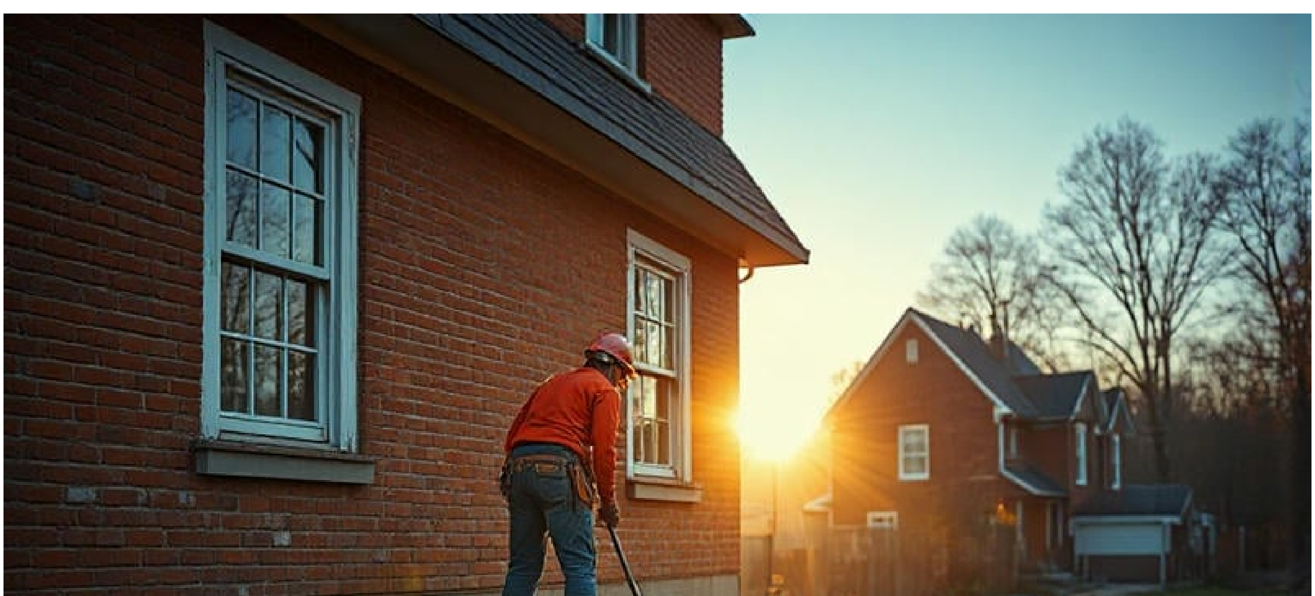


Okay, lets talk foundation repair budgets. Ugh, budgets. Nobody loves them, but theyre absolutely essential, especially when were dealing with something as critical (and often expensive) as fixing a foundation. The relationship between water and your foundation is like that toxic ex who keeps coming back to cause more damage **structural wall bracing Arlington Heights** drainage. It all starts with that initial budgeting and cost estimation phase. Think of it as laying the groundwork for the entire project – pun intended!

Before a single shovel hits the dirt, you need to get a handle on what this whole thing is likely to cost. This isnt just a guess; its a process of gathering information and making educated predictions. The first step? Inspections. Multiple inspections, ideally. Get different contractors to come out, assess the damage, and give you detailed estimates. Dont just go with the lowest bid. Dig into what each estimate includes. Are they addressing the root cause of the problem, or just slapping a bandage on it?

The initial budget isn't just about the cost of the repair itself. Think about permits, engineering fees (you might need a structural engineer to sign off on certain repairs), potential landscaping costs to restore your yard after the work is done, and even temporary housing if the repairs are extensive enough that you cant live in the house during the process. Dont forget a contingency fund! This is crucial. Foundation repairs often uncover unexpected issues, and you want to have a buffer for those surprises. A good rule of thumb is to add at least 10-15% to your initial estimate for contingencies.

Getting a handle on material costs is key, too. Are they using high-quality materials? Are those materials readily available, or are they subject to supply chain delays? All of this factors into the overall cost and the timeline of the project.

The initial budget is essentially your roadmap. Its a living document that youll refine as the project progresses, but having a solid understanding of the potential costs upfront is absolutely essential for controlling your spending and avoiding nasty financial surprises down the line. Its the first, and arguably most important, step in keeping your foundation repair project from becoming a bottomless money pit.

Tracking project expenses and monitoring cash flow are crucial components of budget control methods for foundation projects, where financial oversight can mean the difference between success and failure. In the context of foundation projects, which often involve significant investments in infrastructure or community development, maintaining a tight grip on finances ensures that resources are allocated efficiently and objectives are met without unnecessary financial strain.

The first step in effectively tracking project expenses is to establish a comprehensive budget at the outset. This budget should detail all anticipated costs, from materials and labor to permits and unforeseen contingencies. Once the framework is set, regular monitoring becomes essential. This involves recording every transaction meticulously-whether it's a purchase of concrete for a buildings foundation or wages for skilled workers. Utilizing software tools tailored for construction or project management can streamline this process, providing real-time updates and reducing human error in data entry.

Monitoring cash flow goes hand-in-hand with expense tracking but focuses on the timing of income versus expenditures. For foundation projects, which might span several months or even years, understanding when money comes in (from funding sources like grants, donations, or loans) versus when it goes out is vital for maintaining liquidity. A cash flow forecast helps project managers anticipate periods of high expenditure against lower income phases, allowing them to plan accordingly-perhaps by securing short-term financing or adjusting payment schedules with suppliers.

Effective communication plays a pivotal role here as well. Regular financial meetings with stakeholders ensure everyone is on the same page regarding the projects financial health. These discussions can lead to strategic decisions like cost-cutting measures if expenses begin to exceed forecasts or reallocating funds where they're needed most urgently.

Moreover, unexpected issues often arise in foundation projects; perhaps soil conditions require additional groundwork or weather delays extend timelines. Here, having a system to monitor expenses allows for quick recalibrations of the budget without losing sight of the overall financial strategy. It also provides transparency with funders who appreciate seeing their contributions managed wisely.

In conclusion, tracking project expenses and monitoring cash flow within foundation projects isnt just about keeping numbers in check; its about ensuring project viability from start to finish. By integrating these practices into daily operations, project leaders not only safeguard their budgets but also build trust with investors and stakeholders through demonstrated fiscal responsibility. This disciplined approach ultimately supports the sustainable development goals that many foundation projects aim to achieve.

Material Procurement and Quality Control Procedures

Change Order Management and Contingency Planning are pivotal aspects of budget control methods, especially in the context of foundation projects where unexpected challenges can significantly impact costs. Foundation projects, by their nature, involve dealing with the earth, which is inherently unpredictable. Soil conditions can vary dramatically from what initial surveys might predict, leading to unforeseen expenses.

Change Order Management begins with a structured process for handling alterations to the original project scope. When changes become necessary-be it due to site conditions, regulatory requirements, or design flaws-a well-defined change order process ensures that these modifications are documented, approved, and their financial implications are understood before implementation. This systematic approach prevents scope creep and unauthorized expenditures which could derail budget constraints. For instance, if during excavation an unexpected bedrock layer is encountered requiring specialized equipment or techniques, a change order would outline the additional costs and get stakeholder approval before proceeding.

Contingency Planning complements this by setting aside a portion of the budget specifically for unforeseen events. This reserve acts as a financial buffer against surprises that are almost inevitable in foundation work. The size of this contingency fund is typically based on risk assessments conducted at the projects outset. These assessments consider factors like geological uncertainty, weather impacts, and potential labor or material shortages. By having a contingency plan in place, project managers can address issues without needing to seek additional funding mid-project, which could delay timelines or increase costs due to emergency procurement rates.

In practice, both strategies require clear communication channels. Regular updates on project progress help in identifying when a change order might be necessary or when contingency funds should be tapped into. Moreover, transparency with all stakeholders about why certain decisions are made fosters trust and understanding regarding budget adjustments.

In conclusion, effective budget control in foundation projects hinges on proactive change order management and prudent contingency planning. These methodologies ensure that while flexibility is maintained to adapt to real-world conditions, financial discipline is not compromised, keeping the project within its fiscal boundaries while still reaching successful completion.

Inspection and Testing Protocols During Foundation

Repair

When it comes to foundation repair, one of the critical aspects that project managers and homeowners must consider is the implementation of cost-saving techniques within the framework of budget control methods. Foundation projects often come with hefty price tags due to the critical nature of the work and the specialized skills required. However, there are several strategies that can be employed to keep costs under control without compromising on quality or safety.

First and foremost, thorough planning and assessment are key. Before any work begins, a detailed inspection should be carried out to understand the extent of damage and what exactly needs repair. This step prevents over-specification where more extensive repairs might be suggested than necessary, which in turn saves money by avoiding unnecessary work.

Another effective method is timing the project wisely. Scheduling foundation repairs during off-peak seasons can significantly reduce costs due to lower demand for labor and materials. Contractors might offer discounts during these times to keep their workforce engaged, providing an opportunity for savings.

Material selection also plays a pivotal role in cost management. Opting for locally sourced materials can cut down on transportation costs and support local economies, which often results in better deals due to reduced logistics expenses. Additionally, considering alternative materials that provide similar durability at a lower cost could be beneficial. For instance, using steel piers instead of concrete might be cheaper in some regions due to availability and installation efficiency.

Labor costs can also be managed through competitive bidding processes where multiple contractors are invited to bid on the project. This not only ensures that you get the best price but also encourages contractors to streamline their operations for efficiency, potentially passing those savings onto you.

Moreover, embracing technology can lead to significant savings. Modern techniques like laser leveling or drones for site surveys increase accuracy while reducing time spent on-site preparation and measurement errors which could lead to costly mistakes.

Finally, ongoing maintenance rather than waiting for major repairs is a proactive approach that saves money over time. Regular checks can identify minor issues before they escalate into major problems requiring extensive-and expensive-foundation repair work.

In conclusion, controlling costs in foundation projects doesnt mean cutting corners; its about intelligent decision-making from start to finish. By planning meticulously, choosing the right time and materials, leveraging competition among contractors, utilizing technology, and maintaining regular upkeep, substantial savings can be achieved while ensuring the longevity and stability of your foundation. These methods ensure that budget constraints do not compromise the integrity of what is arguably one of the most important parts of any structure – its foundation.

Documentation and Reporting for Permitting Compliance and QA/QC

In the realm of foundation projects, where precision and accountability are paramount, utilizing technology for budget control and reporting has become an indispensable strategy. Foundation projects often involve significant financial outlays, necessitating meticulous management to ensure funds are allocated efficiently and transparently. Heres how modern technology enhances this process.

Firstly, digital budgeting tools have revolutionized the way project managers approach financial planning. Software solutions like QuickBooks or specialized project management platforms allow for real-time tracking of expenditures against the budget. These tools offer customizable dashboards where all stakeholders can view current spending, forecast future costs, and adjust plans accordingly. This immediacy in data access reduces the lag between financial decisions and their implementation, which is crucial in dynamic construction environments.

Moreover, cloud-based technologies facilitate seamless collaboration among team members spread across different geographical locations. With cloud storage solutions such as Google Drive or Dropbox, documents related to budget proposals, expenditure reports, and financial forecasts can be shared instantly. This not only speeds up the decision-making process but also ensures that everyone involved has access to the latest information, reducing errors from outdated data.

Another significant advantage is the integration of AI and machine learning into budget control systems. These technologies can analyze historical data from similar projects to predict potential overspends or underspends with surprising accuracy. For instance, AI can flag discrepancies early by comparing actual spend against expected trends derived from past projects data. This predictive capability allows project managers to take preemptive actions rather than reactive measures after issues arise.

For reporting purposes, automated systems generate detailed reports at scheduled intervals or on demand. These reports can be tailored to provide insights at various levels - from high-level overviews for board meetings to granular details for on-site supervisors. The automation of report generation not only saves time but also minimizes human error in data transcription, ensuring that stakeholders receive consistent and accurate information.

Furthermore, mobile technology plays a vital role in field operations where immediate decisions might affect the budget directly. Apps designed for construction workers allow them to log expenses or request materials directly from their devices while on-site. This direct input into the system ensures real-time updates to the budget status, enhancing responsiveness in managing unexpected costs or savings.

In conclusion, leveraging technology for budget control and reporting in foundation projects offers a multi-faceted approach that enhances efficiency, accuracy, and transparency. It empowers every stakeholder with timely information necessary for making informed decisions that keep projects financially healthy while maintaining focus on quality outcomes. As technology continues to evolve, so too will its applications in financial oversight within construction sectors like foundation projects, promising even more sophisticated tools for managing budgets with precision in the future.

Risk Management and Mitigation Strategies in Project Logistics

Regular budget reviews and performance analysis are critical components of effective budget control methods for foundation projects. These processes ensure that financial resources are utilized efficiently and project goals are met within the stipulated timeframes and cost constraints.

In the context of foundation projects, which often involve significant initial investments in infrastructure or research, regular budget reviews help in maintaining financial discipline. By scheduling periodic reviews, project managers can keep a close eye on expenditures, comparing actual spending against planned budgets. This not only highlights any discrepancies but also allows for timely adjustments to avoid overspending or underutilization of funds.

Performance analysis complements these reviews by providing a deeper insight into how well the financial inputs are translating into project outputs. This involves looking at various metrics such as cost efficiency, time to completion of milestones, and quality of work delivered. For instance, if a particular phase of the foundation project is consuming more funds than expected without corresponding progress in terms of quality or advancement towards completion, it signals a need for strategic reevaluation.

Moreover, these analyses foster accountability among team members. When everyone knows that their work will be regularly assessed in terms of both budget adherence and performance outcomes, it encourages a culture of responsibility and proactive problem-solving. Regular meetings where these analyses are discussed can also enhance communication within the team, leading to better collaboration and innovation in overcoming budgetary challenges.

An additional benefit is the ability to forecast future needs based on historical data from these reviews and analyses. This predictive aspect helps in refining budgeting strategies for upcoming phases or similar future projects, ensuring that lessons learned contribute positively to organizational learning and efficiency.

In summary, integrating regular budget reviews with thorough performance analysis forms a robust framework for controlling budgets in foundation projects. It ensures not just fiscal prudence but also aligns financial management with project performance, ultimately leading to successful project outcomes while maintaining financial health.

Post-Repair Verification and Long-Term Monitoring for QA/QC

Budget control methods for foundation projects are crucial, and two particularly thorny areas are controlling labor costs and material procurement. Think about it: youre laying the literal groundwork for something big, and if your costs spiral out of control in these two areas, the whole project can be jeopardized.

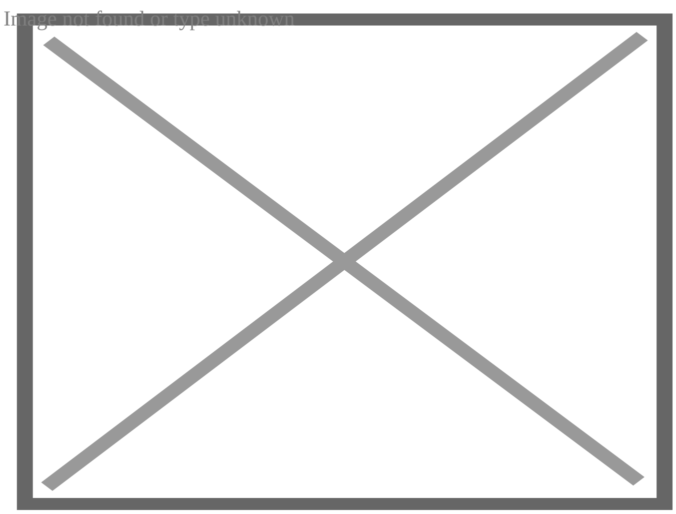
When it comes to labor costs, its not just about wages. Its about efficiency, scheduling, and managing unexpected delays. A detailed work breakdown structure is key here. You need to know exactly what tasks need to be done, how long they should take, and how many people you need. Regular progress monitoring is essential. Are things on track? Are there bottlenecks? Addressing these issues proactively can prevent overtime, which is a huge cost driver. Also, investing in good training and equipment can actually save money in the long run by improving productivity and reducing errors.

Material procurement is another battleground. Getting the right materials, at the right price, at the right time, is a constant juggling act. It starts with accurate quantity estimates based on the design specifications. Then you need to shop around, get multiple quotes, and negotiate favorable terms with suppliers. Consider bulk discounts and long-term contracts where it makes sense. Just-in-time delivery can minimize storage costs, but you need to be confident in your suppliers reliability. And dont forget about quality control! Defective materials can lead to costly rework and delays. Implementing a robust system for tracking material usage and managing inventory is vital to prevent waste and theft.

Ultimately, controlling labor costs and material procurement requires a proactive, data-driven approach. Its about planning, monitoring, and adapting as circumstances change. Its not just about cutting corners; its about working smarter to ensure the foundation project stays within budget and delivers the desired results.

About Pile driver

This article is about the mechanical device used in construction. For other uses, see Pile driver (disambiguation).



Tracked vehicle configured as a dedicated pile driver

A **pile driver** is a heavy-duty tool used to drive piles into soil to build piers, bridges, cofferdams, and other "pole" supported structures, and patterns of pilings as part of permanent deep foundations for buildings or other structures. Pilings may be made of wood, solid steel, or tubular steel (often later filled with concrete), and may be driven entirely underwater/underground, or remain partially aboveground as elements of a finished structure.

The term "pile driver" is also used to describe members of the construction crew associated with the task,[1] also colloquially known as "pile bucks".[2]

The most common form of pile driver uses a heavy weight situated between vertical guides placed above a pile. The weight is raised by some motive power (which may include hydraulics, steam, diesel, electrical motor, or manual labor). At its apex the weight is released, impacting the pile and driving it into the ground.[1][3]

History

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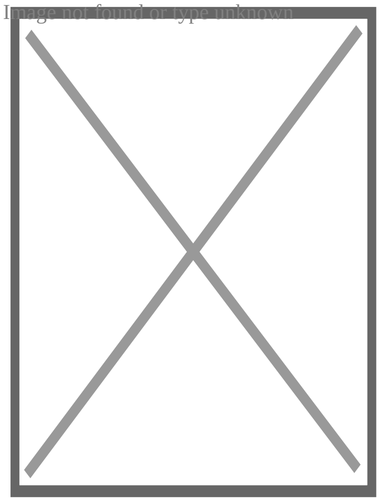
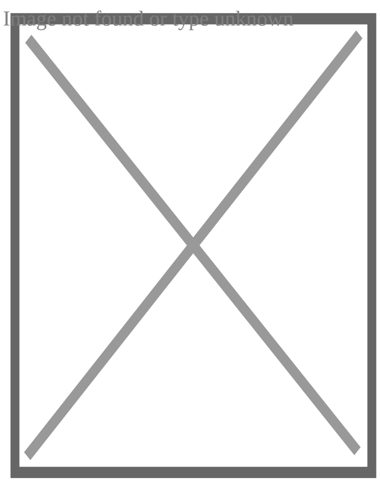


Replica of Ancient Roman pile driver used at the construction of Caesar's Rhine bridges (55 BC)



18th-century Pile driver, from *Abhandlung vom Wasserbau an Strömen*, 1769

There are a number of claims to the invention of the pile driver. A mechanically sound drawing of a pile driver appeared as early as 1475 in Francesco di Giorgio Martini's treatise *Trattato di Architectura*.[4] Also, several other prominent inventors—James Nasmyth (son of Alexander Nasmyth), who invented a steam-powered pile driver in 1845,[5] watchmaker James Valoué,[6] Count Giovan Battista Gazzola,[7] and Leonardo da Vinci[8]—have all been credited with inventing the device. However, there is evidence that a comparable device was used in the construction of Crannogs at Oakbank and Loch Tay in Scotland as early as 5000 years ago.[9] In 1801 John Rennie came up with a steam pile driver in Britain.[10] Otis Tufts is credited with inventing the steam pile driver in the United States.[11]

Types

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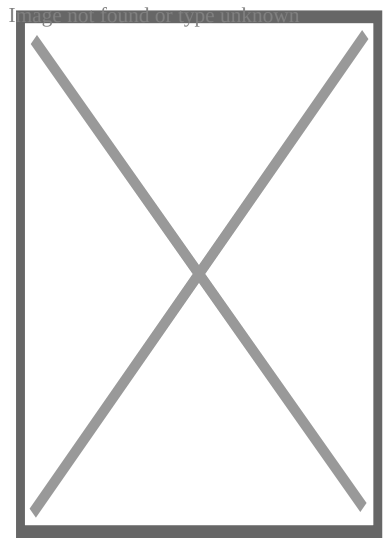

Pile driver, 1917

Ancient pile driving equipment used human or animal labor to lift weights, usually by means of pulleys, then dropping the weight onto the upper end of the pile. Modern piledriving equipment variously uses hydraulics, steam, diesel, or electric power to raise the weight and guide the pile.

Diesel hammer

[edit]

Concrete spun pile driving using diesel hammer in Patimban Deep Sea Port, Indonesia

A modern diesel pile hammer is a large two-stroke diesel engine. The weight is the piston, and the apparatus which connects to the top of the pile is the cylinder. Piledriving is started by raising the weight; usually a cable from the crane holding the pile driver — This draws air into the cylinder. Diesel fuel is injected into the cylinder. The weight is dropped, using a quick-release. The weight of the piston compresses the air/fuel mixture, heating it to the ignition point of diesel fuel. The mixture ignites, transferring the energy of the falling weight to the pile head, and driving the weight up. The rising weight draws in fresh air, and the cycle continues until the fuel is depleted or is halted by the crew.[12]

From an army manual on pile driving hammers: The initial start-up of the hammer requires that the piston (ram) be raised to a point where the trip automatically releases the piston, allowing it to fall. As the piston falls, it activates the fuel pump, which discharges a metered amount of fuel into the ball pan of the impact block. The falling piston blocks the exhaust ports, and compression of fuel trapped in the cylinder begins. The compressed air exerts a pre-load force to hold the impact block firmly against the drive cap and pile. At the bottom of the compression stroke, the piston strikes the impact block, atomizing the fuel and starting the pile on its downward movement. In the instant after the piston strikes, the atomized fuel ignites, and the resulting explosion exerts a greater force on the already moving pile, driving it further into the ground. The reaction of the explosion rebounding from the resistance of the pile drives the piston upward. As the piston rises, the exhaust ports open, releasing the exhaust gases to the atmosphere. After the piston stops its upward movement, it again falls by gravity to start another cycle.

Vertical travel lead systems

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Berminghammer vertical travel leads in use

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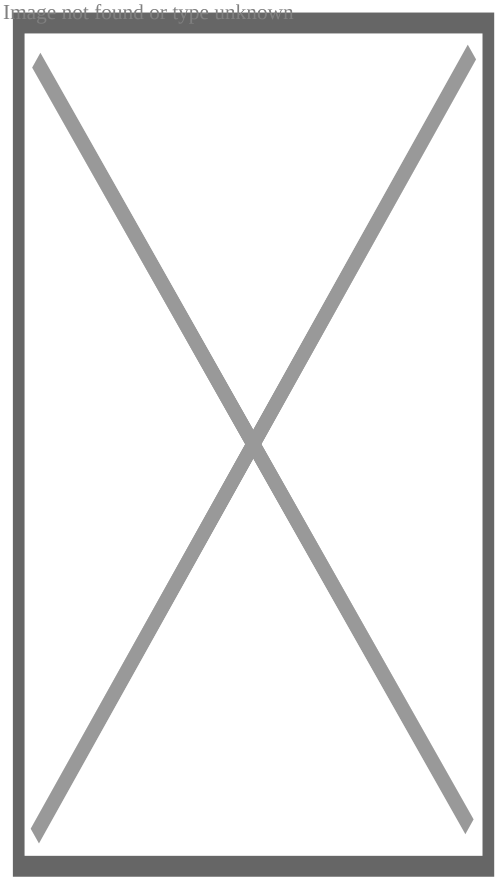


Military building mobile unit on "Army-2021" exhibition

Vertical travel leads come in two main forms: spud and box lead types. Box leads are very common in the Southern United States and spud leads are common in the

Northern United States, Canada and Europe.

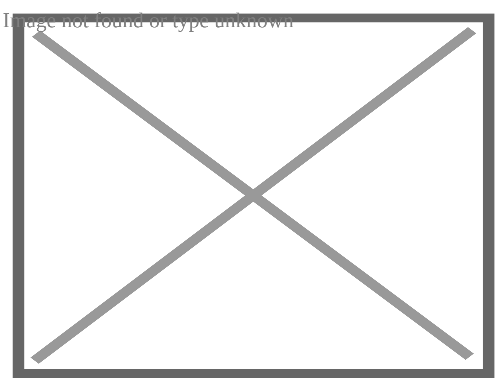
Hydraulic hammer

[edit]

A hydraulic hammer is a modern type of piling hammer used instead of diesel and air hammers for driving steel pipe, precast concrete, and timber piles. Hydraulic hammers are more environmentally acceptable than older, less efficient hammers as they generate less noise and pollutants. In many cases the dominant noise is caused by the impact of the hammer on the pile, or the impacts between components of the hammer, so that the resulting noise level can be similar to diesel hammers.[12]

Hydraulic press-in

[edit]



A steel sheet pile being hydraulically pressed

Hydraulic press-in equipment installs piles using hydraulic rams to press piles into the ground. This system is preferred where vibration is a concern. There are press attachments that can adapt to conventional pile driving rigs to press 2 pairs of sheet piles simultaneously. Other types of press equipment sit atop existing sheet piles and grip previously driven piles. This system allows for greater press-in and extraction force to be used since more reaction force is developed.[12] The reaction-based machines operate at only 69 dB at 23 ft allowing for installation and extraction of piles in close proximity to sensitive areas where traditional methods may threaten the stability of existing structures.

Such equipment and methods are specified in portions of the internal drainage system in the New Orleans area after Hurricane Katrina, as well as projects where noise, vibration and access are a concern.

Vibratory pile driver/extractor

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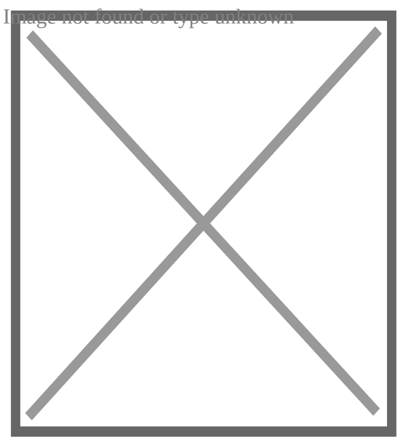

A diesel-powered vibratory pile driver on a steel I-beam

Vibratory pile hammers contain a system of counter-rotating eccentric weights, powered by hydraulic motors, and designed so that horizontal vibrations cancel out, while vertical vibrations are transmitted into the pile. The pile driving machine positioned over the pile with an excavator or crane, and is fastened to the pile by a clamp and/or bolts. Vibratory hammers can drive or extract a pile. Extraction is commonly used to recover steel I-beams used in temporary foundation shoring. Hydraulic fluid is supplied to the driver by a diesel engine-powered pump mounted in a trailer or van, and connected to the driver head via hoses. When the pile driver is connected to a dragline excavator, it is powered by the excavator's diesel engine. Vibratory pile drivers are often chosen to mitigate noise, as when the construction is near residences or office buildings, or when there is insufficient vertical clearance to permit use of a conventional pile hammer (for example when retrofitting additional piles to a bridge column or abutment footing). Hammers are available with several different vibration rates, ranging from 1200 vibrations per minute to 2400 VPM. The vibration rate chosen is influenced by soil conditions and other factors, such as power requirements and equipment cost.

Piling rig

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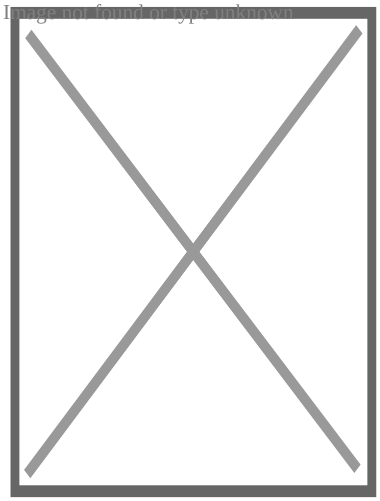

A Junttan purpose-built piledriving rig in Jyväskylä, Finland

A piling rig is a large track-mounted drill used in foundation projects which require drilling into sandy soil, clay, silty clay, and similar environments. Such rigs are similar in function to oil drilling rigs, and can be equipped with a short screw (for dry soil), rotary bucket (for wet soil) or core drill (for rock), along with other options. Expressways, bridges, industrial and civil buildings, diaphragm walls, water conservancy projects, slope protection, and seismic retrofitting are all projects which may require piling rigs.

Environmental effects

[edit]

The underwater sound pressure caused by pile-driving may be deleterious to nearby fish.[13][14] State and local regulatory agencies manage environment issues associated with pile-driving.[15] Mitigation methods include bubble curtains, balloons, internal combustion water hammers.[16]

See also

[edit]

- Auger (drill)
- Deep foundation
- Post pounder
- Drilling rig

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[edit]

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16. ^ *"Noise mitigation for the construction of increasingly large offshore wind turbines" (PDF). Federal Agency for Nature Conservation. November 2018.*

External links

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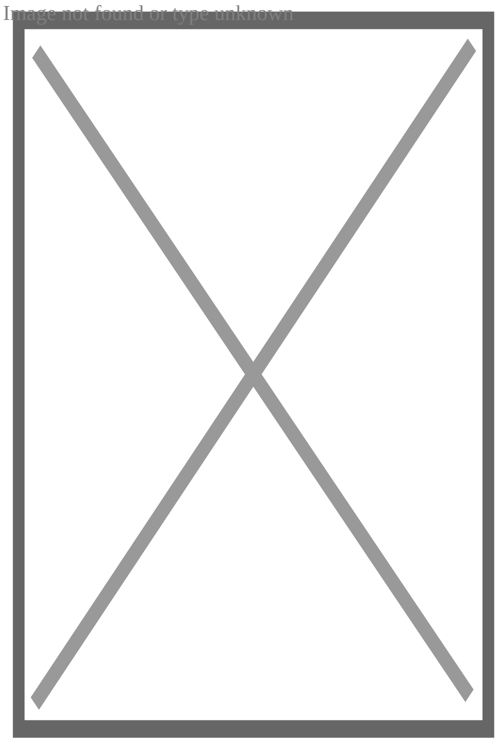
Wikimedia Commons has media related to ***Pile drivers***.

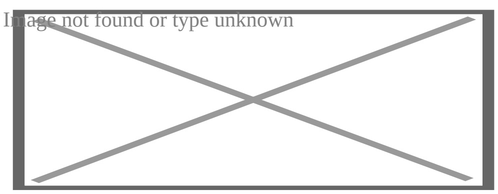
- Website about Vulcan Iron Works, which produced pile drivers from the 1870s through the 1990s

About Cement

For other uses, see Cement (disambiguation).
Not to be confused with Concrete.



Cement powder in a bag, ready to be mixed with aggregates and water.[1]



Cement block construction examples from the Multiplex Manufacturing Company of Toledo, Ohio, in 1905

A **cement** is a binder, a chemical substance used for construction that sets, hardens, and adheres to other materials to bind them together. Cement is seldom used on its own, but rather to bind sand and gravel (aggregate) together. Cement mixed with fine aggregate produces mortar for masonry, or with sand and gravel, produces concrete. Concrete is the most widely used material in existence and is behind only water as the planet's most-consumed resource.[2]

Cements used in construction are usually inorganic, often lime- or calcium silicate-based, and are either **hydraulic** or less commonly **non-hydraulic**, depending on the ability of the cement to set in the presence of water (see hydraulic and non-hydraulic lime plaster).

Hydraulic cements (e.g., Portland cement) set and become adhesive through a chemical reaction between the dry ingredients and water. The chemical reaction results in mineral hydrates that are not very water-soluble. This allows setting in wet conditions or under water and further protects the hardened material from chemical attack. The chemical process for hydraulic cement was found by ancient Romans who used volcanic ash (pozzolana) with added lime (calcium oxide).

Non-hydraulic cement (less common) does not set in wet conditions or under water. Rather, it sets as it dries and reacts with carbon dioxide in the air. It is resistant to attack by chemicals after setting.

The word "cement" can be traced back to the Ancient Roman term *opus caementicium* , used to describe masonry resembling modern concrete that was made from crushed rock with burnt lime as binder.[3] The volcanic ash and pulverized brick supplements that were added to the burnt lime, to obtain a hydraulic binder, were later referred to as *cementum*, *cimentum*, *cäment*, and *cement*. In modern times, organic polymers are sometimes used as cements in concrete.

World production of cement is about 4.4 billion tonnes per year (2021, estimation),[4][5] of which about half is made in China, followed by India and Vietnam.[4][6]

The cement production process is responsible for nearly 8% (2018) of global CO_2 emissions,[5] which includes heating raw materials in a cement kiln by fuel combustion and release of CO_2 stored in the calcium carbonate (calcination process). Its hydrated products, such as concrete, gradually reabsorb atmospheric CO_2 (carbonation process), compensating for approximately 30% of the initial CO_2 emissions.[7]

Chemistry

[edit]

Cement materials can be classified into two distinct categories: hydraulic cements and non-hydraulic cements according to their respective setting and hardening mechanisms. Hydraulic cement setting and hardening involves hydration reactions and therefore requires water, while non-hydraulic cements only react with a gas and can directly set under air.

Hydraulic cement

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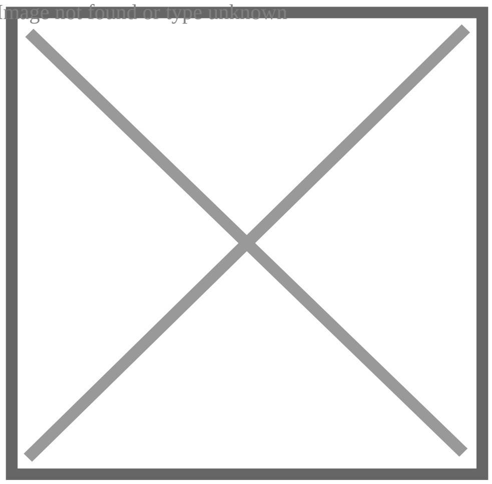

Clinker nodules produced by sintering at 1450 °C

By far the most common type of cement is **hydraulic cement**, which hardens by hydration (when water is added) of the clinker minerals. Hydraulic cements (such as Portland cement) are made of a mixture of silicates and oxides, the four main mineral phases of the clinker, abbreviated in the cement chemist notation, being:

- C_3S: alite ($3CaO{\cdot}SiO_2$);
- C_2S: belite ($2CaO{\cdot}SiO_2$);
- C_3A: tricalcium aluminate ($3CaO{\cdot}Al_2O_3$) (historically, and still occasionally, called *celite*);
- C_4AF: brownmillerite ($4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$).

The silicates are responsible for the cement's mechanical properties — the tricalcium aluminate and brownmillerite are essential for the formation of the liquid phase during the sintering (firing) process of clinker at high temperature in the kiln. The chemistry of these reactions is not completely clear and is still the object of research.[8]

First, the limestone (calcium carbonate) is burned to remove its carbon, producing lime (calcium oxide) in what is known as a calcination reaction. This single chemical reaction is a major emitter of global carbon dioxide emissions.[9]

$$\displaystyle \ce{CaCO3 -> CaO + CO2}$$

The lime reacts with silicon dioxide to produce dicalcium silicate and tricalcium silicate.

$$\displaystyle \ce{2CaO + SiO2 -> 2CaO.SiO2}$$

$$\displaystyle \ce{3CaO + SiO2 -> 3CaO.SiO2}$$

The lime also reacts with aluminium oxide to form tricalcium aluminate.

$$\displaystyle \ce{3CaO + Al2O3 -> 3CaO.Al2O3}$$

In the last step, calcium oxide, aluminium oxide, and ferric oxide react together to form brownmillerite.

$$\displaystyle \ce{4CaO + Al2O3 + Fe2O3 -> 4CaO.Al2O3.Fe2O3}$$
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Non-hydraulic cement

[edit]

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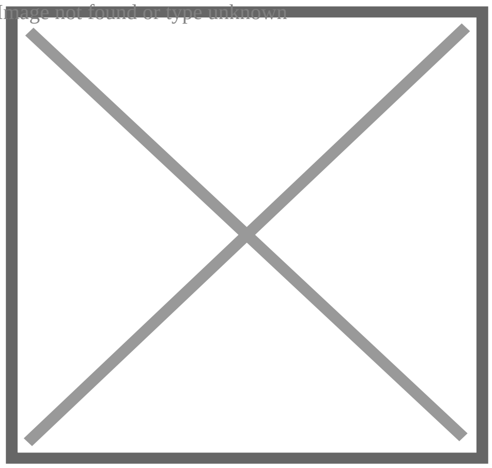

Calcium oxide obtained by thermal decomposition of calcium carbonate at high temperature (above 825 °C).

A less common form of cement is **non-hydraulic cement**, such as slaked lime (calcium oxide mixed with water), which hardens by carbonation in contact with carbon dioxide, which is present in the air (~ 412 vol. ppm ÃƒÂ¢Ã¢â‚¬Â°Ã†â€™ 0.04 vol. %). First calcium oxide (lime) is produced from calcium carbonate (limestone or chalk) by calcination at temperatures above 825 °C (1,517 °F) for about 10 hours at atmospheric pressure:

$$\displaystyle \ce{CaCO3 -> CaO + CO2}$$
Image not found or type unknown

The calcium oxide is then *spent* (slaked) by mixing it with water to make slaked lime (calcium hydroxide):

$$\displaystyle \ce{CaO + H2O -> Ca(OH)2}$$
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Once the excess water is completely evaporated (this process is technically called *setting*), the carbonation starts:

$$\displaystyle \ce{Ca(OH)2 + CO2 -> CaCO3 + H2O}$$
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This reaction is slow, because the partial pressure of carbon dioxide in the air is low (~ 0.4 millibar). The carbonation reaction requires that the dry cement be exposed to air, so the slaked lime is a non-hydraulic cement and cannot be used under water. This process is called the *lime cycle*.

History

[edit]

Perhaps the earliest known occurrence of cement is from twelve million years ago. A deposit of cement was formed after an occurrence of oil shale located adjacent to a bed of limestone burned by natural causes. These ancient deposits were investigated in the 1960s and 1970s.[10]

Alternatives to cement used in antiquity

[edit]

Cement, chemically speaking, is a product that includes lime as the primary binding ingredient, but is far from the first material used for cementation. The Babylonians and Assyrians used bitumen (asphalt or pitch) to bind together burnt brick or alabaster slabs. In Ancient Egypt, stone blocks were cemented together with a mortar made of sand and roughly burnt gypsum ($CaSO_4 \cdot 2H_2O$), which is plaster of Paris, which often contained calcium carbonate ($CaCO_3$),[11]

Ancient Greece and Rome

[edit]

Lime (calcium oxide) was used on Crete and by the Ancient Greeks. There is evidence that the Minoans of Crete used crushed potsherds as an artificial pozzolan for hydraulic cement.[11] Nobody knows who first discovered that a combination of hydrated non-hydraulic lime and a pozzolan produces a hydraulic mixture (see also: Pozzolanic reaction), but such concrete was used by the Greeks, specifically the Ancient Macedonians,[12][13] and three centuries later on a large scale by Roman engineers.[14][15][16]

> There is... a kind of powder which from natural causes produces astonishing results. It is found in the neighborhood of Baiae and in the country belonging to the towns round about Mount Vesuvius. This substance when mixed with lime and rubble not only lends strength to buildings of other kinds but even when piers of it are constructed in the sea, they set hard underwater.
>
> —ÃƒÂ¢Ã¢â€šÂ¬Ã…Â *Marcus Vitruvius Pollio, Liber II, De Architectura, Chapter VI "Pozzolana" Sec. 1*

The Greeks used volcanic tuff from the island of Thera as their pozzolan and the Romans used crushed volcanic ash (activated aluminium silicates) with lime. This mixture could set under water, increasing its resistance to corrosion like rust.[17] The material was called *pozzolana* from the town of Pozzuoli, west of Naples where volcanic ash was extracted.[18] In the absence of pozzolanic ash, the Romans used powdered brick or pottery as a substitute and they may have used crushed tiles for this purpose before discovering natural sources near Rome.[11] The huge dome of the Pantheon in Rome and the massive Baths of Caracalla are examples of ancient structures made from these concretes, many of which still stand.[19][2] The vast system of Roman aqueducts also made extensive use of hydraulic cement.[20] Roman concrete was rarely used on the outside of buildings. The normal technique was to use brick facing material as the formwork for an infill of mortar mixed with an aggregate of broken pieces of stone, brick, potsherds, recycled chunks of concrete, or other building rubble.[21]

Mesoamerica

[edit]

Lightweight concrete was designed and used for the construction of structural elements by the pre-Columbian builders who lived in a very advanced civilisation in El Tajin near Mexico City, in Mexico. A detailed study of the composition of the aggregate and binder show that the aggregate was pumice and the binder was a pozzolanic cement made with volcanic ash and lime.[22]

Middle Ages

[edit]

Any preservation of this knowledge in literature from the Middle Ages is unknown, but medieval masons and some military engineers actively used hydraulic cement in structures such as canals, fortresses, harbors, and shipbuilding facilities.[23][24] A mixture of lime mortar and aggregate with brick or stone facing material was used in the Eastern Roman Empire as well as in the West into the Gothic period. The German Rhineland continued to use hydraulic mortar throughout the Middle Ages, having local pozzolana deposits called trass.[21]

16th century

[edit]

Tabby is a building material made from oyster shell lime, sand, and whole oyster shells to form a concrete. The Spanish introduced it to the Americas in the sixteenth century.[25]

18th century

[edit]

The technical knowledge for making hydraulic cement was formalized by French and British engineers in the 18th century.[23]

John Smeaton made an important contribution to the development of cements while planning the construction of the third Eddystone Lighthouse (1755–59) in the English Channel now known as Smeaton's Tower. He needed a hydraulic mortar that would set and develop some strength in the twelve-hour period between successive high tides. He performed experiments with combinations of different limestones and additives including trass and pozzolanas[11] and did exhaustive market research on the available hydraulic limes, visiting their production sites, and noted that the "hydraulicity" of the lime was directly related to the clay content of the limestone used to make it. Smeaton was a civil engineer by profession, and took the idea no further.

In the South Atlantic seaboard of the United States, tabby relying on the oyster-shell middens of earlier Native American populations was used in house construction from the 1730s to the 1860s.[25]

In Britain particularly, good quality building stone became ever more expensive during a period of rapid growth, and it became a common practice to construct prestige buildings from the new industrial bricks, and to finish them with a stucco to imitate stone. Hydraulic limes were favored for this, but the need for a fast set time encouraged the development of new cements. Most famous was Parker's "Roman cement".[26] This was developed by James Parker in the 1780s, and finally patented in 1796. It was, in fact, nothing like material used by the Romans, but was a "natural cement" made by burning septaria – nodules that are found in certain clay deposits, and that contain both clay minerals and calcium carbonate. The burnt nodules were ground to a fine powder. This product, made into a mortar with sand, set in 5–15 minutes. The success of "Roman cement" led other manufacturers to develop rival products by burning artificial hydraulic lime cements of clay and chalk. Roman cement quickly became popular but was largely replaced by Portland cement in the 1850s.[11]

19th century

[edit]

Apparently unaware of Smeaton's work, the same principle was identified by Frenchman Louis Vicat in the first decade of the nineteenth century. Vicat went on to devise a method of combining chalk and clay into an intimate mixture, and, burning this, produced an "artificial cement" in 1817[27] considered the "principal forerunner"[11] of Portland cement and "...Edgar Dobbs of Southwark patented a cement of this kind in 1811."[11]

In Russia, Egor Cheliev created a new binder by mixing lime and clay. His results were published in 1822 in his book *A Treatise on the Art to Prepare a Good Mortar* published in St. Petersburg. A few years later in 1825, he published another book, which described various methods of making cement and concrete, and the benefits of cement in the construction of buildings and embankments.[28][29]

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William Aspdin is considered the inventor of "modern" Portland cement.[30]

Portland cement, the most common type of cement in general use around the world as a basic ingredient of concrete, mortar, stucco, and non-speciality grout, was developed in England in the mid 19th century, and usually originates from limestone. James Frost produced what he called "British cement" in a similar manner around the same time, but did not obtain a patent until 1822.[31] In 1824, Joseph Aspdin patented a similar material, which he called *Portland cement*, because the render made from it was in color similar to the prestigious Portland stone quarried on the Isle of Portland, Dorset, England. However, Aspdins' cement was nothing like modern Portland cement but was a first step in its development, called a *proto-Portland cement*.[11] Joseph Aspdins' son William Aspdin had left his father's company and in his cement manufacturing apparently accidentally produced calcium silicates in the 1840s, a middle step in the development of Portland cement. William Aspdin's innovation was counterintuitive for manufacturers of "artificial cements", because they required more lime in the mix (a problem for his father), a much higher kiln temperature (and therefore more fuel), and the resulting clinker was very hard and rapidly wore down the millstones, which were the only available grinding technology of the time. Manufacturing costs were therefore considerably higher, but the product set reasonably slowly and developed strength quickly, thus opening up a market for use in concrete. The use of concrete in construction grew rapidly from 1850 onward, and was soon the dominant use for cements. Thus Portland cement began its predominant role. Isaac Charles Johnson further refined the production of *meso-Portland cement* (middle stage of development) and claimed he was the real father of Portland cement.[32]

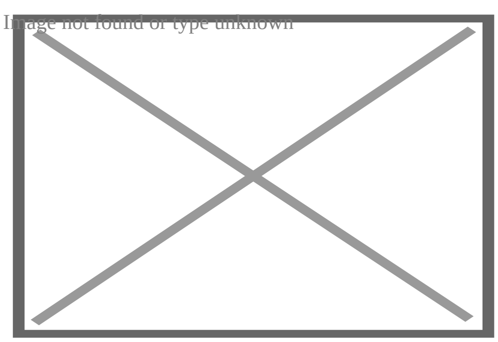
Setting time and "early strength" are important characteristics of cements. Hydraulic limes, "natural" cements, and "artificial" cements all rely on their belite (2 CaO · SiO_2, abbreviated as C_2S) content for strength development. Belite develops strength slowly. Because they were burned at temperatures below 1,250 °C (2,280 °F), they contained no alite (3 CaO · SiO_2, abbreviated as C_3S), which is responsible for early strength in modern cements. The first cement to consistently contain alite was made by William Aspdin in the early 1840s: This was what we call today "modern" Portland cement. Because of the air of mystery with which William Aspdin surrounded his product, others (*e.g.,* Vicat and Johnson) have claimed precedence in this invention, but recent analysis[33] of both his concrete and raw cement have shown that William Aspdin's product made at Northfleet, Kent was a true alite-based cement. However, Aspdin's methods were "rule-of-thumb": Vicat is responsible for establishing the chemical basis of these cements, and Johnson established the importance of sintering the mix in the kiln.

In the US the first large-scale use of cement was Rosendale cement, a natural cement mined from a massive deposit of dolomite discovered in the early 19th century near Rosendale, New York. Rosendale cement was extremely popular for the foundation of buildings (*e.g.*, Statue of Liberty, Capitol Building, Brooklyn Bridge) and lining water pipes.[34] Sorel cement, or magnesia-based cement, was patented in 1867 by the Frenchman Stanislas Sorel.[35] It was stronger than Portland cement but its poor water resistance (leaching) and corrosive properties (pitting corrosion due to the presence of leachable chloride anions and the low pH (8.5–9.5) of its pore water) limited its use as reinforced concrete for building construction.[36]

The next development in the manufacture of Portland cement was the introduction of the rotary kiln. It produced a clinker mixture that was both stronger, because more alite (C_3S) is formed at the higher temperature it achieved (1450 °C), and more homogeneous. Because raw material is constantly fed into a rotary kiln, it allowed a continuous manufacturing process to replace lower capacity batch production processes.[11]

20th century

[edit]



The National Cement Share Company of Ethiopia's new plant in Dire Dawa

Calcium aluminate cements were patented in 1908 in France by Jules Bied for better resistance to sulfates.[37] Also in 1908, Thomas Edison experimented with pre-cast concrete in houses in Union, N.J.[38]

In the US, after World War One, the long curing time of at least a month for Rosendale cement made it unpopular for constructing highways and bridges, and many states and construction firms turned to Portland cement. Because of the switch to Portland cement, by the end of the 1920s only one of the 15 Rosendale cement companies had survived. But in the early 1930s, builders discovered that, while Portland cement set faster, it was not as durable, especially for highways—to the point that some states stopped building highways and roads with cement. Bertrain H. Wait, an engineer whose company had helped construct the New York City's Catskill Aqueduct, was impressed with the durability of Rosendale cement, and came up with a blend of both Rosendale and Portland cements that had the good attributes of both. It was highly durable and had a much faster setting time. Wait convinced the New York Commissioner of Highways to construct an experimental section of highway near New Paltz, New York, using one sack of Rosendale to six sacks of Portland cement. It was a success, and for decades the Rosendale-Portland cement blend was used in concrete highway and concrete bridge construction.[34]

Cementitious materials have been used as a nuclear waste immobilizing matrix for more than a half-century.[39] Technologies of waste cementation have been developed and deployed at industrial scale in many countries. Cementitious wasteforms require a careful selection and design process adapted to each specific type of waste to satisfy the strict waste acceptance criteria for long-term storage and disposal.[40]

Types

[edit]

Components of cement:
comparison of chemical and physical characteristics[a][41][42][43]

Property		Portland cement	Siliceous[b] fly ash	Calcareous[c] fly ash	Slag cement	Silica fume
Proportion by mass (%)	SiO_2	21.9	52	35	35	85–97
	Al_2O_3	6.9	23	18	12	—
	Fe_2O_3	3	11	6	1	—

CaO	63	5	21	40	< 1
MgO	2.5	—	—	—	—
SO_3	1.7	—	—	—	—
Specific surface (m^2/kg) [d]	370	420	420	400	15,000 – 30,000
Specific gravity	3.15	2.38	2.65	2.94	2.22
General purpose	Primary binder	Cement replacement	Cement replacement	Cement replacement	Property enhancer

1. ^ Values shown are approximate: those of a specific material may vary.
2. ^ ASTM C618 Class F
3. ^ ASTM C618 Class C
4. ^ Specific surface measurements for silica fume by nitrogen adsorption (BET) method, others by air permeability method (Blaine).

Modern development of hydraulic cement began with the start of the Industrial Revolution (around 1800), driven by three main needs:

- Hydraulic cement render (stucco) for finishing brick buildings in wet climates
- Hydraulic mortars for masonry construction of harbor works, etc., in contact with sea water
- Development of strong concretes

Modern cements are often Portland cement or Portland cement blends, but other cement blends are used in some industrial settings.

Portland cement

[edit]
Main article: Portland cement

Portland cement, a form of hydraulic cement, is by far the most common type of cement in general use around the world. This cement is made by heating limestone (calcium carbonate) with other materials (such as clay) to 1,450 °C (2,640 °F) in a kiln, in a process known as calcination that liberates a molecule of carbon dioxide from the calcium carbonate to form calcium oxide, or quicklime, which then chemically combines with the other materials in the mix to form calcium silicates and other cementitious compounds. The resulting hard substance, called 'clinker', is then ground with a small amount of gypsum ($CaSO_4 \cdot 2H_2O$) into a powder to make *ordinary Portland cement*, the most commonly used type of cement (often referred to as OPC). Portland cement is a basic ingredient of concrete, mortar, and most non-specialty grout. The most common use for Portland cement is to make concrete. Portland cement may be grey or white.

Portland cement blend

[edit]

Portland cement blends are often available as inter-ground mixtures from cement producers, but similar formulations are often also mixed from the ground components at the concrete mixing plant.

Portland blast-furnace slag cement**, or blast furnace** cement (ASTM C595 and EN 197-1 nomenclature respectively), contains up to 95% ground granulated blast furnace slag, with the rest Portland clinker and a little gypsum. All compositions produce high ultimate strength, but as slag content is increased, early strength is reduced, while sulfate resistance increases and heat evolution diminishes. Used as an economic alternative to Portland sulfate-resisting and low-heat cements.

Portland-fly ash cement contains up to 40% fly ash under ASTM standards (ASTM C595), or 35% under EN standards (EN 197–1). The fly ash is pozzolanic, so that ultimate strength is maintained. Because fly ash addition allows a lower concrete water content, early strength can also be maintained. Where good quality cheap fly ash is available, this can be an economic alternative to ordinary Portland cement.[44]

Portland pozzolan cement includes fly ash cement, since fly ash is a pozzolan, but also includes cements made from other natural or artificial pozzolans. In countries where volcanic ashes are available (e.g., Italy, Chile, Mexico, the Philippines), these cements are often the most common form in use. The maximum replacement ratios are generally defined as for Portland-fly ash cement.

Portland silica fume cement. Addition of silica fume can yield exceptionally high strengths, and cements containing 5–20% silica fume are occasionally produced, with 10% being the maximum allowed addition under EN 197–1. However, silica fume is more usually added to Portland cement at the concrete mixer.[45]

Masonry cements are used for preparing bricklaying mortars and stuccos, and must not be used in concrete. They are usually complex proprietary formulations containing Portland clinker and a number of other ingredients that may include limestone, hydrated lime, air entrainers, retarders, waterproofers, and coloring agents. They are formulated to yield workable mortars that allow rapid and consistent masonry work. Subtle variations of masonry cement in North America are plastic cements and stucco cements. These are designed to produce a controlled bond with masonry blocks.

Expansive cements contain, in addition to Portland clinker, expansive clinkers (usually sulfoaluminate clinkers), and are designed to offset the effects of drying shrinkage normally encountered in hydraulic cements. This cement can make concrete for floor slabs (up to 60 m square) without contraction joints.

White blended cements may be made using white clinker (containing little or no iron) and white supplementary materials such as high-purity metakaolin. **Colored** cements serve decorative purposes. Some standards allow the addition of pigments to produce colored Portland cement. Other standards (e.g., ASTM) do not allow pigments in Portland cement, and colored cements are sold as blended hydraulic cements.

Very finely ground cements are cement mixed with sand or with slag or other pozzolan type minerals that are extremely finely ground together. Such cements can have the same physical characteristics as normal cement but with 50% less cement, particularly because there is more surface area for the chemical reaction. Even with intensive grinding they can use up to 50% less energy (and thus less carbon emissions) to fabricate than ordinary Portland cements.[46]

Other

[edit]

Pozzolan-lime cements are mixtures of ground pozzolan and lime. These are the cements the Romans used, and are present in surviving Roman structures like the Pantheon in Rome. They develop strength slowly, but their ultimate strength can be very high. The hydration products that produce strength are essentially the same as those in Portland cement.

Slag-lime cements—ground granulated blast-furnace slag—are not hydraulic on their own, but are "activated" by addition of alkalis, most economically using lime. They are similar to pozzolan lime cements in their properties. Only granulated slag (i.e., water-quenched, glassy slag) is effective as a cement component.

Supersulfated cements contain about 80% ground granulated blast furnace slag, 15% gypsum or anhydrite and a little Portland clinker or lime as an activator. They produce strength by formation of ettringite, with strength growth similar to a slow

Portland cement. They exhibit good resistance to aggressive agents, including sulfate.

Calcium aluminate cements are hydraulic cements made primarily from limestone and bauxite. The active ingredients are monocalcium aluminate $CaAl_2O_4$ ($CaO \cdot Al_2O_3$ or CA in cement chemist notation, CCN) and mayenite $Ca_{12}Al_{14}O_{33}$ ($12\ CaO \cdot 7\ Al_2O_3$, or $C_{12}A_7$ in CCN). Strength forms by hydration to calcium aluminate hydrates. They are well-adapted for use in refractory (high-temperature resistant) concretes, e.g., for furnace linings.

Calcium sulfoaluminate cements are made from clinkers that include ye'elimite ($Ca_4(AlO_2)_6SO_4$ or $C_4A_3\overline{S}$ in Cement chemist's notation) as a primary phase. They are used in expansive cements, in ultra-high early strength cements, and in "low-energy" cements. Hydration produces ettringite, and specialized physical properties (such as expansion or rapid reaction) are obtained by adjustment of the availability of calcium and sulfate ions. Their use as a low-energy alternative to Portland cement has been pioneered in China, where several million tonnes per year are produced.[47][48] Energy requirements are lower because of the lower kiln temperatures required for reaction, and the lower amount of limestone (which must be endothermically decarbonated) in the mix. In addition, the lower limestone content and lower fuel consumption leads to a CO_2 emission around half that associated with Portland clinker. However, SO_2 emissions are usually significantly higher.

"Natural" cements corresponding to certain cements of the pre-Portland era, are produced by burning argillaceous limestones at moderate temperatures. The level of clay components in the limestone (around 30–35%) is such that large amounts of belite (the low-early strength, high-late strength mineral in Portland cement) are formed without the formation of excessive amounts of free lime. As with any natural material, such cements have highly variable properties.

Geopolymer cements are made from mixtures of water-soluble alkali metal silicates, and aluminosilicate mineral powders such as fly ash and metakaolin.

Polymer cements are made from organic chemicals that polymerise. Producers often use thermoset materials. While they are often significantly more expensive, they can give a water proof material that has useful tensile strength.

Sorel cement is a hard, durable cement made by combining magnesium oxide and a magnesium chloride solution

Fiber mesh cement or fiber reinforced concrete is cement that is made up of fibrous materials like synthetic fibers, glass fibers, natural fibers, and steel fibers. This type of mesh is distributed evenly throughout the wet concrete. The purpose of fiber mesh is to reduce water loss from the concrete as well as enhance its structural integrity.[49] When used in plasters, fiber mesh increases cohesiveness, tensile strength, impact resistance, and to reduce shrinkage; ultimately, the main purpose of these combined properties is to reduce cracking.[50]

Electric cement is proposed to be made by recycling cement from demolition wastes in an electric arc furnace as part of a steelmaking process. The recycled cement is intended to be used to replace part or all of the lime used in steelmaking, resulting in a slag-like material that is similar in mineralogy to Portland cement, eliminating most of the associated carbon emissions.[51]

Setting, hardening and curing

[edit]

Cement starts to set when mixed with water, which causes a series of hydration chemical reactions. The constituents slowly hydrate and the mineral hydrates solidify and harden. The interlocking of the hydrates gives cement its strength. Contrary to popular belief, hydraulic cement does not set by drying out — proper curing requires maintaining the appropriate moisture content necessary for the hydration reactions during the setting and the hardening processes. If hydraulic cements dry out during the curing phase, the resulting product can be insufficiently hydrated and significantly weakened. A minimum temperature of 5 °C is recommended, and no more than 30 °C.[52] The concrete at young age must be protected against water evaporation due to direct insolation, elevated temperature, low relative humidity and wind.

The *interfacial transition zone* (ITZ) is a region of the cement paste around the aggregate particles in concrete. In the zone, a gradual transition in the microstructural features occurs.[53] This zone can be up to 35 micrometer wide.[54] :ÃƒÂ¢Ã¢â€šÂ¬Ã…Â 351ÃƒÂ¢Ã¢â€šÂ¬Ã…Â Other studies have shown that the width can be up to 50 micrometer. The average content of unreacted clinker phase decreases and porosity decreases towards the aggregate surface. Similarly, the content of ettringite increases in ITZ. [54] :ÃƒÂ¢Ã¢â€šÂ¬Ã…Â 352ÃƒÂ¢Ã¢â€šÂ¬Ã…Â

Safety issues

[edit]

Bags of cement routinely have health and safety warnings printed on them because not only is cement highly alkaline, but the setting process is exothermic. As a result, wet cement is strongly caustic (pH = 13.5) and can easily cause severe skin burns if not promptly washed off with water. Similarly, dry cement powder in contact with mucous membranes can cause severe eye or respiratory irritation. Some trace elements, such as chromium, from impurities naturally present in the raw materials used to produce cement may cause allergic dermatitis.[55] Reducing agents such as ferrous sulfate ($FeSO_4$) are often added to cement to convert the carcinogenic hexavalent chromate ($CrO_4^{2?}$) into trivalent chromium (Cr^{3+}), a less toxic chemical species. Cement users need also to wear appropriate gloves and protective clothing.[56]

Cement industry in the world

[edit]

Global cement production (2022)

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Global cement production in 2022

Global cement capacity (2022)

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Global cement capacity in 2022

See also: List of countries by cement production and Cement industry in the United States

In 2010, the world production of hydraulic cement was 3,300 megatonnes ($3{,}600 \times 10^6$ short tons). The top three producers were China with 1,800, India with 220, and the United States with 63.5 million tonnes for a total of over half the world total by the world's three most populated states.[57]

For the world capacity to produce cement in 2010, the situation was similar with the top three states (China, India, and the US) accounting for just under half the world total capacity.[58]

Over 2011 and 2012, global consumption continued to climb, rising to 3585 Mt in 2011 and 3736 Mt in 2012, while annual growth rates eased to 8.3% and 4.2%, respectively.

China, representing an increasing share of world cement consumption, remains the main engine of global growth. By 2012, Chinese demand was recorded at 2160 Mt, representing 58% of world consumption. Annual growth rates, which reached 16% in 2010, appear to have softened, slowing to 5–6% over 2011 and 2012, as China's economy targets a more sustainable growth rate.

Outside of China, worldwide consumption climbed by 4.4% to 1462 Mt in 2010, 5% to 1535 Mt in 2011, and finally 2.7% to 1576 Mt in 2012.

Iran is now the 3rd largest cement producer in the world and has increased its output by over 10% from 2008 to 2011.[59] Because of climbing energy costs in Pakistan and other major cement-producing countries, Iran is in a unique position as a trading partner, utilizing its own surplus petroleum to power clinker plants. Now a top producer in the Middle-East, Iran is further increasing its dominant position in local markets and abroad.[60]

The performance in North America and Europe over the 2010–12 period contrasted strikingly with that of China, as the global financial crisis evolved into a sovereign debt crisis for many economies in this region[*clarification needed*] and recession. Cement consumption levels for this region fell by 1.9% in 2010 to 445 Mt, recovered by 4.9% in 2011, then dipped again by 1.1% in 2012.

The performance in the rest of the world, which includes many emerging economies in Asia, Africa and Latin America and representing some 1020 Mt cement demand in 2010, was positive and more than offset the declines in North America and Europe. Annual consumption growth was recorded at 7.4% in 2010, moderating to 5.1% and 4.3% in 2011 and 2012, respectively.

As at year-end 2012, the global cement industry consisted of 5673 cement production facilities, including both integrated and grinding, of which 3900 were located in China and 1773 in the rest of the world.

Total cement capacity worldwide was recorded at 5245 Mt in 2012, with 2950 Mt located in China and 2295 Mt in the rest of the world.[6]

China

[edit]

Main article: Cement industry in China

"For the past 18 years, China consistently has produced more cement than any other country in the world. [...] (However,) China's cement export peaked in 1994 with 11 million tonnes shipped out and has been in steady decline ever since. Only 5.18 million tonnes were exported out of China in 2002. Offered at $34 a ton, Chinese cement is pricing itself out of the market as Thailand is asking as little as $20 for the same quality."[61]

In 2006, it was estimated that China manufactured 1.235 billion tonnes of cement, which was 44% of the world total cement production.[62] "Demand for cement in China is expected to advance 5.4% annually and exceed 1 billion tonnes in 2008, driven by slowing but healthy growth in construction expenditures. Cement consumed in China will amount to 44% of global demand, and China will remain the world's largest national consumer of cement by a large margin."[63]

In 2010, 3.3 billion tonnes of cement was consumed globally. Of this, China accounted for 1.8 billion tonnes.[64]

Environmental impacts

[edit]
Further information: Environmental impact of concrete

Cement manufacture causes environmental impacts at all stages of the process. These include emissions of airborne pollution in the form of dust, gases, noise and vibration when operating machinery and during blasting in quarries, and damage to countryside from quarrying. Equipment to reduce dust emissions during quarrying and manufacture of cement is widely used, and equipment to trap and separate exhaust gases are coming into increased use. Environmental protection also includes the re-integration of quarries into the countryside after they have been closed down by returning them to nature or re-cultivating them.

CO_2 emissions

[edit]

Global carbon emission by type to 2018

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Global carbon emission by type to 2018

Carbon concentration in cement spans from ?5% in cement structures to ?8% in the case of roads in cement.[65] Cement manufacturing releases CO_2 in the atmosphere both directly when calcium carbonate is heated, producing lime and carbon dioxide,[66][67] and also indirectly through the use of energy if its production involves the emission of CO_2. The cement industry produces about 10% of global human-made CO_2 emissions, of which 60% is from the chemical process, and 40% from burning fuel.[68] A Chatham House study from 2018 estimates that the 4 billion tonnes of cement produced annually account for 8% of worldwide CO_2 emissions.[5]

Nearly 900 kg of CO_2 are emitted for every 1000 kg of Portland cement produced. In the European Union, the specific energy consumption for the production of cement clinker has been reduced by approximately 30% since the 1970s. This reduction in primary energy requirements is equivalent to approximately 11 million tonnes of coal per year with corresponding benefits in reduction of CO_2 emissions. This accounts for approximately 5% of anthropogenic CO_2.[69]

The majority of carbon dioxide emissions in the manufacture of Portland cement (approximately 60%) are produced from the chemical decomposition of limestone to lime, an ingredient in Portland cement clinker. These emissions may be reduced by lowering the clinker content of cement. They can also be reduced by alternative fabrication methods such as the intergrinding cement with sand or with slag or other pozzolan type minerals to a very fine powder.[70]

To reduce the transport of heavier raw materials and to minimize the associated costs, it is more economical to build cement plants closer to the limestone quarries rather than to the consumer centers.[71]

As of 2019 carbon capture and storage is about to be trialed, but its financial viability is uncertain.[72]

CO_2 absorption

[edit]

Hydrated products of Portland cement, such as concrete and mortars, slowly reabsorb atmospheric CO2 gas, which has been released during calcination in a kiln. This natural process, reversed to calcination, is called carbonation.[73] As it depends on CO2 diffusion into the bulk of concrete, its rate depends on many parameters, such as environmental conditions and surface area exposed to the atmosphere.[74][75] Carbonation is particularly significant at the latter stages of the concrete life - after demolition and crushing of the debris. It was estimated that during the whole life-cycle of cement products, it can be reabsorbed nearly 30% of atmospheric CO2 generated by cement production.[75]

Carbonation process is considered as a mechanism of concrete degradation. It reduces pH of concrete that promotes reinforcement steel corrosion.[73] However, as the product of Ca(OH)2 carbonation, CaCO3, occupies a greater volume, porosity of concrete reduces. This increases strength and hardness of concrete.[76]

There are proposals to reduce carbon footprint of hydraulic cement by adopting non-hydraulic cement, lime mortar, for certain applications. It reabsorbs some of the CO_2 during hardening, and has a lower energy requirement in production than Portland cement.[77]

A few other attempts to increase absorption of carbon dioxide include cements based on magnesium (Sorel cement).[78][79][80]

Heavy metal emissions in the air

[edit]

In some circumstances, mainly depending on the origin and the composition of the raw materials used, the high-temperature calcination process of limestone and clay minerals can release in the atmosphere gases and dust rich in volatile heavy metals, e.g. thallium,[81] cadmium and mercury are the most toxic. Heavy metals (Tl, Cd, Hg, ...) and also selenium are often found as trace elements in common metal sulfides (pyrite (FeS_2), zinc blende (ZnS), galena (PbS), ...) present as secondary minerals in most of the raw materials. Environmental regulations exist in many countries to limit these emissions. As of 2011 in the United States, cement kilns are "legally allowed to pump more toxins into the air than are hazardous-waste incinerators."[82]

Heavy metals present in the clinker

[edit]

The presence of heavy metals in the clinker arises both from the natural raw materials and from the use of recycled by-products or alternative fuels. The high pH prevailing in the cement porewater ($12.5 < pH < 13.5$) limits the mobility of many heavy metals by decreasing their solubility and increasing their sorption onto the cement mineral phases. Nickel, zinc and lead are commonly found in cement in non-negligible concentrations. Chromium may also directly arise as natural impurity from the raw materials or as secondary contamination from the abrasion of hard chromium steel alloys used in the ball mills when the clinker is ground. As chromate ($CrO_4^{2?}$) is toxic and may cause severe skin allergies at trace concentration, it is sometimes reduced into trivalent Cr(III) by addition of ferrous sulfate ($FeSO_4$).

Use of alternative fuels and by-products materials

[edit]

A cement plant consumes 3 to 6 GJ of fuel per tonne of clinker produced, depending on the raw materials and the process used. Most cement kilns today use coal and petroleum coke as primary fuels, and to a lesser extent natural gas and fuel oil. Selected waste and by-products with recoverable calorific value can be used as fuels in a cement kiln (referred to as co-processing), replacing a portion of conventional fossil fuels, like coal, if they meet strict specifications. Selected waste and by-products containing useful minerals such as calcium, silica, alumina, and iron can be used as raw materials in the kiln, replacing raw materials such as clay, shale, and limestone. Because some materials have both useful mineral content and recoverable calorific value, the distinction between alternative fuels and raw materials is not always clear. For example, sewage sludge has a low but significant calorific value, and burns to give ash containing minerals useful in the clinker matrix.[83] Scrap automobile and truck tires are useful in cement manufacturing as they have high calorific value and the iron embedded in tires is useful as a feed stock.[84]:ÃƒÂ¢Ã¢â€šÂ¬Ã…Â p. 27ÃƒÂ¢Ã¢â€šÂ¬Ã…Â

Clinker is manufactured by heating raw materials inside the main burner of a kiln to a temperature of 1,450 °C. The flame reaches temperatures of 1,800 °C. The material remains at 1,200 °C for 12–15 seconds at 1,800 °C or sometimes for 5–8 seconds (also referred to as residence time). These characteristics of a clinker kiln offer numerous benefits and they ensure a complete destruction of organic compounds, a total neutralization of acid gases, sulphur oxides and hydrogen chloride. Furthermore, heavy metal traces are embedded in the clinker structure and no by-products, such as ash or residues, are produced.[85]

The EU cement industry already uses more than 40% fuels derived from waste and biomass in supplying the thermal energy to the grey clinker making process. Although the choice for this so-called alternative fuels (AF) is typically cost driven, other factors are becoming more important. Use of alternative fuels provides benefits for both society and the company: CO_2-emissions are lower than with fossil fuels, waste can be co-processed in an efficient and sustainable manner and the demand for certain virgin materials can be reduced. Yet there are large differences in the share of alternative fuels used between the European Union (EU) member states. The societal benefits could be improved if more member states increase their alternative fuels share. The Ecofys study[86] assessed the barriers and opportunities for further uptake of alternative fuels in 14 EU member states. The Ecofys study found that local factors constrain the market potential to a much larger extent than the technical and economic feasibility of the cement industry itself.

Reduced-footprint cement

[edit]

Growing environmental concerns and the increasing cost of fossil fuels have resulted, in many countries, in a sharp reduction of the resources needed to produce cement, as well as effluents (dust and exhaust gases).[87] Reduced-footprint cement is a cementitious material that meets or exceeds the functional performance capabilities of Portland cement. Various techniques are under development. One is geopolymer cement, which incorporates recycled materials, thereby reducing consumption of raw materials, water, and energy. Another approach is to reduce or eliminate the production and release of damaging pollutants and greenhouse gasses, particularly CO_2.[88] Recycling old cement in electric arc furnaces is another approach.[89] Also, a team at the University of Edinburgh has developed the 'DUPE' process based on the microbial activity of *Sporosarcina pasteurii*, a bacterium precipitating calcium carbonate, which, when mixed with sand and urine, can produce mortar blocks with a compressive strength 70% of that of concrete.[90] An overview of climate-friendly methods for cement production can be found here.[91]

See also

[edit]

- Asphalt concrete
- Calcium aluminate cements
- Cement chemist notation
- Cement render
- Cenocell
- Energetically modified cement (EMC)
- Fly ash
- Geopolymer cement
- Portland cement
- Rosendale cement
- Sulfate attack in concrete and mortar
- Sulfur concrete
- Tiocem
- List of countries by cement production

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Technology and related concepts

Major technologies	

Necessities	◦ Agriculture
	  ◦ Domestication
	  ◦ Grafting
	  ◦ Working animal
	◦ Clothing
	  ◦ Sewing machine
	◦ Cooking
	  ◦ Beer
	  ◦ Bread
	  ◦ Cheese
	  ◦ Milling
	  ◦ Wine
	◦ Food storage
	  ◦ Pottery
	◦ Sanitation
	  ◦ Plumbing
	  ◦ Toilet
	◦ Tool / Equipment
	  ◦ Blade
	  ◦ Hammer
	  ◦ Plough
	  ◦ Wedge
	◦ Weapon
	  ◦ Gun

Social	◦ Accounting
	◦ Calculation
	  ◦ Abacus
	  ◦ Calendar
	◦ Cryptography
	◦ Lock and key
	◦ Money
	  ◦ Banknote
	  ◦ Coin
	◦ Musical instrument
	  ◦ Phonograph
	◦ Toy
	  ◦ Game
	  ◦ Video game
	◦ Writing
	  ◦ Book
	  ◦ Map
	  ◦ Printing press
	  ◦ Typewriter

	◦ Aqueduct

	Perspectives

Criticism	○ Appropriate technology
	  ○ Low technology
	○ Luddite
	  ○ Neo-Luddism
	○ Precautionary principle

Ecotechnology	○ Environmental technology
	  ○ Clean technology
	○ Sustainable design
	  ○ Sustainable engineering

Policy & politics	○ Government by algorithm
	○ Intellectual property
	  ○ Patent
	  ○ Trade secret
	○ Persuasive technology
	○ Science policy
	○ Strategy of Technology
	○ Technology assessment
	○ Technorealism

Progressivism	○ Futures studies
	  ○ Technology forecasting
	○ Technological utopianism
	  ○ Technocracy movement
	  ○ Technological singularity
	  ○ Transhumanism

Studies	○ Diffusion of innovations
	  ○ Technology transfer
	○ History
	  ○ Timeline of historic inventions
	○ Philosophy
	  ○ Social construction of technology
	  ○ Technological determinism
	○ Technology acceptance model

Related concepts

Applied science

- Agronomy
- Architecture
- Construction
- Engineering
- Forensics
- Forestry
- Logistics
- Medicine
- Mining
- Navigation
- Surveying

Innovation

- Design
- High tech
- Invention
- Mature technology
- Research and development
- Technological convergence
- Technology lifecycle

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Concrete

History

- Ancient Roman architecture
- Roman architectural revolution
- Roman concrete
- Roman engineering
- Roman technology

Composition

- Cement
  - Calcium aluminate
  - Energetically modified
  - Portland
  - Rosendale
- Water
- Water–cement ratio
- Aggregate
- Reinforcement
- Fly ash
- Ground granulated blast-furnace slag
- Silica fume
- Metakaolin

Production

- Plant
- Concrete mixer
- Volumetric mixer
- Reversing drum mixer
- Slump test
- Flow table test
- Curing

Construction

- Concrete cover
- Cover meter
- Rebar
- Precast
- Cast-in-place
- Formwork
- Climbing formwork
- Slip forming
- Screed
- Power screed
- Finisher
- Grinder
- Power trowel
- Pump
- Float
- Sealer
- Tremie

Science	◦ Properties ◦ Durability ◦ Degradation ◦ Environmental impact ◦ Recycling ◦ Segregation ◦ Alkali–silica reaction

Types	◦ AstroCrete
	◦ Fiber-reinforced
	◦ Filigree
	◦ Foam
	◦ Lunarcrete
	◦ Mass
	◦ Nanoconcrete
	◦ Pervious
	◦ Polished
	◦ Polymer
	◦ Prestressed
	◦ Ready-mix
	◦ Reinforced
	◦ Roller-compacting
	◦ Self-consolidating
	◦ Self-leveling
	◦ Sulfur
	◦ Tabby
	◦ Translucent
	◦ Waste light
	◦ Aerated
	    ◦ AAC
	    ◦ RAAC

Applications	◦ Slab
	    ◦ waffle
	    ◦ hollow-core
	    ◦ voided biaxial
	    ◦ slab on grade
	◦ Concrete block
	◦ Step barrier
	◦ Roads
	◦ Columns
	◦ Structures

Organizations

- American Concrete Institute
- Concrete Society
- Institution of Structural Engineers
- Indian Concrete Institute
- Nanocem
- Portland Cement Association
- International Federation for Structural Concrete

Standards

- Eurocode 2
- EN 197-1
- EN 206-1
- EN 10080

See also

- Hempcrete

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Major industries

Natural sector

Agriculture

- Arable farming
  - Cereals
  - Legumes
  - Vegetables
  - Fiber crops
  - Oilseeds
  - Sugar
  - Tobacco
- Permanent crops
  - Apples et al.
  - Berries
  - Citrus
  - Stone fruits
  - Tropical fruit
  - Viticulture
  - Cocoa
  - Coffee
  - Tea
  - Nuts
  - Olives
  - Medicinal plants
  - Spices
- Horticulture
  - Flowers
  - Seeds
- Animal husbandry
  - Beef cattle
  - Dairy farming
  - Fur farming
  - Horses
  - Other livestock
  - Pig
  - Wool
  - Poultry
  - Beekeeping
  - Cochineal
  - Shellac
  - Silk
- Hunting
  - Fur trapping
- Silviculture
  - Bamboo
- Logging

Industrial sector

Light industry

- Food
  - Animal feed
  - Baking
  - Canning
  - Dairy products
  - Flour
  - Meat
  - Prepared
  - Preserved
  - Sweets
  - Vegetable oils
- Beverages
  - Beer
  - Bottled water
  - Liquor
  - Soft drinks
  - Wine
- Textiles
  - Carding
  - Dyeing
  - Prints
  - Spinning
  - Weaving
  - Carpets
  - Lace
  - Linens
  - Rope
- Clothing
  - Accessories
  - Dressmaking
  - Furs
  - Hatmaking
  - Sewing
  - Shoemaking
  - Tailoring
- Printing
  - Bookbinding
  - Embossing
  - Engraving
  - Secure
  - Typesetting
- Media reproduction
  - Cassette tapes

	Service sector

Sales	◦ Retail
	  ◦ Car dealership
	  ◦ Consumer goods
	  ◦ General store
	  ◦ Grocery store
	  ◦ Department store
	  ◦ Mail order
	  ◦ Online shopping
	  ◦ Specialty store
	◦ Wholesale
	  ◦ Auction
	  ◦ Brokerage
	  ◦ Distribution

Transport & Storage	◦ Cargo
	  ◦ Air cargo
	  ◦ Intermodal
	  ◦ Mail
	  ◦ Moving company
	  ◦ Rail
	  ◦ Trucking
	◦ Passenger transport
	  ◦ Airlines
	  ◦ Car rentals
	  ◦ Passenger rail
	  ◦ Ridesharing
	  ◦ Taxis
	◦ Warehousing
	  ◦ Self storage

Hospitality	◦ Foodservice
	  ◦ Drink service
	  ◦ Cafés
	  ◦ Catering
	  ◦ Fast food
	  ◦ Food delivery
	  ◦ Restaurants
	  ◦ Teahouses
	◦ Hotels

	◦ Financial services
	  ◦ Banking
	  ◦ Credit
	  ◦ Financial advice
	  ◦ Holding company
	  ◦ Money transfer
	  ◦ Payment cards

	Related
Classification standards	Production-based ◦ ANZSIC ◦ ***ISIC*** ◦ NACE ◦ NAICS ◦ SIC ◦ UKSIC Market-based ◦ GICS ◦ ICB ◦ TRBC Other ◦ Aftermarket ◦ Generic ◦ OEM
Inputs & outputs	Externalities ◦ Community ◦ Crime ◦ Culture ◦ Pollution ◦ Well-being Funding Goods ◦ Commodities ◦ Final ◦ Intermediate ◦ Raw material Innovation Primary inputs ◦ Labor ◦ Natural resources ◦ Physical capital Services Technology
	Centralization ◦ Cartel ◦ Conglomerate ◦ Horizontal integration ◦ Mergers and acquisitions ◦ Monopoly ◦ Monopsony ◦ Vertical integration Decentralization ◦ Enforced breakup

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Driving Directions From 42.017845685371, -88.11591807218 to

Driving Directions From 42.084324223519, -88.137710099374 to

Driving Directions From 42.10843482977, -88.114090738222 to

Driving Directions From 42.086153671225, -88.19640031169 to

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