from the general revenue fund. Even with this influx of money, the project would take far longer and cost far more than anyone had anticipated earlier in the planning process.

The man most involved in the conception of the program was Thomas MacDonald, who first proposed a similar highway system. MacDonald was chief of the Bureau of Public Roads since 1919 and had overseen and promoted the federal involvement in highway construction. After 34 years in the position, Eisenhower chose not to renew his contract in 1953. He was replaced by Francis DuPont, who immediately proposed that the system be

FIG. 10. Francis Turner

financed entirely by the federal government. His assistant, Francis Turner (Fig. 10), was appointed federal highway administrator in 1969 and became the face of the Interstate Highway System. These men were the guiding force behind the system, but the states did the actual designing and construction of the system. They needed to expand their highway departments and colleges had to increase their production of engineers to design and build the system. Construction companies expanded to complete the ambitious schedule of road construction, and organizations like the American Association of State Highway Officials developed guidelines and standards for all to follow. It was an exciting time to be a civil engineer.

In the early days of the program's implementation, the bulldozer mentality of many engineers resulted in a public uprising against placing highways in cities and the encouragement of alternate means of meeting the transportation needs of the community. Prime examples of this were in New Orleans, Boston, and San Francisco. As their primary charges, highway engineers considered the safety and convenience of the motorists and their need to get as close as possible to their destinations. The fact that the highway might disrupt the social and economic fabric of a community was far less important to the engineer than was the efficiency of the system. Over the 1970s and into the 1980s that approach was modified, and engineers began to take into account other factors than cost per mile and accessibility. The system continued its expansion well into the 1990s, when it was officially completed 37 years after its creation. In reality, however, the system will never be completed—new mileage is being added and the cost of maintaining and upgrading the road continues to the present day. The program was followed in 1991 by ISTEA (the Intermodal Surface Transportation Efficiency Act), and in 1999 by TEA21 (the Transportation Equity Act of the Twenty-First Century). These programs recognize that highways are important but are only one part of the overall transportation needs of the country.

As had the Intercontinental Railroad over a century earlier, the highway system had changed the way Americans lived and traveled. It was now possible to cross the United States in three to four days in your own automobile without stopping except for gasoline, food, and breaks. Cross-country trucking became economical and competed with the railroad for its market. It was now possible to live miles away from your place of employment and make the commute in a short period of time. City dwellers moved to the suburbs to live and retailers followed, building malls at interchanges of the system. Manufacturers and distributors located their new facilities at or near interchanges to cut down on their costs.

The Interstate Highway System, with its approximately 42,000 miles of roadway, comprises only 1% of the total highway mileage in the country but carries 24% of the passenger traffic and 45% of truck traffic in a safe and fast manner. On the downside, people, retailers, manufacturers, etc., left the cities for the suburbs and downtowns became decimated. The interstates directed traffic away from many small towns and cities that relied upon passing traffic for part of their business, and these communities suffered the consequences. In summary, even with these negative effects, engineers can be proud that they created a system that enhanced people's mobility and freedom to work and play at far greater distances from their homes. Companies can move freight and goods much faster and cheaper than at any time in the history of the country. So it is clear that the Interstate Highway System changed the way Americans live, work, and dream in much the same way that the Intercontinental Railroad did a century earlier.

CONCLUSION

Over the past 150 years the American Society of Civil Engineers has witnessed the United States progress rapidly, at a pace far exceeding that of any other country in the world. Some of that progress was due to the fact that in 1852 the country was just starting to flex its muscle and expand its view of what was possible in a free society with abundant natural resources. All these opportunities still needed a native-born citizenry and large numbers of naturalized citizens who had the vision and energy to develop the land of the free to its fullest potential. The Civil Engineer was the one who made much of this happen as he/she developed the waterway, railway, and highway systems, designed and built sewage and water treatment facilities, and built higher and higher buildings and longer and longer bridges. As we look back on this century-and-a-half of progress, we can be proud of what we as a profession have created. Would we have done certain things differently if we had them to do over again? Certainly, but that is from the perspective of hindsight, and it must be recognized that every major project was a creature of its time. Conditions usually are never exactly the same again. From our current vantage point we should not be overly critical of our predecessors, but instead rejoice in their accomplishments and our vision as we plan to create the world of the 21st century.