America's Greatest Projects and Their Engineers I

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America's Greatest Projects & Their Engineers-I

Introduction

During the past 150 years, Americans have achieved phenomenal success on our way to becoming the greatest nation in the history of the world. Notwithstanding the many inventions that we have created, such as the electric light bulb and the telephone and the airplane and the internet, Americans have been responsible for some of the greatest and most beneficial projects in the modern era.

The intent of this course, the first in a series, is to determine how these projects benefitted Americans in particular, and also how these great projects were developed and managed. Clearly, some of these projects have positively impacted the entire world as well as the United States of America. Some of these projects were on the so-called "drawing board" for several years, or even decades, before they were initiated and developed. Some, such as the Lunar Landing, involved our government (NASA) and many engineering firms and sub-contractors. Others, such as the first atomic bomb, caused enormous devastation to the Japanese, while ending the proliferation of mass casualties and destruction from the greatest war that the world, hopefully, will ever see.

Many of these projects are probably considered by most Americans to be construction projects, but there is little doubt that any of these projects could have been successfully accomplished without administrative support or without the proper planning and design of quality engineers, architects and designers. The strong efforts of dedicated individual engineers as well as the commitments of architectural/engineering firms and the vision and wisdom of quality project managers all resulted in these projects coming to a successful conclusion. This statement is not intended to demean the construction companies or the many manufacturers who were involved in these projects, because their foresight and experience were paramount to the success of each of these projects.

This first section of this course will focus on the Panama Canal Construction and the many largely unknown events, some dating back to the sixteenth and seventeenth centuries, leading up to its development. In addition, this course also includes a description of the construction of the Hoover Dam, emphasizing the wisdom and tenacity of the engineers in the Federal Government to initiate and plan this huge project, as well as the engineers and supervisors of the contractors in the private sector to carry out such an enormous project. Each of these projects has lessons to be learned and, hopefully, each reader will be motivated to do greater things.

Outline

1. Panama Canal

This course traces the history leading up to the actual opening of the Panama Canal in 1914, including the ideas and the attempts by other nations to develop a canal that would join the two oceans. Course also describes the efforts of individual engineers to achieve such an engineering feat.

A. Early Events

B. Enter the United States

C. U. S. Construction Begins

D. Summary

2. Hoover Dam

Also included in this course is a synopsis of the construction of the Hoover Dam, another early twentieth century project that was on the forefront of engineering technology. This course details the contributions of several engineers who participated in this remarkable achievement.

A. Hoover Dam Approval and Administration

B. Hoover Dam Engineering and Design

C. Hoover Dam Construction

D. Summary

Panama Canal

A. Early Events

Nearly every major project in the United States has been influenced by both the needs of its citizens as well as by the political atmosphere of the country. The history, planning, and construction of the Panama Canal were certainly no exception. Considered by most professional engineers and by nearly all civil engineers to be one of the wonders of the modern world, the Panama Canal was many decades in the planning and political stages.

As early as the sixteenth century an access through the Isthmus of Panama was recognized by European leaders and magnates to afford their nations an advantage in shipping and world power. A direct route between the Atlantic Ocean via the Caribbean Sea and the Pacific Ocean would not only cut weeks from their travels around South America's Cape Horn, and through the treacherous Straits of Magellan, but would also strengthen their nation's economic and military power. Even after the American Revolution in 1776 world powers such as Great Britain and Spain continued to explore alternate routes to travel from the Atlantic to the Pacific.

Panama Railroad Company

Nevertheless, the very first official connection between the two great bodies of water turned out to be a railroad. In 1846 a group of investors in New York City managed to raise $1 million, in order to build a railroad that would transfer people and goods from the east coast to the west coast of the United States and then on to Asia. A survey was commissioned and engineering companies were hired in 1848 by William Aspinwall, who had conceived the idea of constructing the railway and who had the federal contracts to deliver mail between the east and west coasts of the United States. Prior to the railway being built, the many travelers who were intent on reaching the West Coast from the eastern U.S. through Panama had used small boats on the very dangerous Chagres River and mules for the last several miles of the journey, which normally took about seven to eight days.

An optimum route of just over 47 miles was chosen, and construction of the railroad began in January of 1850, but many problems were encountered during the first phase of the construction. The survey had many inaccuracies and gross miscalculations, including not being done during the nine-month rainy season when the Chagres River would rise as much as forty feet. Agreements had to be signed between the firm, known as the Panama Railroad Company (PRC) and the Colombian government, which owned the entire Panama region at that time. A port had to be constructed at each end of the railroad to accommodate the steamships that would bring mail, cargo, and people to and from the Isthmus of Panama. Millions of cubic yards of fill had to be brought in to allow the railroad to span vast regions of swamp land (fortunately, PRC was given access by the Colombian government to a nearby rock quarry.)

The bad news was that after two years of construction, less than eight miles of track had been laid, and the original investment of $1 million had been depleted. The good news was that gold had been discovered in California a few years earlier, and more and more people were appearing every day to seek their fortunes. They were willing to pay large fees to the PRC to take them at least part way across Panama by rail. As the result of these unexpected revenues, the entire railroad was able to be completed by 1855 from end to end at an additional cost of $7 million. The engineers and construction crews had managed to overcome the many problems that would continue to plague them in the future: not just a rainy season that lasted from April to December; or flood waters that caused the nearby Chagres River to rise, but also the alligators that proliferated in the swamp lands, and the diseases of cholera, malaria, and yellow fever that were carried by the millions of mosquitoes and were responsible for the deaths of an estimated 5,000 to 10,000 construction workers.

Furthermore, the railroad was in a continuously rebuilding stage, in large part due to the climate conditions of that area. Because of the nearly bottomless swamplands, the ballast under the tracks was constantly being added. The original railroad ties of pine had to all be replaced within a year, due to the high humidity, with creosote-impregnated ties. Every wooden bridge and trestle was eventually replaced with iron structures, and locomotives, gondolas, and passenger cars were made of iron and other metals. Due to the advances in engineering and technology during that era of the Industrial Revolution, as well as the gold rush in California and the willingness of the ownership to reinvest in the nuts and bolts of the business, the Panama Railroad eventually became the most profitable railroad in the world.

Suez Canal

At about the same time that the PRC was beginning to emerge as the world's preeminent railroad, the French embarked on a project that would connect the eastern Mediterranean Sea to the Red Sea and on into the Indian Ocean. Ferdinand de Lesseps, a career French diplomat, had befriended Egyptian royalty in his role as ambassador, and in 1856 was granted exclusive rights to build a canal through the Isthmus of Suez. The British, who had the largest naval fleet in the world at that time, were extremely opposed to the project. They were initially embittered by this seeming takeover by France of Egypt, which had once been an English colony, and that their monopoly on trade with India and Southeast Asia would be jeopardized. However, the advantage of shorter trade access to India (still a British colony at that time) as well as to southeast Asia markets assuaged the British. Within a few years after voicing their objections, and having been assured by the French that slave labor would not be utilized during the construction of the canal, the British reluctantly agreed to the project. Great Britain came to recognize the great benefits of the Suez Canal to the entire world.

The Joint Venture that was formed allowed that the Egyptians owned the land, and the French, who were financing the project, would retain a ninety-nine years lease on the canal. The preliminary planning of the Suez Canal had begun as far back as Napoleon Bonaparte's time as ruler of France. However, inaccurate surveys indicated that the water levels between the two seas were significantly different, so that the project was abandoned. De Lesseps had read about attempts to build a canal in the Suez, and commissioned a survey team to provide sea level information at each end of the isthmus. He and his team discovered that the original survey had numerous errors in the elevation calculations and, except for some differences in the tides, the seas were at the same level. De Lesseps, a developer without any engineering background, determined that a sea level canal could be constructed.

Construction of the Suez Canal, a single lane canal measuring slightly over 102 miles long, was begun in April of 1859 under French management. De Lesseps plan was to construct a smaller utility canal the full length of the main canal to move machinery and workers. The project had several delays due to lack of capital, even though more than 200 million Francs had been raised initially by de Lesseps' company. A further delay occurred when the royal emirate of Egypt died in 1864, and the French government had to rescue the project financially.

John Robinson McLean, a British civil engineer who later became the President of the Institution of Civil Engineers in London was instrumental in developing the actual dredging plan for the canal, and designed methods to use two different-sized dredges to both dredge the canal and build up the embankment. The initial single lane canal did have two large lake areas to allow ships going in opposite directions to pass each other. There are still some major improvements being made to the Suez Canal, the last being in 2015. The original plan was to dig a canal, using forced Egyptian labor, deep enough to fill with water and allow small dredgers to float to the worksites and dig a deeper canal. The smaller dredgers would then dig deep enough to allow the larger dredgers to float to the worksites and dig to the final depth of about 25 feet, which at the time was sufficient for the draft of all maritime travel. Constant improvements in dredging equipment and embankment techniques over the decades have seen the depth of the Suez Canal today reach 66 feet.

Enter the French in Panama

The French, largely due to the great financial success of the Suez Canal, were quite open and in favor of the Atlantic to Pacific Canal project. The fact that the project would be under the direction of Ferdinand de Lesseps, the developer of the Suez Canal, allowed the French to initially raise in the vicinity of US$100,000,000. Whereas many nations had understood the economic significance that this canal would bring, the French were actually the first nation to seriously develop plans and initiate construction of the Panama Canal in 1881. Although de Lesseps had been the primary figure behind the financial investment of the very successful and financially rewarding construction of the Suez Canal, he was not an engineer. Nevertheless, owing to his reputation for the success of the Suez Canal, de Lesseps was able to secure the financing as well as an agreement with Colombia to build the canal in its Panama Territory. De Lesseps and his team had originally estimated the cost of a sea level canal to be in the vicinity of 500,000,000 francs ($100,000,000). De Lesseps was named as the president of the French canal company and, with the confidence that his engineers had developed the optimum design for the route, construction on the canal and the ports at each end of the canal began in 1881.

De Lesseps was convinced that a sea level canal, similar to the design of the Suez Canal, could be built without locks due to the relatively equal levels of the ocean waters and in spite of the potential tide differentials between the Atlantic and Pacific Oceans. This concept had been disputed by Baron Godin de Lepinay, who was the chief engineer for the French Department of Bridges and Highways. His plan was to build dams on the rivers at each end of the canal, and to create an eighty feet deep artificial lake that would be accessible through locks. Nevertheless, de Lesseps plan was accepted by the French Technical Committee, and the work proceeded. Ironically, had de Lepinay's proposal been accepted, the French might have actually successfully completed construction of the Panama Canal.

The first major mistake that de Lesseps and his project team made was that they had never visited the site during the eight-month rainy season when the waters in the Chagres River, which was a large part of their planned route for the canal, would rise as much as thirty-five to forty feet. Arguably the most important obstacle that the French failed to realize was the significant amount of hard rock and clay that they would have to cut away through the Continental Divide; due to the heavy rains, the constant mud slides required much more shallow embankments, and their estimates for this scope of the project were miscalculated by millions of cubic yards. Adding to these problems were the same environmental and contaminating conditions that the Panama Railroad Company workers had faced: snake- and alligator-infested swamplands, a swollen and constantly rising river, and diseases of cholera, malaria, and yellow fever that would often take the lives of more than two hundred workers a month. The diseases took their toll, not only on the thousands of workers in the field, but also on many of the engineers, managers, and construction supervisors as well.

By the summer of 1886, and having exhausted hundreds of millions of francs, using more than half a dozen Project Managers, and losing thousands of workers and engineers and their family members to fatal diseases, the decision was finally made by the French government to change the design of the Panama Canal to a lock and dam design. With the realization of just about everyone but the stubborn and still determined de Lesseps, and with some areas of the canal work nearly completed, the first lock was ready for construction and design work had begun on the first dam. Suddenly, however, the money had run out in late 1888, albeit some work continued until May of 1889, and the company filed for bankruptcy in the French courts shortly thereafter. The cost of the project to that point had been the original investment of US$100 million plus an additional US$180 million that had been raised during the project's construction.

After much turmoil and litigation in France owing to the failure of the Panama Canal Project, the French tried again to complete the canal work by raising enough money in 1894 to resurrect the project. However, the widespread scandal and subsequent litigation that surrounded the project following the bankruptcy in 1889 had soured the French government and their citizens regarding further activities on the Panama Canal Project. A bond issue was rejected, directly because the French public had lost all faith in the project.

B. Enter the United States

The French Look for a Bailout, Turn to the U. S.

With little or no capital available, the French Canal Company had few choices at this point; they could either abandon the project completely, or they could try to sell what remained of it. Company directors decided to take their chances with the United States of America, which seemed to be interested in an isthmus canal, either through Nicaragua or Panama. The initial French proposal was made to President William McKinley in December, 1999 by a young French engineer named Philippe Bunau-Varilla, formerly one of the six project directors for the French Canal Project. The canal construction had proceeded most successfully under his leadership, and he was thus appointed by the French as the "front man" to sell the remnants. The deal between the French and the United States was five years in the making due to a series of unfortunate circumstances.

McKinley had been reelected President of the U. S. in 1900, and began his second term in January, 1901. He had won reelection in part largely due to a rebound in strong economic growth that he had helped to foster due to his recommendations for tariffs on imported goods following a recession in 1893. However, now that American manufacturing was growing and prospering, McKinley saw an opportunity to increase domestic exports dramatically. One of his grand plans was to open trade routes between the Atlantic and Pacific Oceans through the Central American Canal. Unfortunately, his plan was put on temporary hold when he was killed by an assassin's bullets in Buffalo, New York in September, 1901. He was succeeded by Vice President Teddy Roosevelt, whose primary focus at that time was to create a Secret Service that would protect future presidents.

U. S. Political Intrigue

Vice President Roosevelt had a varied background leading to his becoming the 26th president of the United States. He had been an author, explorer and naturalist, and was an excellent hunter and horseman. He had gotten into politics in New York City and New York State, and had served as Assistant Secretary of the Navy in the first year of President McKinley's presidency. He abruptly resigned his position in order to join in the Spanish-American War, and to lead an all-volunteer army as their Lieutenant-Colonel. His regiment of volunteers, made up primarily of "cowboys", outdoorsmen, and hunters was sent to the Santiago, Cuba area in the summer of 1898. Their initial role was to support the two divisions of the regular U. S. Army in their battle to capture the city and the port of Santiago from the Spanish. While in Cuba he experienced first-hand the tropical heat and humidity as well as the death-causing diseases of malaria and yellow fever.

During the course of the fighting Roosevelt, who was on horseback, led his Rough Riders and the other two regular army divisions in a charge up San Juan Hill, successfully overrunning the Spanish army. Within a few weeks the Americans had taken over the city, and the U .S. Navy then completed the mission by destroying the Spanish fleet and taking over the Santiago Harbor. Roosevelt and his Rough Riders returned to the mainland in the summer of 1898 as war heroes, and Roosevelt was requested to run for Governor of New York. Although he was victorious in his election, many of the so-called Republican "establishment" in New York State were unhappy with Roosevelt's being in such a powerful leadership role. Basically a corrupt group, they worked tirelessly to remove him from New York office, finally convincing President McKinley to accept Roosevelt as his Vice-Presidential running mate in 1900. Their feeling was that the Vice President's position was a powerless, figurehead role. As an assassin's bullets were to prove when McKinley was assassinated in Buffalo, New York in September, 1901, power can change dramatically in an instant.

Events Leading to the Panama Canal Construction

As was, and maybe unfortunately still is, the common practice in government, a commission (Isthmus Canal Commission) was established. Made up of diplomats and career politicians, the commission showed little or no interest in purchasing anything from France in Panama, proposing that the U. S. develop the canal in Nicaragua. Actual negotiations for the U. S. Canal Project began in earnest in the spring of 1902. The French contingency, led by Bunau-Varilla, was eager to sell whatever they could to the U. S. in order to recoup some of their huge financial losses.

During the proceedings Bunau-Varilla was able to convince President Roosevelt and some of the Americans that the Panama route was far better than going through Nicaragua's thick jungles, and that the cheapest and safest construction for the canal would be to utilize the last plan of the French before they abandoned the project, which included locks, dams, and a large artificial lake. President Roosevelt, believing that the French plan was more expedient and being eager to honor the wishes of a fallen president, pushed through Congress as quickly as possible an agreement to purchase the assets of the French Panama Canal for a price of US$40 million.

The fact that the Panama Territory was owned by Colombia, which initially refused to authorize the French to enter into negotiations with the U. S., did not deter either the French or the Americans. A new Panamanian government made up mostly of Panamanian rebels was hastily formed and quickly authorized Bunau-Varilla to negotiate an agreement with the U. S. Whereas McKinley had viewed the canal across the isthmus of Central America to be a huge boost to the American economy, Roosevelt's experiences in the Spanish-American War also led him to believe that a U. S.-controlled canal would be vital to the military interests of the U. S.

A battle ensued between the Colombians and the new Panama government, but the Colombians were unable to break through a naval blockade established by the U. S., thus giving rise to the claim of American Imperialism. In return for the U. S. protectionism, the new Panama government allowed the U. S. to have total control of the Panama Canal Zone for the next 99 years, while the U. S. made amends with Colombia by agreeing to pay them the sum of $10 million. Although this 10-miles-wide zone (Panama Canal Zone) split the country in half, the U. S. paid the new Panama government a small annual fee and maintained complete control of this zone until December, 1977.

Medical Breakthrough

While these political and military activities were going on, the U. S. biomedical field had made enormous strides in the fight against cholera and malaria. Cholera illnesses were recognized in the early 1880's as being caused by polluted water and contaminated food. At about the same time Dr. Carlos Finlay, a physician from Alabama, studied the causes of malaria and yellow fever, and published the first papers attributing the disease to airborne, female mosquitoes. However, his early studies and test results languished until a U. S. Army doctor named Walter Reed proved Dr. Dunlap's theories accurate. Dr. Reed spent considerable time in 1898 in Cuba, where many U. S. soldiers contacted malaria and died of yellow fever.

Over the next three years Dr. Reed conducted experiments with the many ways to obliterate mosquito infestation and to protect resting soldiers by placing screens and nets around eating and sleeping quarters. His actions and experiments nearly eliminated malaria and yellow fever as a fatal disease in the tropics and sub-tropics. His efforts and success were timely and almost miraculously paved the way for a much safer and more worker-friendly environment when the

U. S. began the Panama Canal Project three years later and ultimately saved the lives of thousands of workers.

C. U. S. Construction Begins

Following the agreement with the new Panamanian government, the U. S. officially began their phase of the canal project on May 4, 1904. On that date the ownership and the rights of way were officially presented to Lt. Jatara O'Neal, a U. S. Army veteran.

Whereas the U. S. had believed that they were receiving an active project with work in progress, the opposite was true. The Americans inherited a small workforce of canal workers who mostly maintained existing plant and equipment, but were not necessarily involved in construction of the canal. The Americans also discovered a jumble of buildings and equipment that had been under designed as well as seriously neglected since the last actual French activities in 1889. Although the majority of the buildings were dilapidated or in need of major repairs, many were salvageable in order to accommodate the large workforce that was required.

Dr. John Wallace, First Engineer

Shortly after the agreement was signed, John Wallace was assigned as the Chief Engineer of the project. Wallace had attended Monmouth College in Illinois, received his engineering certificate from the University of Wooster, and finally a Doctor of Science from Armour Institute in 1904. He began an inventory of buildings and other infrastructure that would be available. The harsh, humid environment had also taken its toll on the Panama Railway, which was also in a serious state of decay. Wallace was expected to show marked progress in the canal's construction inasmuch as both President Roosevelt and the ICC were led to believe that U. S. had purchased an ongoing operation.

Wallace set about to describe the real situation, spending months to catalog the hodge-podge of buildings and equipment on site. Functional housing was almost non-existent, and much of the drilling and dredging equipment was either undersized or had severely weathered in the tropical climate. The Panama Railway, which was expected to have a significant role in the construction of the Panama Canal, was in a severe state of decay. In spite of the deteriorated state of the infrastructure and his efforts to prepare the canal sites to utilize large workforces and large equipment, his requests were stifled by the Canal Commission. Frustrated by the incompetency and inactions of the commission, Wallace abruptly resigned only about one year later in 1905. However, his time served was apparently not in vain. In spite of his many disputes with the ICC, he made the Roosevelt administration very aware of the necessity for upgrading the existing infrastructure, and Congress was able to more readily meet the financial demands of the project.

John Stevens, Practical Engineer

Wallace was replaced as chief engineer a few months later in July, 1905 by John Stevens, an engineer who had been responsible for the design and construction of Western railroads in the U. S. Stevens had only two years of formal engineering training before moving from his home in Maine to Minneapolis, where he earned his reputation as well as his undocumented degree in practical engineering by his involvement in the design of several railroad lines in Minnesota and Michigan. Hired in 1889 by the C.E.O. of Great Northern Railway, Stevens received wide acclaim for his design of routes through mountain passes and tunnels that expanded the lines of Great Northern Railway by over 1,000 miles.

When Stevens assumed his role as Chief Engineer of the Panama Canal Project, there had still been no firm decision regarding whether the canal should be a sea level or a lock and dam canal. Stevens directed the project so that the excavation would be beneficial in either case. In the meantime, he recognized that a major investment in infrastructure was necessary. Now having the ear of the Roosevelt administration, he established a scope of work, a cost structure and a timeline for the requirements that Wallace was unable to have approved by the commission. His formal plan included:

1. Upgrade the Panama Railway
2. Improve sanitation in the cities of Panama and Colon.
3. Remodel most of the old French buildings
4. Build hundreds of new buildings for the necessary workforce

Stevens began almost immediately upon his arrival in Panama to rebuild the Canal's infrastructure, setting up locations and building warehouses as well as machine shops and other repair shops. He had piers constructed for the offloading of personnel as well as equipment and parts. He even established entire planned communities around the cities of Colon and Panama to include housing, hospitals churches and hotels. Now that the causes of many of the tropic diseases were known, he authorized mosquito-control programs (DDT's insecticidal action wasn't discovered until 1939 and hysterically banned by the EPA in 1972) that virtually eliminated yellow fever in the workplace. His policies and practices for extensive sanitation and clean water removed cholera and other digestive diseases almost completely from the Panama Isthmus. He rightfully realized that the railway system was the major component for removing and redistributing the excavation material from the Canal Zone, so he set about rebuilding and refurbishing the Panama Railway. Stevens and his team had designed a rail-based system for disposal of excavated material that was used throughout the project.

During the period under Stevens' leadership, Roosevelt had sent a team of engineers to Panama to determine the merits of a sea level versus lock and dam canal. Those engineers decided in favor of a sea level canal; however, both the ICC as well as Stevens opposed the sea level design, due to time constraints as well as to the estimated project costs. Stevens' progress report was very instrumental in convincing Roosevelt of the relative merits of a lock and dam design, which the House of Representatives and the Senate ratified shortly thereafter, and final design was initiated to that end.

Stevens resigned as the Project Director (Chief Engineer) of the Panama Canal Project) quietly in the summer of 1907, much to the consternation of President Roosevelt and his administration. Stevens, primarily a railroad engineer, felt that he had accomplished all that he could offer to the project. He had proven to Roosevelt that the cost to construct a sea level canal per the original French design would be cost-prohibitive. Furthermore, he had convinced Roosevelt and the now acquiescent ICC that a system of locks and dams would be the best and least costly way to build the canal. Not considering himself to be knowledgeable in those areas, he felt obligated to turn the project over to those who had the necessary expertise, feeling that he was leaving the project in a very good position to be successful.

Major General George Goethals

Stevens' resignation left the door open for Roosevelt to eschew utilizing outside contractors for any of the lock and dam construction, believing that army engineers would be the most reliable resource for the lock and dam system. Under those guidelines Roosevelt appointed Major General George Goethals as Chief Engineer to replace Stevens. Goethals had begun his engineering career at the City College of New York. After three years there he had received an appointment to the U. S. Military Academy and, following graduation, was commissioned a 2nd Lieutenant in the Army Corps of Engineers.

The Corps of Engineers had actually been initiated by the Continental Congress in 1775, and was officially authorized as an engineering arm of the U. S. Military by President Thomas Jefferson in 1802.The Corps academy was located at West Point in upstate New York, and was the only graduate engineering school in the U. S. for the first half of the nineteenth century. The Corps was essentially split in half during the American Civil War of 1861-1865, after which it was reconnected and finished the nineteenth century with a flurry of successful locks, dams, waterways, bridges, and other federal projects. This success gave rise to the reputation of the Corps' abilities and resulted in the confidence that President Roosevelt and Congress had in the Corps.

Although the actual work on the canal was still not meeting the expectations of the commission, the majority of the necessary infrastructure had been put in place. Nevertheless, when Major General Goethals took the project over, having sufficient workforce was an issue. He established the improvement of basic living conditions by building YMCA-managed clubhouses which included libraries, bowling alleys, ice cream parlors and gymnasiums. The workforce, which had been largely nomadic and in a constant state of flux, greatly stabilized, and the problems of drunkenness and absenteeism largely disappeared. While the engineering staff was mostly white Americans, the workforce, which at one point numbered over thirty thousand, came largely from the British and French West Indies.

Major Goethals made the decision to divide the Panama Canal Project into three divisions:

a) Atlantic - under Major William Sibert: Construction of the breakwater at the Atlantic Ocean side, the Gatun locks and their 3 1/2 miles approach channel, and the large Gatun Dam.

b) Pacific - under Sydney Williamson: Construction of the Pacific entrance to the canal, the Miraflores and Pedro Miguel locks, and their associated dams and channel from the Pacific Ocean.

c)) Central - under Major David Gaillard: construction of everything in between, including excavation of the Culebra Cut, which involved cutting an eight-mile path through the continental divide. This mostly rock formation, which was originally about 370 feet above sea level, was eventually cut down to an elevation of just forty feet above sea level. This proved to be the greatest challenge to the Panama Canal construction, and its success was widely hailed as one of the great achievements of the Panama Canal project.

As President Roosevelt had anticipated, and as was evident from the above scenario, the design and construction of the Panama Canal was being directed by the Corps of Engineers. Even Mr. Williamson, who was one of the few civilians that was involved to any extent in the project, had considerable experience working with the U. S. Army Corps of Engineers on several other projects.

Major William Sibert

Originally from Alabama, Major Sibert began his engineering career at the University of Alabama. He transferred to the U. S. Military Academy where he graduated as a 2nd Lieutenant in the engineering program in 1884. He served in the Corps of Engineers with both domestic and overseas assignments for the next two decades. In 1907 he became a member of the Panama Canal Commission and was assigned by Major General Goethals to manage the very important front end of the Panama Canal Project. In addition he also shared the responsibility for the building of the channel from Gatun Lake to the Atlantic Ocean.

Following the successful opening of the Panama Canal in 1914, Major Sibert was erroneously promoted to the rank of Brigadier General even though, as an engineer in the Corps of Engineers, he had never led troops into battle. This situation promulgated into a real near-disaster when the U. S. entered into World War I, and then B/G Sibert was the only ranking officer available to be put in charge of the 1st Infantry Division in Europe in 1917. To his credit Sibert knew that he would be a liability in combat, and requested to be released of his military duties by American Expeditionary Forces Commander General John Pershing. General Pershing had Sibert returned to the United States in January, 1918, where he became the commanding general of the Corps of Engineers. When the War Department created the Chemical Warfare Service later that year, General Pershing recommended Major General Sibert to be the commander of that service, recognizing Sibert's true abilities as an engineer and project manager.

Major General Sibert retired from active duty in 1920, directed the project to modernize the docks and waterways in Mobile, Alabama, and served on the Presidential Commission that led to the building of the Hoover Dam. Sibert died in 1935, was buried at Arlington National Cemetery, and was later elected to the University of Alabama Engineering Hall of Fame.

Sydney Williamson

Even though he graduated from the Virginia Military Institute at age 19 in civil engineering, Sydney Williamson was one of a very few engineers who was not part of the Corps of Engineers. Born in Lexington, Virginia in 1865, Mr. Williamson graduated from the Virginia Military Institute at age 19 in 1884. He worked as a math instructor and civil engineer for various railroads, first meeting and working for General George Goethals in the early 1890's, designing improvements to canal locks on the Tennessee River. He again worked under General Goethals from 1901 until 1903 at Newport, Rhode Island, where he impressed the general with his planning and organizational skills.

In need of a strong, well organized engineer to design and manage the construction of the western third of the Panama Canal project, General Goethals called upon Mr. Williamson for this task in 1906. Spending the better part of the next nine years, he managed both the wet and dry excavation of the Pedro Miguel and Miraflores locks on the Pacific side of the canal. He also helped design and managed the construction of the Pacific Terminal docks as well as water supplies, sewers, roads and streets for the city of Panama and other communities on the Pacific side.

Following the successful conclusion of the Panama Canal construction in 1914, Williamson went on to a distinguished engineering career with assignments in South American and the United States, including his service on the Inter-Oceanic Canal Board. His collection of Panama Canal project and planning files, engineering drawings and specifications, reports and other papers are on display at the Virginia Military Institute. Also included are numerous photographs of the enormous construction tasks, as well as several photos of President William H. Taft's six inspection visits between 1909 and 1912. Mr. Williamson died in January, 1939.

Major David Gaillard

Major Gaillard was born in South Carolina in 1865, and graduated from the U. S. Military Academy at West Point in 1884. After graduating as a 2nd Lieutenant in the U. S. Army Corps of Engineers, he rose through the ranks until, by 1903, he was promoted to Captain. In 1908 he was called upon by Major Goethals to manage the most critical aspect of the Panama Canal project, was promoted to major and was put in charge of the central portion of the Panama Canal, which included the notorious Culebra Cut through the backbone of the Continental Divide. He worked rigorously for the next five years, often spending more than twelve hours per day on the site, and engaging in the labor as well as the administration of the project.

Major Gaillard was extremely conscientious about each dollar being spent on his portion of the project, and he was attributed to having saved the U. S. Government more than $17 million. As the project manager for this very important phase of the Canal project, his vision of how to cut through the mountainous terrain of the Panama Isthmus was carried out by his workforce as well as himself. His mission succeeded, but Gaillard was not around at the end to see that success personally. He returned to the United States in late 1913 with a condition that was initially suspected of being work-related exhaustion. He was admitted to Johns Hopkins Hospital in Baltimore where he was diagnosed with a brain tumor; he died a short time later in early December, 1913.

Even though Major Gaillard did not live long enough to see the opening of the Panama Canal, which occurred just nine months after his death, he is well remembered for his work ethic and his ingenuity. Until the United States finally relinquished its ownership of the Canal Zone in 2000, the artificial valley through the Continental Divide in Panama was known as the Gaillard Cut. Today the Culebra Cut is still considered one of the great engineering feats of its time.

Design and Construction of Locks and Dams

Once the decision was made by President Roosevelt and the Commission that the Panama Canal would be comprised of locks and dams, Major General Goethals and his staff did a thorough search to determine the engineers qualified to design the locks. Lieutenant Colonel

Harry Hodges became a valuable assistant to General Goethals and had the overall responsibility for the technically difficult design, fabrication, and construction of the lock gates. Lt. Col. Hodges had previously worked with Gen. Goethals on other lock projects, including the Muscle Shoals canal, and had become fairly familiar with a new building material called concrete.

A three-step lock approach was designed on the Atlantic Ocean side, which could raise or lower ships as much as 85 feet above sea level and onto Gatun Lake. On the Pacific side there were two locks that provided the same amount of lift, but still allowed for the larger tides of the Pacific Ocean. General Goethals divided the responsibility for the actual lock construction between two engineers, Major Sibert on the Atlantic side and civilian Williamson on the Pacific side. Each of the engineers devised ways and means to bring the enormous quantities of concrete to the exact jobsite locations, and to return the empty buckets back to the concrete plants. Their systems utilized large cableways, huge cranes, and steam-powered rail cars for both delivery and return. At that time reinforced concrete was not a known commodity, so Hodges chose to use massive blocks of cement, sand, and rock to build the five sets of locks, which are still functioning 100 years later. Each lock system consisted of two lock chambers for bi-directional traffic, and each chamber was approximately 1000 feet long by 100 feet wide by slightly more than eighty feet high.

Lt. Col. Hodges was also responsible for the overall design of the lock gates, an extremely important component of the Panama Canal, since there are no pumps and all water flow in and out of the locks is by gravity. The lock gates, truly an engineering marvel, range in size from 47 feet to 82 feet in height, and have hollow bottom halves to make them more buoyant in the water. The gate operating mechanism was designed by Edward Schildhauer, a Wisconsin native who had both electrical and mechanical engineering degrees. Schildhauer had numerous patents by the time he was in his mid-thirties, when he was assigned to General Goethals Panama Canal team in 1906. His first year on the project was spent in the States planning and designing the drive systems for the lock gates. He moved to the Panama site the next year and stayed with the project until its completion in 1914. The design required that the doors open and close flawlessly under tremendous pressures, with large bull wheels built within the lock walls. Each twenty-foot diameter bull wheel was driven through a gear by an electric motor, and the entire assembly is similar to the drive wheels and connecting bar of a railroad locomotive. The fabrication and construction of the lock gates was actually begun in 1909, and was tested (except for the final controls) in the summer of 1913.

Schildhauer, in conjunction with the General Electric Company of Schenectady, New York, designed the basic concept of the lock and lock gate control system, utilizing a miniature control board to mimic the precise operation in any of the locks to raise or lower a ship.

Interlocking bars are located below the control board so that any handle must be turned in the correct sequence, thus eliminating performing an operation out of order or otherwise forgetting an operation. Schildhauer also designed the electric locomotive towing system, which provides complete control over vessels transiting the locks. The locomotives operate on a track built on the top of the lock walls, and are able to travel the 45-degree incline between the lock chambers.

Project Statistics

The cost of the French effort nearly twenty-five years earlier had been close to a quarter of a billion dollars in U. S. currency, slightly less than double what they had estimated. For their efforts, which spanned more than a decade, they had very little success in their endeavors. They were able to recoup some of their investment when the U. S. agreed to pay $40,000,000 to the French for what amounted to quasi-rights to the Panama Isthmus as well as several inadequate community structures.

Including the $40,000,000 paid to the French and another $10,000,000 paid as a form of reparation to the government of Colombia, the total cost of the Panama Canal construction to the United States was about $375,000,000, only slightly less than the 1907 estimate of $390,000,000. This was in spite of a large investment in maintaining a sufficient workforce, a substantial increase in the canal's width and new and largely unproven equipment and technology for virtually every phase of the project. More than 75,000 men and women from America, Europe, Africa, China, Central America, and the Caribbean worked on the project. At the height of the canal project, there were more than 40,000 workers employed.

D. Summary

The technology developed by the U. S. Army Corps of Engineers and their counterpart civilian engineers in the planning, design, and construction of the Panama Canal so early in the twentieth century was truly a marvel. At that time the Panama Canal was the largest, and arguably the most complex, engineering project of that time.

While the engineering feats associated with the Panama Canal Project are tremendous, we cannot overlook the significant contributions made by Major Walter Reed prior to 1901, or by those of Colonel William Gorgas from 1904 to 1906. By recognizing that malaria was a mosquito-borne disease, and thereby eliminating or greatly reducing the breeding grounds of the mosquitoes, the number of deaths attributable to yellow fever during the construction of the Panama Canal from 1906 through 1914 was greatly minimized. According to records at that time, the total number of deaths due to disease and accidents were less than 6,000, including less than 400 Americans and Europeans.

Since 2000 the Panama Canal has been under the authority and the control of the nation of Panama, although it is managed by a third party from mainland China. As shipbuilding nations like the United States continue to produce larger vessels, work on the Panama Canal will continue and new and wider lock projects will occur.

Hoover Dam

A. Hoover Dam Approval and Administration

The Hoover Dam proved to be another engineering marvel of the early twentieth century. The continuing life-threatening flooding of the Imperial Valley in Southern California from the Colorado River led to the idea of the need for a dam on the Colorado River to provide flood control. A dam to control the sometimes-raging waters of the Colorado River in order to protect rapidly developing property in the Southwestern United States had been in the talking stages for several years. Although several canals were built to distribute the Colorado more uniformly to various arid areas in the Southwest, there were times in the spring and early summer when the river would cause severe damage and loss of life, while in the fall and early winter the river bottoms were visible.

Initially it was known as the Boulder Dam, or even the Grand Canyon Dam, even though the actual site for the dam had been shifted downriver by several miles to the Black Canyon. President Calvin Coolidge actually signed the dam into law just before he left office in December, 1928, under the Boulder Canyon Act of 1928, but no name was assigned to the dam at that time. When then Secretary of the Interior spoke at a ceremony to commemorate the beginning of construction of a railway connecting the small city of Las Vegas, Nevada to the dam site, he was the first to call it Hoover Dam. The name was politically controversial for the next several years until it was officially named the Hoover Dam in 1947 by an act of the U. S. Congress.

As technologies developed in the areas of electricity generation and irrigation, the possibility of a dam finally became a potential reality in 1922 under then Secretary of Commerce Herbert Hoover. That year the Reclamation Service received a report from Service Chief Arthur Davis and Secretary of the Interior Albert Fall proposing that a concrete dam be built in the Black Canyon between the states of Nevada and Arizona. As the technology of electric power transmission improved, the potential for hydroelectric power from the Colorado River became a reality. As with the water supply, the power generated was to be evenly distributed among the states, with the largest recipients being Phoenix, Arizona and Los Angeles, California. One city that benefitted greatly was a small community of a few thousand residents called Las Vegas. There were seven states which fell within the Colorado River's basin; the river began its 1400-mile journey in the foothills of the Rocky Mountains and ran through a short stretch of Mexico before emptying into the Gulf of California. Amazingly five of the seven states reached an agreement by Thanksgiving of 1922.

However, repeated efforts by House and Senate leaders to fund the project for the dam met resistance over the next five years from members of Congress who believed that the expense was too great and would only benefit the state of California. The thinking changed considerably after the Great Mississippi River Flood of 1927 devastated the states of Mississippi, Arkansas and Louisiana, causing untold damage and great loss of life, and resulting in more than 200,000 Americans of African descent leaving their agricultural homes along the river and moving north to the northern industrial cities.

In that year Congress authorized a Board of Engineers to review the preliminary plans for the dam, which was now being proposed by the Bureau of Reclamation to be located at Black Canyon and would be of a curved arch-gravity type. Because a dam of a similar design for the City of Los Angeles had recently failed, killing more than 400 people, there was great concern for the construction of the arch-gravity dam that was being proposed for the Colorado River. Nevertheless, the Board found the project to be not only feasible but also necessary, fearing that the river might ultimately change its course and cause great destruction. The Board in its report cautioned that the Colorado River Dam must be designed and constructed using ultra-conservative practices to avoid a similar civil engineering disaster such as had occurred to the City of Los Angeles.

In December of 1928 President Coolidge signed the bill, known as the Boulder Canyon Project Act, authorizing the construction of the dam. The bill appropriated $165 million for the new dam as well as for a canal and a smaller dam (later named the Davis Dam) further downriver. It also permitted the States' agreement to go into effect as soon as six of the seven states had approved it. The State of Utah became the sixth state to ratify the agreement on March 5, 1929. As an integral part of the Project Act, each state was allocated a portion of the water that would flow through their basins. For some inexplicable reason the State of Arizona did not ratify the agreement until 1944.

Arthur Powell Davis

Arthur Powell Davis was a native of Illinois, and received his degree in Civil Engineering from George Washington University at the age of 27 in 1888. After graduation he worked with an uncle doing topography and hydrography surveying, primarily in the southwestern states of

New Mexico, Arizona, and California, and later became a co-founder of the National Geographic Society. He served as the Director of the U. S. Reclamation Service from 1914 until 1923, and developed the concept of a Colorado River Dam during that period.

Davis had originally proposed using dynamite to collapse the walls of Boulder Canyon and building a dam over the ensuing rubble; however, both Davis and the Reclamation Service Board later rejected this proposal as being impractical regarding technology as well as cost. Davis left the Reclamation Service in 1923, coincidentally the same year that it was renamed the Bureau of Reclamation. Davis later was appointed consulting engineer on the Hoover Dam Project in 1933, but died only one month after his appointment. A dam which was a part of the original project and located approximately 70 miles downstream of the Hoover Dam was named the Davis Dam in his honor upon its completion in 1951.

B. Hoover Dam Engineering and Design

Certainly there were critics at every phase of the design and planning of the new dam; some postulated that the fluctuations in the reservoir's elevation level would cause cracking of the earth's surfaces, which would result in the dam experiencing cracks and breaches. Others just simply believed that the dam would never hold the tremendous amount of water that would need to be contained in the reservoir.

Design of the Hoover Dam began in earnest in the spring of 1929. Having already concluded that the basic design would be an arch-gravity type, with the arch facing the upriver flow of the Colorado, many other engineering parameters had to be resolved. The exact location of the dam in the Black Canyon had to be determined. A method for diverting the upstream flow of the Colorado River around the dam site was devised, and the depth of the river bottom at the dam's precise location was also determined as best as possible. Calculations for the thicknesses of the tops and bottoms of the dam to safely hold the water (later named Lake Mead) that would accumulate behind the new dam were made.

There was considerable effort given to how much power generation could be designed and installed, based on the limits of existing transmission line technology. This factor was extremely important, inasmuch as payback for the initial investment of $165 million by the U. S. government was totally dependent on power sales, primarily to the residents and businesses of the City of Los Angeles. And, of course, there was considerable concern over where and how these transmission lines and their towers would be located in order to transmit the power out of the Canyon. This phase of the project was neglected until after the actual dam had been constructed, and wasn't resolved until just before the first generators went into operation in 1936.

John Lucian Savage

Prior to the planning and design of the Hoover Dam, there was no other dam in the world on which to base design calculations or to model as even a comparable example. The engineers who were designing the dam were unsure that their design would withstand the tremendous pressures of the reservoir behind the dam which they had calculated to be between 40,000 and an absolute maximum of 45,000 pounds per square foot. Such large quantities of necessary concrete had never been used before, and certainly not in such a hot and humid climate. Furthermore, the use of iron or steel rods to improve the overall strength of concrete placements was still not an exact science. To be absolutely on the safe side of the design parameters, the dam was designed as an enormously heavy and thick horizontal arch, with its convex arch facing upstream to the Colorado River flow.

John Savage had been the chief engineer and supervisor for the design of numerous dams throughout the western United States. A graduate of the University of Wisconsin in 1903 with a B. S. in Civil Engineering, Savage began his career as an engineering aide with the Bureau of Reclamation in Idaho. He left that position in 1908 and joined with A. J. Wiley to form an association that prospered greatly, due to the many dams, canals and power plants that were being constructed in the American West.

Following a successful career with A. J. Wiley, Savage bought a cattle ranch in Idaho with the thought of retiring from the hectic life of dam and power plant building. However, he was apparently coaxed out of semi-retirement by Arthur Davis, who recruited Savage as the first designing engineer in charge of all civil, mechanical, and electrical engineering for the Bureau of Reclamation. Having lost considerable expertise since both Crowe and Davis had left the Bureau of Reclamation, the newly appointed Chief Engineer for the Bureau gave Savage almost complete autonomy. Working in this independent capacity because of his abilities, Savage and his design team became responsible not only for the Hoover Dam, but also for the Parker Dam, the Shasta Dam, and even the Grand Coulee Dam.

Designing the Diversion of the Colorado River

The first step to the success of the Hoover Dam was the diversion of the Colorado River around the Black Canyon area where the dam was to be constructed. In order to accomplish this, the specifications called for four tunnels to be drilled through the mountains surrounding the Black Canyon area, with sufficient size and flow characteristics to accommodate the river flow's worst case. These tunnels were to be each 56 feet in diameter, with a concrete lining of three feet on the circumference for the full length of each tunnel. The debris from the drilling activities plus the construction of two temporary coffer dams were to be used as temporary dams while the main dam was being constructed.

Main Dam Specifications

Specifications for the main dam construction were extremely conservative, as mentioned earlier. Regarding the basic width and thickness of the dam from the bottom to the top, the estimated width at the bottom of the dam in order to withstand the calculated pressures of 40,000 pounds per square foot was approximately 660 feet, while the thickness of the dam at the top of the arch was calculated to be only about 45 feet. The dam was to be watertight, as we could understand, with no leakage at any point. This factor presented two problems to the construction teams:

1. A huge amount of reinforced concrete had to be placed in a very short period of time, thus creating a minimal allowance for proper curing time.

2. The Canyon walls, which were nearly vertical, were uneven and craggy and contained many conditions for potential leakage and breakthrough.

The depth of the riverbed at the base of the dam was assumed to be only slightly lower than the estimation by the Bureau of Reclamation. Even allowing for this realistic assumption by the Bureau, the resulting walls of the Hoover Dam would have to rise about 726 feet above bedrock, and the length of the crest of the top of the dam between the canyon walls of Arizona and Nevada would be nearly one-quarter of a mile.

Hydroelectric Power Plants

Hydroelectric power plants had become relatively commonplace in the United States by the early 1920's, although none were as large or as complex as the one being considered at the Hoover Dam. Hydroelectric power was very cheap at that time, somewhere in the range of 2 to 2.5 cents per kilowatt hour. Environmental issues such as salmon being able to swim upstream to spawn their young, or a small animal or bird losing its natural habitat and facing potential extinction, was not a concern, and humans were still able to improve their lifestyles as they deemed necessary.

Bid Documents

Once the basic designs and plans were developed, they were placed in bid packages that, for a project of this scope and size, were hardly common. The resulting success of the Hoover Dam is not only a result of superb construction practices, but also a tribute to the many and varied engineers who were intimately involved with the project. Regarding the bidding parameters, just the opportunity to bid on the Hoover Dam Project required a construction company to provide a bid bond of $2 million, while a performance bond had a $5 million bond requirement.

With hydroelectric power being so inexpensive, the Bureau of Reclamation had to develop a large enough system that would recoup the government's investment of $165 million, and still make it fit into the plans of the basic Hoover Dam design. They developed a design that would include a total of seventeen synchronous generators, nine in the north (Nevada) wing and eight in the south (Arizona) wing. These generators were expected to produce approximately 1,345 Megawatts of total capacity, which would realize a payback of the original investment in fifty years - incomprehensible by today's standards but, nevertheless, an accurate estimate which actually resulted. The genesis of the design was to produce supplemental power to the states that signed the 1928 compact; today the Hoover Dam supplies reserve electrical power to the grids of Arizona, California, Nevada, New Mexico and Utah.

The bid documents were made available in January of 1931 and consisted of more than one hundred pages of specifications in exhaustive detail as well as seventy-six design drawings. As a part of the specification the U. S. government would provide the necessary building materials, while the contractor was to prepare the dam site, provide the workforce, and construct the dam and associated structures. Because of the size and complexity of the project, no single construction company had either the financial resources or the financial backing of lending institutions to fulfill the requirements of either $2 million for a bid bond let alone $5 million for a performance bond.

Francis T. Crowe

Prior to 1925 the Reclamation Service (renamed the Bureau of Reclamation) had always been responsible for the design and construction of the many dams that were being built in the United States up to that time. When a dam needed to be built, the federal government did the project itself, using the U. S. Army Corps of Engineers and hiring its own workforce. In 1925 the government had made the decision to no longer self-construct future dams, but to bid the work out to outside sources in order to improve efficiency and save money.

At that time the leading dam builder in the United States and one of the pivotal engineers in the Bureau of Reclamation under the direction of Arthur Davis was a young engineer from Quebec, Frank T. Crowe. Crowe had graduated from the University of Maine in 1905, and had gone to work immediately with the Reclamation Service. Crowe had spent more than twenty years working for Reclamation as well as for private construction companies. He had helped to build Arrowrock Dam in Idaho, the Jackson Lake Dam in Wyoming, and Washington's Tieton Dam. Much of Crowe's success and reputation were attributable to a cableway system which he had developed and perfected that delivered large batches of concrete to the work areas. This same system would also be used to deliver moving equipment to the construction site, and it was far more advanced than any other system of its time.

Crowe wanted very badly to work on the Hoover Dam project, which had actually been an ambition of his for a very long time. And after the Bureau had changed its way of doing business, Crowe was forced to choose between staying in his government job or working on the future projects such as the Hoover Dam with an outside contractor. Having been at the Bureau for all those years had allowed Crowe to learn the dam construction business first-hand, and he was considered by his peers to be the most knowledgeable dam constructor in the United States. Upon leaving the Bureau, he joined the construction firm of Morrison-Knudsen of Boise, Idaho, which had recently signed a partnership agreement with the Utah Construction Company to build dams. In order to fulfill his seemingly life's ambition, Crowe resigned his job with the Bureau and teamed up with Morrison-Knudsen, a construction company based in Boise, Idaho.

Everything Crowe had ever done during his career had helped to prepare him for the building of the Hoover Dam, which would be the biggest challenge of his life. Crowe had aided Reclamation Services Commissioner Arthur Powell Davis in developing a comprehensive cost estimate for a dam on the lower Colorado River as early as 1919, and had also helped him with the preliminary design in 1924. There is little doubt that Crowe was instrumental in persuading Morrison-Knudsen to pursue the Hoover Dam project, and to assist in forming a joint venture. Crowe's knowledge and familiarity with the Bureau of Reclamation and with dam construction in the United States in particular undoubtedly convinced Harry Morrison, his boss at Morrison-Knudsen, that with the right supervision they could meet the performance criteria and still make a substantial profit. Crowe also realized that not only did no single company have sufficient financial means to manage the project, but also no construction company had either the manpower and equipment or the expertise to perform all aspects of such an enormous task of constructing the dam, and that a partnership with the right construction companies was a necessity.

Initially Morrison had approached financial institutions such as San Francisco banker Leland Cutler to seek financial backing for his construction company for the Hoover Dam project. Cutler refused, primarily because he didn't think any one company could raise the $5 million in capital that was necessary for the performance bond. However, he did give Morrison the names of several other construction companies who might be interested in a joint venture. Not only was the U. S. entering into a deep recession in 1931, but also there was strong skepticism that any one company could meet the rigid standards that had been established by the Bureau of Reclamation.

Six Companies, Inc.

Morrison was in total agreement with Crowe and went about contacting several interested construction companies in that region who were familiar with the project, and in short order was able to create a consortium called Six Companies, Inc., a joint venture made up of design/construct companies from the states that were affected by the Colorado River. The consortium included his company along with five others, each of which added a certain value and expertise to the project. In addition to Morrison-Knudsen they included:

1. Utah Construction Company (Wattis Brothers) - Utah

   Note: In 1922, Utah Construction Company had formed a partnership with the Morrison-Knudsen Company of Boise. With Frank Crowe as the chief engineer, the MK-UC partnership successfully built dams throughout the American west.

2. Henry J. Kaiser and Bechtel Corporation - San Francisco, California
3. MacDonald & Kahn Ltd. - Los Angeles, California
4. J. F. Shea Company - Portland, Oregon
5. Pacific Bridge Company - Portland, Oregon
6. Morrison-Knudsen Construction - Boise, Idaho

This consortium included many of the large design/build companies of that era which are still well-known today. Morrison was then primarily responsible for gathering together the construction companies that would make up the Six Companies, Inc. He then recommended that Frank Crowe be made the Chief Engineer/ Project Director/Construction Manager of the project for the joint venture. Since Crowe had two decades of experience building dams for the Reclamation Service and had actually been intimately involved in working up the Hoover Dam's project cost estimate for the government, he knew what went into the calculations that had been used to develop the estimated costs. Not surprisingly Six Companies, Inc., with their strength and experience, including having Frank Crowe in the position of authority, won the contract on 04 March 1931 with a bid of $48.9 million. This bid was just $24,000 higher than the Department of the Interior had budgeted for the actual construction of the project, and was more than $20 million lower than the next closest bid. At the time this was the largest single contract that the U. S. Government had ever awarded, a contract that in today's dollars would be more than $1.1 billion. But now the onus to perform was on Frank Crowe and Six Companies, Inc.

C. Hoover Dam Construction

Construction Beginning

Initially there was no shortage of laborers for the workforce, as the Great Depression of the 1930's had officially begun the preceding year. The Depression was worldwide and had seriously affected all classes of people, but especially farmers in the United States. In 1930 men began to make their way to Nevada at least one full year before the actual contract was awarded to Six Companies, Inc. Some brought their wives and children and were barely able to afford to settle in Las Vegas, not realizing that Las Vegas was some thirty miles from the jobsite in Black Canyon. Others who could not afford to pay for accommodations or who wanted to be as close to the jobsite as possible set up temporary quarters in tents, cardboard shelters, or similar arrangements. The living conditions that year were brutal, as the summers were extremely hot while the winters were open and cold. After the contract was awarded by the U. S. Government in March of 1931 there was a steady stream of migrant workers from all over the country who moved into this tent city now known as Ragtown. The Bureau of Reclamation had recognized the potential of this situation occurring, and had included in their plans that a city with the necessary worker and family accommodations be built as a first order of business. As one of the top priorities of the Hoover Dam construction, a city was planned and built before the end of 1931 which included decent housing, stores, schools, a hospital, and churches. It was located in the Nevada desert about five miles from the dam site and was called Boulder City; today it is a resort/retirement community of about 15,000 people and sits on the edge of Lake Mead.

Diverting the Colorado

The second priority of Six Companies, Inc. was to divert the Colorado River around Black Canyon in order to begin construction on the dam proper and the hydroelectric generating stations as soon as possible. This portion of the project was largely the responsibility of the J. F. Shea Company under the watchful eye of Frank Crowe. Shea had built its reputation and its workforce by constructing several hundred miles of railroad tracks in the Rocky Mountains and the Pacific Northwest, including drilling through mountains and constructing large tunnels. As this portion of the project was considered to be one of the more tedious as well as dangerous aspects of the overall construction, this work was scheduled to be completed in no less than two years.

Four Diversion tunnels were to be drilled through the canyon walls, each to be about 15 m (50 ft.) in diameter, starting with the two planned for the Nevada side in May of 1931, and shortly thereafter with the two planned for the Arizona side. Six Companies had a separate bonus-penalty clause in their contract for this diversion work, with a daily fine to be levied by the government. In the beginning large numbers of workers were employed to make even the slightest progress into the canyon. To hasten the progress, Shea developed a "Jumbo Truck", which was a large drilling rig equipped with two platforms on which workers could access the canyon walls. As many as thirty workers would be backed into the canyon openings, and simultaneously drill holes for the placement of dynamite. These trucks were so successful in allowing large sections of the tunnels to be blasted that eventually eight of them were employed.

After each explosion men and dump trucks would enter the blasted areas and the trucks, with their engines running and spewing carbon monoxide in the confined quarters would be loaded and would haul the loose debris downriver to be used as spoils at a later date. With rocks still falling as the result of the recent blasting, and although compressed air was being introduced into the tunnels, several dozen men died during this construction cycle. However, there was no OSHA or Workmen's Compensation insurance at that time, so most of the deaths were attributed to pneumonia and other natural causes. Irrespective of the circumstances that claimed the lives of more than ninety workers, within a year the tunnels had been bored through, a combined distance of more than three miles for all four tunnels, which was well ahead of schedule.

During this period there was also an attempt by national union organizers to form a union with the workers, which the workers themselves rejected. At about the same time Six Companies chose, for some unexplained reason, to reduce the hourly rate for the workers. This caused the workers to go out on strike and to present a list of grievances and demands which were given to Frank Crowe. Crowe considered their demands and met with the workers' committee briefly, then refused all of their demands, shut the project down entirely except for a few office workers, and laid every other employee off. Less than a week later Six Companies began to hire workers again, and the strike was called off, but the company agreed not to cut wages again.

Once a tunnel was broken through to the other side of the Hoover Dam location, it was rough bored to a diameter of approximately 56 feet and then lined with a three-foot thick concrete lining. Pneumatic guns were used to place the concrete into the overhead forms, thus resulting in a net tunnel diameter of fifty feet. During the diversion of the river, two coffer dams were constructed at the entrances to the tunnels so that they all worked in unison to divert the Colorado River flow around the Hoover Dam site. The coffer dams, made of rocks, rubble, sediment and more than one million cubic yards of concrete, were designed to protect the thousands of workers at the dam site. The specifications for the coffer dams were nearly as stringent as the specs for the main dam itself, with the upper coffer dam having a total thickness at the base of more than 750 feet and a height of about 96 feet.

A temporary earth and rock dam had been built at the entrance to the tunnels, forming a barrier ahead of the tunnels. When the tunnels were each cured and ready to accept Colorado River water, this temporary dam was breached with explosives, forcing the river water to be diverted and the Colorado River to begin flowing through the two tunnels on the Arizona side. These two tunnels were the primary carriers of the river flow, while the Nevada tunnels were kept in reserve for high water conditions in the spring and summer. Due to innovation and a hard-charging Frank Crowe, the diversion tunnels and coffer dams were completed one year ahead of the construction schedule. Now the construction of the Hoover Dam could begin in earnest.

Preparation and Excavation

In the five or six years prior to the Colorado River being diverted around Black Canyon, the Bureau of Reclamation engineering group (some estimates were that more than two hundred engineers and designers were involved) under the direction of Chief Engineer John T. Savage had made the decision that the dam would be an **arch-gravity type.** This meant that the arch, or convex portion of the dam, would be facing upriver against the river's flow and would allow for much of the force vectors of the accumulated water being directed against the canyon walls. Nevertheless, this wedge-shaped design would still need to be about 660 feet thick at the bottom, gradually tapering at the top of the dam to approximately forty-five feet. When the roadway was constructed across the top of the dam which connected Nevada to Arizona the elevation was slightly more than 762 feet above the riverbed.

The first phase of the dam's construction involved preparation of the riverbed and the canyon sidewalls. To prepare the canyon sidewalls Six Companies hired mostly athletic types called "high scalers", men who would hang from a long rope anchored at the top of the canyon and could climb up and down the sheer canyon walls. These men, many of whom were Native Americans, would remove loose rock and other debris from the canyon walls while being suspended from these ropes. Many used heavy hammers, jackhammers, and even core drills for dynamite in order to prepare the sidewalls for a grout surface that would provide a tight seal with the concrete of the dam. Even though their pay was higher than the other workers, the "high scaler" job was considered the most dangerous by far. One such high scaler had invented a hat with a hard tar top to protect himself from falling debris, and soon nearly all of the high scalers had followed suit with similar hats. When the Six Companies supervision saw the effectiveness of these hats that were hard on top, they proceeded to order "hard hats" for every worker and supervisor. Although many lives were lost during the construction of the Hoover Dam, the hard hats were credited with saving many lives and avoiding many serious injuries.

Clearing the riverbed down to the bedrock was an equally tedious task. Not only did all loose material and sediment have to be removed, but also holes had to be drilled and ng led for cavities to prevent future leakage. More than one million cubic meters of loose materials and erosion soils were removed in order to reach the river's bedrock and allow a thick curtain of grout to be laid as the base for the dam's bottom seal. The project was apparently under considerable time constraints during this period, so that the effort to fill larger cavities with grout and no confront underground springs was not given the time necessary to fill those voids.

Although there was no condition that would create "uplift" due to pressure from water seeping under the dam, completion of the dam and the filling of Lake Mead would later reveal that there were several instances where the cavities had not been filled, or else the grouting had been done improperly. There was no evidence that constant visual inspection of these areas would have given any assurance that these problems could have been prevented. Once the reservoir began to fill and leaks began to occur, the Bureau of Reclamation was called to examine the situation. They determined that the work of nearly sixty voids had been incompletely or improperly done and that there was also a misunderstanding of the geology of Black Canyon.

As a "fix" to this serious and potentially catastrophic problem, Bureau of Reclamation engineers determined that new holes could be drilled deep into the canyon bedrock from cavity positions inside the dam, and a supplemental grout curtain could be added into each leaking void. This process was actively carried out during the next nine years without any knowledge of the general public, and success was achieved. This coordinated effort by the Reclamation engineers and the construction forces from Six Companies, Inc. eliminated the leaks and resulted in the Hoover Dam being leak proof at last.

Constructing the Dam Proper

Going back to 1922 when the Reclamation Service presented its first report, which was principally authored by Arthur Davis and co-signed by Interior Secretary Albert Fall, the Boulder (Hoover) Dam had been designed and planned to be a monolithic pour. As the years passed and the dam project became a reality in 1929, the design of the dam by the Reclamation engineers as a monolithic structure became impractical. The engineers had calculated that a monolithic pour could take upwards of 125 years no cool and cure, in the meantime causing stresses and cracks in the dam that would result in catastrophic failure. In light of this potential disaster the engineers developed a plan to mark the ground where the dam would rise with rectangles, and to form columns with blocks of concrete. Furthermore, they worked with the construction companies to develop an ingenious, possibly heaven-sent plan to quickly cool and cure the concrete blocks. Each concrete block, roughly fifty feet square and five feet high, contained a pre-designed arrangement of one-inch steel pipes. To accelerate the cooling of the concrete blocks, first river water and then refrigerated water was circulated through the steel pipes. Once the concrete had been cured, the empty steel pipes were filled with grout as were the small gaps between the blocks of the adjacent columns.

Two massive concrete plants were set up on the Nevada side of the Black Canyon, where they mixed huge quantities of cement, sand and different sizes of aggregate, from pea gravel to large stones, depending on the placement location of the blocks. Another blessing of the Hoover Dam builders was that they **JUST HAPPENED** to use a non-reactive aggregate which was not subject to deterioration, and core samples taken some sixty years after the last concrete was placed show that the concrete had continued to gain in strength.

The batches of concrete were poured into huge steel buckets invented by Frank Crowe (one if his many patents) and delivered to the site by railcar. Each bucket, weighing more than eighteen tons when full, was then suspended from an aerial cableway (another Frank Crowe patent) and delivered to the correct column. When the bottom of the bucket was opened, about 8 cubic yards of concrete were placed inside the forms of that particular column and were quickly and evenly spread.

When concrete placement had ceased in May, 1935, more than 3 million cubic yards of concrete had been used to build the dam, while another one million plus cubic yards of concrete were used for the coffer dams, diversion tunnels, power plants, and intake towers. The story that was circulated back in the late 1930's was that there is enough concrete in the Hoover Dam to pave a two-lane highway from San Francisco to New York City. That is probably a very accurate statement, but more importantly, that highway would likely still be in service today.

Spillways

The Hoover Dam was designed to have all Colorado River water flow through and out of the hydroelectric generator stations, one on the Nevada side and one on the Arizona side. There is, however, a spillway on either side of Lake Mead about one thousand feet ahead of the dam, and these spillways were to be used in an emergency in the event that the water level in Lake

Mead approached approximately fifty feet to the top of Hoover Dam. The spillways presented a difficult engineering problem and caused numerous design challenges to the Bureau of Reclamation engineers.

The spillways run roughly parallel to the canyon walls, with each spillway being controlled by four 16 ft. high drum gates. Each drum gate can be operated automatically as well as manually, although each gate weighs close to five million pounds. Water flowing over the spillways free falls into separate tunnels that are 600 feet in length by 50 feet wide. These tunnels then connect to the downstream side of the outer diversion tunnels, and the water reenters the Colorado River channel well below the dam and generating stations. Each spillway was emergency ng led about thirty years ago when Lake Mead reached a record elevation. Although the design concept proved to be empirically sound, the walls of the spillway tunnels were badly damaged, resulting in replacement of the tunnel linings which are high-impact and smoothly polished.

Hydroelectric Power Plants

Controlling the flow of the Colorado River and providing an irrigation system for the arid regions of Nevada, Arizona and Southern California were the primary reasons for the building of the Hoover Dam. Nevertheless, the dam could not have been financed, especially during the era of the 1930's depression, without the benefit of hydroelectric power production. The financing of the dam was to be spread out over a fifty-year period beginning in 1937, and was to be paid back by the sales of cheaply generated power to those three states. Even today Nevada and Arizona receive a combined total of about forty-two percent of the power generated, Los Angeles and other Southern California cities are the beneficiaries of about fifty-two percent, with the balance going to native American communities in the region (five percent) and the remainder being used for Hoover Dam maintenance.

The initial design concept was to have eight large turbine-generators in each power generation station, with one on the Nevada side of the river and one on the Arizona side. When the Hoover Dam was designated as complete and a formal dedication was held by President Franklin Roosevelt on 30 September 1935, the federal government settled all claims with Six Companies, Inc. and arranged for formal transfer of the Hoover Dam to the U. S. The construction companies stayed on site for the next six months to complete the unfinished powerhouses. The Bureau of Reclamation inherited the dam, including the powerhouses, in the spring of 1936.

As water levels in Lake Mead began to increase in the latter half of 1936 the first three Allis-Chalmers synchronous generators powered by Francis turbines, all located in the powerhouse on the Nevada side, began generating power. Francis turbines had become the turbines of choice for all hydroelectric generation during the previous fifty years since their invention by

James B. Francis, an engineer at a textile mill in Lowell, Massachusetts. Their unique design allowed them to use a broad range of head pressures, their efficiencies exceeded 90%, and they could each produce upwards of 800 MW.

Allis-Chalmers, based in Milwaukee, Wisconsin, manufactured primarily farm equipment in the early part of the twentieth century. During the 1920's it expanded into the large generator business, primarily for the greatly expanding industrial complex in the United States, and was positioned to devote its high efficiency electric generators to hydroelectric generation. Allis-Chalmers provided the vast majority of electrical generation equipment to the Hoover Dam powerhouses and continued to prosper as an open shop manufacturer throughout World War II and the 1950's. Eventually the unions made enough headway into the many Allis-Chalmers manufacturing facilities, including one lengthy strike of nearly one year, that the company was forced to divest most of its facilities by the early 1980's, and today Allis-Chalmers is simply a name brand.

In March, 1937 a fourth generator went online on the Nevada side, and the first generator on the Arizona side went online that August. By 1939 a total of nine generators were in operation, and Hoover Dam was by then the largest hydroelectric generating station in the world. The final generator was not placed into service until 1961, at which time the maximum generating capacity was nearly 1,345 megawatts. Eventually there were eight large generators on the Nevada side as was originally planned, but there were seven large generators and two smaller generators on the Arizona side to serve smaller communities. This was done at a time before the power grid concept had materialized, and the power generating stations were supplying specific communities.

In order to rotate these giant generators, they were each coupled by long vertical shafts to the water turbines in order to keep the water that rotated the turbines isolated from the generators. There are also two smaller self-starting, waterwheel stations - one in each wing - which provide electrical services in their respective areas to auxiliary equipment such as overhead cranes and elevator operations, emergency pumping of water, and exciter voltages for the synchronous generators. This system also allows the power plant to black start any of the 130 KW generators without outside assistance, thus assuring that the Hoover Dam power plant can operate through any unforeseen grid catastrophe. The primary voltage is 2300 VAC, three-phase, and was coordinated with an initial system of thirty-eight 2300-volt isolation breakers and tie-breakers.

Each wing sits on a large plateau carved out of the canyon walls on either side of the Black Canyon approximately 240 feet above the Colorado River bed and 400 feet downriver from the base of the Hoover Dam. Each power plant wing is 650 feet long and nearly 300 feet high from the base of the foundation to the top of the roof.

Intake Towers and Penstocks

Not only did Bureau of Reclamation engineers have to determine the minimum elevation of the powerhouses, they also had to calculate the optimum flow rate of the penstocks in order to maximize hydroelectric generation. Walls of the canyon between 200 and 600 feet upstream of the dam on both the Nevada side and the Arizona side were blasted and jack hammered to give the intake towers a relatively level rock table on which to sit. Similarly, the large bases required for the two powerhouses on the Nevada side and the Arizona side were also carved out of the canyon walls during the initial excavation.

Large sections of the canyon walls were blasted and contoured along the dam abutments on either side of the river to connect the penstocks coming from the intake towers to the powerhouses. Each of these four intake towers, measuring more than 1000 feet above the riverbed of the Colorado river, contained a penstock system, much of which was more than thirty feet in diameter, and was designed to be gradually reducing in size in order for the water at the turbines to achieve an optimum velocity of 85 miles per hour (approximately 125 feet/second) at a constant head of 590 feet.

The water of the Lake Mead reservoir is channeled through the four penstocks, two on each side of Lake Mead, and the delivery of water to the turbines is controlled by wicket gates resembling large butterfly valves operating against sealed openings. Water travels through the penstocks at a maintained elevation, although drought conditions in the Rockies and in the southwestern United States as well as Southern California have caused the water elevation in Lake Mead to fall precipitously low in the past decade. Inasmuch as power generation in a hydroelectric plant is a direct function of head pressure and water flow, this factor has caused much concern regarding power output by the Hoover Dam in the Southwest. There is wide speculation that, unless the area affected by the power generation, particularly Southern California, receives at least its average rainfall over the next few years, irrigation and the amount of electric power generated by Hoover Dam will be greatly restricted.

D. Summary

The success of the Hoover Dam is a prime example of how well the end result can be achieved when there is strong coordination among the parties involved: the planning by the Interior and the Bureau of Reclamation, the specifications and design by the Reclamation engineers and designers, and the construction efforts of the supervision and workforce of Six Companies, Inc. There was also some divine intervention with the realization that a monolithic pour would require 125 years to properly cure (that may be a slight exaggeration), but a relatively complex solution was developed and implemented for that potentially perplexing dilemma.

Furthermore, the conditions associated with the Hoover Dam's planning, design, and construction were extremely hazardous. Many lives were lost because of the harsh environment, beginning with J. G. Tierney, a surveyor who accidentally slipped and fell into the swift-moving Colorado River in 1922 and drowned. Ironically, his son Patrick died while working on the Hoover Dam almost exactly thirteen years later in 1935. Overall there were less than 100 workers who were killed at the dam site, a staggering number by today's standards, but many time fewer in number that what had occurred during the construction of the Panama Canal. Unfortunately, this number of fatalities does not reflect the several dozen workers who, while working in the Diversion Tunnels, were overcome by heat exhaustion and asphyxiation from carbon monoxide, and were later pronounced dead due to pneumonia and other natural causes.

The construction of the Hoover Dam has had a major impact on the Southwest. Not only has it changed the environment and the estuary of the land, but it has also allowed large communities such as Los Angeles, Phoenix and even Las Vegas to develop and prosper. In addition, many smaller cities, primarily in Southern California, are beholding to the Hoover Dam for their electrical and water supplies. The Hoover Dam is a technological marvel in which all Americans should be proud.