ISSN 2348-3156 (Print)
International Journal of Social Science and Humanities Research ISSN 2348-3164 (online)
Vol. 5, Issue 1, pp: (318-342), Month: January - March 2017, Available at: www.researchpublish.com

The Panama Canal: A Man-Made Engineering Marvel

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Abstract: **Panama Canal is a navigation canal that connects the Atlantic and the Pacific oceans and is considered one of the greatest engineering feats of the world. Running a length of 48 miles (77 km), Panama Canal passes through the narrow Isthmus of Panama, in Central America. It extends from the Limone Bay on the Atlantic to the Bay of the Panama on Pacific oceans. The conduit, essential to international trade as a bypass to the hazardous trade routes around South America, has been called one of the seven wonders of the modern world by the American Society of Civil Engineers. The canal has shaved nearly 8,000 sailing miles off a trip between New York and San Francisco. This paper presents a brief history of the construction of the Panama Canal, and highlights the efforts made by the Americans to build this marvel.**

Keywords: **Panama Canal, Pacific oceans.**

1. INTRODUCTION

As the trade flourished between various countries, there was a need for mass transportation of goods, for which different types of ships catered. There was always a need to ship this enormous quantity of goods quickly, for which the canal construction was adopted. The route adopted before the construction of the Panama Canal was to travel around the "Cape Horn" (located in southernmost tip of South America). This travel takes approximately a month. But after the construction of the Panama Canal, which cuts between the North and South continents of America, this substantially saved lot of time and costs. Thus the construction of Panama Canal made a great impact on shipping and world trade.

The Panama Canal was constructed in two stages. The first between 1881 and 1888, being the work carried out by the French company headed by de Lessop and secondly the work by the Americans which eventually completed the canals construction between 1904 and 1914.

The Panama Canal connects the Atlantic and Pacific oceans. The landmass is slightly above the mean sea level, which creates the need to lift the vessel up to 26 meters above mean sea level. As the vessel is lifted and after reaching the other end of the canal, it has to be dropped down to the mean sea level, to enable the ship continue its sea passage. To facilitate the lifting and dropping of the vessel, Lock Gates were provided.

In 1904, the United States, under President Theodore Roosevelt, bought the French equipment and excavations for US $40 million, paid the new country of Panama US $10 million plus more each year, and began work on the Panama Canal on May 4. The US used the most modern equipment at that time and had come up with innovative ways to handle the issues facing the construction.

Very few human endeavors have ever conceded to change the face of the planet on which we live as did the successful completion of the interoceanic Panama Canal in 1914 by the United States. Such projects before this time had only managed to build up or tear down existing geographical features such as - the pyramids of Egypt, the Great Wall of China, the trans-continental railroads - but none had ever even aspired to accomplish something so incredulous as splitting the continents. This the United States did and more - the Panama Canal was soon to become a vital link for the entire world. Despite previous failures by other countries, the United States as a whole was able to overcome the numerous dangers present at the isthmus between North and South America, and build what remains today one of the greatest engineering marvels of the modern world.

Engaging and revelatory, the Canal builders uncovers the human dimension of one of the biggest endeavors in the history of engineering, and, through this lens, recounts how the Panama Canal emerged as a positive symbol of American power, know-how, and beneficence that transformed the American national identity and its relationship with the world up to the present day.

The length of the Panama Canal is (50.72 miles). A trip along the canal from its Atlantic entrance would take you through a 7 mile dredged channel in Limón Bay. The canal then proceeds for a distance of 11.5 miles to the Gatun Locks. This series of three locks raise ships 26 meters to Gatun Lake. It continues south through a channel in Gatun Lake for 32 miles to Gamboa, where the Culebra cut begins. This channel through the cut is 8 miles long and 150 meters wide. At the end of this cut are the locks at Pedro Miguel. The Pedro Miguel locks lower ships 9.4 meters to a lake which then takes you to the Miraflores Locks which lower ships 16 meters to sea level at the canals Pacific terminus in the bay of Panama.

The Panama Canal was, is, and shall remain the terrain engineering marvel of the 20th century. Never before nor since has any project accomplished the feats of mastering the elements, of engineering and construction, or of future planning as has been done at Panama. After about 100 years of continuous service, it continues to be as useful as the day it became operational. An operation that was impossible only 30 years earlier, the American country rallied behind the energetic laborers that were going to bend the isthmus between North and South America until it broke and a new path between the seas was created. Killer diseases, high costs, seemingly impossible excavations, all faced the engineers at the Canal Zone, but one by one they were overcome until the Panama Canal alone stood out from among the rubble and invited people of the world to come and cruise her waters - a new pathway for the ever-expanding, ever-changing human race. More than 65000 men and women worked on the project in total; at the height of construction, there were 40000 workers working on it. About 5000 workers died from disease and accidents during the American construction era.

A total of 182,610,550 m3 (238,845,582 cu yd) of material was excavated in the American effort, including the approach channels at both ends of the canal. Adding the work inherited from the French, the total excavation required by the canal was around 204,900,000 m3 (268,000,000 cu yd).

Of the three presidents whose periods in office span the construction period, the name of President Roosevelt is often the one most associated with the canal, and Woodrow Wilson was the president who presided over its opening (1) (2) (3). However, it may have been William Howard Taft who gave the greatest personal impetus to the canal over the longest period. Taft visited Panama five times as Roosevelt's Secretary of War, and twice as President. Taft became president in 1909, when canal construction was only at the halfway mark, and remained in office for most of the remainder of the work. However, Goethals later wrote that "the real builder of the Panama Canal was Theodore Roosevelt".

The following words of President Theodore Roosevelt are displayed in the Rotunda of the Administration Building:

“It is not the critic who counts, not the man who points out how the strong man stumbled, or where the doer of deeds could have done them better. The credit belongs to the man who is actually in the arena; whose face is marred by dust and sweat and blood; who strives valiantly, who errs and comes short again and again; who knows the great enthusiasms, the great devotions, and spends himself in a worthy cause; who, at the best, knows in the end the triumph of high achievement; and who, at the worst, if he fails, at least fails while daring greatly, so that his place shall never be with those cold and timid souls who know neither victory nor defeat”.

The story is a great work of David McCullough in 1971 in his book “The Path between the Seas: The Creation of the Panama Canal, 1870-1914”. The author has tried to narrate the story relating to the construction of the Panama Canal. It represents Nova’s look on this particular aspect. This paper aims to summarize the main idea of the article and establishes a view as to how it relates to the United States history, public health, engineering, innovation, and construction industry.

2. A BRIEF HISTORY OF PANAMA CANAL

The idea of a path between North and South America is older than their respective names. Columbus had searched in vain for a passage through the land that would lead him to the Indies where treasures awaited, and repeated sailors since had done the same. Emperor Napoleon III of France once toyed with the idea of building a canal in France's land across the sea, but never with much enthusiasm. No real progress, other than ideas and brainstorms, was made until the nineteenth century, when a French diplomat felt it was time for a French-owned canal at Panama, then a republic of Colombia. This individual was Ferdinand de Lesseps, the most important man involved with Egypt's Suez Canal, he was known as "the hero of Suez". Lesseps' success at Suez made him confident, that a canal at Panama would be no different (1) (3).

Work began in 1882 along the route of the 1855 Panama Railroad (the concession having been given by Colombia in 1878), Lesseps was in his seventies. From that point on, the company and the canal were plagued by troubles, most being financial, and poor engineering planning. The machinery was often too light for the massive task of mountain-moving. And worst of all, thousands of people were unable to withstand the harsh climate and tropical fevers. Serious also were unexpected setbacks in the actual excavation of the Canal Zone. Disease, in the forms of yellow fever and malaria, put much of the work force in the hospitals or underground. The rocky ground of the formerly volcanic area proved to be too much for the French steam shovels and dredges. Of no help was Lesseps' insistence on a sea-level canal, like he had done at Suez, as opposed to a lock canal, while the latter proved to be cheaper and more feasible even by reports of the time.

In 1885, due to the tremendous problems encountered in trying to excavate a sea-level canal, the plan was changed to include a single, temporary lock and other adjustments in order to speed up the availability of the canal for traffic, but still, it was of no use. France resented the loss of millions of francs and subsequent trials of the heads of Lesseps' company, including Lesseps himself, began in 1893. Lesseps was condemned by the court, but never fined nor jailed. France had determined that the country could not possibly complete the canal. With a lease on land in Colombia until 1903, the search was on for a buyer. Eventually, France found a friend in the United States of America.

At the time, a canal in the Latin American isthmus was not a new idea to America, either. In 1887, the government sent a regiment under Lieutenant Menocal to survey Nicaragua for a canal site. In 1889, Congress chartered the Maritime Canal Company, headed by J.P. Morgan to build a canal in either Nicaragua or Panama. After discussions, the Nicaragua route was chosen, and construction began. In 1893, a stock panic in America caused Maritime to lose all funding, and excavation stopped - the first and last of America's blunders on the canal. In 1897, congress appointed a fact-finding Canal Commission, which promptly recommended the Nicaraguan route. In 1899, the second Canal Commission did the same. President McKinley probably would have signed a bill introduced by Senator J.T. Morgan securing funds for a Nicaraguan canal on September, 1901. The subsequent inauguration of President Theodore Roosevelt was to become a time of strained relations with Colombia, and new friendship in a brand new nation - the Republic of Panama.

President Roosevelt was especially proud of America's navy, and its naval power. The incident during the Spanish War involving the battleship Oregon's two-month trip around South America (by which time the war was nearly over), which had sponsored Morgan's bill for a canal, had also affected the president, and the rest of America, in a big way.

Panama planned a revolution, and President Roosevelt sent a battleship, the Nashville to protect "American lives in Panama", which meant that no other country was going to land on the isthmus. Panama declared its independence from Colombia, and America recognized their declaration, else Colombia would have reconquered the area, endangering American interests. Philippe Bunau-Varilla was made American ambassador for Panama by telegram after the independence, and consequently wrote up a treaty between Panama and America with Senator John Hay - the Hay-Bunau-Varilla treaty - which was ratified by the new Panamanian Government in 1903 and by the American Senate in early 1904.

The US then began negotiating with Columbian government for access to the land. Soon an agreement was reached. Initially, a treaty was agreed to by the United States and Columbia for the construction of a canal. While the Senate in America agreed to the Hay -Herran Treaty, the Columbian Senate did not. With a rebellion brewing in Panama, Columbia attempted to hold out for a better deal, hoping to secure troops and money from the US Government by stalling on approval of the treaty. The attempt backfired. Instead of sending troops to support Columbia, the US decided to throw its support to the rebels. President Theodore Roosevelt sent warships to the area. While not directly fighting with Columbia, the warships aided the rebel cause by blocking the sea lanes Columbia would use to put down the revolt. United States troops were also dispatched into the area to protect the Panama Railroad. These troops did not engage with the Columbians but instead acted as a barrier for Columbian troop passage. Forced to find another way, the Columbian force of 2,000 send to put down the rebellion could not get through the Darien jungle. With this support, from the United States In 1903, Panama declared its independence from Colombia, and America recognized their declaration, else Colombia would have reconquered the area, endangering American interests. Philippe Bunau-Varilla was made American ambassador for Panama by telegram after the independence, and consequently wrote up a treaty between Panama and

America with Senator John Hay - the Hay-Bunau-Varilla treaty - which was ratified by the new Panamanian Government in 1903, and by the American Senate in early 1904. The Hay-Herran treaty (22 January 1903), granted the United States a ninety-nine-year lease over a 6-mile-wide zone in the province of Panama, in return for $10 million in cash and an annual rental of $250,000 beginning nine years after the ratification of the treaty. The U.S. Senate ratified the treaty, but the Colombian Senate refused for nationalistic reasons (Colombia had recently gone through a civil war) and also because they hoped to obtain better terms. The Colombians made a series of miscalculations, by misjudging U.S. President Roosevelt and Secretary of State John Hay's commitment to the canal, and by underestimating the New Panama Canal Company and the separatist feelings of the inhabitants of the province, who saw their hopes of economic prosperity thwarted by the government of Colombia, against whom they had often rebelled. The treaty granted America as if sovereign a canal concession in perpetuity. Panama had no choice but to accept this arrangement. Without United States support, they were not strong enough to deal with Colombia. Now began the relatively easy part for America - actually building the canal. First Congress set up a Commission to be the ruling body over the canal area - any goods or funds requested by the chief engineer were to be confirmed as necessary by the Commission. The last thing America wanted was to have their canal attempt fail because of overspending and loose watch on funds, that which had killed the French mission. The first thing necessary to do was to comply with the Hay-Bunau-Varilla treaty, and fix up Panama City and Colon. Men were hired locally and overseas to pave the roads, put in decent sewer and water systems, and repair the buildings. Also taken up was the elimination of mosquitos and other pests from places of residence. In no time, the cities were built better than they had ever been, and it was time to pour all attention to the canal.

Isthmian Canal Commission was charged with examining the possibilities of a canal in Central America and to recommend a route. Originally, the Commission opted for a Nicaraguan route, but later recommended to Congress a canal through the Isthmus of Panama, along essentially the same route that the French had attempted. Part of the reason was the possibility of active volcanoes in Nicaragua. Congress was given this idea by an impressive political campaign. In the spring, of 1902, those who favored a canal in Panama gave the members of Congress a Nicaraguan postage stamp that showed Mount Monotomboin full eruption. This cast doubt on a Nicaraguan route and led Congress and the United States to prefer the Panamanian route. Congress responded with the passage of the Spooner Act in June of 1902. Protecting all its bases, the Act allowed for the US to negotiate with Nicaragua should Panama fail to provide the land necessary for a canal.

Diseases, Sanitation, and Public Health:

One the greatest obstacle to building the Panama Canal was disease. The Panama Canal is an area prone to malaria, with a rainy season lasting nine months in a tropical environment. The most troublesome diseases were the mosquito-carried malaria and yellow fever. In addition, tuberculosis, cholera, diphtheria, smallpox, bubonic plague - all were cases on file at Panama hospitals in 1904.

Before any work could begin, the most deadly of the problems on the isthmus had to be overcome - disease. The United States government wasn't going to allow mortality rates like had been seen during the French reign - somewhere between ten and twenty thousand were estimated to have died at the Canal Zone between 1882 and 1888.

For this purpose, Colonel William C. Gorgas an American doctor, famous for wiping out yellow fever in Cuba, took charge of improving sanitary conditions and to destroy the types of mosquitoes that carried malaria and yellow fever in the Canal Zone.

The theory and proven fact was that malaria and yellow fever were transmitted from infected to healthy individual by female mosquitos of the Anapheles and Stegomyia breeds, breeds only common along the equator.

The successful completion of the Panama Canal was a tribute to its organizers and specialists, among them Dr. Gorgas, whose highly effective sanitation measures eliminated the lethal or debilitating, effects of yellow fever and malaria among workers (2).

Gorgas had his first contact with yellow fever in 1883 while stationed at Fort Brown, Texas, located on the Rio Grande River. Some twenty-three hundred sufferers from the disease were quarantined at the fort, and Gorgas was under orders not to have contact with any of them. Nevertheless, Gorgas undertook an autopsy on a fever victim and was promptly placed under house arrest by the fort commander. The arrest order was soon overturned, and Gorgas was assigned to care for the yellow fever patients. One victim who came under his care was Marie Doughty, the sister-in-law of a fort officer.

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International Journal of Social Science and Humanities Research ISSN 2348-3164 (online)
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Marie became so ill that Gorgas had a grave prepared for her. Although she lived, Gorgas contracted the disease, and the pair recovered together. The two were married in the fall of 1884.

By the end of the nineteenth century, most American cities had been able to control diseases such as typhoid, plague, cholera, and dysentery with improved sanitation. Meanwhile, in the southern states, malarial regions were diminishing and yellow fever was becoming increasingly rare. When Americans entered new overseas territories during and following the Spanish-American War, however, the nation acquired fresh medical problems, both familiar and exotic. The arrival of large numbers of outsiders in these places tended to induce epidemics among the visitors, who were not as well adapted as the indigenous populations to the local pathogens—the bacteria and viruses that cause illnesses. This situation was particularly the case in Panama, long considered one of the unhealthiest places on earth because it harbored such deadly diseases as yellow fever, malaria, bubonic plague, and typhoid. Thousands of canal workers also fell victim to pneumonia, and accidental explosions and railroad wrecks killed hundreds more. Gorgas and his Army medical officers thus fought sickness and injury on a number of fronts. Their experience with trauma on the battlefield and tropical medicine during campaigns and occupations would serve them well in this environment. Similar to their mission in wartime, they had to keep as many men as possible healthy and effective in order to win the fight. Yellow fever was one of the most intimidating tropical diseases. Although outbreaks were infrequent, they were terrifying.

Symptoms included high fever, chills, headache, jaundice (hence the name yellow fever), and at times hemorrhaging into the stomach and intestinal tract, causing the horrifying “black vomit.” Mortality rates ranged from 10 to 60 percent of those infected, and death typically occurred between the seventh and tenth day of the illness. An attack could be mild, however, and would induce lifetime immunity to the disease. Because frost killed the mosquitoes that carried yellow fever, it was not endemic in the United States and usually arrived in U.S. ports from tropical areas where it persisted year-round. The most extensive yellow fever epidemic in America struck in 1878, beginning in New Orleans and moving up the Mississippi River, causing more than 100,000 cases and killing from 13,000 to 20,000 people. In addition to the toll on health, large-scale outbreaks could devastate the economy.

Dr. Gorgas, a veteran of many yellow fever epidemics, observed that when this disease was announced in a town, everybody left who could. The sicks were frequently left without care, and often a great deal of cruelty and cowardice was shown (1). People who became ill were treated like lepers and all business is entirely paralyzed, the quarantines not allowing any communication between the affected districts and those not affected. In regions where yellow fever was endemic, such as Panama, it was rare among adults, since the vast majority had immunity from surviving a bout with it as a child. Extensive outbreaks occurred only when “non-immunes” arrived in an area-such as when the Americans came to construct the canal. Gorgas, one of the first Americans to go to Panama in 1904, was an expert in this disease. He had acquired prominence following the Spanish-American War, when the surgeon general sent him to Cuba to run a yellow fever camp. He stayed on in Havana, developing a program to implement the Reed Commission’s historic findings that the Aedesaegypti mosquito transmitted yellow fever. His efforts succeeded in a matter of months in eliminating the disease from the city and also greatly reducing malaria.

The names of two Army medical officers are linked forever by their fight against yellow fever-Walter Reed and William C. Gorgas. Reed led the effort that unlocked the key to yellow fever; Gorgas put the new knowledge to practical effect.

A yellow fever patient is isolated in a screened enclosure in the hospital. The disease was only transmitted by a mosquito that had fed on an infected person, so preventing the insects from getting such a meal helped contain the spread of the illness. Eager to apply the mosquito control methods he had developed in Cuba to the canal project, Gorgas had asked the surgeon general to send him to Panama. Instead of fighting insects in a single city such as Havana, however, he now faced a battleground consisting of two small urban areas and the 500 square miles of an elongated zone of jungle and swamp that separated them.

The Americans were well aware that several thousand workers had died in the 1850s while building the railroad across Panama, and Gorgas later estimated that 22,000 people died and one-third of the workers were sick annually when the French attempted to construct a canal. But Gorgas and his contemporaries believed that new scientific knowledge and techniques would enable them to succeed where de Lesseps had failed.

As it turned out, the political opposition would prove to be more daunting than the mosquitoes. The Panama Canal Treaty gave the United States the authority to manage public health measures in the cities of Panama and Colon and throughout the Canal Zone. Responsibilities included maintaining the health of the canal workforce, caring for the sick and injured, and implementing sanitation measures such as street cleaning and garbage collection. The medical department oversaw an extensive hospital system, which included two large, well-equipped facilities in Ancon and Colon, medium-sized buildings of twenty to one hundred beds in each of the public health districts, and smaller ones in forty villages throughout the zone. The Panama Railroad even had a special car to transport the seriously sick and injured to the two major hospitals. Beyond these more typical medical responsibilities, Gorgas also believed that his duty required killing mosquitoes and he set out to learn more. He had begun preparations for the project in 1902, attending a tropical medicine conference in Cairo, traveling to the Suez Canal to consult with the British about mosquito control there, and going to Paris to discuss the health problems the French had encountered in the 1880s. Meanwhile, the American Medical Association had urged President Roosevelt to include a "medical sanitarian" such as Gorgas in the Isthmian Canal Commission. Roosevelt had declined, however, and Gorgas thus went to Panama as the chief public health officer in an advisory capacity, reporting to the commission, but having little real authority.

When the United States took possession of the Canal Zone, Gorgas surveyed the region to determine what kinds of resources he would need to tackle yellow fever. He developed a million-dollar proposal for a program similar to the one he had executed in Havana. The plan laid out requirements for the professional staff of the hospitals and medical system; the labor required to screen and fumigate homes and barracks, drain swamps, eliminate mosquito propagation areas, and inspect the results; and supplies such as screening, lumber, and insecticides that the department needed to carry out the enormous task. Admiral Walker, head of the canal commission, was concerned about costs and skeptical of the need to control mosquitoes, so he only authorized Gorgas a staff of seven and $50,000 for supplies.

The public health department's first inspection found mosquito larvae in almost every house in Panama, revealing the need for an army of inspectors and a mountain of supplies. Whereas General Wood had supported Gorgas' work in Cuba, members of the canal commission thought Gorgas should be cleaning up filth in the cities, instead of chasing insects. The commission's view seemed justified when the first Americans arrived, because initially there was no yellow fever present. Gorgas, however, knew that yellow fever was a strangers' disease and that, with the addition of thousands of workers, an epidemic would occur. The first yellow fever case appeared on 21 November 1904, and six more developed in December, but no one died. In January, out of another six cases, two proved fatal. Gorgas fought the disease by screening patients and killing mosquitoes, but did so with inadequate resources because the commission still repeatedly refused or ignored his requests for supplies and personnel. For example, fumigation involved clearing buildings of all people and pets, sealing them airtight with paper and wood framing, and then burning an insecticide such as pyrethrum or sulfur. But when Gorgas requisitioned tons of newspaper for this purpose, commissioners misunderstood and denied it, believing it was too much reading material for his department. When he asked for one hundred trained female nurses, the commission approved only forty. The senior leaders also rejected his requests for ambulances and laboratory equipment.

Weeks went by without buildings being screened against mosquitoes. Le Prince told of a young architect, charged with designing structures for the canal project, who ridiculed the public health crew for their insistence on screening the doors and windows, until he himself got yellow fever and paid with his life for his erroneous view. In January, Gorgas provided Army Surgeon General Robert M. O'Reilly with an upbeat assessment, noting that the quarantine and hospital departments were organized and working well. He then proceeded to outline his problems obtaining staff and getting supplies and construction projects approved by other elements of the bureaucracy.

As yellow fever cases continued to appear, Secretary Taft sent his friend, Charles A. L. Reed (a physician and former American Medical Association president) to investigate. Reed toured Panama for fifteen days, reviewing health conditions and the public health department's work. Gorgas provided him with a memorandum dated 17 February 1905, describing the commission's failures to act on his requests for supplies, personnel, and authority to carry out his program, and outlining recommendations for reform. His major complaint was that delays caused by layers of oversight prevented him from obtaining the materials he needed to fight mosquitoes. After praising Gorgas' public health program, Reed issued a scathing Yellow fever continued to spread through the vulnerable workforce.

In April 1905, several high-ranking canal officials succumbed to the disease. In May, 63 people contracted yellow fever and 19, almost a third, died. Panic ensued. From April to June, five hundred American employees (three-fourths of the total) fled for home. Most alarming, the project's chief engineer, John Wallace, and his wife left precipitously. Newspapers carried stories about yellow fever cases from Panama arriving in U.S. ports, causing fears that the epidemic might spread to the United States. To add to the alarm, in July an Italian in the town of La Boca in the Canal Zone died of bubonic plague. However, that same month the yellow fever epidemic began to subside with only forty-two cases, and opposition to Gorgas remained.

The new chairman of the canal commission, Theodore P. Shonts, and John Stevens, Wallace's successor as chief engineer, arrived in Panama at the end of July. While Stevens supported Gorgas' work, Shonts did not and he soon recommended removing the chief public health officer. Despite Charles Reed's report and praise for Gorgas' programs, Secretary Taft forwarded Shonts' proposal to Roosevelt. The president was inclined to accept the advice of his new commission head, but he decided to confer with physicians William H. Welch of Johns Hopkins and Alexander Lambert, a personal friend and hunting companion. Both men told him frankly that Gorgas was the best person for the job. Lambert explained to the president that the whole canal project rested on his decision, and if he would back up Gorgas and let him pursue his campaign against the mosquitoes, he would get the canal. Roosevelt took the advice and admonished Shonts to give Gorgas the political support and resources he needed. Shonts complied, making public health an independent bureau with Gorgas reporting directly to him. Mosquito eradication could now begin in earnest. It had not been an easy thing for Gorgas to endure powerful and ill-informed opposition. Neither arrogant nor combative, he had relied, in part, on a strong support system, including his close-knit family. He also had the backing of the Army Medical Department, from Surgeon General O'Reilly down to talented, loyal assistants such as Carter and Le Prince. The American Medical Association strongly defended him, as well, waging an editorial campaign in its journal on behalf of his program. Equally important, Gorgas had confidence in his science. In later years he mused: "It seems singular that, after the demonstration at Havana, there should

He was confident he could stop infection in Panama, but he needed the political will and the financial resources to rid nearly 500 square miles of swamp and jungle clear of the disease-carrying mosquitoes.

Dr. Gorgas, while not the discoverer of the ability of mosquitos to transmit certain diseases, that credit is reserved to Dr. Ronald Reed, he brought what he had learned at Havana to Panama. He devoted considerable time and effort clearing brush, draining swamps, and cutting out large areas of grass where the mosquitoes swarmed.

The yellow fever, a viral disease, plagued people who hadn't become immune as children. It could appear suddenly and often ended in agonizing death. The at first unbelievable discovery that mosquitoes spread yellow fever and malaria led to a mass sanitary campaign to clean up Panama, Colon and other canal sites. Col. William Gorgas headed sanitation squads that fumigated houses, searched for the stagnant water that could support mosquito larvae and checked screens for signs of rust. The efforts worked; the fever that had been attributed to everything from poor morals to bad dirt was finally eradicated.

He managed to wipe out yellow fever and eliminated the rats that carried bubonic plague; he had also reduced the rate of deaths caused by malaria in the Canal Zone. Dr. Gorgas' troops busied themselves with covering all standing or slow-moving bodies of water with a combination oil and insecticide, and isolating infected persons in wire-screen tents.

To combat yellow fever, doors and windows were screened. Groups went door to door in Panama City fumigating houses. Cistern and cesspools received weekly oiling.

In the fall of 1904, Dr. Gorgas returned to Washington with a $1 million plan to fumigate the isthmus and eradicate the disease. But officials scoffed at Gorgas' high price tag and his mosquito hypothesis, instead adhering to the prevailing "miasma theory" which stipulated that diseases are carried by bad air or toxins in tropical soil.

The following spring, the first significant yellow fever scare hit the Canal Zone. Quarantining patients in Ancon Hospital did little to slow the rate of disease, and the panic reached a fever pitch as more and more workers fell ill. Chief Engineer John Wallace was powerless to calm his workers and a quarter of the U.S. workforce deserted the project. If the numbers of ill and deserting laborers continued to rise, the project would face significant production delays or worse.

Therefore, President Roosevelt granted the funding, and Gorgas unleashed one of the most extensive sanitary campaigns in history. In the summer and fall of 1905, more than 4,000 people worked for Gorgas on his "mosquito brigades" in what would become a yearlong effort to prevent the insects from depositing their eggs. An army of fumigators visited every private home in Panama repeatedly, armed with cleaning agents, insecticide powder, and wire mesh for screen windows and doors. Teams sprayed drains and cesspools with oil and filled in pools of standing water. In all, Dr. Gorgas' group used 120 tons of pyrethrum powder, 300 tons of sulfur, 600,000 gallons of oil, 3,000 garbage cans, 4,000 buckets, 1,000 brooms, and 1,200 fumigation pots.

Dr. Gorgas urged the screening of the boxcars in which some workers lived. Wherever possible, he had accumulations of water drained and water that could not be drained treated with a larvacide or covered with oil. Brush and grass and, when necessary, gardens were cut down. Because even wagon tracks and hoof prints could hold water long enough for a brood of Anopheles to mature, the eradication of this insect throughout the Canal Zone would obviously be an enormous undertaking. Since Anopheles mosquitoes did not usually fly far during their life cycle, Dr. Gorgas concluded that it would be feasible to concentrate his efforts within a radius of 200 yards around human habitation.

Colonel Gorgas placed Le Prince, his chief sanitary inspector, in charge of the new campaign and provided him with three assistants and a clerical staff. He then divided the countryside into seventeen sanitary districts and assigned an inspector to each district to supervise the work of the forty to fifty laborers who dug drainage ditches and carpenters who installed screens. A district physician was also appointed to keep both the central office and the district inspector informed about the number of cases of malaria he encountered each day. Dr. Gorgas required that all anti-mosquito work be done in an inspector's presence and under his control, since the ordinary engineer has no special knowledge of the life history of the mosquito, and therefore might not understand how to design and place drainage ditches to achieve a maximum beneficial effect. The drainage system eventually included 5 million feet of open, 1.5 million feet of concrete-lined, and 1 million feet of rock-filled ditches, plus 1 million feet of drain tile, all to drain 100 square miles of land. After discovering that grass tended to clog open ditches and that debris could dam concrete-lined ditches, Dr. Gorgas decided to rely more heavily on subsurface drainage tile. Because the Anopheles favored slow-moving water, he had vegetation removed from an entire mouth of a river to increase its flow. Dr. Gorgas also had the channel deepened and narrowed and the banks lined with stone. Leaving little to chance, when he learned that small fish, lizards, and even spiders could take a high toll in mosquito larvae, he had these natural predators bred and introduced into streams and areas of lush plant growth to increase still further the devastation among the mosquito populations.

Because destroying all infected mosquitoes in the entire Canal Zone was impossible, the fight to reduce malaria rates required eternal vigilance and considerable ingenuity. Any time a district physician reported a significant rise in the number of malaria cases, Le Prince was required to send experts to assess the situation and pinpoint the cause of the increase. Sometimes it was determined that the mosquitoes were breeding in a swamp too large to be dealt with by ordinary methods. In one instance, investigation revealed that silt was being dumped into a swamp from the canal construction and that the Anopheles were apparently very fond of the resultant brackish water. Colonel Gorgas had large quantities of salt water pumped from the canal into the swamp, producing a mixture that was too salty to suit these insects. A particularly severe problem developed despite precautions around a quarry from which stone for a set of locks was being taken. The malaria rate at nearby Porto Bello was high, but the town was outside the Canal Zone and beyond the Medical Department's authority. After consultation, the Panamanian government gave Gorgas the authority to manage sanitation in Porto Bello and to introduce whatever control measures he deemed necessary.

Occasionally when inspectors were unsure about the origin of mosquitoes causing high malaria rates, they had a large number of Anopheles sprayed with aniline blue dye and then, since these insects seemed to find a strong light repulsive, released at night from the area suspected of harboring the guilty mosquitoes. At the affected campsite, a man willing to serve as bait was set up for the night in an open tent near where workers were camped. In the morning the tent was closed, thus trapping the insects so that they could be examined. Should blue mosquitoes be found among them, the inspectors knew where they should concentrate their efforts against larvae. To guarantee as much success as possible in this endeavor, one or two men in each district were sent among the workers to offer pills, capsules, and a liquid quinine solution to all who would take it. Quinine was even placed on the table in all messes.

In 1906, of the 26,000 people working on the canal, more than 21,000 had been hospitalized for malaria at some time during their employment (2) (3).

But Dr. Gorgas' effort did seem to be working. By August 1906, the monthly tally of new yellow fever cases had fallen by nearly half. In September, there were just seven new cases. On November 11, 1906, the last victim of yellow fever on the Panama Canal died. Malaria would take longer to conquer, but death rates would drop to less than one percent by January of 1910.

Dr. Gorgas reduced the percentage of malaria-infected canal workers from 9% in 1905 to 5% in 1906, and finally to 1.6% in 1909. Working with Gorgas, Joseph Augustin LePrince, developed a larvacide mixture; Samel T. Darling introduced a daytime tent inspection program that was simple yet highly effective. By 1906, the Canal Zone was also cleared of yellow fever.

The eradication of yellow fever and significant reduction in the number of malaria cases on the isthmus were two of the most revolutionary developments in the Canal Project. Workers no longer feared becoming ill on the job, and tourism began to flourish along the construction route.

Additionally, like malaria and yellow fever, respiratory diseases were one of Colonel Gorgas' major concerns. For the canal workers, and especially for the black laborers from the Barbados who formed a large part of the work force, one of the most serious threats was pneumonia, sometimes complicated by tuberculosis. Physical examinations excluded many unhealthy men from the work force, and all new hires were vaccinated against smallpox when they were put on the rolls. Many were from the West Indies and immune to yellow fever, and since they often lived with their families outside the Canal Zone, they were found in its network of hospitals much less frequently than whites.

Colonel Gorgas made a strenuous effort to avoid having infectious ills imported to the Canal Zone from the outside. He had a quarantine established at Porto Bello in an attempt to keep the local Indians from introducing disease when they entered the city to sell coconuts. The Public Health and Marine Hospital Service, which had been inspecting ships bound from Panama to the United States since 1893, set up quarantine to protect the isthmus from imported disease. Ships arriving with yellow fever victims on board were fumigated and all no immune passengers isolated at a quarantine station for six days. The vessel and those on board who could prove their immunity to yellow fever were released from quarantine when the fumigation process had been completed. Quarantine officers also kept a particularly sharp watch for signs of plague, endemic in some areas of South America, after a worker on a wharf at La Boca died of this disease. A campaign against rats and the fumigation of ships and quarters in the wharf area prevented the appearance of any more cases. The quarantine stations established and run by the Public Health and Marine Hospital Service at either end of the canal were equipped with fumigating equipment, and hospital facilities were divided so as to be able to isolate patients with several different contagious diseases, one from the other.

Gorgas did not deny the need for greatly improved sanitation in the Canal Zone, and the cleanup of local communities was not long delayed once the yellow fever threat had been removed. The treaty with the Panamanian government obligated U.S. authorities to install sewage and water systems in the Zone. Both were duly established in Panama City and in Colon, where cisterns had been collecting water that drained from roofs swarming with vultures cover the roofs with fecal matter. Eventually smaller communities, where even the most rudimentary ideas of cleanliness unknown, acquired sewers and water systems, to which increasing numbers of homes were hooked up. The elimination of cisterns and standing water containers was then possible, further reducing the number of places where mosquitoes could breed.

In time, Colonel Gorgas' success in reducing the incidence of disease also reduced the need for hospital beds in the Canal Zone. In setting up the hospital system in Panama, he had originally estimated that the sick rate might run 50 per 1,000 or more at any one time-about half that of U.S. soldiers in the Spanish-American War. Thus he initially concluded that he would need a minimum of 2,500 beds and possibly considerably more. Starting with three and expanding the network as construction of the canal progressed, he established in each sanitary district one or more 20- to 100-bed hospitals. Many such facilities held dispensaries for outpatients, and at least one in each sanitary district could handle emergency surgery. Patients whose condition made moving unwise could also receive care in these small facilities. Since each district physician was responsible for the health of all who lived in his district, whether or not they worked on the canal, he knew about prevailing diseases and could act promptly at the first sign of an impending epidemic. Dr. Gorgas also had "rest camps," or hospitals with 5 to 15 beds, set up in each worker village, where those with minor ills could rest for a day or two until able to return to work. Regardless of the size of the facility they served, all physicians had to be medical school graduates and eventually were also required to pass a civil service examination. Because they were paid a salary, they received no fee from the sick, and the medicines they dispensed were also free of charge to workers who could not pay for them.

Dr. Gorgas not only freed the Canal Zone from yellow fever but he made the cities of Panama and Colon models of sanitation comparable with any city of the United States. In the meantime his reputation had extended until he was generally regarded as the world's foremost sanitary expert.

Dr. Gorgas's work is credited with saving at least 71,000 lives and some 40 million days of sickness. The cleaner, safer conditions enabled the canal diggers to attract a labor force. By 1913 approximately 65,000 men were on the payroll. Five thousand United States citizens filled the administrative, professional, and supervisory jobs.

Though Dr. William Crawford Gorgas, served as Chief Sanitary Officer, yet the Public Health Service (PHS) was integral to American sanitation in Panama. PHS physicians managed quarantine operations, oversaw the eradication of rats and mosquito larvae, superintended hospitals, attended patients, and staffed laboratories.

These efforts transformed the Canal Zone and environs into a working laboratory where U.S. health officials had an enormous amount of power to study disease and enforce strategies of containment and eradication.

PHS officers took advantage of this arrangement and were the first American representatives to gather data on patterns of health and disease in preparation for the start of dredging and construction. For example, several months before Dr. Gorgas had assembled his sanitary corps, Pierce filed a report on Panama City and its surrounding areas. He described the city's shoddy sewage infrastructure of partially exposed underground channels and its nonexistent water system; included demographic and vital statistics drawn from municipal records; and detailed the architecture and capacities of the local hospitals, including the 700-bed hospital, which was once the clinical centerpiece of the French Canal Company. Pierce bemoaned the lack of a functional quarantine station and sterilization equipment and stressed the urgency to create a station immediately because Panama is the gateway from the whole world to the west coast of America, from San Francisco to Valparaiso.

Several dispatches written by PHS physician James C. Perry followed Pierce's report. Describing Colón's urban districts, Perry evinced dismay with the conditions of the city's poorer neighborhood, which extended over a swampy area, Perry often saw cleanliness and dirt, health and disease as reflections of racial differences in personal and public hygiene, wherein dark-skinned inhabitants tended to be dirtier and more unkempt than their fairer counterparts. Such prejudices constituted the ugly underside of tropical medicine, which in its initial phases partook of the colonialist belief that it was white man's burden to lift up, civilize, and sanitize the natives. For Perry, this mission involved making Colón into a healthy tropical city through the two-pronged approach of sanitary engineering and hygienic education.

When Dr. Gorgas formed his sanitation team in the summer of 1904, he appointed Perry as Chief Quarantine Officer and Pierce as Quarantine Officer at Cristóbal. They remained in Panama for the duration of construction and were joined by additional PHS physicians. For instance, Henry Rose Carter, who determined the extrinsic incubation period of yellow fever and produced a series of authoritative papers on the epidemiology of and eradication methods for mosquito-borne diseases, served as Director of Hospitals. About one dozen other PHS physicians served alongside this trio from 1904 to 1914, many fulfilling temporary rotations at the Colón, Cristóbal, and Bocas Del Toro quarantine stations.

For PHS physicians, to serve in the Canal Zone was an exciting opportunity to advance the emergent field of tropical medicine and implement effective prophylactic health measures. In addition to quarantine duty, PHS officers pursued clinical studies in the hospital wards, aided urban and rural sanitation campaigns, and participated in the mosquito brigades that marched through Colón, Panama City, and along the cantons that snaked through the Canal Zone.

Undoubtedly, PHS physicians improved the overall health of the canal laborers and tended to those hospitalized. They also gathered epidemiological, entomological, and bacteriological knowledge that helped to refine models for disease eradication, particularly for future campaigns against mosquito-borne ailments in Latin America. Also, PHS physicians in Panama helped to perpetuate a hierarchical health system that was structured starkly by racism. For it was the minority of white laborers, paid in gold, not the diverse majority of black laborers (frequently hailing from Barbados and Jamaica), paid in silver, who received premier clinical care in the Canal Zone and whose homes benefited from mosquito screens.

Eventually, the strategies employed to protect gold workers from tropical diseases were stripped of their explicit racial conceits and implemented in health campaigns across many regions of the world. Subsequent generations of PHS officers would reject the prejudicial values embedded in U.S. public health activities in Panama. Nevertheless, the history of U.S. sanitation in the Panama Canal reveals how significant medical developments can be intertwined with disturbing—and from today's standards, unethical—approaches to health care delivery. Precisely because of this uneasy combination, it is important to learn from the PHS experience in Panama.

Chief Engineers of the Panama Canal:

The first chief engineer was John F. Wallace, an American civilian railroad engineer and general manager of the Illinois Railroad when he took the job to build the canal. He was elected by the Canal Commission, and he arrived at the isthmus in June 1904 to take the job over from acting chief engineer Major Black in July 1904 (3). Wallace started the excavation at Culebra Cut - a ten mile long stretch through the highest and rockiest area of the canal route - and after almost a year, American machinery was being used to dig the huge expanse of mountain.

Wallace concentrated initially on providing water and sewer systems and building better housing for workers. Replacing much of the equipment left by the French with sturdier, more efficient American models, he then ordered the resumption of digging and the continuation of a survey to determine the center line of the canal.

Wallace resigned in June 1905, overcome by the harsh tropical climate, difficulties of procuring equipment and supplies and red tape from the Washington, D.C.-based commission supervising the project.

The second Panama Canal Chief Engineer was John Stevens. Selected to replace Wallace by the Commission in July of 1905, Stevens was another American civilian Railroad engineer, an executive with the Chicago, Rock Island, and Pacific Railroad - replaced Wallace and arrived in Panama in July 1905. He remained longer than Wallace and was successful in building a solid infrastructure that included worker and family quarters. Immediately work began on repairing the falling French buildings left there since the 1880's. Also, new railroad track had to be laid because the French's track width was much too narrow to hold the American railroad cars. The red tape was a tremendous setback - it often took months for orders for equipment to reach the isthmus. He set about revamping the sadly deteriorated Panama Railroad and reorganizing the engineering and construction bureaus. Stevens made substantial headway in surveying the canal’s route; conducting soil borings at projected lock sites; acquiring better equipment; and building the necessary docks, warehouses, and workshops. He moved the project’s headquarters from Panama City to Culebra, where he could directly observe work on one of the greatest challenges he faced—digging through the highest point on the canal route. He expanded Wallace’s programs for municipal improvements and worker housing at Panama City, Colon, and other communities in the zone. He also created commissary and hotel systems and provided wholesome food at reasonable cost and recreational facilities for the labor force.

Mapping of the Chagres River - the huge river that was to be turned into an artificial lake for the lock-canal proposal - was accomplished, and locations to block the river and put the locks was completed. President Roosevelt visited the Canal Zone for the first time in 1906, and diseases that ran rampant through the Canal Zone began to be distinctly reduced in occurrence at that time.

Stevens, a veteran of railroad construction in the Rocky Mountains, recognized that the challenge of the canal was simultaneously one of excavation and transportation. Rock had to be moved from the mountains, where it blocked the canal, to the river delta, where it formed the core of the new Gatun Dam. His railroad excavation system functioned like a conveyor belt with the trains carrying the dirt from the steam shovels directly to the dump sites. The mainstay of the construction effort was the 95-ton, track-mounted, Bucyrus steam shovel. Six million pounds of dynamite per year blasted the hundreds of feet of basalt that blocked the route. At the peak of the construction effort, 25,000 men removed a million cubic yards of material every day. This massive excavation capability was balanced with dumping capacity, using a complex rail system of one-sided flatcars that hauled away 200 trainloads of excavated material daily. As the digging progressed, enormous track shifters moved the rail lines to the main areas of excavation.

Stevens was ready to dig in 1906, but the type of canal - sea-level or lock - remained a question. Wallace had recommended a sea-level canal, but Stevens favored a lock canal. Even at this date, no decision had been taken regarding whether the canal should be a lock canal or a sea-level canal — the excavation that was under way would be useful in either case. Towards the end of 1905, President Roosevelt sent a team of engineers to Panama to investigate the relative merits of both schemes, as regards their costs and time requirements. The engineers decided in favor of a sea-level canal, by a vote of eight to five; but the Canal Commission, and Stevens himself, opposed this scheme, and Stevens' report to Roosevelt was instrumental in convincing the president of the merits of a lock-based scheme. The plan President Roosevelt signed into law in June 1906 called for a canal with three locks on the Atlantic side, three on the Pacific side, and a lake in the middle created by damming the Chagres River at Gatun.

On March 4, 1907, Goethals was appointed by President Theodore Roosevelt Chairman and Chief Engineer of the Isthmian Canal Commission (I.C.C.). He served in that position until completion of Canal construction in 1914, following which he served as Governor of the Panama Canal until his resignation January, 1917.

Goethals was appointed when John F. Stevens resigned because of the difficulties in the first three years of construction. Goethals supervised nearly all major excavation and all construction. He vastly expanded the proposed canal’s size, taking into account U.S. Navy preferences for access, passage, and defense. To oversee the building of immense locks and dams, Goethals brought in army and civilian engineers who had distinguished themselves in similar work. He then set the two groups to work on opposite sides of the canal, expectant that professional rivalry would encourage speed and excellence.

As Chief Engineer of the I.C.C., Goethals faced many daunting tasks. Aside from the task of eliminating disease, Goethals was faced by many unique problems, any one which was a stupendous work in itself. The first of these was the cutting down to a much lower level several good sized mountains near the center of the Isthmus in order to minimize the elevation of the canal itself (1) (2) (3).

The second mightiest feat was the damming of the powerful and erratic Chagres River with the Gatun Dam and the formation of Gatun Lake. The third was the building of the huge concrete locks with filling and emptying systems and great steel gates with opening and closing devices.

Goethals was 47 years old and had almost 30 years' experience as an officer in the Corps of Engineers. Upon graduation from West Point in 1880, he entered the Corps and began a career of river-and-harbor and lock-and dam construction work on the Ohio and Tennessee Rivers, canal work at Muscle Shoals, and coast defense construction work in New England.

If any one person can be credited for this achievement it is George W. Goethals, the project's chief engineer, 1907-1915. The first two chief engineers, both civilians, resigned after short tenures. President Theodore Roosevelt announced that the next chief would be an Army officer, Major George W. Goethals of the U.S. Army Corps of Engineers.

As a member of the Army General Staff, Major Goethals had accompanied Secretary of War William Howard Taft to the Canal Zone in 1905 to recommend sites for coast defense fortifications.

Stevens had been much loved by those who had been laboring on the Canal. They worried that Goethals would impose a military regime. He dispelled these fears by appearing only in civilian clothing and inviting all workers to talk freely with him regarding any grievances. Goethals reported only to the president and secretary of war.

Promoted to Lieutenant Colonel in March 1907, Goethals took with him to Panama as members of the commission ICC two other Army engineers, Majors David Gaillard and William Sibert. Both were members of the West Point class of 1884. Gaillard was serving on the General Staff with Goethals and had experience in river-and-harbor work, while Sibert had a river-and-canal work background. Goethals placed Army engineer Major Harry F. Hodges in charge of the ICC office in Washington, DC, where he could use Corps personnel throughout the United States to help select and inspect equipment to be sent to the Canal Zone. Goethals initially organized the canal work by type, putting Gaillard in charge of excavation and dredging and assigning Sibert to lock-and-dam construction.

After several months of observation, Goethals was ready to make some changes. In late 1907, he moved the two Sosa Hill locks on the Pacific side inland to Miraflores because of the threat of naval bombardment. He brought Hodges to Panama as assistant engineer in charge of lock design and replaced him in Washington with Army engineer Major Frank C. Boggs. He widened the bottom width of the Culebra Cut, a channel through the Culebra Mountain in the Continental Divide, from 200 to 300 feet; and, on the recommendation of the Navy, increased the lock widths from 100 to 110 feet.

Goethals regularly oversaw the work at the various construction sites. These included two dams, six sets of locks, two artificial lakes, regulating works, entrance channels, breakwaters, telephone and telegraph systems, a hydroelectric station, a rebuilt railroad, and the excavation of the challenging Culebra Cut.

Goethals divided the project into three divisions: Atlantic, Central and Pacific. Work at the Atlantic division involved construction of a breakwater at the entrance of Limon Bay, dredging a 3.5-mile channel inland, damming the Chagres River and building three pairs of locks. The Gatun Dam, built by hydraulic fill, was 1.5-miles long, 105 ft high and 1,200 ft wide at its base. It created the 23.5-mile-long Gatun Lake. Of the canal's 50.5 miles, half are covered by man-made lakes.

The Pacific Division's task was to build a 3-mile breakwater at Panama Bay, excavate a channel along the bed of the Rio Grande River and build three additional flights of locks. But it was the Central division that faced the greatest challenge--digging an 8-mile, 45-ft-deep channel to a depth of 40 ft above sea level through the Continental Divide, which was 260-ft-high Culebra Mountain.

Goethals reorganized construction responsibility, and Major Sibert got the Atlantic Division from the ocean through the Gatun Locks to the Gatun Dam, and Major Gaillard got the Central Division of Gatun Lake and the Culebra Cut. Sydney Williamson, a Corps civilian engineer who had worked with Goethals in Tennessee and New England, got the Pacific Division from the Pedro Miguel Lock through the Miraflores Locks to the ocean.

Goethals divided each division into districts, with a superintendent of construction in charge, and he organized his headquarters into sections responsible for design, buildings and equipment, and survey and personnel. Similar to the Corps system, design and general planning came from the headquarters while the details were left to the divisions.

Goethals’ responsibilities at Panama extended well beyond construction. He organized a strictly regimented social order, with engineers and designers at the top and workers at the bottom. Each lived in separate communities with separate amenities, with a court system adjudicated by Goethals himself. Goethals had the ability to manage an incredibly diverse number of workers.

Workers were organized on projects in order to keep everyone busy. Goethals set up a complaint board every Sunday where workers could come and state their grievances directly to Goethals. Most of the workers came to respect Goethals and what he did for the organization of the canal in a very short time.

There were rewards and honors for all for completing the canal, highlighted by the March 1915 promotions of George W. Goethals and Harry F. Hodges to major general and William Sibert to brigadier general. The completion of the Canal in 1914 made Goethals an American hero and international celebrity.

Goethals (1858–1928) is the man who accomplished one of the greatest feats of engineering and construction since the Egyptians completed the mighty pyramids—the construction of the Panama Canal. Goethals viewed the military simply as a vehicle through which he could express his talent.

He served as Chief Engineer of the Isthmian Canal Commission (ICC) until completion of Canal construction in 1914, following which he served as Governor of the Panama Canal until his resignation in January, 1917.

Labor at Panama Canal:

From 1904-1914, one of the greatest labor mobilizations in history took place as tens of thousands of workers traveled from all over the globe to hew the Panama Canal from the wilds of Central America.

In many respects, the laborers of the Panama Canal construction days were real heroes. Their great efforts made possible the arrival of August 15, 1914, when the first steamship, the SS Ancon, made the first inaugural crossing. Many gave their lives, victims of diseases such as malaria, yellow fever, typhus, tuberculosis, pneumonia, dysentery, etc., as well as accidents of many different types.

Long before the U.S. attempt at building the Panama Canal began in 1904, workers from around the world had been coming to the isthmus. In the early 1850s, the Panama Railroad Company imported thousands of African and Chinese workers to lay the tracks for the railway lines that would make the construction of the Panama Canal possible. Most would die from malaria or other diseases.

When the United States announced its plan to build in Panama, promises of grandeur breathed fresh life into workers recruited to the area. President Roosevelt announced to workers during his trip to Panama in November 1906 that this is one of the great works of the world, and the labor bringing to completion this great enterprise was standing exactly as a soldier of the few great wars of the world's history. Laborers could be tasked to virtually any project in the Canal Zone, each with unique dangers and each requiring its own set of skills.

In December of that year 1906, two years into the project, there were already more than 24,000 men working on the Panama Canal. Within five years, the number had swelled to 45,000. These workers were not all from the United States, but from Panama, the West Indies, Europe, and Asia (2) (3).

The base of the workforce, however, came from the West Indies. After experiencing the empty promises of the French in the 1880s, most Jamaican workers were unwilling to try their luck on the American canal project, and so in 1905 recruiters turned their attention to the island of Barbados. West Indian labor was cheaper than American or European labor, and by the end of the year, 20 percent of the 17,000 canal workers were Barbadian.

The dense and untamed jungle that covered the 50 miles between coasts was filled with deadly snakes. The venom of the coral snake attacked the nervous system, and a bite from the ten-foot mapana snake caused internal bleeding and organ degeneration. The rainy season, which lasted from May to November, kept workers perpetually wet and coated in mud.

Initially, accommodations for canal employees provided little protection against the wet weather or jungle life. The Isthmian Canal Commission (ICC) housed most workers in dilapidated barracks built two decades earlier by the French.

Construction camps in tropical climes are not usually distinguished for order and good morals. The Americans determined to make an exception at Panama. They had a perfectly free hand and the enjoyment of all sovereign rights at the isthmus, and were able to construct a brand-new little state on the most approved and ideal principles. We have seen

The instructions given by President Roosevelt to the first commission included an entire administrative system had to be established within this little plot 10 miles wide and 50 long. Laws had to be framed and civil government established, with all the needful accessories of judicial courts, police force, fire-brigades, customs and revenue service, post-offices, public works and financial department. The administration carried what is known as paternalism to all lengths. That is, it did all the catering and providing itself, and left little or nothing to private companies. Of course, everything had to be imported, for the little territory itself produced nothing. Whole villages and settlements with

All the accessories of social life had to be built along the line of works. Over 2000 structures, including offices, hospitals, hotels, messes, kitchens, shops, storehouses, and living quarters, were constructed, and more than 1,500 buildings taken over from the French, which were made available by necessary repairs. The Commissary Department of the Panama Railroad Company was enlarged until it was now a great department store, supplying to the employees whatever may be necessary for their comfort and Manufacturing, cold-storage, and laundry plants were established, and turn out each day about 90 tons of ice, 14,000 loaves of bread, 2,400 rolls, 250 gallons of ice-cream, 1,000 pounds of roasted coffee, and 7,500 pieces of laundry. Four or five refrigerator cars, loaded with meats, vegetables, and such fruits as can be obtained, were sent out on the night freight to distant points, and every morning a supply train of about 16 cars, of which number six to eight were refrigerator cars, leaves Cristobal at 4.30 to distribute foodstuffs and laundry to the local commissaries along the line, where the employees make their purchases, and where the hotels, messes, and kitchens secure their supplies for the day (1) (2) (3).

In December 1905 there were 5000 employees; in 1906, 24000; in 1908, 31000; the highest figure being reached in 1910, when there were 50000 workers available for duty. Of the employees, speaking roughly, one-seventh have been white Americans, all, of course, skilled workers, one-seventh European laborers, and five-sevenths West Indian negroes.

Perhaps the worst job was dynamiting. The greatest danger lay with the material's instability; it could blow up at any moment or malfunction upon detonation, remaining unignited until exploding later by accident. Laborers heading out for dynamiting duty frequently carried all their belongings with them, understanding their relatively low odds of a safe return to the barracks.

As work on the canal entered its second year, the death toll for laborers was four percent and 22,000 were hospitalized. Every evening, a train traveled to Mount Hope Cemetery by the city of Colón, its cars brimming with coffins, forcing the men to confront the great odds against their survival.

U.S. citizens were used sparingly in Panama because they were both disease-prone and demanded higher wages. In North America, however, the transcontinental railroad had been completed in 1869 and produced many U.S. workers adept at rail jobs: switchmen, signalmen, locomotive drivers, mechanics, electrical engineers, and foremen. Skilled U.S. laborers came to the canal with the promise of a generous pay package that included free benefits and services, 42 paid vacation days and 30 days paid sick leave - much more than the majority of West Indian canal workers could expect.

The local Panamanian citizens were initially tapped as a logical and cheap source of unskilled labor. Though more resistant to yellow fever than the foreign workers, locals proved to be equally susceptible to malaria and pneumonia.

Skilled employees went on the Gold Roll and were paid in gold coins. These workers earned paid sick and vacation time and were housed in better accommodations than their unskilled counterparts. Those on the Silver Roll, the unskilled workers, were paid in balboas, or local Panamanian silver. West Indian workers, plentiful in numbers and eager to work, could be paid 10 cents an hour - half of the salary of a European or white U.S. worker. Over time, the Gold Roll became comprised of white U.S. citizens exclusively, while the workers on the Silver Roll, by far the majority of the workforce by the end of the construction period, were largely non-white.

When the turnover rate of skilled U.S. laborers reached 75% in the summer of 1905, the ICC realized they needed to create incentives for Americans to stay on the isthmus. One of the first projects was building a new cold-storage unit to keep fresh, perishable foods. Then, the ICC set to work improving the living conditions.

It was clear that conditions had to be improved if the project was to succeed; so a program of improvements was put in place. To begin with, a number of clubhouses were built, managed by the YMCA, which contained billiard rooms, an assembly room, a reading room, bowling alleys, dark rooms for the camera clubs, gymnastic equipment, an ice cream parlor and soda fountain, and a circulating library.

Baseball fields were built by the commission, and special trains were laid on to take people to the games; a very competitive league soon developed. Fortnightly Saturday night dances were held at the Hotel Tivoli, which had a spacious ballroom.

In 1906, 2500 structures were either renovated or built new, including two-story family homes that featured screened-in verandas, and modern plumbing.

A year later, American workers provided with games, athletic competitions, and dancing. This was the beginning of recreation in the Canal Zone. Baseball leagues, social clubs, and fraternal organizations sprang up to fill Sundays. By that winter, the Canal Zone had paved roads, warehouses, dormitories, and dining halls.

Attractive enticements to keep white workers on the isthmus became the norm. New cottage homes, public schools, churches and bakeries opened in towns and camps along the route of the canal. White workers were encouraged to bring their wives and families to the isthmus with increasingly extravagant incentives. Housing for married workers was provided rent-free, and homes increased in luxury according to a worker's place on the pay scale.

The most taxing physical labor was in the excavation of the Culebra Cut. Each day workers moved miles of construction track and filled the 160 spoil trains that ran in and out of the Cut. Landslides occurred in the Cut with little to no warning, often burying workers and equipment within seconds and wiping out months of progress.

In 1909, construction of the locks brought a new host of potentially lethal dangers. Eight stories up, riveters worked without safety harnesses on precarious scaffolding, which could become unhooked with any sudden movement. Falling materials would hit other sets of scaffolding on the way down, causing scores of deaths and injuries. A job on the railroad was no easier. Due to the number of train cars running from multiple directions around the clock, working by the spoil dumps on the rail track required constant vigilance so as to avoid getting run over or hit by a swinging boom.

Although the ICC made significant improvements in the second half of the U.S. construction period, treacherous construction methods and deadly diseases took their toll: at least 25,000 workers died during the combined French and U.S. construction periods of the Panama Canal.

More than 75,000 men and women worked on the project in total; at the height of construction, there were 40,000 workers working on it. According to hospital records, 5609 workers died from disease and accidents during the American construction era.

Construction of Panama Canal:

The first major divergence from the French strategy was changing the engineering plan to a lock-style canal. American engineers realized the folly of a sea-level canal: the difference in tidal ranges at each end of the canal (up to 20 feet at the Pacific and only 1 foot at the Atlantic), coupled with well-known and severe river flooding, meant that a sea-level option would be more expensive to build/maintain and more dangerous to traverse (1) (2) (3).

The American force also had the benefit of more suitable machinery. The evolution of more powerful engines made it possible for increasingly larger pumps that could move increasingly more material. The French had relied on the bucket ladder dredger, which proved an outdated technology ill-suited for the Panamanian terrain. The Americans switched to the more efficient hydraulic cutter suction dredger with a rotating cutter at the end of a suction line. Because of the ability to change the edges of the rotating blades, this type of dredger can be adapted for cutting into various materials.

The Americans completely renovated the Panama Railroad (finished in 1855) with heavier track and upgraded bridges to accommodate more powerful engines, freight cars, dump cars, and refrigerator cars. This served a dual purpose: bringing in workers and supplies and taking out excavated spoil. The renovation enabled the development of an efficient spoil disposal system, with excavated earth dumped far enough away from the dredging site to prevent slides from refilling any of the excavation sites. The railroad also paved the way for the high quality of American heavy machinery that made the United States venture in Panama a success: inventions originally developed for the burgeoning rail United States industry were adapted for use on this enormous excavation.

The engineering problems of the canal were many, and they were large in size. For one, the path of the canal meant digging through the Continental Divide. Construction of the canal also meant construction of the largest dam the earth had seen up to that point. The canal also required the design and construction of the largest locks of all time, and the building of the largest gates ever used. The US also had to deal with environmental problems of tremendous degrees.

The construction of the canal began in 1904. For it, the US used the most modern equipment at that time and had come up with innovative ways to handle the issues facing the construction.

The construction involved three major engineering projects; the Gaillard Cut had to be excavated, a dam across the Chagres River had to be built to create Gatun Lake, and the canal's locks had to be constructed.

The hardest task was digging the Gaillard Cut through hills of soft volcanic material. It was much like digging into a pile of grain as soon as workers dug a hole, more rock and earth would slide into the space, or push up from below. Instead of the estimated 73 million cubic metres of earth and rock the builders had to move more than 160 million cubic metres.

The first and greatest engineering challenge was cutting a pass through the Continental Divide which made it necessary to dig through the mountain ridge at Culebra. This area was chosen because it was the narrowest and lowest point in the mountainous Isthmus that joins the North and South American continents. Over 100,000,000 cubic yards of soil and rock had to be removed. Mudslides, accidents and equipment loss threatened to hinder the process, but when it was completed, the Culebra Cut, later renamed the Gaillard cut, was a minimum of 300 feet wide along its entire 7.8 miles' length.

The most difficult area of excavation was the area at Culebra Mountain - Culebra Cut. The canal had to be dug out of the largest mountain in the path, which was one of the smallest mountain on the isthmus. The French had floundered at Culebra because they had attempted to maintain a certain slope at the sides - an angle that became impossible to hold.

The first American steam shovel started work on the Culebra Cut on 11th November 1904. By December 1905 there were 2,600 men at work in the Culebra Cut.

Excavating Gaillard Cut (originally known as Culebra Cut), the point at which the Canal passes through the Continental Divide, took 9 years of near-constant digging through dangerous mountainous terrain. Although the Cut is less than 9 miles long, some 100 million cubic yards of spoil was removed and then used to create land for a number of related projects, including a 3-mile-long causeway in Panama Bay, the Balboa town site, the Fort Amador military reservation, and sites for locks and dams.

Because of the magnitude of the excavation, earth slides were a constant danger. Heavy rains weakened the already-precarious landscape, often pouring mud and rock back into cleared areas and reversing months of headway. The original engineering at Gaillard Cut planned for a width of 670 feet at the top; however, because of the instability of the earth along the sides of the Cut, the end result was almost three times as large. Slides necessitated an increase in the amount of excavation within the Cut and the repeatedly altered cross-section of the canal directly accounted for excavation increases of 15.3 million cubic meters over the original estimate. The infamous Cucaracha slide of 1907, one of the most destructive in Gaillard Cut, earned the characterization of a tropical glacier — of mud instead of ice. After years of continual slide, during which millions of cubic meters of spoil poured back into the canal excavation, engineers decided to flood the cut and finish the work with dredgers - including, incidentally, the antiquated French ladder dredger Marmot.

The engineers were, in one way, fortunate that the amount of material excavated from Gaillard Cut was so vast. Spoil reclamation became a ready resource for other construction needs along the Canal. One such need was the damming of the Chagres River. To solve the well-known problem of severe flooding along the Chagres River, engineers constructed a monstrous earth dam across the river at Gatún. The resulting Gatún Lake, at the time the largest manmade lake in the world, was able to accommodate floodwaters and became more than 20 miles (30 km) of the canal route.

Gaillard spoil was also used in the creation of the three systems of locks, built between 1909 and 1913. The three-stage Gatún Locks, 1.2 miles (1.9 km) long with a lift of 85 feet (26 meters), were constructed with concrete comprised of rock excavated from the Gaillard Cut. The single-stage Pedro Miguel Locks, 0.87 mile (1.4 km) long with a lift of 31 feet (9.5 meters) up to the main level of the canal, include an earthen dam with a concrete core wall. The two-stage Miraflores Locks, 1.1 miles (1.7 km) long with a lift of 54 feet (16.5 meters), involve two dams constructed in part with Gaillard spoil that created a small lake.

The locks have been called the structural triumph of the Panama Canal and are a unique aspect of the waterway. At the time of their construction, their overall mass, dimensions and innovative design surpassed any similar existing structures, and they are still considered to be an engineering wonder of the world. After about 100 years of service, the concrete of the Panama Canal locks and spillways is in near perfect condition, which to present-day engineers is among the most exceptional aspects of the entire Canal.

Sidings and tracks for the spoil wagons had been laid, the dredging at both the Atlantic and Pacific portions of the canal were being carried out and a survey of the area for the largest dam along the canal had been started. It wasn't until June 1906 that the decision on type of canal was decided. It was to be a lock canal. This would enable the river Chagres to form a lake.

For nearly ten years, the focus of the excavation effort was Gaillard Cut, where the canal passes through nine miles of craggy hills. Slopes in the cut are very unstable, and work was hampered by constant slides that buried machinery, increased the volume of excavation, and extended construction by almost two years. These slides and the limitations they impose on the width of the channel are major constraints of the Canal. While the width of the original 300-foot channel has been doubled, the cut remains too narrow for large ships to pass one another.

Peak excavation within the Culebra Cut exceeded 512,500 cubic meters of material in the first three months of 1907 and the total workforce exceeded 39,000. The rock was broken up by dynamite, of which up to 4,535,000 kilograms were used every year.

The plant used in the Culebra cut included in excess of 100 Bucyrus steam shovels each capable of excavating approximately 920 cubic meters in an eight-hour day.

The heavy Panamanian rainfall caused mudslides year round until a very gradual slope was attained by the massive steam-shovels working almost twenty-four hours a day. About 96 million cubic yards of dirt were removed from the Cut, 30 million of that being soil deposited in the bottom of the Cut by landslides. Dynamite was the tool of choice for loosening the rocky ground - over 19 million pounds of explosives were used in the Cut alone - and only eight fatalities resulted. More than 4,000 wagons were used for the removal of the excavated material. Each wagon was capable of carrying 15 cubic meters of material. These wagons were hauled by 160 locomotives and unloaded by 30 Lidgerwood unloads.

When the canal was first designed, the problem of landslides had been ignored. Slides of earth and more importantly rock, increased the amount of excavation within Culebra. The cross section of the canal was constantly being changed to accommodate for the landslides. The slides caused the upper edge of the cut to be taken back beyond their original lines. The original design for the banks comprised a series of narrow benches which acted as rock catchers, alternating with short steep slopes.

Numerous test borings had been carried out and samples of the rock were taken, therefore, the quality of the rock was known. The reason for the misjudgment of the strength was due to the underlying strata which contained bands of clay and iron pyrites. The iron pyrites seemed to cause the problems, as it is liable to oxidize when exposed to the air and moisture, with the result that the rock would disintegrate. Therefore, when the overlying material had been removed, rainwater precipitated through to the lower strata which included the pyrites, whereby rapid deterioration occurred.

The first major slide occurred in 1907 at Cucaracha. The initial crack was first noted on October 4th, 1907, then without warning approximately 382,000 cubic meters of clay, moved more than 4 meters in 24 hours. This slide caused many people to suggest the construction of the Panama Canal would be impossible. The clay was too soft to be excavated by the steam shovels and was eventually removed by sluicing with water from a high level.

The Cucuracha slide was to become a problem again in 1913, when it crossed the cut until it reached the opposite bank. The steam shovels excavated the slide as it was moving and eventually won the battle.

Further movements were experienced at the base of the cut, including the sudden upheaval of the ground at the middle and a sinking of the ground in other areas. These movements were caused by the pressure of the rock, which seemed to flow as soil and not having the typical behavior of rock. This problem was overcome by removing material from the upper levels of the cut thus, reducing the pressure.

As a direct result of all the slides and upheavals encountered, excavation increased by 15.3 million cubic meters. This was about 25% of the total estimated amount of earth moved. The slides which were encountered didn't cause any delay in the progress of the canal, as this was determined by the speed at which the locks were constructed.

The overall design of the canal was this : a dam built at Gatun (to create the largest artificial lake in the world at the time) to fuel the locks; a series of three locks at Gatun (to get past the dam), each would raise or lower ships 85 feet vertically; another set of two locks at Pedro Miguel and a single at Miraflores (Gatun, Pedro Miguel, and Miraflores are cities within the Canal Zone) on the Pacific side; the width at the bottom of the canal was to be 300 feet, the width at the top was dependent on the location (1800 feet at Culebra). Along the route of the canal there is a series of 3 sets of locks, the Gatun, Pedro Miguel and the Miraflores locks.

At Gatun there are 2 parallel sets of locks each consisting of 3 flights. This set of locks lift ships a total of 26 meters. The locks are constructed from concrete from which the aggregate originated from the excavated rock at Culebra. The excavated rock was crushed and then used as aggregate. In excess of 1.53 million cubic meters of concrete was used in the construction of the Gatun locks alone.

Initially the locks at Gatun had been designed as 28.5 meters wide. In 1908 the United States Navy requested that the locks should be increased to have a width of at least 36 meters. This would allow for the passage of US naval ships. Eventually a compromise was made and the locks were to be constructed to a width of 33 meters. Each lock is 300 meters long with the walls ranging in thickness from 15 meters at the base to 3 meters at the top. The central wall between the parallel locks at Gatun has a thickness of 18 meters and stands in excess of 24 meters in height. The lock gates are made from steel and measure an average of 2 meters thick, 19.5 meters in length and stand 20 meters in height.

The smallest set of locks along the Panama Canal are at Pedro Miguel and have one flight which raise or lower ships 10 meters. The Miraflores locks have two flights with a combined lift or decent of 16.5 meters. Both the single flight of locks at Pedro Miguel and the twin flights at Miraflores are constructed and operated in a similar method as the Gatun locks, but with differing dimensions.

The locks were in pairs, so that if any lock is out of service navigation will not be interrupted. Thus, also, when all the locks were in use, the passage of shipping will be expedited by using one set of locks for the ascent and the other for descent. The locks were 110 feet wide and have usable lengths of 1,000 feet.

The system of filling adopted consisted of a culvert in each side wall feeding laterals perpendicular to the axis of the lock, from which were openings upward into the lock chamber. This system distributed the water as evenly as possible over the entire horizontal area of the lock, and reduced the disturbance of the chamber when the latter is being filled or emptied (2) (3).

The middle or separating wall contained a single culvert of the same area as the culverts in the side walls, which feeds in both directions through laterals controlled by valves designed to operate against a head from either direction. This arrangement permited communication between the chambers of twin locks, so that water may be passed from one lock to the other of the pair, effecting a saving of water. The main culverts were controlled by Stoney valves, and the laterals leading from the center wall by cylindrical valves.

Assuming a difference of head of 30 feet, it was estimated that the entire lock can be filled or emptied using one culvert in 15 minutes and 42 seconds, and in 7 minutes and 51 seconds when both culverts are used.

The lock gates were of the mitering type, double leaf, straight gates, varying in height from 45 feet 7 inches to 79 feet; the length of each leaf is about 65 feet.

The Gatun Locks, Pedro Miguel Locks, and Miraflores Locks were created to raise the ships to the lake, almost twenty-six meters above sea level, and then lower them. The original lock canal plan called for a three-step set of locks at Gatun, one step at Pedro Miguel and a two-step at Sosa Hill. At the Gatun Locks on the Atlantic side, workers poured enough concrete to build a wall 8 ft wide, 12 ft high, and 133 miles long. They built culverts the size of railroad tunnels to channel water from Gatun Lake into the locks. Pittsburgh's furnaces roared as more than fifty mills, foundries, and machine shops churned out the rivets, bolts, nut, girders, and other steel pieces the canal builders needed. In late 1907, it was decided to move the Sosa Hill locks further inland to Miraflores, mostly because the new site provided a more stable construction foundation, but also because it afforded greater protection against sea bombardment.

The locks themselves were enormous, in keeping with the canal tradition. Over a thousand feet long each, they were manufactured in the States and transported to the site in sections and cemented together, of which the engineers did a remarkable job since cementing was a relatively new and unstudied area of construction. Water was to flow into or out of the locks through gigantic culverts in the walls of the locks, each being many times the height of a person. The lock gates were also sent down in pieces and completed on site, and double sets of doors (two gates at each end of a lock) were installed for protection of the canal (in case one gate were damaged or malfunctioning). Another series of precautionary measures were later installed in the control house, all to keep anything from damaging the canal. (When the canal went into operation, it was built to survive a naval bombardment, runaway ships in the locks, malfunctioning equipment, and inept controllers.) Railroad-type cars held and moved the ships - vessels did not traverse the locks under their own power.

It had been accepted as a fundamental feature of the design that at each flight of locks there must always be two barriers separating the high level from the level next below. To carry this out, two sets of mitering gates were placed at the upper and two at the lower end of each of the uppermost locks in each flight.

In addition, a chain device was used to guard the barrier gages against accident, and so controlled as to be capable of checking a ship of 10,000 tons moving at the rate of about five miles an hour.

Guide piers were provided both up-stream and down, to which vessels will tie before entering the locks. Designs for electric towing machines were being prepared, which would be used for towing vessels into and controlling their passage through the locks by means of lines or cables attached to what may be considered the four corners of the ship.

Even with all of these precautions accidents might still be happened, and emergency dams were provided at the head of each flight of locks, consisting of swing bridges, which can be thrown across the locks in case of an accident which makes a connection between the top level and the level below; wicket girders are let down from these swing bridges, supported by a sill at the bottom and the horizontal truss work of the bridge at the top. These wicket girders acted as runways for gates, which were lowered and gradually stop the flow. Many engineering aspects of the Panama Canal point out the concern for the protection of the environment and natural resources.

As the excavations were being carried out, an enormous amount of excess soil was produced. The French initially hauled the soil to an adjacent valley where the soil was dumped and allowed to build up. This itself caused many problems during the rainy season and was the cause behind many of the landslides.

When the Americans started work on the canal, the engineers decided to reuse this soil for the building of the Gatun dam. This dam held back the water from the Chagres River and thus creating the Gatun Lake. As time passed, the soil would continue to settle thus, increasing the strength of the dam (1) (2) (3).

Construction of the Gatun Dam began in 1907. The 1.5-mile earthen dam, with a concrete spillway in the middle, crossed the Chagres River to create a 164-square-mile lake as part of the canal. Gatun Dam, on the Atlantic was, at the time of its construction, the largest earthen dam in the world and Gatun Lake the largest manmade body of water in the world. Two other dams were built on the Pacific side - the Miraflores Spillway and The Madden Dam. With the building of the Gatun Dam, the Chagres River valley between Gamboa and Gatun became Gatun Lake, with the Chagres flowing into it at Gamboa. The building of the Gaillard Cut then extended the lake across the Continental Divide to Pedro Miguel Locks. Lock construction began in 1909, with Army Engineer Major James P. Jervey supervising masonry work of the triple locks. In 1912 Army engineer Lieutenant Frederick Mears completed relocation of the Panama railroad required by the creation of Gatun Lake. The canal was near completion in 1913, when steam shovels working from both ends of the Culebra Cut met in May and Gatun Lake began to fill in June. In September a trial lockage at the Gatun Locks resulted in the tug Gatun rising from the lowest chamber to the lake in 1 hour and 51 minutes. The canal would have opened in 1913 but for slides in the Culebra Cut.

The dam itself is 1.5 miles in length and is nearly 0.5-mile-wide at its base. The construction of the dam involved constructing 2 walls along its length using the excavated rock from the Culebra Cut. The space between these 2 walls was then built up with impervious clay. This clay gradually dried and hardened into a solid mass almost equal to concrete in its water-resistant properties. This dam contains 16.9 million cubic meters of rock and clay, equivalent to about one tenth of the entire excavation of the canal.

The dams at Pedro Miguel and Miraflores are small in comparison to Gatun. Their foundations are on solid rock and are subjected to a head of water of 12 meters, whereas the Gatun dam is subjected to a 24-meter head. The dam at Pedro Miguel is an earth dam approximately 300 meters in length with a concrete core wall.

At Miraflores there are two dams forming a small lake with an area of about 2 square miles. One of the dams is constructed of earth and is 210 meters in length. The second of the dams at Miraflores is 150 meters in length and is made from concrete.

At Gatun three locks in flight overcome the difference in level between the lake and sea, and are being constructed in a cutting made through a hill. The excavation, consisting of upwards of 5,000,000 cubic yards, mostly rock, is practically completed. the locks are of concrete, and contain about 2,046,100 cubic yards of this material. On January 1 last they were 49 per cent completed.

The broken stone for the concrete was quarried and transported from Porto Bello, about 20 miles east of Colon, and the sand was procured from Nombre de Dios, about 20 miles farther to the east. Both were transported direct to Gatun in barges through the French Canal, which was dredged of rock ledges and accumulated deposits for the purpose. Since the canal line was cut through to the French Canal this new channel was also used. The cement was purchased under contract at docks in Jersey City and shipped to Cristobal, thence by barges to Gatun or cars to Pedro Miguel and Miraflores.

The material taken to Gatun in barges was landed at unloading docks, conveniently located on the old east diversion, to which a channel from the French Canal was excavated by dredges. The east dock was enclosed, forming the cement storehouse. Its floor dimensions were 106 feet by 490 feet. The roof projected 35 feet beyond the face of the dock, affording some protection against the rains.

The building was divided into ten bays, in each of which a two-ton travelling crane, worked by electric motors, operate entirely across the building. In the rear of the building 30 cement hoppers were placed in the floors and covered with steel screens. The cement was delivered through these hoppers into cars running on a track below the floor. The cement for this work was in barrels, which were first put into the storehouse and subsequently moved to the hoppers.

Grab buckets, operated by cableways, remove the sand and stone from the barges, moored against the west dock, and deliver the materials in stock piles. The towers of the cableways were of steel, 85 feet high and 800 feet apart. They were mounted on cars, which enable movement at right angles to the line of the cable; one single and two duplex cableways are provided. The cableways were equipped with five 70 cubic feet self-digging grab buckets, each having an independent run from the barge to the stock pile. The cableways have not the capacity to unload the material required with sufficient rapidity, and had been augmented by three derricks operating on a dock north of the cement shed, transferring sand and stone to bins.

The cars used for transferring the material were of steel with hinged side doors, and bottoms inclined outward at an angle of 52 degrees from the horizontal. A steel partition divided each car into compartments, one for rock and cement and one for sand. The car started at the cement shed, where it received two barrels of cement, thence run through one of the tunnels, receiving a full charge of stone and sand in the proper compartment, and proceeded to deliver this load in the mixer hopper.

A four-track electric railway, third-rail system, operated the length of the locks and carried the concrete from the mixers to the cableways over the locks, by which it was placed. The equipment for this road consisted of 12 electric four-wheel mine-locomotive-type engines and 24 flat cars fitted with automatic couplers, each designed to carry a two-yard concrete bucket. Two charges of concrete were taken by each train and carried to the cableways. Four duplex cableways span the locks with steel towers 85 feet high and 800 feet apart, similar in design to the unloading cableways.

The forms used in concrete laying were of steel and, for the straight portion of the walls, so designed as to permit construction of monoliths 36 feet in length extending from the floor to the top of the walls. The forms for the main and the lateral culverts were of steel and are collapsible.

The technology that was employed to construct Panama waterway by French was sea level design. This is because they had successfully employed the same technology in construction of Suez Canal. Unfortunately, the technique did not work in the Panama Canal project. With the development of technology in field of engineering, the United States ignored the design of French and continued with the design based on a huge lake raised with one and two lock combination on the side of pacific and three locks at the Atlantic side at Gatun. The technology employed in design of sea level suffered severely from the huge volume of digging needed and from flooding that would have happened on the Charges River. This river was usually frequented by flooding that would have put the waterway into peril and affect traffic flow. The engineering technology allowed US to build dam close to the Chagres River mouth in order to mitigate impacts of flood and reduce excavation. The locks were controlled by highly designed electro-mechanical control system that is still functioning since 1914.

The Panama Canal belongs to the "age of concrete." At Panama everything-locks, wharves, piers, breakwaters-has been constructed of concrete. The Americans have not only built these incomparable piles of masonry; they have manufactured the material out of which they are built. This circumstance makes the rapid completion of the canal all the more wonderful. Not less than four and a half million cubic yards of artificial stone have been produced for the built portions of the canal and its accessories. Dozens of mighty "mixers" were ready to receive these diverse materials. Each of these could accommodate ten tons of sand, cement, crushed stones, and water. This indigestible mixture the machine would toss and churn round for a minute or so in its interior and then belch it all out in the shape of unhardened artificial stone. The belief in concrete among the builders of the Panama Canal has been almost a superstition. They invented a sort of cement gun to shoot sand and water against the sides of the Culebra Cut, so as to form a coating of solid artificial rock, but the experiment rather deserved than achieved success. Every means was taken of testing such important matters as the effect of sea-water on this material, the time it takes for these huge masses of artificial stone to settle, and many other questions on the answer to which the permanence and stability of the locks and the entire waterway would depend.

The construction of the Suez Canal was a work of excavation pure and simple. The construction of any kind of canal across the Isthmus of Panama involves another task, regulating the rivers. In the case of a sea-level canal the problem would have been how to get rid of their waters, particularly in the rainy season. In the actual case of an 85-foot-level canal, the regulation of the rivers, particularly of the Chagres River, presents two aspects (1) in the wet season, disposing of the floods and the surplus waters. (2) In the dry season, conserving water supplied by the rains so as to meet the waste caused; by locking; by evaporation; by percolation. The arrangements for taming the torrents of the Chagres and its tributaries were, briefly, the construction of the Gatun dam and its spillway.

The greatest difficulty of the Panama route was the control or disposition of the Chagres River and its tributaries. The Chagres River rises in the San Blas Mountains and drains a basin of 1,320 square miles, about half of which is above the mouth of the Obispo River.

The main problem which the American engineers had to solve was how to deal with the Chagres River. On the tide-level scheme, that violent and capricious stream, which in the rainy season was navigable for half its length of 100 miles, would have had to be diverted into another channel or ponded back in its upper waters by a high dam at Gamboa, some of the overflow of which might perhaps have been permitted to pass into the canal. But, as we have seen, the Chagres would have to be utilized and at the same time controlled if the high-level plan was adopted. A river which is capable of rising 35½ feet in twenty-four hours needed a great deal of regulation and discipline before it could be used as the feeder of the upper reaches of a lock canal. The only way to do this was to diffuse its waters over a vast artificial lake which it would keep full, but in which its floods and current would be effectually tamed. This could only be done by a huge dam intercepting the course of the river in its lower reaches, at some point before it entered the Caribbean Sea. When the New Panama Canal Company changed its plans and decided for an elevated waterway, it was intended to construct such a barrier at Bohio, a point much higher up stream than Gatun, the site ultimately chosen by the American engineers. But when the Americans finally decided on the high-level type in 1906, the site of the proposed dam was shifted from Bohio to Gatun, nearer the river's mouth, which involved the inundation of a much vaster area of country.

The maximum observed rainfall is 5.86 inches in one hour; the greatest recorded change in the river at Gamboa is a rise of 25.6 feet in 24 hours. Its discharge at the beginning of the rise was 8,200 cubic feet per second, increasing to 90,000 cubic feet per second at the peak of the flood. The excessive rainfall and precipitous character of the hills enclosing the valley make it a torrential stream. The bars formed during floods differ materially, and are of sand, gravel, pebbles, and rounded stones three inches to six inches in diameter. The sand and clay deposits are useful in giving suitable material for the impervious portion of the dams, while the gravel beds furnish ballast for the railroad and for other purposes (2) (3).

The efficient and economical working of the plan required that provisions be made for the disposition of the large quantities of water that result from the rains. Whatever water is not carried off by the streams enters the cut, either through direct fall over the excavated area or by seepage into it. Proper drainage of the cut was therefore an ever existing problem, and two distinct phases were presented; to keep out the water of the surrounding country; to rid the excavated area of the water that collects in it. A system of diversion channels accomplished the first, and gravity drains and pumps solved the second.

The French so planned the excavation that after the removal of the peak of the divide and lesser summits they could work a number of excavators simultaneously at several points, so that a succession of benches resulted, lying one above the other, each with the natural surface as the point of beginning. By working in the direction of the length of the cut, the face of the bank gives the longest cutting possible, reduces the number of times the excavator must be hauled back, and secures a satisfactory drainage arrangement, since the cutting is carried up grade on either side of the summit.

The Americans have followed this same method, the only difference being in the character of machinery used. The width of the channel adopted by the French was 74 feet; the width adopted by the American was a channel 300 feet at the bottom, so that the first work undertaken by the Americans was directed to securing the necessary widths for the upper reaches before attempting any increase in depth.

Whatever water entered from rains and seepage was drained from the summit of the cutting by gravity to the Rio Grande on the south and to the Chagres River on the north. As shovels in excess of those required for widening became available, they were put to work to secure increase depth, care being taken to maintain, as far as possible, free, easy, and rapid drainage. Shovels are started at either end and carried towards each other, cutting out at a new summit. These pioneer shovels on the next lower grade make the pilot cuts, which constitute the new drains and to which water is led by laterals from various parts of the excavated area adjacent.

To get rid of the accumulated flood water, 24-inch pipes were laid through the dike, each with a suitable valve, and so arranged that all water above the pipes is carried into the Chagres by gravity and after the subsidence of any flood.

Completion of the Panama Canal:

On August 15, 1914, the first sea-going vessel crossed Panama, and the Panama Canal opened all the way through. This huge accomplishment was reported far and wide as the biggest news of the day. The attention lasted only a short time, though, as soon World War I broke out in Europe and quickly overshadowed the canal story.

In retrospect, the 80-kilometer (51-mile) lock-and-dam canal was completed, slightly more than ten years after the congressional act that initiated the work. About 5,000 lives were lost finishing the U.S. project. Some died from disease and others from explosives. The canal opened six months ahead of the schedule set earlier by John Stevens. The Panama Canal cost the United States around $375,000,000, including the $10,000,000 paid to Panama and the $40,000,000 paid to the French company. It was the single most expensive construction project in United States history to that time; remarkably, however, it was actually some $23,000,000 below the 1907 estimate, in spite of landslides and an increase in the canal's width. (US$352 million had been approved). If this is not the only U.S. government project ever to finish both early and under budget, it is certainly the largest one to do so.

Most of the credit goes to George Washington Goethals. Although he acknowledged his debt to John Stevens, nearly all the work was accomplished while Goethals was Chief Engineer. After the opening of the canal, Goethals remained in Panama as governor of the Canal Zone, to oversee its early operation and deal with any problems.

3. CONCLUSION

The Panama Canal was the world's greatest engineering and construction achievement, and the most expensive at the time, although few may realize that the megaproject under U.S. management actually came in six months ahead of schedule and $23 million under estimate.

The history of the Panama Canal goes back almost to the earliest explorers of the Americas. The narrow land bridge between North and South America offers a unique opportunity to create a water passage between the Atlantic and Pacific Oceans. The earliest European colonists of Central America recognized this potential, and schemes for such a canal were floated several times in the subsequent years. By the late 19th century, technological advances and commercial pressure advanced to the point where construction started in earnest.

Work on a sea-level canal across the Isthmus of Panama to create a water route between the Atlantic and Pacific oceans was begun by France in 1881, but bankruptcy halted construction nine years later. The US took over work on May 4, 1904, not long after Panama declared its independence from Colombia and signed a treaty with the U.S. for the Canal Zone.

The project's first chief engineer was John Findley Wallace, a prominent railroad engineer appointed in 1904 by President Theodore Roosevelt. But his tenure was short. Wallace resigned just a year later, overcome by the harsh tropical climate, difficulties of procuring equipment and supplies and red tape from the Washington, D.C.-based commission supervising the project.

Wallace was succeeded by John F. Stevens, also a railroad engineer but experienced in rough climate from years of building rail lines on the western frontier. Under his direction, heavy equipment brought in and massive construction of housing, a railway and port facilities under way.

Goethals divided the project into three divisions: Atlantic, Central and Pacific. Work at the Atlantic division involved construction of a breakwater at the entrance of Limon Bay, dredging a 3.5-mile channel inland, damming the Chagres River and building three pairs of locks. The Gatun Dam, built by hydraulic fill, was 1.5-miles long, 105 ft high and 1,200 ft wide at its base. It created the 23.5-mile-long Gatun Lake. Of the canal's 50.72 miles, half are covered by man-made lakes. The Pacific Division's task was to build a 3-mile breakwater at Panama Bay, excavate a channel along the bed of the Rio Grande River and build three additional flights of locks. But it was the Central division that faced the greatest challenge-digging an 8-mile, 45-ft-deep channel to a depth of 40 ft above sea level through the Continental Divide, which was 260-ft-high Culebra Mountain.

Challenges of building the canal were exacerbated by the infectious diseases that ran rampant in the hot, wet Panamanian climate. By 1906, more than 85% of the canal workers had been hospitalized. The threat of yellow fever created panic and made the site undesirable and feared by employees. Malaria was no better - someone who fell ill usually required a stay in the hospital, and recovery did not ensure immunity. During the course of canal construction, tens of thousands of workers fell ill with yellow fever or malaria.

The Isthmus of Panama was an ideal environment for mosquitoes. The high temperature varies little during the year. The rainy season lasts for nine months and the interior of the Isthmus is tropical jungle, ideal for mosquito breeding. One the greatest obstacle to building the Panama Canal was disease.

Before any work could begin, the most deadly of the problems on the isthmus had to be overcome - disease. The United States government wasn't going to allow mortality rates like had been seen during the French reign. For this purpose, Colonel William C. Gorgas an American doctor, famous for wiping out yellow fever in Cuba, took charge of improving sanitary conditions and to destroy the types of mosquitoes that carried malaria and yellow fever in the Canal Zone. He devoted considerable time and effort clearing brush, draining swamps, and cutting out large areas of grass where the mosquitoes swarmed.

An integrated program of mosquito control was initiated that involved seven basic programs that were strictly enforced. These were, in order of importance:

Drainage: All pools within 200 yards of all villages and 100 yards of all individual houses were drained. Subsoil drainage was preferred followed by concrete ditches. Lastly, open ditches were constructed. Paid inspectors made sure ditches remained free of obstructions.

Brush and grass cutting: All brush and grass was cut and maintained at less than one foot high within 200 yards of villages and 100 yards of individual houses. The rationale was that mosquitoes would not cross open areas over 100 yards.

Oiling: When drainage was not possible along the grassy edges of ponds and swamps, oil was added to kill mosquito larvae.

Larviciding: When oiling was not sufficient, larvaciding was done. Chief Sanitary Inspector for the Canal Zone developed a larvacide mixture of carbolic acid, resin and caustic soda that was spread in great quantity.

Prophylactic quinine: Quinine was provided freely to all workers along the construction line at 21 dispensaries. In addition, quinine dispensers were on all hotel and mess tables. On average, half of the work force took a prophylactic dose of quinine each day.

Screening: Following the great success in Havana, all governmental buildings and quarters were screened against mosquitoes.

Killing adult mosquitoes: Because the mosquitoes usually stayed in the tent or the house after feeding, collectors were hired to gather the adult mosquitoes that remained in the houses during the daytime. This proved to be very effective.

Dr. Gorgas' effort did seem to be working. By August 1906, the monthly tally of new yellow fever cases had fallen by nearly half. In September, there were just seven new cases. Dr. Gorgas reduced the percentage of malaria-infected canal workers from 9% in 1905 to 5% in 1906, and finally to 1.6% in 1909. By the end of 1906, the Canal Zone was cleared of yellow fever.

The eradication of yellow fever and significant reduction in the number of malaria cases on the isthmus were two of the most revolutionary developments in the Canal Project.

The construction involved three major engineering projects.

The Gaillard Cut had to be excavated, a dam across the Chagres River had to be built to create Gatun Lake, and the canal's locks had to be constructed.

One of the greatest barriers to a canal was the continental divide, which originally rose to 110 meters (361 ft) above sea level at its highest point; the effort to create a cut through this barrier of rock was clearly one of the greatest challenges faced by the project, and indeed gave rise to one of the greatest engineering feats of its time.

The scale of the work was massive: six thousand men worked in the cut, drilling holes in which were placed a total of 27,000 ton (60,000,000 lb) of dynamite to break up the rock, which was then taken away by as many as 160 trains in a day.

Until 1906, there was no decision regarding whether the canal should be a lock canal or a sea-level canal - the excavation that was under way would be useful in either case. Towards the end of 1905, President Roosevelt sent a team of engineers to Panama to investigate the relative merits of both schemes, as regards their costs and time requirements. The engineers decided in favor of a sea-level canal, by a vote of eight to five; but the Canal Commission, and Stevens himself, opposed this scheme, and Stevens' report to President Roosevelt was instrumental in convincing the president of the merits of a lock-based scheme.

More than 75,000 men and women worked on the project in total; at the height of construction, there were 40,000 workers working on it. Nearly, 5000 workers died from disease and accidents during the American construction era. When the canal opened on Aug 15, 1914, it was a technological marvel. It was an important strategic and economic asset to the U.S., and revolutionized world shipping patterns, as its opening removed the need for ships to travel the long and dangerous route via the Drake Passage and Cape Horn (at the southernmost tip of South America). The canal saves a total of about 8000 miles (12,600 km) on a trip from New York to San Francisco by sea.

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ISSN 2348-3156 (Print)
International Journal of Social Science and Humanities Research ISSN 2348-3164 (online)
Vol. 5, Issue 1, pp: (318-342), Month: January - March 2017, Available at: www.researchpublish.com

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