Rainer Nobis

ILLUSTRATED HISTORY OF CEMENT AND CONCRETE

The Exciting Development of Two Outstanding Building Materials

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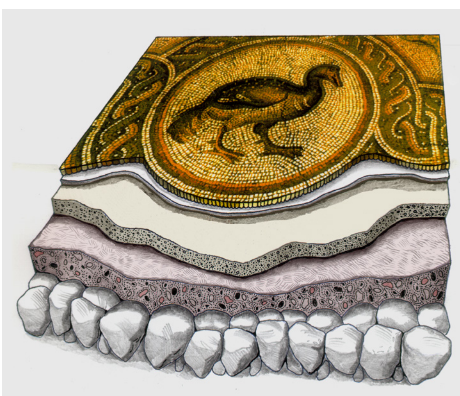

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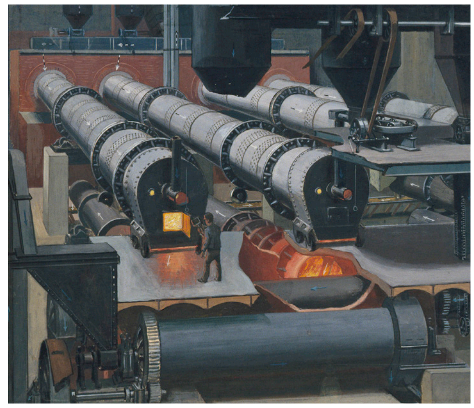


The beginning

The life of the early, mostly nomadic people took place mainly in natural caves. People lived from hunting, collecting berries, roots and seeds. They were strong and healthy. (1.1)

The evolution of mankind began at least two million years ago. The Middle Palaeolithic is dated to the period between 250,000 and 50,000 BC. The Palaeolithic period or Old Stone Age began with the evolution of Homo Sapiens as we imagine them today. People tried to protect themselves from wind, cold, sun, rain and dangers in natural caves. Their inhabitants were not yet sedentary, but followed the animal migrations or visited warmer regions according to the seasons. They lived by hunting and collecting wild berries, roots and seeds.

At about the same time, the quality of stone tools and weapons began to improve. Cave paintings or artistic artefacts began to be more expressive. Their depictions bear witness to the importance of hunting and presumably high female fertility. People were healthy because they lived in harmony with nature.

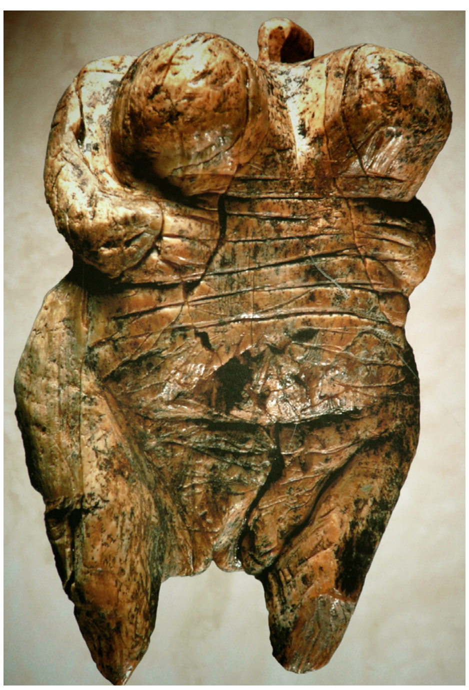
Nomadic families and clans probably had certain hunting grounds and waterholes, but needed practical and mobile shelters during their migrations. Thus tents made of various materials were used. They had to be easy to transport, watertight and windproof.

As the earth's climate became warmer, the Sahara region became more arid and northern latitudes became free of ice. Now the transition from the Old Stone Age to the New Stone Age began. Archaeologists date this period between 10,000 and 3,000 years BC.

Early Neolithic cultures build first permanent dwellings

Compared to the Palaeolithic period with its very slow technical development, the Neolithic period brought extensive innovations that took a few millennia. People began to live in larger settlements, build permanent dwellings and protect themselves against enemies by means of defensive structures. In this early Neolithic period, the first known permanent settlements were built around 10,000 BC. It was the time when primitive agriculture began, sheep were domesticated, the first woven fabrics and, above all, pottery made of fired clay were made. The processing of burnt lime has been proven. The first tools made from copper appeared in the 8th millennium BC, while bronze tools were only made 5,000 years later. The first evidence of wheels dates back to the 4th millennium BC.

Until not long ago archaeologists believed that one of the oldest settlements in human history was to be found in Jericho, Palestine. Its origin is dated around 9,000 BC. The proven circular buildings, measuring approx. five meters in diameter, consist-

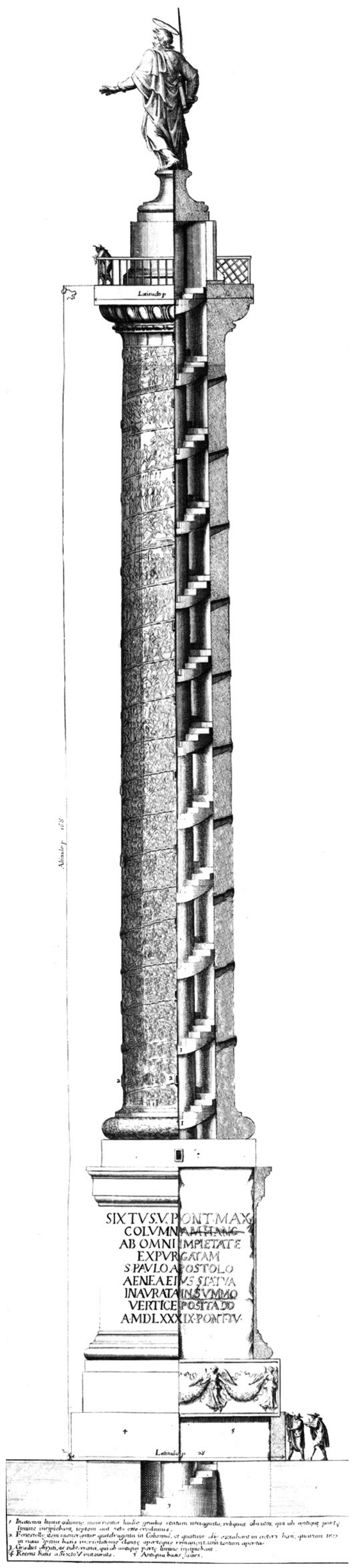


The Venus of the Hohlefels is a figurine about six centimeters high, carved from mammoth ivory, which was found during excavations in a karst cave in southern Germany. At an age of over 30,000 years, it is one of the oldest representations of the human body in the world. (1.2)

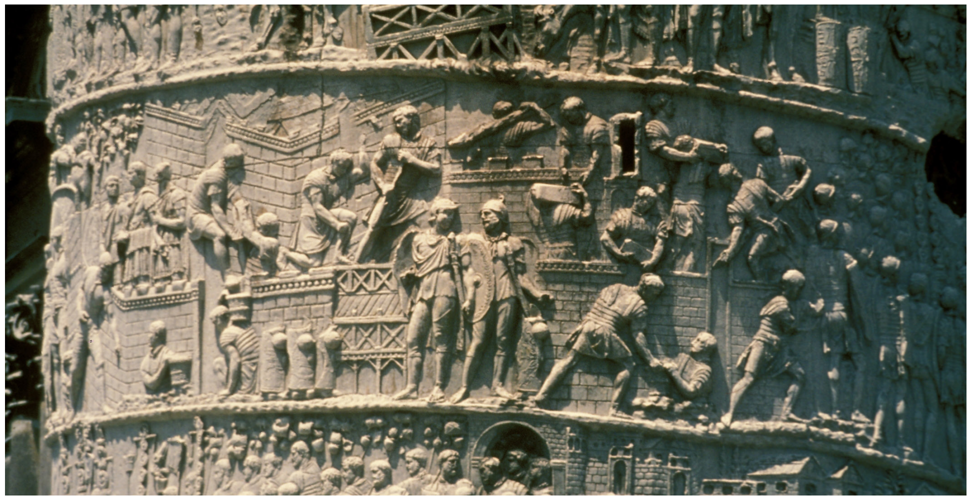
One of the oldest cave paintings in the world is located in the Spanish Altamira Cave near Santillana. The bison painting is estimated to be over 20,000 years old. (1.3)

A major developmental step at the end of the Palaeolithic period was the transition from knapped stone tools (e.g. hand-wedges) to finely polished stone tools, e.g. stone axes. (1.4)

Rome builds on monumental scale with opus caementitium



Trajan's column in Rome proudly displays Roman achievements. (11.1)



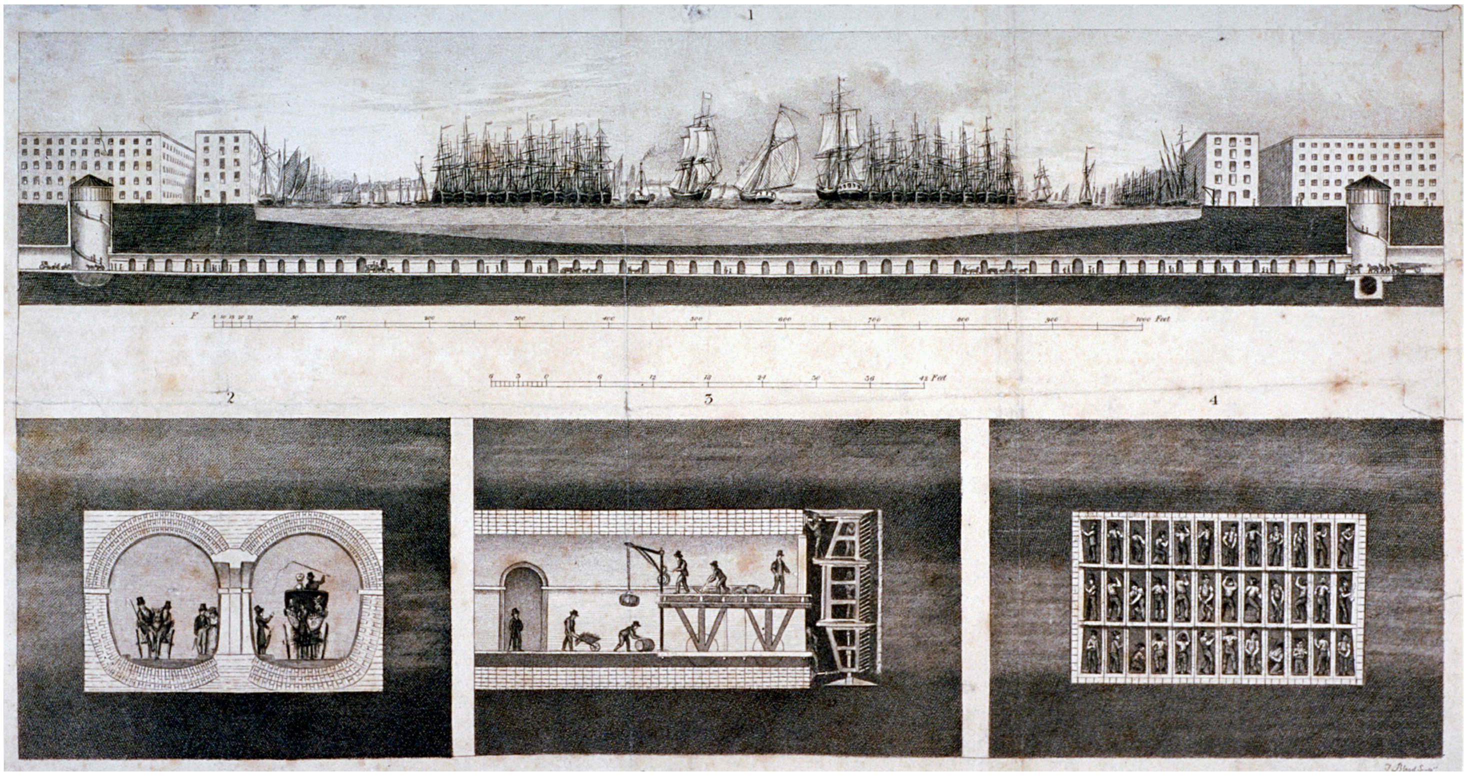
A section of Trajan's Column on which construction workers are depicted building a city wall with opus caementitium. (11.2)

The architectural heyday of Rome with its unparalleled size and splendour, as well as its unrivalled luxury, was between 40 BC and 200 AD. The Romans learned early on from the Greeks, broadened the horizon and applied the knowledge practically.
With ever more refined construction methods and the development of better building materials, the architects of Rome were able to construct a multitude of colossal buildings using completely new architectural and structural possibilities. These mainly related to infrastructure projects such as roads, harbours, viaducts, aqueducts and amphitheatres, as well as palaces and palaces of worship.

Harbours

Rome needed ports to defend and expand its vast empire. Finished goods and equipment for distant armies were exported, while bulk goods, especially grain, were imported. Harbours were planned primarily for the western coast of the core empire, where natural bays and estuaries were already particularly suitable for construction.
From around the 3rd century BC, the port of Pozzuoli, located in the Bay of Naples, was one of the first to develop into one of the most important ports in the western Mediterranean. The city was located on the Via Appia, one of the most significant long-distant roads at that time. From its port there was lively transport of people and goods, especially to Egypt, from where Rome received its grain deliveries. Its pier, built at the beginning of the 2nd century BC, is said to have been 372 meters long and around 15–16 meters wide. It is believed to have stood on 15 huge pillars of opus caementitium.
Around the turn of the millenium, activities in Pozzuoli decreased and were concentrated more on the famous ports of Caesarea on the coast of Judea and Ostia at the Tiber estuary, the gate to Rome.
Herod the Great (73 BC–4 AD), appointed as king of the Jews and vassal of the Romans, was obsessed with building a port that would serve as a link between the Roman estates in the region and the core empire. It was to be built in front of the beaches of a small settlement where the ruins of the Strato Tower were located, a remnant of Phoenician fortifications.
However the location was highly unsuitable. Strong sea surges and currents, soft

Fresco from the town of Stabiae probably showing the harbour of Pozzuoli around 200 BC. (11.3)



The Thames Tunnel in London represents the first example of being able to transverse the river underwater. New excavation methods and tools were applied, significantly improving the construction progress and safety of the workers. Nevertheless, the construction of the 370 m long tunnel took about 18 years due to financial and technical problems, water ingress and other considerable interruptions. (15.3)

the production of large blocks for piers, harbour fortifications and breakwaters, and plaster for brick facing.

In 1880, English Portland cement exports accounted for about 30% of the country's production. Abroad it was of unbeatable quality.

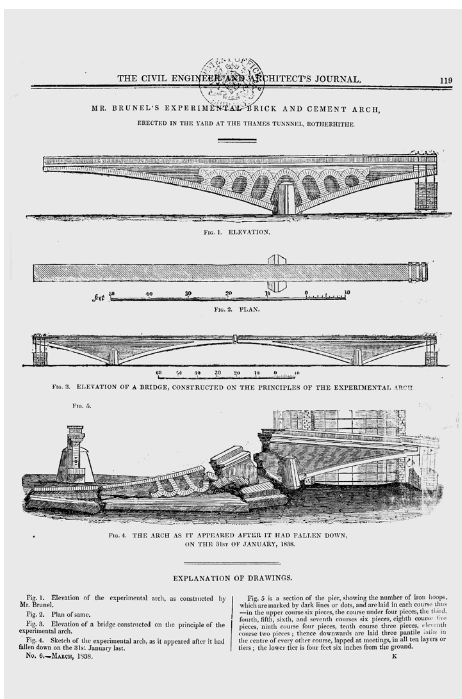
The Thames Tunnel

Early on there were two particularly prominent construction projects in England, which quickly made Roman and Portland cement very popular.

In 1824, under the technical direction of Marc Isambard Brunel, a company was founded to build a 370-meter-long pedestrian tunnel under the River Thames between Rotherhithe and Wapping. There had already been two unsuccessful attempts by other companies.

Brunel was a highly talented French engineer who fled the French Revolution and acquired English citizenship. His new tunnel construction concept was based on shields that were driven into the existing clay by means of heavy threads, thus stabilizing the unsecured tunnel wall and protecting the workers during advancement of the work. The lining of the tunnel wall immediately followed the shields.

Work began in Rotherhithe in March 1825 with the sinking of a vertical shaft, later used as an entrance to the tunnel. The tunnel was built completely from using several layers of clay bricks. The danger of water ingress was constantly present. Thus, it



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MR. BRUNEL'S EXPERIMENTAL BRICK AND CEMENT ARCH,

ERECTED IN THE YARD AT THE THAMES TUNNNEL, ROTHERHITHE.

FIG. 1. ELEVATION.

FIG. 2. PLAN.

FIG. 3. ELEVATION OF A BRIDGE, CONSTRUCTED ON THE PRINCIPLES OF THE EXPERIMENTAL ARCH

FIG. 5.

FIG. 4. THE ARCH AS IT APPEARED AFTER IT HAD FALLEN DOWN, ON THE 31ST OF JANUARY, 1838.

EXPLANATION OF DRAWINGS.

Fig. 1. Elevation of the experimental arch, as constructed by Mr. Brunel.

Fig. 2. Plan of same.

Fig. 3. Elevation of a bridge constructed on the principle of the experimental arch.

Fig. 4. Sketch of the experimental arch, as it appeared after it had fallen down on the 31st January last.

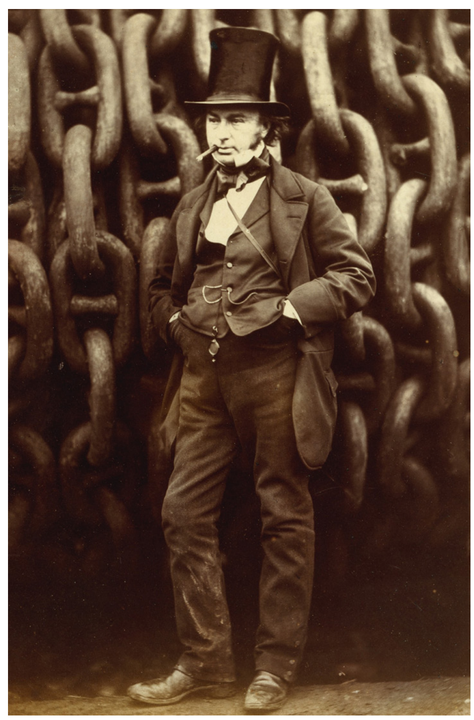
No. 6.—MARCH, 1838.

Fig. 5 is a section of the pier, showing the number of iron hoops, which are marked by dark lines or dots, and are laid in each course thus—in the upper course six pieces, the course under four pieces, the third, fourth, fifth, sixth, and seventh courses six pieces, eighth course five pieces, ninth course four pieces, tenth course three pieces, eleventh course two pieces; thence downwards are laid three pantile laths in the centre of every other course, lapped at meetings, in all ten layers or tiers; the lower tier is four feet six inches from the ground.

K

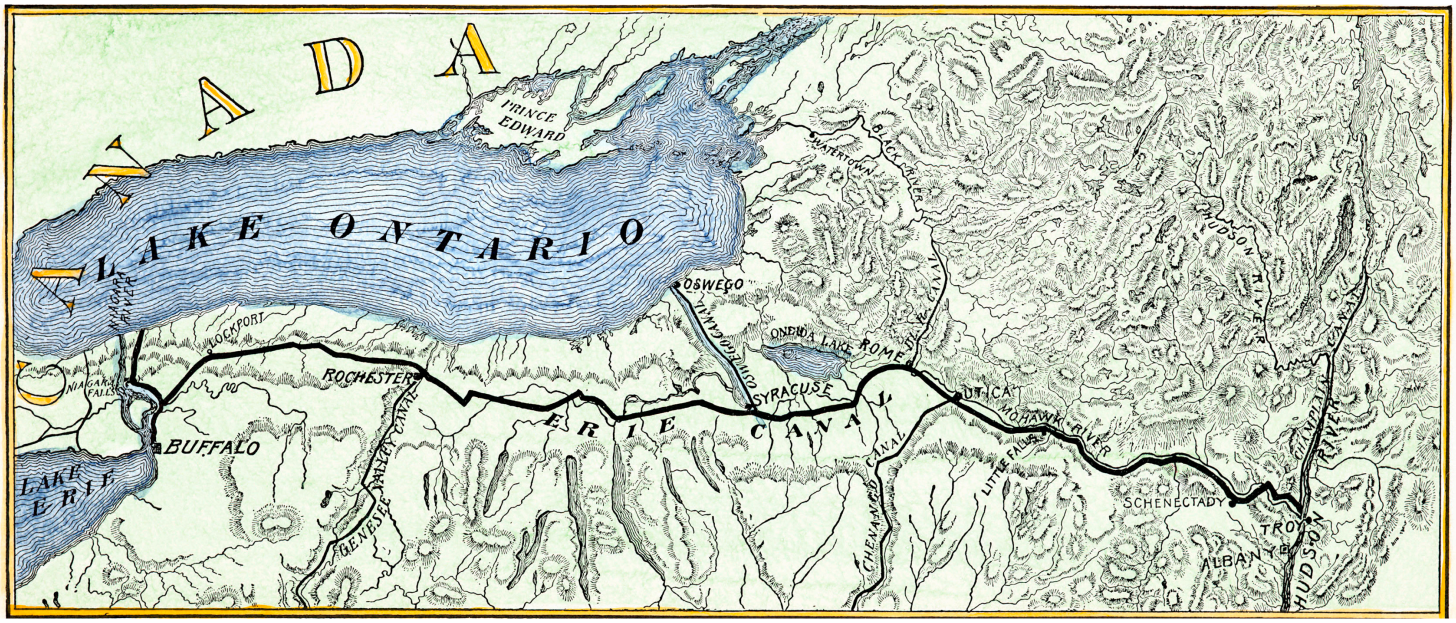
The adhesive properties and hardening times of the mortar were particularly important for tunnel construction. Brunel also built complex structures for test purposes, such as the one shown here. (15.4)

was particularly important that the mortar to be used set very quickly, providing support and preventing water ingress. Brunel learned that exported English Roman ce-



Isambard Kingdom Brunel took over the construction management at the age of only 20 from his father Marc Brunel who was in poor health. Later he became very popular constructing ships and bridges. (15.5)

America wakes up



The Erie Canal connects the city of New York (on the mouth of the Hudson River) with Buffalo on Lake Erie. This made a safe and efficient transport route between the Atlantic and the Great Lakes possible. Its length is 584 km. It was the largest infrastructure project of its time. (17.1)

The Erie Canal plays an important role

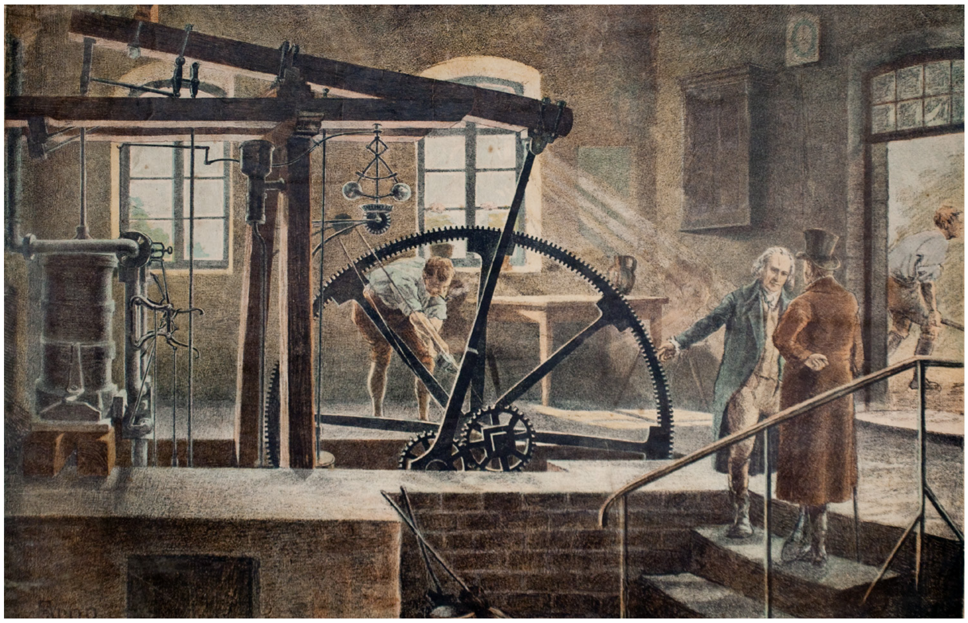
At the beginning of the nineteenth century the United States of America was largely confined to the Atlantic coast and, although it significantly extended its territories with the "Louisiana Purchase" of 1803, the Appalachian Mountains in the west and the absence of roads or waterways made it extremely difficult to develop the interior. Transporting bulk goods by land was so expensive that it was hardly practicable. On the worst roads, horse-drawn wagons were the only means of transport. In fact, for the 300 mile track from Albany (NY) to Buffalo (NY) an eight-horse wagon took between 15 and 45 days. The transport costs for goods were an incredible $100 per ton. The rapid economic growth of the western part of New York state and the cities on the edge of the Great Lakes necessitated better transportation to and from the Atlantic coast. Moreover, large salt deposits near Syracuse were awaiting exploitation. Drawing on examples from Europe, the State of New York came to the conclusion that canals were the solution to the transport problem. However, the then President Thomas Jefferson did not believe in the feasibility of a canal across such impassable terrain—he was more interested in a road to the west, starting from Baltimore—so the central government's financial support for a canal from New York to the Great Lakes was out of the question for the time being. The State of New York was on its own and put the project on ice.

After the War of 1812 with the United Kingdom of Great Britain ended, however, popular pressure for a waterway became so great that the State of New York approved $20,000 for the surveying and construction of a canal to connect New York City with Buffalo on Lake Erie. Surveying was undertaken in 1816 and, on 4 July 1817, construction of the Erie Canal began. This would make a safe and efficient transport route between the Great Lakes and the Atlantic Ocean possible, but it was a huge challenge. Not only was the new canal 584 km long—twice as long as any other canal built up to then, with 83 locks—but building materials and qualified engineers were also scarce in America at that time. The

One of the locks of the Erie Canal. The construction of the canal required considerable quantities of good building materials, which first had to be imported from England. The opening of the canal reduced the transport costs from New York City to Buffalo from about $100 to $10 per ton. The use of the canal was thus so great that after only nine years the construction costs had been recouped. (17.2)

An emerging world market

After the industrial revolution began in the second half of the 18th century and intensified in the 19th century in Britain, then throughout Western Europe and the USA, and later also in Japan, Central Europe and Asia, it led in many regions to the transition from agricultural to industrial societies. This was also associated with profound changes, e.g. developments in new technology and science accelerated as did products and productivity. Trade expanded and became more international. Manufacturing changed from small-scale to industrial production. The population increased, accompanied by massive urbanization. People moved from the countryside to the cities to find a better livelihood.



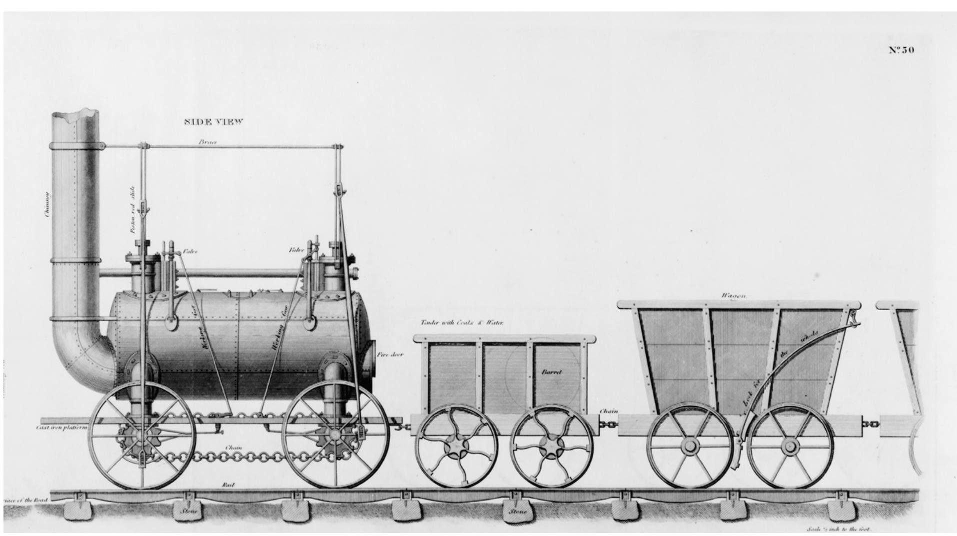
The use of serviceable steam engines was especially important and revolutionary. These could now drive pumps, ships, locomotives and textile machines. They proved to be an important part of the emerging industrialisation and expansion of the infrastructure. (18.1)

The achievements of the industrial revolution boost the economy

During the boom in commercial production and trade the roads in Western Europe, many of which still dated back to the Roman Empire, and those in North America based on dirt tracks, often proved to be completely inadequate for the increasing demand for transport and traffic. The existing natural waterways were often not navigable or were not located close to the important raw material deposits and production centres.

Road construction was not only expensive but also often impossible with the resources available at that time and the problem was ultimately not resolved until intensive construction of new canals started at the beginning of the 19th century. They connected cities, mining regions or navigable rivers. New railway connections were added from the middle of the century and contributed further to industrial advances. The lime and cement industry also benefited from this as raw materials and coal could now be procured from great distances at favourable prices. Steam navigation, which had become important in the USA by the beginning of the 19th century, soon arrived in Great Britain and continental Europe. Paddle steamers were often seen both on rivers and along the coasts. It soon became possible to cross the Atlantic in 14 days and goods could be transported significantly faster and more reliably all over the world.

Lime was used in the construction industry as a raw material for mortar. It was understood that additives could be employed to impart hydraulic properties but it soon be-



In the 1820s, a new process for rolling wrought iron made it possible to produce rail that was strong enough to withstand the long-term weight of locomotives on them. The associated construction and operation of railways gave a considerable boost to goods traffic and the development of the early industrial economy. (18.2)

The British SS Savannah was the first steam ship to cross the Atlantic Ocean. Fast and reliable transport between the continents was now possible. (18.3)

When Japanese troops captured the city of Nanjing and started a massacre in December 1937, the remaining foreigners set up security zones for civilians. The Jiangna plant of the Chee Hin (Qixin) Cement Co. plant was one of them. Under the leadership of the Dane Bernhard Arp Lindberg and the German Dr. Carl Günther, almost 30,000 civilians were saved. (20.12)

the development of the national economy and the restriction of private industry and trade.

The nationalisation of all cement companies began immediately. The cement plants that were still in a repairable condition were reactivated using their own means. It was only possible to modernise very important plants. One of them was the Guangdong Xicun cement plant with its export potential. FLSmidth, the Danish machinery supplier, expanded it in 1954 to an annual capacity of 300,000 tonnes. The plant exported to Hong Kong, Macao and Southeast Asia. The same applied to the Sichuan cement plant; as early on as 1951, the US engineering company Allis-Chalmers supplied it with a new kiln.

Despite considerable economic progress, the government's so-called Three-Anti and Five-Anti Campaigns began early in 1951 and 1952, respectively. These were directed against the evils of corruption, waste and bureaucracy, and later also against bribery and tax evasion. The campaigns ruthlessly opposed certain members of the Communist Party, former Kuomintang and bureaucratic officials. The "purges" also went through the cement industry. Mao's power base was thus consolidated.

The first five-year plan to rebuild the economy was drawn up in 1953. It concentrated on 156 projects supported by the Soviet Union to advance China's industrialisation.

The "Great Leap Forward"

One of the most momentous programmes to boost China's economic performance was the "Great Leap Forward" initiated by Mao Zedong between 1958 and 1961. For the Chinese leadership, the production of steel, building materials, electricity and grain was an indicator of a country's level of development.

Production of Strategic Products in China

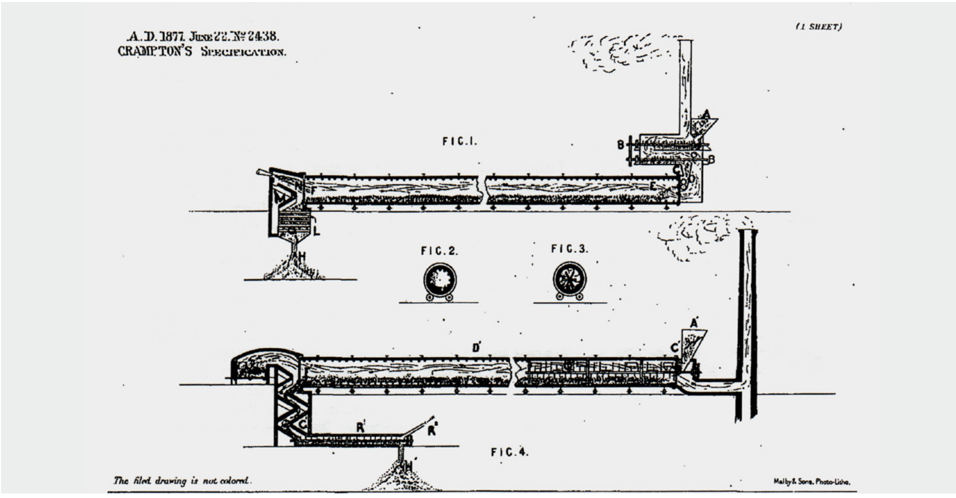
	Iron (Mio. t)	Electricity (Bn.Kwh)	Cement (Mio. t)
1949	0.3	4.3	0.7
1952	1.9	7.3	2.9
1955	3.6	12.3	4.5
1957	5.4	19.3	6.9

After the communists took over the country production of basic goods rose rapidly in China. The production of goods were regarded as an indicator of economic strength. (20.13)

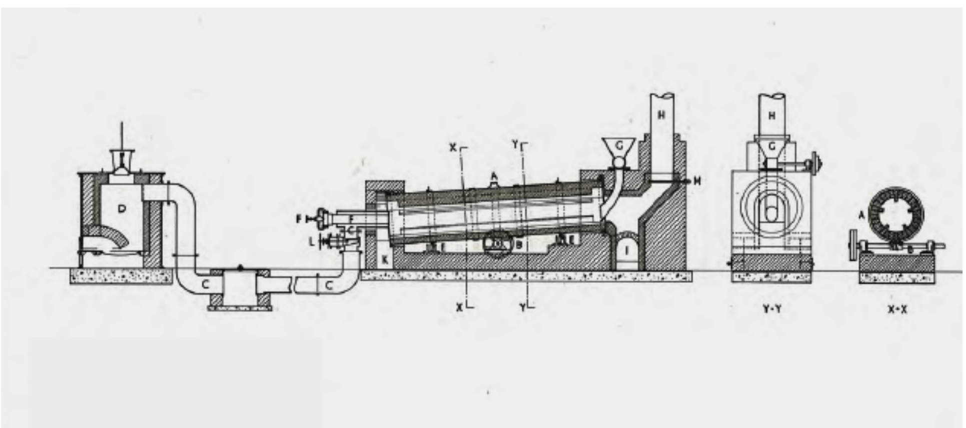
Under the slogan "*Always striving forwards, more, faster, better and more economically to build socialism under the tension of all forces*", steel production in particular was to be doubled.

In a speech at the 8th Party Congress in February 1958, Mao noted: "*With eleven million tonnes of steel next year and 17 million tonnes of steel the following year, we will shake up the world. If we can reach 40 million tonnes in five years, we will have*

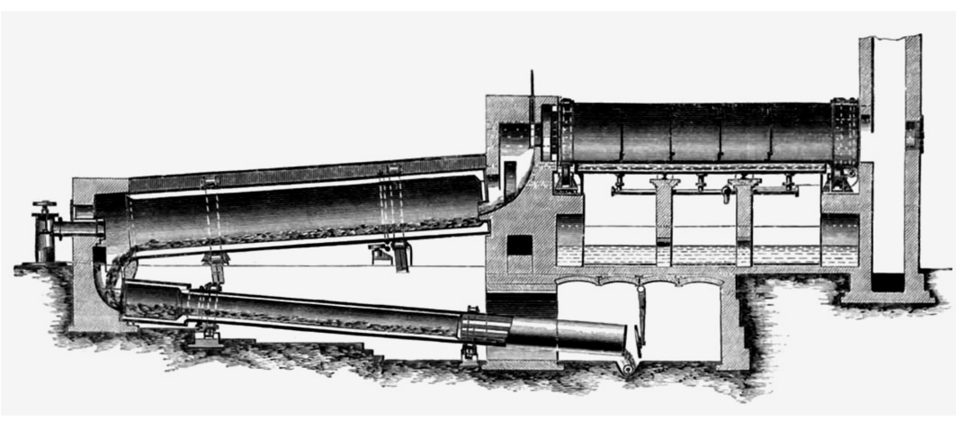
On 1 October 1949, Mao Zedong proclaimed the People's Republic of China. In the first years the reconstruction of the country was the main focus. The nationalization of the cement industry, among other things, began immediately. The factories that were in a reparable condition were activated with their own funds. But due to scarce foreign currency, only a few plants could be modernized or newly built. (20.14)



Excerpt from Thomas R. Crampton's British patent No. 2438 of 1877. For the cement industry the idea was completely new. A few important details were already recognisable features of modern kilns—the passage of the raw mix in counter-flow to the combustion gases, the need for turning over the raw mix in its passage though the kiln, the transfer of heat from the finished clinker to the combustion air and the use of pulverized coal as fuel. Unfortunately, the patent was never implemented. (28.23)



Frederick Ransome, a keen engineer and inventor, took over Crampton's general idea and concept. In 1885 he was granted British patent No. 5442 in which he put forward a new rotary kiln in combination with a gas generator. A first pilot project was built at the Mitcheldean plant close to Gloucester in 1885 and a second one at the Barnstone cement plant, close to Nottingham. A few kilns followed with alternative designs but unfortunately none of them were able to achieve continuous operation. (28.24)



The kiln developed and patented in 1888 (No. 9986) by Frederick W. S. Stokes, also a British designer, introduced some innovative ideas. The patent shows a rotating kiln, still fired with producer gas. Upstream of this is a drying cylinder heated by the kiln gases, in which slurry is dried, scraped off and dropped into the kiln. Downstream is a rotary cooler that supplies hot secondary air to the kiln. Due to its complexity the system did not find favour at that time. (28.25)

tonnes) per day, the first functioning rotary kilns were able to produce up to 200 barrels (34 tonnes) per day. They also allowed production of a much more homogeneous clinker. Rotary kilns had been known in other industries since around 1855. In the late 19th century, English engineers came up with the ideas of revolutionize the backward cement industry with new burning technologies. Although the ideas were interesting and forward-looking, the conservative cement producers in England were very reluctant to embrace them and failed to get the new machines to function. Only the younger producers in the United States, plagued by high wages and high production costs, recognized the possibilities and were the first to take up the new idea.

In 1877, Thomas R. Crampton, a railway engineer, was the first to be awarded the English Patent No. 2438 for the production of clinker in rotary kilns. The idea was to produce clinker in slowly rotating, inclined iron cylinders lined with refractory material. The raw material moves during the rotation in counter-flow by inclination towards a single flame and is burned to clinker. He understood the importance of the intensive mixing of raw feed by the rotation of the kiln's drum and the utilization of heat from the finished clinker to the combustion air to obtain a hot flame. However, the new idea was not realized for the time being, since the cement industry did not see the possibilities.

The Ransome kiln

The Englishman Frederick Ransome (1818–1893) knew Crampton's design and was determined to continue its development. In 1885, he was granted patent No. 5442 for a rotary kiln producing clinker in England. Like Crampton, he also did not come from the cement industry, but was a designer of heavy boiler plants.

He described the new kiln in very similar form to that of Crampton, and in a way very similar to that still used today in modern rotary kilns. In order to distinguish his new patent from the Crampton patent he expressly names producer gas as fuel and specifies that the raw mix should be finely ground.The raw material ground to powder is fed to the inclined, cylindrical rotating kiln and moves against the flame. The agitation should result in very good mixing, slow calcination and sintering. Ransome's assumption was that the clinker emerged as dust similar to ready-ground cement. This is one reason the new concept


In the end, U.S. infantry troops breach the "unbreachable" Siegfried Line. (34.15)

1944, Hitler ordered the Siegfried Line to be completed and extended to the north.
On 1 September 1944 the panic expansion began with a public mobilisation. In neighbouring districts, the entire available male population aged between 16 and 60 years was called up for the "people's volunteer corps". In addition, thousands of forced labourers and prisoners of war were forced to participate. The plan was based on 300,000 workers. On 1 October 1944, the commandants' offices were able to report a total of 385,000 deployed workers. Around 128,000 of these were foreigners. As a rule, German workers were called away from their previous jobs within hours and immediately transported to the west in scheduled or special trains. However, due to illness, exhaustion, air raids or mandatory participation in the "Volkssturm" (the people's defence storm), the number of available workers quickly dropped. By January 1945, work capacity had fallen by 60% everywhere. The desperate efforts to secure the western border with concrete structures could no longer be achieved. At the beginning of 1945, the American Army breached the Siegfried Line and, thus, the western German border.
During the war years, cement production in Germany could only be maintained with the help of prisoners of war and forced labourers. In 1944, for example, the cement industry employed 10,340 German workers as well as 10,178 prisoners of war and foreign forced labourers from more than 15 countries, including women and youth. The quantities of material required for the Siegfried Line were so enormous that these had to be brought in from considerable distances. During the most active period, up to 140,000 tonnes of aggregates, 10,000 tonnes of cement, as well as large quantities of timber, steel and iron arrived at construction sites along the Siegfried Line every day. In 1938, 40% of all concrete mixers of 250 litre and greater in Germany were confiscated. Also, 60% of all compressors suitable for tunnel construction and 20% of all construction rams were transported and used on the Siegfried Line. In total, around 8 million tonnes of cement, 1.2 million tonnes of steel and over 20 million tonnes of aggregates were used, while at the peak up to 8,000 railroad cars arrived at construction sites every day.

The Atlantic Wall

The Siegfried Line, however, was surpassed in scope and cost by what was known as the Atlantic Wall. This stretched over 2,700 km from the North Cape in Norway to the French–Spanish border. Between 1940 and 1944, several 100 million cubic meters of concrete were placed for the Atlantic Wall—a project of vast proportions. A total of 8,119 bunkers were actually built. The fortifications were designed to prevent invasion from the sea. Many of the bunkers were the largest of their time, with guns reaching from the French coast to England. Thus, it was not a wall in the true sense of the word, but a number of individual coastal fortifications, including submarine, railway and harbour bunkers.
The construction required huge resources in terms of people and materials. All areas under German occupation were forced to deliver vast quantities of steel and cement to the construction sites of the Atlantic Wall. In order to be able to meet the enormous demand for labour, an order was issued on 8 September 1942, forcing the population of the occupied territory into forced labour. In France alone, a total of 291,000 men worked from November 1943 onwards, including 15,000 Germans and 85,000 French. The rest were prisoners of war and forced labourers from various countries. Construction sites with more than 1,000 workers were not uncommon. Despite all these efforts, the installations were not able to fulfil their purpose - English and US aerial bombs broke through them and they were overrun by US landing units. Thus it had been prov-


Construction of a gun emplacement at the Atlantic Wall. The defensive installations reached from Norway to the border of Spain and were supposed to make any attack from the sea impossible. (34.11)