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## **Roman Engineering**

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## **Introduction**

The Roman Empire brought us many things that we take for granted today. It had effects on literature, politics, and engineering. Urban planning, public water supplies, and transportation of water via aqueducts were introduced by the ancient Romans. They also developed roads and concrete. Many of these advancements were based on ancient Greek ideas that were further refined by the Romans.

The Roman Empire was an ancient superpower that went through various phases. It began as a Kingdom (an elective monarchy), then transitioned into a Republic, and eventually became an Empire. It expanded its influence throughout the Mediterranean region. The Roman Kingdom lasted from 753 to 509 B.C. The Republic existed from 509 to 27 B.C. The Roman Empire lasted from 27 B.C. to 476 A.D., when the western empire collapsed and fragmented into independent Barbarian kingdoms. The eastern part of the Roman Empire, known as the Byzantine Empire, persisted until its fall in 1453 A.D.

## **The History and Government of Rome**

The early Romans settled along the Tiber River. The climate was temperate and had rain throughout the year, making it ideal for raising animals and growing crops. This area also provided easy access to the Mediterranean Sea for fishing and trade. Agriculture appeared in Italy around 4000 B.C., with copper tools appearing around 2000 B.C. The earliest settlers were called Latins, who were mostly farmers and herders. Greeks settled south of Rome (beginning in 800 B.C.), which was ideal for establishing trading posts. They also settled in Sicily. Etruscans settled north of Rome. They mined copper and iron for weapons and armor and also mined marble for building.

The village of Rome was established in 753 B.C. on the Tiber River. Around 680 B.C., the Etruscans invaded Rome. They ruled it as one of their city-states, where they expanded its size and laid out city streets. Rome became a major trading port. In 642 B.C., Romans constructed the first bridge over the Tiber River, known as Pons Sublicius. A palace known as the Regia was built around 625 B.C. Rome had a territory of approximately 300 square miles and a population of almost 35,000 by the end of the sixth century B.C. During this time, Rome entered a period of turbulence that led to large-scale warfare and the eventual creation of the Roman Republic.

Rome became a republic in 509 B.C., after the overthrow of its seventh king, Tarquin the Proud, and lasted for over 400 years. The last monarch was Lucius Tarquinius Superbus, who was known as a cruel and tyrannical king, in contrast to his benevolent predecessors. In the early Roman Republic, the powers held by the monarch were transferred to two consuls. Consuls were annually elected magistrates who also served as commanders in chief of the Roman army. The magistrates were largely drawn from the Roman Senate, even though they were elected by the people. A constitution was established, which included a series of checks and balances as well as a separation of powers.

The most powerful ruling body of the Roman Republic was the Senate, which consisted of elected representatives. The wealthy people elected to office were called patricians, and they governed Rome. The working-class people were known as plebeians, and they had no say in the government and could not hold office. The Senate chose two consuls each year, who took over the king's powers, to make decisions on laws, taxes, and war.

The first Roman legal code was issued in 449-450 B.C. It was known as the Twelve Tables since it was inscribed on twelve bronze tablets. They provided the basis for all future civil law in ancient Rome.

Over time, the plebeians obtained more power. They gained the right to vote (for their patrician representative) by 494 B.C. Tribunes were elected by the plebeians, and they had the power to veto decisions made by the senate.

The Gauls sacked and burned Rome in 390 B.C. The Gallic army, led by Brennus, defeated the Romans on July 16, 390 B.C., north of Rome along the Allia River, and then sacked the city. The Romans returned after seven months to defeat the Gauls, under the leadership of Marcus Furius Camillus.

The last threat to Roman domination was defeated in 281 B.C. This was when Tarentum, a major Greek colony, requested the help of the Greek statesman and king Pyrrhus of Epirus.

The Romans gained control of the entire Italian peninsula by the year 264 B.C. Rome had three wars with Carthage, known as the Punic Wars, which gave Rome control of the Mediterranean. The first Punic War was fought from 264 to 241 B.C. over control of Sicily and the sea lanes of the western Mediterranean. Rome was victorious, although both sides suffered great losses of

men and ships. Rome did not have much experience with naval battles before this time, and Carthage was an established maritime power.

The Second Punic War was fought from 218 to 201 B.C., partially due to the war reparations from the end of the First Punic War. In 218 B.C., the Carthaginian general Hannibal attacked Roman territory. Hannibal was eventually defeated at the Battle of Zama in 202 B.C. The second Punic War was fought simultaneously with the First Macedonian War. The third Punic War took place from 149 to 146 B.C. This was the siege and destruction of Carthage that led to Roman domination over the Mediterranean. The survivors were enslaved, and this section of northern Africa became a Roman province.

There were reformers who attempted to address social problems in ancient Rome. There was a widening gap between the rich and poor as wealthy landowners drove small farmers from public land. Access to resources became increasingly concentrated in the hands of the wealthy elite, leading to economic inequality and social unrest. The Gracchi brothers, Tiberius and Gaius Gracchus, were notable reformers who advocated for land redistribution and the rights of the plebeians. They were both assassinated for their efforts.

Julius Caesar emerged as a prominent figure during the late Roman Republic. He played a crucial role in the transition from the Republic to the Roman Empire. Caesar was a military general who achieved significant military victories, including the conquest of Gaul (modern-day France). In 49 B.C., Caesar crossed the Rubicon River and marched on Rome, triggering a civil war against his rival, Pompey. Caesar emerged victorious and became the sole ruler of Rome.

Caesar implemented various reforms during his rule, including the introduction of the Julian calendar, which is the basis for the modern calendar. He also initiated public works projects to provide employment, granted citizenship to more people, and enacted land reforms to alleviate some of the social issues. However, his increasing power and perceived threat to the traditional republican system led to his assassination in 44 B.C. by a group of senators, including Brutus and Cassius.

The end of the Republic began when Julius Caesar came to power. When he became the dictator of Rome for life at the age of 55, it effectively marked the end of the Roman Republic. He was assassinated by a group of senators on the floor of the Roman Senate on March 15, 44 B.C. (the Ides of March). The group was led by Marcus Junius Brutus and Gaius Cassius.

Caesar's great-nephew Octavian joined forces with a consul named Mark Antony to crush the leaders of the conspiracy that killed Julius Caesar. They had a temporary alliance with Lepidus (a former consul) established in 43 B.C. that lasted for five years.

Following Caesar's assassination, a power struggle ensued, leading to the rise of Caesar's adopted son and heir, Octavian, who later became known as Augustus Caesar. Augustus established the Roman Empire in 27 B.C. and became its first emperor. He implemented various reforms and centralized power in his hands, effectively ending the Roman Republic. Augustus' reign marked the beginning of the Pax Romana (Roman Peace), a period of relative stability and prosperity that lasted for approximately two centuries.

The Roman Empire continued to expand under subsequent emperors, reaching its greatest territorial extent during the reign of Trajan (98-117 A.D.). The empire encompassed vast territories in Europe, North Africa, and the Middle East. The Roman Empire had a complex administrative system, with provinces governed by appointed officials and a centralized bureaucracy in Rome.

The Roman Empire faced numerous challenges throughout its history. In the third century A.D., it experienced a period of political and economic instability known as the Crisis of the Third Century. The empire faced invasions from various Germanic tribes and experienced internal conflicts and economic decline. Diocletian, an emperor who came to power in 284 A.D., implemented reforms to stabilize the empire, including the division of power between multiple emperors and the establishment of the Tetrarchy.

In the fourth and fifth centuries, the Western Roman Empire faced increasing pressure from barbarian invasions, particularly by Germanic tribes such as the Visigoths, Vandals, and Ostrogoths. In 476 A.D., the last Roman emperor of the West, Romulus Augustulus, was deposed by the Germanic chieftain Odoacer, marking the end of the Western Roman Empire. The Eastern Roman Empire, also known as the Byzantine Empire, continued to thrive and endure for several more centuries. Centered around the capital of Constantinople (modern-day Istanbul), it preserved many aspects of Roman culture and law while incorporating Greek influences. The Byzantine Empire faced numerous challenges, including conflicts with neighboring powers, such as the Sassanid Persians and later the Islamic Caliphates. It eventually fell to the Ottoman Turks in 1453, ending the Roman Empire altogether.

The Roman Empire left a lasting legacy in various areas, including architecture, engineering, law, language, and governance. Roman architectural achievements, such as aqueducts, amphitheaters (including the Colosseum), and monumental structures like the Pantheon, continue to inspire and awe people today. Roman law, with its emphasis on legal principles and rights, has influenced legal systems around the world. Latin, the language of the Romans, evolved into the Romance languages spoken today, such as Italian, Spanish, French, Portuguese, and Romanian.

Overall, the history of ancient Rome spans over a thousand years and encompasses significant political, social, and cultural developments. It has had a profound impact on the development of Western civilization and continues to be studied and admired for its achievements and contributions.

Octavian defeated the forces of Mark Antony and Queen Cleopatra of Egypt in 31 B.C. Mark Antony's affair with Cleopatra was considered an act of treason since she was the queen of another country. Octavian emerged as the sole leader of Rome by 29 B.C. He outwardly restored some of the institutions of the Roman Republic but retained all the real power. He assumed the name Augustus in 27 B.C. and became the first emperor of Rome. The age of the Roman emperors began with Augustus. He instituted many social reforms, was supported by the army, and was popular with the people. He created the Praetorian Guard and established a standing army. He diminished the political influence of the senatorial class by boosting the equestrian class. For example, senators lost their right to rule certain Roman provinces, such as Egypt. This was because the governor of that province was directly nominated by the emperor. Augustus was elevated by the Senate to the status of a god after his death.

After the death of Augustus in 14 A.D., his power passed to his stepson, Tiberius Caesar Augustus (Tiberius). Tiberius ruled from 14-37 A.D. and was unpopular, especially with the Senate. He was regarded as evil and melancholic and may have ordered the murder of some of his relatives. He died (or was killed) in 37 A.D.

The Julio-Claudian dynasty began with Augustus. This dynasty included Augustus, Tiberius, Caligula, Claudius, and Nero. They initiated the destruction of republican values and elevated Rome's status as the central power in the Mediterranean region. Any attempt to reestablish a Republic was defeated during this period. They continued to rule Rome after the death of Augustus until the death of Nero in 68 A.D.

The third Roman emperor was Gaius Caesar Augustus Germanicus, who was better known as Caligula. He was known as a bloodthirsty tyrant who ruled from 37-41 A.D. He met the same fate as Julius Caesar, being assassinated by the Praetorian Guard. Caligula was succeeded by Tiberius Claudius Caesar Augustus Germanicus, who was Caligula's uncle. Tiberius ruled from 41-54 A.D. and was best known for conquering Britain. He was poisoned by his wife in 54 A.D. The end of the Augustan dynasty came with Nero Claudius Caesar Augustus Germanicus (Nero), who ruled from 54-68 A.D. He was known for excesses that drained the treasury of Rome. Nero is known as the first to persecute Christians. He is also known for the Great Fire of Rome in 64 A.D., where he is rumored to have started the fire himself and blamed Christians. He eventually committed suicide after being condemned to death by the Senate and deserted by the Praetorian Guard.

A Roman engineer and architect named Vitruvius published *De Architectura* in 20 B.C. His ideas that all buildings should have the attributes of strength, utility, and beauty were adopted into Roman architecture.

Construction of the largest Roman aqueduct began in 19 B.C. It was located at Pont du Gard in present-day France. It would be completed by 50 A.D.

After the death of Nero, there were four emperors within a year. The last one, Vespasian, served from 69-79 A.D. His birth name was Titus Flavius Vespasianus. He and his successors were known as the Flavians and attempted to restore Senate authority, promote the public welfare, and mitigate the excesses of the Roman court. Construction of the Colosseum in Rome began approximately in 70 A.D. under Vespasian.

Titus served as emperor from 79-81 A.D. It was under Titus, as a general, that the siege and destruction of Jerusalem occurred in 70 A.D. The destruction followed the Jewish uprising of 66 A.D. As emperor, he completed the Flavian Amphitheater (Colosseum). Titus handled the recovery efforts, as emperor, after the eruption of Mount Vesuvius that destroyed the cities of Pompeii and Herculaneum in 79 A.D.

After the reign of Titus, his younger brother, Domitian, became emperor and ruled from 81-96 A.D. Domitian was known for his autocratic rule and his persecution of perceived enemies, including senators and intellectuals. He was assassinated in a conspiracy involving members of his own court.



The Flavian dynasty ended with Domitian's death, and the Roman Empire transitioned into the period known as the Five Good Emperors. These emperors were Nerva (96-98 A.D.), Trajan (98-117 A.D.), Hadrian (117-138 A.D.), Antoninus Pius (138-161 A.D.), and Marcus Aurelius (161-180 A.D.). This period is often considered a time of stability and prosperity for the Roman Empire.

The decline of the Roman Empire began in the 3rd century A.D. with a series of military, economic, and political challenges. The empire faced invasions from various Germanic and Persian tribes, economic instability, and internal power struggles. The Crisis of the Third Century, which lasted from approximately 235 to 284 A.D., was a particularly turbulent period marked by frequent changes in emperors and civil wars.

In 285 A.D., Emperor Diocletian came to power and implemented a series of reforms known as the Tetrarchy, dividing the empire into four regions with two co-emperors ruling each. This system aimed to improve administrative efficiency and stability. However, after Diocletian's retirement in 305 A.D., the tetrarchy system collapsed, leading to a new wave of civil wars and power struggles.

The Roman Empire continued to face external threats from barbarian invasions, especially from Germanic tribes such as the Visigoths, Ostrogoths, Vandals, and Huns. In 410 A.D., the Visigoths, led by Alaric, sacked Rome, marking the first time the city had been captured by an enemy in over 800 years. In 476 A.D., the last Western Roman Emperor, Romulus Augustus, was deposed by the Germanic chieftain Odoacer, effectively ending the Western Roman Empire.

The Eastern Roman Empire, also known as the Byzantine Empire, continued to exist for several more centuries, with its capital in Constantinople (modern-day Istanbul). The Byzantine Empire faced its own set of challenges, including conflicts with neighboring powers, territorial losses, and internal strife. It ultimately fell to the Ottoman Turks in 1453, when Constantinople was captured and renamed Istanbul.

The fall of the Western Roman Empire marked the end of ancient Rome and the beginning of the Middle Ages in Europe. The legacy of the Roman Empire, however, continued to influence art, architecture, law, language, and various aspects of Western civilization for centuries to come.

## **Life in Ancient Rome**

The people of ancient Rome lived in both the countryside and the cities. In the countryside, they were mostly farmers, with a few wealthy landowners. The majority of the rural population was poor. In the cities, there were merchants, scholars, traders, skilled workers, and artists. Many men in ancient Rome were soldiers.

Wealthy Romans resided in large houses that faced away from the street. These houses had courtyards and often had slaves, many of whom were captured during the conquest of territories. The wealthy also had kitchens in their houses. Most people used public bathhouses for bathing. The poorer residents of the cities lived in apartment buildings, while the poorer people in the countryside lived in mud-brick huts.

The oldest male citizen was the head of the Roman family, which was the basic unit of Roman society. Children were typically educated at home since there were no public schools in the early Republic. However, wealthy families often had Greek slaves as teachers. Boys from affluent families could attend school to learn mathematics, languages, sciences, or the arts. Children between the ages of 7 and 11 were sent to a private school called a "ludus" if their parents could afford it. The ludus taught basic reading, writing, and arithmetic. From the age of 12, children attended secondary schools where they learned Greek and Roman literature. The primary goal of education during the early Republic was to train young men in agriculture, Roman traditions, public affairs, and warfare. Young boys learned about civic life by accompanying their fathers to religious and political functions.

Marriages could occur at the age of 14 for males and 12 for females. The average life expectancy in ancient Rome was approximately 28 years.

The Romans believed in multiple gods. Some of these gods were the same as those worshipped by the Greeks, albeit with different names due to the strong Greek influence in Rome. The most powerful god in Roman belief was Jupiter, the god of the sky. Saturn was associated with farmers, while Mercury was associated with merchants. Mars was the god of war. In some parts of the Roman Empire, emperors were worshipped as gods. Other gods represented various aspects of Roman life. Temples were built to honor these gods, with the most important one being the Pantheon in Rome, which still stands today. Festivals were also held to honor the gods.

Roman families worshipped household gods called "lares." These gods had shrines built in Roman houses, and daily offerings were made to them.

Roman society had a hierarchical structure. Slaves occupied the lowest position, with freedmen above them, and free-born citizens at the top. Free citizens were further divided by class, with patricians at the top and plebeians below them.

Women were not considered full citizens and were therefore not allowed to vote or participate in politics. Over time, they gained limited rights that gradually expanded, including property rights and judicial rights, but they never gained the right to vote.

Ancient Romans typically had a meal at dawn called "ientaculum," which was similar to our breakfast. The main meal of the day, called "cena," was eaten in the mid-day to early afternoon. The evening meal, called "vesperna," was a lighter supper. Over time, as a wider range of foods became available, the cena shifted towards the evening, and a lighter mid-day meal called "prandium" was adopted.

Life in ancient Rome revolved around the city of Rome. The city had various monuments, such as the Colosseum, Trajan's Forum, and the Pantheon. Rome was situated on seven hills: Quirinal Hill, Viminal Hill, Capitoline Hill, Esquiline Hill, Palatine Hill, Caelian Hill, and Aventine Hill. Palatine Hill was home to imperial residences, giving rise to the term "palace." The lower plebeian and middle equestrian classes lived in the city center, often residing in crowded apartments similar to modern ghettos.

The Roman economy focused on farming and trade. By the 1st century B.C., vast grape and olive estates had developed, and olive oil and wine became the main exports as the Empire expanded. Farming utilized a two-tier crop rotation system, but productivity remained low. Industrial and manufacturing activities primarily centered around mining and quarrying stone, which served as the basic construction material for buildings and roads.

In the early Republic, the economy consisted mainly of small farms and paid labor. However, as Rome expanded, the conquests brought an influx of cheap slaves. By the late Republic, the economy relied heavily on slave labor for both skilled and unskilled work, with slaves estimated to account for 40 percent of the population in the city of Rome and 20 percent of the

total population of the Empire. When territorial expansion ceased, the prices of slaves increased, making hired labor more economically viable.

Bartering was common in ancient Rome, including in tax collection, but the Romans also had a system of currency. The main currency in ancient Rome was the denarius, a silver coin. Other coins, such as the aureus (gold coin) and the sestertius (bronze coin), were also used. The denarius was the most common and widely circulated coin, used for daily transactions.

Trade in ancient Rome was extensive, both within the empire and with other regions. The Romans built an extensive network of roads and sea routes that facilitated trade and communication. Goods such as grain, wine, olive oil, pottery, metals, and textiles were traded throughout the empire. The city of Rome itself served as a major hub for trade, attracting merchants and traders from various regions.

The Roman government played a significant role in regulating and overseeing trade. It imposed taxes and tariffs on goods transported within the empire, and it also provided protection for merchants and their goods. The Roman navy protected trade routes from pirates and ensured the safety of maritime trade.

In summary, life in ancient Rome varied depending on one's social status, with wealthy Romans enjoying luxurious lifestyles and the majority of the population engaged in farming or working in the cities. Education was primarily for the privileged, and the Roman religion centered around multiple gods. Roman society had a hierarchical structure, and women had limited rights. The Roman economy relied on farming and trade, with the use of slaves becoming widespread.

## Engineering Accomplishments

The Romans had many engineering accomplishments that still survive today. They often improved on older ideas, such as Greek ones, and developed them with new innovations or materials. There was a significant Greek influence, and their achievements generated wealth and improved the lives of Roman citizens. Their technical superiority was largely due to their expertise in civil and military engineering.

### 1. Aqueducts

One of the engineering ideas developed by the Romans was the aqueduct. Some of the aqueduct elements still supply water to fountains in the city of Rome. These structures had existed before the Romans built their first aqueduct, known as Aqua Appia, in 312 B.C. It was a little over 10 miles long. The aqueducts consisted of conduits, tunnels, canals, ditches, bridges, and pipelines that brought water from springs and mountains to the cities and towns of the Roman world.

Aqueducts were used to supply water to Roman cities, improving public health and sanitation. They also supplied industrial sites and provided irrigation for agriculture. This water was available to all citizens, and there were public fountains, baths, and toilets that flushed using the flowing water. The water was also used for firefighting purposes, as many parts of Roman cities were constructed with wood.

Aqueducts transported water from higher elevations to lower ones using only gravity. They typically descended from an elevation of 1,000 feet above sea level (at the source) to 330 feet (at the reservoir near Rome). A slight downward inclination allowed the water to flow naturally from higher to lower elevations, supplying water for drinking, fountains, latrines, wealthy households, public bathhouses, and water-powered mills or machines. Settling tanks were used at regular intervals to regulate water flow.

The aqueducts varied in length, with some extending over 60 miles. They were constructed both above and below ground. One notable aqueduct was the Aqua Marcia, built between 144 B.C. and 140 B.C. It had an underground section spanning 57 miles and an aboveground section of about 6 miles leading into Rome. In total, eleven aqueducts transported water to Rome, delivering approximately 260,000 gallons per day.

Aqueducts were carefully planned and constructed, often by Roman legions, to ensure proper water flow. They were built using materials such as wood, brick, stone, or a combination. For underground construction, tunnels were cut through solid rock, typically measuring three feet wide by six feet high to accommodate workers. The tunnels were lined with stone after excavation.

Tanks were frequently incorporated into the tunnels to slow down water and filter impurities from the aqueduct. These tanks were built into the tunnel floor, allowing water to collect and overflow while leaving impurities like rocks and sand at the bottom.

In some cases, the tunnel was lined with porous rocks, and a special volcanic ash cement known as pozzolana was used to prevent water from leaking through the pores.

Aboveground sections of the aqueducts were constructed using stones or bricks. They resembled bridges, with water flowing in a channel on top. In situations where building a raised aqueduct was impractical, an inverted siphon was used to transport water across valleys.

Upon reaching the city, the water flowed into a cistern, which was a reservoir built on high ground. This allowed the water to flow downhill quickly to reach the city.

Regular maintenance was essential for the aqueducts and was primarily carried out by slaves. This involved repairing leaks and clearing accumulated debris. The tanks also required regular cleaning to ensure effective filtration of impurities.

## **2. The Arch**

Although the arch had been present for centuries in ancient Egypt and Greece, the Romans made significant improvements to it. The arch can be observed in their buildings, bridges, and aqueducts, among other structures. Even today, arches can be seen in modern buildings and bridges.

The Romans are renowned for their mastery of the arch. An arch is a curved structure that spans an opening and supports loads. Arches serve as the foundation for vaults and domes. The arch is constructed using wedge-shaped blocks known as voussoirs, where the upper edge is wider than the lower edge. These voussoirs are placed side by side, creating an arch. The key idea is that each voussoir is firmly pressed against the neighboring blocks, allowing for the uniform distribution of loads. The central voussoir is called the keystone, and the point at

which the arch begins to rise from its vertical supports is known as the springing line. During the construction of an arch, the voussoirs need to be supported from below until the keystone is set in place. Temporary supports used for this purpose are called centring and are typically made of wood.

The curve of an arch can be either semicircular or segmental. Arches have proven to be advantageous compared to horizontal beams. They can span wider openings while being constructed from smaller bricks or stones, as opposed to a large and heavy horizontal stone member. Additionally, an arch can bear a greater load than a horizontal beam. This is because the downward pressure on an arch forces the voussoirs together, exerting a diagonal force that squeezes the blocks outward radially. This force, known as thrust, can cause the arch to collapse if it is not adequately supported or buttressed. In most cases, the Romans did not use mortar for arch construction.

The Romans also realized that an arch did not necessarily have to be continuous or a full semicircle. They developed the segmented arch, which allowed for more flexible and efficient construction. They further advanced the concept of the arch by creating the dome, which is essentially an extension of the arch in three dimensions. The construction of domes became possible due to the availability of concrete, a material the Romans extensively used.

### **3. Bridges**

Another development of the Roman Empire was bridges that relied on the arch structure for longer spans and greater strength. They built large stone bridges as early as the second century B.C. One of these was the Pons Aemilius in Rome, built in 142 B.C. It was 443 feet long. Their first stone bridges used blocks held together using iron clamps. By the mid-second century B.C., Romans made use of concrete to build bridges and used a concrete core with a stone facing. The use of concrete increased the bridges' strength and durability.

The use of the arch as a basic structure significantly increased the strength and length of the bridges. They used semicircular arches and segmental arches for bridges. Some of these bridges still stand today. An example is the Alcantara Bridge over the Tagus River in Spain. It is 597 feet long and has 95-foot arches. Its arch stones weighed up to eight tons each and needed no mortar in the joints due to their perfect shape. The Alcantara Bridge still stands today. The longest bridge was Trajan's Bridge over the lower Danube, built by Apollodorus of Damascus. Roman bridges were normally at least 59 feet above the water level.

In the field of military engineering for which they are famous, the Romans designed pontoon bridges, and they were a specialty of Julius Caesar. In 55 B.C., he built a pontoon bridge to cross the Rhine River that was 1,311 feet long. It is difficult to build a bridge without diverting the river, so engineers rammed timbers into the riverbed at an angle against the current. This gave the foundation extra strength. They placed protective pilings upstream to protect against any destructive logs that might float downstream toward the bridge. The beams were lashed together, and a wooden bridge was built on top. The construction took ten days, which was much less time than building a rock or concrete bridge.

#### **4. Concrete**

Concrete was one of the most important contributions made by the ancient Romans and replaced marble as the primary Roman building material. Concrete was used in bridges, buildings, and aqueducts. It was inexpensive, fireproof, and resistant to earthquake damage. The invention of concrete dates back to the late third century B.C., when pozzolana was added to mortar made from a mixture of brick or rock pieces, lime or gypsum, and water. Pozzolana contains silica and alumina, which created a chemical reaction that strengthened the cohesiveness of the mortar. It was originally used by the Romans to form strong bases for altars. In the second century B.C., the Romans began using concrete to create freestanding structures, such as the Pantheon. Roman concrete has sometimes been said to be better than modern Portland cement, and research has supported this claim. Concrete was widely used by the first century B.C.

Rome had a period of rapid advances in concrete composition. During this time, they learned that crushed terracotta could be added to the mortar, which could be used for waterproofing cisterns or structures exposed to the weather. They developed underwater concrete by the middle of the first century A.D. This was made by mixing one part lime with two parts volcanic ash and placing the mixture in volcanic tuff. It was then hydrated by seawater, which triggered the hardening and heat-releasing chemical reaction of the concrete. This type of construction was used to build harbors, such as the one in the city of Caesarea.

Studies comparing Roman concrete to Portland cement analyzed Roman harbors in the Mediterranean. Roman concrete has remained intact after at least 2,000 years of constant exposure to the sea, while Portland cement starts to erode after 50 years of exposure to seawater and does not bind as well as Roman concrete.



## **5. Dams**

The ancient Romans built many dams to collect water for transportation through aqueducts. An example is the Subiaco dams, one of which was the highest ever built. These were three gravity dams, two of which fed Anio Novus, the largest aqueduct supplying Rome. There were 72 dams built in Spain alone. Several earthen dams were also constructed. An example is Longovicium in Northern England, which was possibly used for industrial smithing or smelting based on slag found at the site.

## **6. Roads**

The ancient Romans developed a network of roads that extended throughout the Empire. Some of these roads, such as the Appian Way, are still in use today, so they were very well constructed. They had a solid foundation and good drainage built into the design. They were originally developed for military use, so the Roman army could get to problem areas in the Empire quickly. They were also used for travel and trade. These roads extended as far north as Northern England and as far south as Southern Egypt. There were almost 75,000 miles of roads built during the Roman Empire.

The Romans used a straight path for their roads as well as they could. They had a tendency to go through obstacles, rather than around them. These obstacles included forests, rivers, and mountains. The first major road was the Via Appia, which was started in 321 B.C. It connected Rome to Capua, which was 118 miles away. Obstacles were avoided in many ways. Bridges were constructed over waterways. Raised causeways went through marshland. Hills were tunneled through.

There were several steps involved in the building of roads in ancient Rome. The first step was to set the curb stones. Then a pit of approximately 3 feet deep was dug between them, spanning the entire width of the road. This served as the base of the road. It was then covered with bricks, rocks, or gravel that was compacted. A layer of finer gravel was then added. The road was then paved with flagstones. The road had a slight incline at the center so that rainwater would flow to the curb on both sides.

The higher-quality Roman roads consisted of five layers. The bottom layer was called *pavimentum* and was one inch thick, made of mortar. There were then four layers of masonry. The layer directly above the *pavimentum* was known as the *statumen*, which was one foot thick and made of stones bound together by clay or cement. Above the *statumen* was the *rudens*,

made of ten inches of rammed concrete. The next layer was the nucleus, 12 to 18 inches of successively laid and rolled layers of concrete. The summa crusta of silex or polygonal lava slabs, one to three feet in diameter and 8 to 12 inches thick, were placed on top of the rudens. The final upper surface was concrete or well-smoothed and fitted flint.

Milestones were placed along the road at intervals of one mile (as Rome defined it). A mile was 1,000 paces. The milestones were 5 feet high and were heavy columns with the mile number, distance to Rome, and the name of the official under which the road was built.

## **7. Tunnels**

Tunnels were widely used by the ancient Romans for their roads and aqueducts. As already mentioned, they tended to go through obstacles, such as mountains, instead of around them. One of the methods of tunnel construction was known as the qanat method. It was developed by the Persians in the early first millennium B.C. and was the most common and quickest method. The tunnel was kept straight using a line of posts going over a hill, and vertical shafts were dug at regular intervals. The vertical shafts ensured that the tunnel maintained the correct trajectory and provided ventilation for the workers.

Another tunnel construction method was the counter-excavation method. It was used to dig through high mountains. The tunnel was dug from both sides of the mountain and met at a central point. This required a lot of planning and checking the progress. The advancing direction had to be checked using surveying and geometry. Ventilation was an issue as shafts could not always be dug from the top of the mountain.

A method used for hard rock was known as fire quenching. This technique required heating the rock with fire and suddenly cooling it (quenching) with cold water, causing it to crack. Tunnels often took years to build. For example, the tunnel that was built in 41 A.D. to drain the Fucine Lake took 11 years to complete.

## **8. Water Power**

Another area in which the Romans excelled was water power, which they developed by combining Greek technologies, such as the water wheel and toothed gear. They were one of the first civilizations to harness the power of water. They had mills to grind grain and produce flour as far back as 300 B.C. After inventing the watermill in the mid-third century B.C., they employed either a vertical or horizontal water wheel to power the mills. The watermills used a

river or aqueduct to drive the water wheel. A system of tanks and pipes was used to control the power of the water hitting the wheels.

One of the more famous mill sites is the Barbegal aqueduct and mills near present-day Arles in Southern France. It is approximately 7.5 miles north of Arles and was built towards the end of the first century A.D. The water passed through a 62-foot downhill path and drove 16 overshot waterwheels. The mill was able to process three tons of grain per hour and produced flour that could feed 40,000 people per day, making it one of the largest in the ancient world.

The Hierapolis sawmill was a Roman water-powered sawmill located in present-day Turkey. It dates back to the third century A.D. It is the earliest known machine to combine a crank with a connecting rod.

There was a complex of mills on the Janiculum hill in Rome, powered by the Aqua Traiana aqueduct. The water mills were likely built during the reign of Aurelian, from 270-275 A.D. The ancient Romans developed the undershot wheel that used flowing water instead of falling water. This innovation was useful during the Gothic siege of Rome in 537 A.D., as it solved the problem of the siege cutting off food supplies to Rome. The mills remained in operation until approximately 827-844 A.D., during the time of Pope Gregory IV.

Mills were not the only water devices used by the ancient Romans. They also had saws for wood and stone, as well as devices for crushing metal ore. Sawmills had stone-cutting saws that were powered by waterwheels. They used a trip hammer that utilized a waterwheel, cam, and hammer for crushing mined ore.

## **9. Mining**

The Romans used their knowledge to develop mining technology. Their mining sites often had aqueducts built around them with giant tanks. The tanks were used for a mining technique called hushing. Hushing involved using water force to wash away earth to reveal mineral veins or rocks. They were also used in fire quenching, where rocks were heated and water released from the tanks, fracturing the rock. This method worked well in open-pit mining but was dangerous underground.

The Romans used water-powered stamp mills and trip hammers to crush ore into small pieces for further processing. The ore was often washed to collect gold dust.

## **10. Weapons**

The Romans were known for their weapons. These weapons allowed them to conquer faraway lands and gave them an advantage in battle. The onager and the ballista were used in siege warfare and were the most powerful weapons the Romans had.

The onager was a Roman-invented one-arm torsion catapult that could launch heavy projectiles. It had a simple design and consisted of a large horizontal frame on the ground and a vertical frame with a padded buffer on the front. The horizontal frame had stretched, twisted ropes made from springy animal sinews (tendons). It was a catapult-like device that fired a bucket or sling of stones or balls of combustible clay weighing up to 55 pounds. The onager was used for bringing down walls and setting fires during siege warfare. However, it was built on location and weighed a significant amount, so it was not mobile.

The Romans also used the ballista in siege warfare. The ballista originated in Greece and was adapted and improved by the Romans. It was essentially a large crossbow that also used sinews and could launch projectiles up to 1,500 feet. It was lighter than the onager and could also be fitted with javelins or large arrows. Ballistas were used to target personnel or smaller buildings during siege warfare. They were more accurate than the onager but far less powerful. Roman engineers invented the carroballista, where the ballista was mounted on a cart.

## **11. Heated Floors**

The ancient Romans developed heated floors in an attempt to control the environment in their buildings. They used sets of hollow clay columns spaced a few feet apart below a raised floor supported by concrete pillars. Hot air and steam were pumped from a furnace through these columns, called hypocausts. The hot air circulated below the floor and through hollow tiles in the walls that absorbed the heat. It was an ancient way of providing central heating.

## **12. Sewers**

Another development of the ancient Romans was their sewer system. The sewers were not originally built as sewers but evolved into them. For example, the Cloaca Maxima was originally a channel to drain some of the local marshes. Construction started around 600 B.C., and waterways were added over the next several centuries. The Cloaca Maxima drained into the Tiber River, which became polluted with human waste.

Many Roman houses came to have indoor plumbing and flush toilets, and Rome had a complex sewer system leading to the Cloaca Maxima. The sewer system had lead pipes, and there have been arguments that lead poisoning contributed to a decline in the birth rate leading up to the fall of Rome. However, there have also been arguments that the lead content would have been minimized due to the constant flow of water and that the pipes would have been coated with deposits that prevented lead from penetrating into the water supply.

### **13. Civil Engineering/Architecture**

Ancient Rome had impressive buildings and entertainment venues. They did not differentiate between civil engineering and architecture as separate fields. One of these venues was the Circus Maximus. It was an entertainment venue used mostly for chariot racing, built on the level ground of the Valley of Murcia. It was the first and largest stadium in ancient Rome. Permanent wooden gated starting stalls for chariot races were built in 329 B.C. A fire in 31 B.C. damaged the wooden bleachers during construction. The bleachers were estimated to hold 150,000 spectators. The Circus Maximus was 2,037 feet long and 387 feet wide.

The Colosseum in Rome began construction around 70 A.D. under the emperor Vespasian. This venue was specifically built for public games. It became a site where a lot of killing occurred for centuries, including gladiator combat, animal fights, and the execution of criminals and Christians.

The Pantheon was completed in 125 A.D. and was a Roman temple. It was built on the site of a former temple. It has been in continuous use throughout its history, making it one of the best-preserved buildings from ancient Rome. It was part of a complex that included three buildings: the Baths of Agrippa, the Basilica of Neptune, and the Pantheon. The present construction began in 114 A.D. under Trajan. Archaeological evidence indicates that previous constructions had been destroyed by fires in 80 A.D. and 110 A.D. The Pantheon had a concrete dome that was supported by a ring of voussoirs. The dimensions would fit a 43.3-meter (142.05 ft) diameter sphere under its dome. Less dense stones were used toward the top to reduce stress.

Today, the Baths of Diocletian and the Baths of Caracalla are known for their state of preservation. The principles behind their design were described by Vitruvius.

## **Conclusion**

Many of inventions that we take for granted today actually came from ancient Rome. Romans often built upon ideas that they borrowed from ancient Greece. They built roads that still exist to this day. They had aqueducts to carry water into the cities. They had plumbing and were able to dispose of waste through their sewer system. They developed weapons to help conquer their enemies. They also developed tools and processes for mining. Many of the structures built by the ancient Romans still exist today.

## Timeline of Major Events in Ancient Rome

<b>Event</b>	<b>Date</b>
Greeks begin settlements in southern Italy	800 B.C.
The village of Rome is founded on the Tiber River	753 B.C.
The Etruscans invade Rome	~680 B.C.
Romans construct the first bridge over the Tiber River (known as Pons Sublicius)	642 B.C.
Palace (Regia) is built	~625 B.C.
Construction starts on the Cloaca Maxima	~600 B.C.
Rome becomes a Republic with the overthrow of Tarquin the Proud	509 B.C.
Plebeians get the right to vote for their patrician representative	494 B.C.
The first Roman legal code (The Twelve Tables) comes out	~450 B.C.
Gallic army under Brennus battled the Romans on the banks of the Allia River	16 Jul 390 B.C.
The Gauls sack and burn Rome	390 B.C.
The first major road is started (Via Appia)	321 B.C.
The first aqueduct is built (Aqua Appia)	312 B.C.
Rome conquers northern Italy	295 B.C.
Tarentum is eliminated as a threat to Roman domination	281 B.C.
Rome conquers southern Italy	275 B.C.

Rome begins war with Carthage (First Punic War)	264 B.C.
First Punic War ends	241 B.C.
Second Punic War begins	218 B.C.
Hannibal is defeated at the Battle of Zama	Oct 202 B.C.
Second Punic War ends	201 B.C.
Rome conquers Greece	149 B.C.
Rome declares war on Carthage, beginning the Third Punic War)	149 B.C.
Third Punic War ends	146 B.C.
Aqua Marcia is started	144 B.C.
Pons Aemilius (bridge) is built	142 B.C.
Aqua Marcia is completed	140 B.C.
Tiberius Gracchus leads a reform movement	133 B.C.
Gaius Gracchus leads a reform movement	123-122 B.C.
Gaius Marius holds the first of seven consulships, due to his military skills	107 B.C.
Gaius Julius Caesar is born	13 Jul 100 B.C.
Marius struggles against attacks from political opponents as well as other generals	91 B.C.
Sulla is elected for his first consulship	88 B.C.
Marius returns to Rome while Sulla was campaigning in Greece	87 B.C.



Marius dies a few months after he seized power	86 B.C.
Cinna is killed	84 B.C.
Sulla becomes military dictator	~82 B.C.
Julius Caesar earns the Civic Crown for courage at the Siege of Mytilene	80 B.C.
Julius Caesar is kidnapped	75 B.C.
Crassus suppresses a slave rebellion led by Spartacus	71 B.C.
Cicero is elected consul	63 B.C.
Julius Caesar is elected senior Roman Consul	59 B.C.
Julius Caesar is appointed as governor of the region of Gaul	58 B.C.
Julius Caesar builds a pontoon bridge across the Rhine River	55 B.C.
Pompey's wife dies	54 B.C.
Crassus is killed in battle	53 B.C.
Pompey takes position as only consul	53 B.C.
Julius Caesar crosses the Rubicon River, invaded Rome, and pursued Pompey as he fled Italy.	49 B.C.
Battle of Pharsalus where Julius Caesar is victorious and destroys the optimates leaders during this and other campaigns	Summer 48 B.C.
Pompey is murdered in Egypt	48 B.C.
Julius Caesar becomes dictator for life	45 B.C.

Julius Caesar is stabbed to death on the floor of the Roman Senate	15 Mar 44 B.C.
Octavian, along with Antony and Marcus Aemilius (Caesar's best friend) establishes Second Triumvirate	43 B.C.
The Roman Senate deifies Caesar and Octavian becomes son of the deified	42 B.C.
Julius Caesar's assassins are defeated in the Battle of Philippi	42 B.C.
Lepidus forced to retire after betraying Octavian in Sicily	36 B.C.
Egyptian forces are defeated at the Battle of Actium. Antony and Cleopatra commit suicide	31 B.C.
Octavian emerges as the sole leader of Rome	29 B.C.
Julius Caesar's adopted son Octavian is named the first emperor of Rome (Augustus)	27 B.C.
Vitruvius publishes "De Architectura"	20 B.C.
The largest Roman aqueduct at Pont du Gard (in present day France) is started	19 B.C.
Augustus dies and is succeeded by Tiberius	14 A.D.
Tiberius retires to Capri after an agreement with the Senate	26 A.D.
Tiberius dies, although he may have been killed and is succeeded by Caligula	37 A.D.
The Praetorian Guard murders Caligula	41 A.D.
Tunnel is built to drain the Fucine lake under Claudius	41 A.D.
Pont du Gard aqueduct is completed	50 A.D.

Claudius is poisoned by his wife and is succeeded by Nero	54 A.D.
Great Fire of Rome	64 A.D.
Jewish uprising in Judea	66 A.D.
Nero kills himself	68 A.D.
Year of the four emperors the last being Vespasian	~68-69 A.D.
Siege and destruction of Jerusalem	70 A.D.
Construction of the colosseum in Rome is begun under Vespasian	~70 A.D.
Death of Vespasian and Titus becomes emperor	79 A.D.
Eruption of Mount Vesuvius and destruction of Pompeii	79 A.D.
Titus dies of a fever and is succeeded by Domitian (his brother)	81 A.D.
Roan-Persian Wars begin	92 A.D.
Domitian is murdered and the Senate appoints Nerva as emperor	96 A.D.
Nerva abdicated and died and was succeeded by general Trajan	98 A.D.
Height of Ancient Rome (covered 1.9 million square miles)	117 A.D.
End of Trajan's rule	117 A.D.
Caesar Trajanus Hadrianus (Hadrian) succeeds Trajan	117 A.D.
Hadrian is succeeded by Antonius Pius	138 A.D.
Antonius Pius dies of an illness and is succeeded by Marcus Aurelius	161 A.D.

Parthian War begins	161 A.D.
Parthian War ends	166 A.D.
Marcus Aurelius dies of unknown causes and is succeeded by his son Commodus	180 A.D.
Commodus is assassinated	192 A.D.
Lucius Septimius Severus becomes emperor	193 A.D.
End of the reign of Severus after becoming ill and dying	211 A.D.
Diocletian (Jovius) becomes emperor	284 A.D.
Diocletian begins the persecution of Christians	303 A.D.
Diocletian abdicates	305 A.D.
Constantine (son of Constantius) assumes power	324 A.D.
Constantine makes Christianity the official religion	325 A.D.
Battle of Samarra	363 A.D.
Battle if Adrianople	378 A.D.
The Empire loses Britain	~410 A.D.
Attila and his Huns invade Gaul and Italy	~450 A.D.
Collapse of the Western Roman Empire	476 A.D.
Gothic siege of Rome	537 A.D.

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