Geotechnical Testing

- Inspection and Monitoring Toolkit

  Inspection and Monitoring Toolkit Using a Laser Level to Map Foundation Elevations Setting Up Permanent Benchmarks for Movement Tracking Interpreting Data From Tilt Meters Installed on Walls LIDAR Scans for High Resolution Displacement Analysis Robotic Total Station Workflows for Residential Sites Creating a Quarterly Report Template for Crack Gauges Selecting Software for Long Term Foundation Monitoring How to Calibrate a Digital Level for Accurate Surveys Advantages of Installing Wireless Inclinometers Safety Checks Before Conducting Basement Scans Data Visualization Techniques for Stakeholder Updates Scheduling Inspections After Major Weather Events

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- About Us

Robotic Total Station Workflows for Residential Sites

Lets be honest, when were talking about using a robotic total station on a residential site, were not just playing with fancy gadgets. Were trying to build something solid, something that lasts. And that means understanding the ground beneath our feet. Ignoring foundation issues and repair needs is like building a house of cards – impressive at first glance, but destined to crumble.

Foundation issues have this infuriating way of starting small and then blooming into financial nightmares like some sort of monetary horror film residential foundation inspection Evanston Delaware.

Think about it. A robotic total station can give you pinpoint accuracy in laying out your foundation, but if the soil is unstable, or there are pre-existing cracks in an existing foundation youre building onto, what's the point? Youre just precisely marking out a future disaster. Thats why a thorough assessment of the existing conditions is absolutely crucial before even setting up the instrument.

We need to be asking questions like: Is the soil properly compacted? Are there signs of erosion or water damage? Is there any evidence of past settlements or foundation movement? Are there tree roots encroaching on the foundation area? These are the things that can undermine even the best-laid plans, and a robotic total station, powerful as it is, cant magically fix them.

Furthermore, understanding the repair needs of an existing foundation, if applicable, is just as important. Are we reinforcing an old structure? What kind of patching or underpinning is necessary? The robotic total station can then be used to precisely monitor the effects of these repairs, ensuring that they're actually working and that no further movement is occurring. Its about using the technology to validate the stability and integrity of the foundation, not just to make the layout process faster.

So, while the allure of robotic total stations lies in their efficiency and accuracy, lets not forget the fundamental principles of construction. Understanding foundation issues and repair needs is the bedrock upon which any successful residential project is built. Its about marrying cutting-edge technology with good old-fashioned due diligence to create structures that stand the test of time.

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Monitoring Tools and Equipment for Foundation Stability

In the realm of land surveying, particularly for residential sites, the evolution from traditional methods to advanced technologies like Robotic Total Stations (RTS) represents a significant leap in efficiency and accuracy. Traditional surveying methods, which have been employed for centuries, involve manual measurements using tools such as theodolites, levels, and tapes. These methods require a team of surveyors to physically move equipment around the site, taking multiple readings which are then manually recorded and calculated. The process is labor-intensive and time-consuming, often susceptible to human error due to the physicality and repetitive nature of the tasks.

Contrastingly, Robotic Total Stations introduce a modern workflow that enhances productivity while minimizing errors. An RTS operates with one surveyor controlling a robotic instrument from a distance via a remote or tablet. This technology integrates laser distance measurement with automated angle readings, providing precise data collection in real-time. For residential sites, where space might be limited and precision is crucial for layout planning or construction oversight, RTS offers unparalleled advantages.

The workflow with an RTS begins with setting up the station at a known point on the site. Once initialized, it can automatically track prisms placed on various points around the property. The surveyor can then move freely across the site, positioning themselves at different locations without needing to physically adjust the station. This mobility reduces setup time between points significantly compared to traditional methods where each setup requires alignment and leveling.

Moreover, data collected by an RTS is directly fed into software that can generate detailed maps or 3D models almost instantaneously. This immediate visualization aids in decision-making processes during construction phases or when planning landscaping features on residential properties. Traditional methods would require additional steps of data transcription and manual plotting before any visual representation could be achieved.

In terms of human resources, an RTS typically requires fewer personnel; often just one skilled operator can manage what would traditionally need several people. This reduction not only cuts labor costs but also speeds up project timelines since theres less coordination needed among team members.

However, despite these advancements, traditional surveying still holds value in scenarios where high-tech solutions might be overkill or cost-prohibitive for small residential projects. Theres also an element of tactile understanding of land that some surveyors argue is lost when relying solely on technology.

In summary, while traditional surveying methods have laid down robust foundations in understanding land measurements through direct human interaction with the environment, Robotic Total Stations offer a futuristic approach tailored for efficiency in modern residential development workflows. The choice between them often depends on project scale, budget considerations, and sometimes personal preference regarding hands-on versus tech-driven work environments. Yet undeniably, RTS represents a forward-moving trend in how we capture and utilize spatial data in our living spaces today.

Data Analysis and Interpretation in Foundation Repair

Do not use any headings or lists in the output. Do not use any citations.

Robotic Total Station Setup and Calibration is absolutely crucial when youre talking about using these high-tech instruments for foundation repair on residential sites. Think about it: youre dealing with incredibly sensitive measurements, often on structures that are already compromised. A tiny error in setup or a slightly off calibration can snowball into major problems, potentially exacerbating the existing damage or leading to incorrect repair strategies.

The initial setup is all about establishing a solid foundation, literally and figuratively, for your surveying work. This means choosing a stable location for the total station, free from vibrations or obstructions that could interfere with the instruments line of sight. Centering the total station perfectly over a known point, usually a control point established with GPS or traditional surveying methods, is paramount. Then, meticulously leveling the instrument is non-negotiable. Even a small bubble off-center can introduce significant errors in your elevation and horizontal angle readings.

Calibration is the next essential step. Its about ensuring the internal components of the robotic total station are functioning correctly and providing accurate data.

This typically involves checking and adjusting the instruments collimation (the alignment of the optical axis), the vertical and horizontal angle encoders, and the reflectorless measurement capabilities. Calibration routines are often built into the instruments software and should be performed regularly, especially before and after moving the total station or encountering any bumps or jolts during transport.

Why is all this so important for foundation repair? Well, consider the types of measurements youll be taking. You might be monitoring foundation movement, measuring the elevation of different points on the structure, mapping cracks and deformations, or establishing precise locations for underpinning or pier installation. The accuracy of these measurements directly impacts the effectiveness of the repair. Imagine installing piers based on inaccurate data – you could end up with an uneven foundation or introduce new stresses into the structure.

In short, robotic total stations are powerful tools for foundation repair, but their accuracy is entirely dependent on proper setup and calibration. Its a meticulous process, but one thats absolutely essential for ensuring the success of the repair and the long-term stability of the home. Cutting corners here simply isnt an option.

Regular Maintenance Schedule for Post-Repair Monitoring

Okay, lets talk about getting good data when youre using a robotic total station to map out the foundation of a house. Think of it like this: the robotic total station is your super-accurate eye, but it still needs to see the right things in the right way to give you a solid foundation (pun intended!) for the whole building project. That means we need to nail down the best data collection techniques.

The accuracy of your foundation map hinges on a few key things. First, *target selection is crucial*. You cant just point the robotic total station at anything and expect good results. Were talking about strategically placing prisms or reflective targets precisely where you need measurements – corners of the proposed foundation, points along the building lines, and any significant grade changes. The more targets, especially at critical locations, the better your data will be. Think of it like placing anchors for a really strong fence; the more you have, the more solid the whole thing is.

Second, *careful instrument setup is non-negotiable*. If your total station isnt perfectly level and oriented, all your measurements will be skewed. That means taking the time to properly level the instrument using the built-in levels, and accurately establishing its location relative to a known benchmark or control point. This might involve setting up over a control point if one exists, or using resection to determine your instruments coordinates. Its like calibrating a scale before you start weighing things – if the scale is off, everything you weigh will be wrong.

Third, *consider your measurement strategy*. Rather than just randomly shooting points, think about a systematic approach. For example, you might establish a grid pattern around the proposed foundation and take measurements at regular intervals. This ensures you have good coverage and can easily identify any unexpected elevation changes or obstructions. Its also smart to take redundant measurements – shooting the same point from different setups to check for consistency. This is like having a backup plan; if one measurement is off, you have others to compare it to.

Finally, *environmental conditions matter*. Rain, fog, and even extreme heat can affect the accuracy of your measurements. Ideally, you want to collect data on a clear, calm day. If you have to work in less-than-ideal conditions, be aware of the potential for errors and take extra precautions. This might involve shortening the measurement distances, using a higher-quality prism, or simply being more vigilant about checking your results.

In short, getting accurate foundation mapping with a robotic total station isnt just about pushing buttons. Its about careful planning, precise execution, and a healthy dose of common sense. By focusing on these data collection techniques, you can ensure that your foundation map is a reliable representation of the site, setting the stage for a successful construction project.

Analyzing survey data is a crucial step in optimizing repair strategies for robotic total station workflows, especially within the context of residential sites. Robotic total stations, advanced surveying tools that automate much of the data collection process, provide precise measurements that are vital for accurate assessments of residential properties. When it comes to determining repair strategies, the detailed data collected by these devices can significantly streamline decision-making processes.

The first step in this analysis involves gathering comprehensive data from the site. This includes measurements of existing structures, ground levels, and any deviations or anomalies that could indicate structural issues. The robotic total station excels in this phase by offering high precision and reducing human error, which is particularly beneficial on residential sites where space can be limited and accuracy is paramount.

Once the raw data is collected, the next phase is to analyze it for patterns or discrepancies that might suggest areas needing repair or reinforcement. For instance, slight shifts in foundation levels could point towards subsidence issues, while irregularities in wall alignment might highlight potential structural weaknesses. Here, software tools come into play, allowing surveyors to visualize the data in 3D models or through detailed charts and graphs. This visualization aids in identifying not just obvious problems but also subtle trends that might be overlooked with traditional methods.

In developing repair strategies based on this analysis, several factors must be considered: cost-effectiveness, disruption to residents, time frame for repairs, and long-term durability. The precision of robotic total station data helps tailor solutions specifically to each sites unique challenges. For example, if data reveals minor but widespread settling across a propertys foundation, a strategy might involve micro-piling or underpinning tailored to specific zones rather than a blanket approach.

Moreover, predictive analysis can be employed using historical data from similar residential sites to forecast potential future issues based on current conditions. This proactive approach ensures that repair strategies are not only reactive but also preventive, potentially saving homeowners from more significant expenses down the line.

Effective communication of these findings to homeowners or stakeholders is also critical. The clarity provided by robotic total station data allows for straightforward explanations backed by visual evidence; this transparency builds trust and facilitates agreement on proposed repair actions.

In conclusion, analyzing survey data from robotic total stations offers a robust foundation for developing nuanced repair strategies at residential sites. By leveraging high-precision technology alongside sophisticated analytical methods, surveyors can ensure repairs are both efficient and effective, preserving the integrity of homes while minimizing inconvenience to residents. This methodical approach not only enhances current repair outcomes but also contributes to sustainable property management practices over time.

Lets talk about using robotic total stations to keep an eye on foundation movement, especially when it comes to homes. Imagine your house is a living thing, subtly shifting and settling over time. Thats perfectly normal, but sometimes, those shifts can become a worry. Thats where robotic total stations come in – think of them as super-accurate, automated surveyors.

Instead of a person constantly peering through a traditional total station, a robotic one can be set up to automatically take precise measurements of key points on your foundation. Were talking millimeters of accuracy here. By comparing these measurements over days, weeks, or even months, we can get a clear picture of how your foundation is moving. Is it a slow, expected settling? Or is it something more concerning that needs attention?

Implementing this kind of monitoring gives you an early warning system. Think of it like a health check for your house. Catching problems early means smaller, less expensive repairs down the road. It also provides valuable data for engineers and builders, allowing them to understand the underlying causes of movement and design solutions that are truly effective. Plus, having that data can be a real asset when it comes to selling your home, providing peace of mind to potential buyers.

The beauty of a robotic total station is its efficiency and consistency. It can work around the clock, unaffected by fatigue or weather conditions (within reason, of course). It also eliminates the potential for human error in data collection, ensuring a reliable and accurate record of foundation behavior. So, while it might seem like a high-tech solution, using a robotic total station for foundation monitoring is really about safeguarding your biggest investment and ensuring the long-term stability of your residential site.

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- Geotechnical Testing and Design Standards
- Sampling Procedures to Avoid Disturbed Specimens
- Cone Penetration Test Data and Its Influence on Design

In the realm of residential foundation repair, precision and efficiency are paramount. The advent of robotic total stations has revolutionized this field, offering a blend of accuracy and speed that traditional methods could hardly match. This essay explores several case studies that highlight the successful application of robotic total stations in residential site workflows.

The first case study involves a historic home in a suburban neighborhood where settling foundations posed a significant threat to the structural integrity of the building. Traditional surveying methods would have been time-consuming and potentially invasive, risking further damage to the delicate structure. Enter the robotic total station: with its ability to automatically measure points with high precision, the team was able to quickly map out the extent of foundation movement without disturbing the surrounding landscape or interior finishes. This non-invasive approach not only preserved the historical value but also allowed for precise planning of repair works.

In another instance, a modern residential complex faced challenges due to uneven ground settlement across multiple units. Here, the use of a robotic total station streamlined what would have been an overwhelming task. The workflow involved setting up the station at strategic locations around the site, allowing for continuous monitoring over weeks. This real-time data collection was instrumental in understanding dynamic soil behavior under varying conditions, leading to tailored repair strategies for each unit. The automated nature of these stations meant fewer personnel were needed on-site, reducing both labor costs and human error.

A third compelling case was in an urban environment where space constraints are often a limiting factor. A narrow townhouse with foundational issues benefited greatly from this technology. The robotic total station could be positioned outside yet still gather detailed measurements through windows or small openings, avoiding the need for internal setup which would have disrupted residents daily lives. The data collected led to micro-piling solutions that were precisely targeted, ensuring minimal disturbance while effectively stabilizing the foundation.

These examples underscore how robotic total stations enhance workflows on residential sites by providing detailed, accurate data swiftly and with minimal intrusion. They allow for better decision-making by providing clear visuals and measurements that guide effective repair strategies. Moreover, their implementation reduces project timelines and costs while increasing safety by limiting human exposure to potentially hazardous construction environments.

In conclusion, as demonstrated by these case studies, integrating robotic total stations into residential foundation repair workflows marks a significant advancement in construction technology. It not only preserves property value but also enhances homeowner satisfaction through less disruptive and more precise repair processes. As this technology continues to evolve, its adoption is likely to become standard practice in ensuring stable foundations for homes across various settings.

When considering the integration of technology into residential construction projects, the use of Robotic Total Stations (RTS) presents a compelling case. These advanced surveying tools have transformed traditional workflows, offering both significant benefits and certain costs that must be weighed for effective implementation.

Benefits:

Firstly, the precision offered by RTS is unparalleled. Unlike manual methods, these devices can measure angles and distances with high accuracy, reducing human error substantially. This precision translates directly into cost savings over time by minimizing rework due to measurement inaccuracies. For residential sites, where space is often at a premium, accurate placement of foundations and structures ensures optimal land use.

Efficiency is another major advantage. An RTS can operate autonomously or with minimal human intervention once set up, speeding up the surveying process. This efficiency is particularly beneficial in residential projects where timelines are tight. The ability to quickly gather data means that project milestones can be met more reliably, improving overall project management and client satisfaction.

Moreover, safety on construction sites is enhanced with RTS usage. Traditional surveying might require personnel to navigate potentially hazardous environments repeatedly to take measurements. With an RTS, this risk is mitigated as the operator can remain at a safe distance while controlling the device remotely.

Costs:

However, the initial investment in an RTS can be substantial. The cost includes not only the purchase price of the equipment but also training for staff to operate it effectively. For smaller residential contractors or those with infrequent need for such precision, this upfront cost might seem prohibitive compared to traditional methods.

Maintenance and calibration are additional considerations. Like all sophisticated electronic equipment, an RTS requires regular maintenance to ensure its performance remains top-notch. Calibration checks need to be scheduled periodically which adds to operational costs.

Theres also a learning curve involved with adopting new technology like an RTS. While long-term efficiency gains are clear, there might be initial delays as teams adapt from manual methods to digital workflows. This transition period could impact project timelines initially before yielding benefits.

In conclusion, while the adoption of Robotic Total Stations in residential construction workflows brings undeniable advantages in terms of accuracy, efficiency, and safety, it does come with financial and logistical challenges that must be carefully considered. For many firms looking towards future-proofing their operations with technology that supports sustainable growth and quality control in residential building projects, the investment in RTS could well prove worthwhile over time as they balance these benefits against the costs involved.

About Drainage

Water drainage is the all-natural or man-made elimination of a surface's water and sub-surface water from a location with excess water. The internal drain of many agricultural soils can avoid severe waterlogging (anaerobic conditions that hurt root development), but numerous soils require artificial water drainage to boost production or to take care of water supplies.

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About Soil mechanics

Soil technicians is a branch of dirt physics and applied mechanics that describes the habits of dirts. It differs from liquid auto mechanics and strong auto mechanics in the sense that dirts include a heterogeneous blend of liquids (usually air and water) and bits (normally clay, silt, sand, and gravel) but dirt might additionally consist of organic solids and various other issue. Along with rock technicians, dirt auto mechanics offers the theoretical basis for analysis in geotechnical engineering, a subdiscipline of civil engineering, and engineering geology, a subdiscipline of geology. Dirt auto mechanics is utilized to assess the contortions of and circulation of fluids within all-natural and manufactured structures that are supported on or made from dirt, or frameworks that are buried in dirts. Instance applications are developing and bridge structures, maintaining walls, dams, and hidden pipe systems. Principles of soil auto mechanics are likewise used in related self-controls such as geophysical engineering, seaside engineering, farming design, and hydrology. This article describes the genesis and composition of soil, the distinction in between pore water pressure and inter-granular efficient stress and anxiety, capillary activity of liquids in the soil pore areas, dirt category, seepage and permeability, time reliant adjustment of quantity due to pressing water out of small pore rooms, likewise called debt consolidation, shear stamina and rigidity of soils. The shear toughness of soils is mostly stemmed from rubbing in between the fragments and interlocking, which are really conscious the efficient anxiety. The write-up ends with some examples of applications of the concepts of soil mechanics such as incline stability, side planet stress on preserving walls, and bearing capacity of structures.

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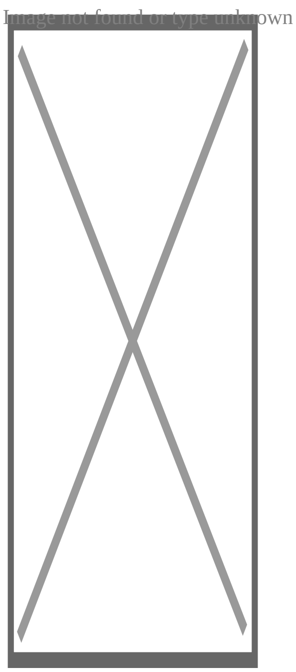
About Carbon-fiber reinforced polymer

"Carbon fiber" redirects here. For fibers of carbon, see Carbon fibers.



Tail of a radio-controlled helicopter, made of CFRP

Carbon fiber-reinforced polymers (American English), **carbon-fibre-reinforced polymers** (Commonwealth English), **carbon-fiber-reinforced plastics**, **carbon-fiber reinforced-thermoplastic** (**CFRP**, **CRP**, **CFRTP**), also known as **carbon fiber**, **carbon composite**, or just **carbon**, are extremely strong and light fiber-reinforced plastics that contain carbon fibers. CFRPs can be expensive to produce, but are commonly used wherever high strength-to-weight ratio and stiffness (rigidity) are required, such as aerospace, superstructures of ships, automotive, civil engineering, sports equipment, and an increasing number of consumer and technical applications.[1][2][3][4]

The binding polymer is often a thermoset resin such as epoxy, but other thermoset or thermoplastic polymers, such as polyester, vinyl ester, or nylon, are sometimes used.[4] The properties of the final CFRP product can be affected by the type of additives introduced to the binding matrix (resin). The most common additive is silica, but other additives such as rubber and carbon nanotubes can be used.

Carbon fiber is sometimes referred to as *graphite-reinforced polymer* or *graphite fiber-reinforced polymer* (*GFRP* is less common, as it clashes with glass-(fiber)-reinforced polymer).

Properties

[edit]

CFRP are composite materials. In this case the composite consists of two parts: a matrix and a reinforcement. In CFRP the reinforcement is carbon fiber, which provides its strength. The matrix is usually a thermosetting plastic, such as polyester resin, to bind the reinforcements together.[5] Because CFRPs consist of two distinct elements, the material properties depend on these two elements.

Reinforcement gives CFRPs their strength and rigidity, measured by stress and elastic modulus respectively. Unlike isotropic materials like steel and aluminum, CFRPs have directional strength properties. The properties of a CFRP depend on the layouts of the carbon fiber and the proportion of the carbon fibers relative to the polymer.[6] The two different equations governing the net elastic modulus of composite materials using the properties of the carbon fibers and the polymer matrix can also be applied to carbon fiber reinforced plastics.[7] The rule of mixtures for the equal strain case gives:

$$E_c=V_mE_m+V_fE_f$$

which is valid for composite materials with the fibers oriented parallel to the applied load. E_c is the total composite modulus, V_m and V_f are the volume fractions of the matrix and fiber respectively in the composite, and E_m and E_f are the elastic moduli of the matrix and fibers respectively.[7] The other extreme case of the elastic modulus of the composite with the fibers oriented transverse to the applied load can be found using the inverse rule of mixtures for the equal stress case:[7]

$$E_c=\left(\frac{V_m}{E_m}+\frac{V_f}{E_f}\right)^{-1}$$

The above equations give an upper and lower bound on the Young's modulus for CFRP and there are many other factors that influence the true value.

The fracture toughness of carbon fiber reinforced plastics is governed by multiple mechanisms:

- Debonding between the carbon fiber and polymer matrix.
- Fiber pull-out.
- Delamination between the CFRP sheets.[8]

Typical epoxy-based CFRPs exhibit virtually no plasticity, with less than 0.5% strain to failure. Although CFRPs with epoxy have high strength and elastic modulus, the brittle fracture mechanics presents unique challenges to engineers in failure detection since failure occurs catastrophically.[8] As such, recent efforts to toughen CFRPs include modifying the existing epoxy material and finding alternative polymer matrix. One such material with high promise is PEEK, which exhibits an order of magnitude greater toughness with similar elastic modulus and tensile strength.[8] However, PEEK is much more difficult to process and more expensive.[8]

Despite their high initial strength-to-weight ratios, a design limitation of CFRPs are their lack of a definable fatigue limit. This means, theoretically, that stress cycle failure cannot be ruled out. While steel and many other structural metals and alloys do have estimable fatigue or endurance limits, the complex failure modes of composites mean that the fatigue failure properties of CFRPs are difficult to predict and design against; however emerging research has shed light on the effects of low velocity impacts on composites.[9] Low velocity impacts can make carbon fiber polymers susceptible to damage.[9][10][11] As a result, when using CFRPs for critical cyclic-loading applications, engineers may need to design in considerable strength safety margins to provide suitable component reliability over its service life.

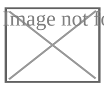
Environmental effects such as temperature and humidity can have profound effects on the polymer-based composites, including most CFRPs. While CFRPs demonstrate excellent corrosion resistance, the effect of moisture at wide ranges of temperatures can lead to degradation of the mechanical properties of CFRPs, particularly at the matrix-fiber interface.[12] While the carbon fibers themselves are not affected by the moisture diffusing into the material, the moisture plasticizes the polymer matrix.[8] This leads to significant changes in properties that are dominantly influenced by the matrix in CFRPs such as compressive, interlaminar shear, and impact properties.[13] The epoxy matrix used for engine fan blades is designed to be impervious against jet fuel, lubrication, and rain water, and external paint on the composites parts is applied to minimize damage from ultraviolet light.[8][14]

Carbon fibers can cause galvanic corrosion when CFRP parts are attached to aluminum or mild steel but not to stainless steel or titanium.[15]

CFRPs are very hard to machine, and cause significant tool wear. The tool wear in CFRP machining is dependent on the fiber orientation and machining condition of the cutting process. To reduce tool wear various types of coated tools are used in machining CFRP and CFRP-metal stack.[1]

Manufacturing

[edit]



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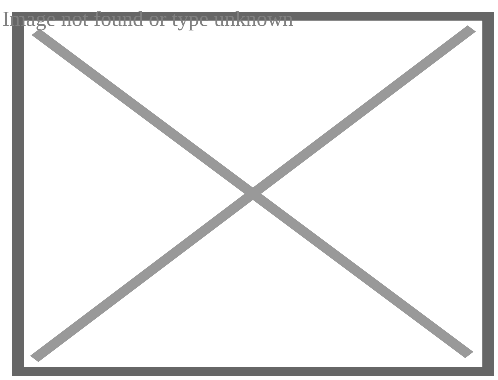

Carbon fiber reinforced polymer

The primary element of CFRPs is a carbon filament; this is produced from a precursor polymer such as polyacrylonitrile (PAN), rayon, or petroleum pitch. For synthetic polymers such as PAN or rayon, the precursor is first spun into filament yarns, using chemical and mechanical processes to initially align the polymer chains in a way to enhance the final physical properties of the completed carbon fiber. Precursor compositions and mechanical processes used during spinning filament yarns may vary among manufacturers. After drawing or spinning, the polymer filament yarns are then heated to drive off non-carbon atoms (

carbonization), producing the final carbon fiber. The carbon fibers filament yarns may be further treated to improve handling qualities, then wound onto bobbins.[16] From these fibers, a unidirectional sheet is created. These sheets are layered onto each other in a quasi-isotropic layup, e.g. 0°, +60°, or -60° relative to each other.

From the elementary fiber, a bidirectional woven sheet can be created, i.e. a twill with a 2/2 weave. The process by which most CFRPs are made varies, depending on the piece being created, the finish (outside gloss) required, and how many of the piece will be produced. In addition, the choice of matrix can have a profound effect on the properties of the finished composite.[17]

Many CFRP parts are created with a single layer of carbon fabric that is backed with fiberglass.[18] A tool called a chopper gun is used to quickly create these composite parts. Once a thin shell is created out of carbon fiber, the chopper gun cuts rolls of fiberglass into short lengths and sprays resin at the same time, so that the fiberglass and resin are mixed on the spot.[19] The resin is either external mix, wherein the hardener and resin are sprayed separately, or internal mixed, which requires cleaning after every use. Manufacturing methods may include the following:

Molding

[edit]

One method of producing CFRP parts is by layering sheets of carbon fiber cloth into a mold in the shape of the final product. The alignment and weave of the cloth fibers is chosen to optimize the strength and stiffness properties of the resulting material. The mold is then filled with epoxy and is heated or air-cured. The resulting part is very corrosion-resistant, stiff, and strong for its weight. Parts used in less critical areas are manufactured by draping cloth over a mold, with epoxy either pre-impregnated into the fibers (also known as *pre-preg*) or "painted" over it. High-performance parts using single molds are often vacuum-bagged and/or autoclave-cured, because even small air bubbles in the material will reduce strength. An alternative to the autoclave method is to use internal pressure via inflatable air bladders or EPS foam inside the non-cured laid-up carbon fiber.

Vacuum bagging

[edit]

For simple pieces of which relatively few copies are needed (one or two per day), a vacuum bag can be used. A fiberglass, carbon fiber, or aluminum mold is polished and waxed, and has a release agent applied before the fabric and resin are applied, and the vacuum is pulled and set aside to allow the piece to cure (harden). There are three ways to apply the resin to the fabric in a vacuum mold.

The first method is manual and called a wet layup, where the two-part resin is mixed and applied before being laid in the mold and placed in the bag. The other one is done by infusion, where the dry fabric and mold are placed inside the bag while the vacuum pulls the resin through a small tube into the bag, then through a tube with holes or something similar to evenly spread the resin throughout the fabric. Wire loom works perfectly for a tube that requires holes inside the bag. Both of these methods of applying resin require hand work to spread the resin evenly for a glossy finish with very small pin-holes.

A third method of constructing composite materials is known as a dry layup. Here, the carbon fiber material is already impregnated with resin (pre-preg) and is applied to the mold in a similar fashion to adhesive film. The assembly is then placed in a vacuum to cure. The dry layup method has the least amount of resin waste and can achieve lighter constructions than wet layup. Also, because larger amounts of resin are more difficult to bleed out with wet layup methods, pre-preg parts generally have fewer pinholes. Pinhole elimination with minimal resin amounts generally require the use of autoclave pressures to purge the residual gases out.

Compression molding

[edit]

A quicker method uses a compression mold, also commonly known as carbon fiber forging. This is a two (male and female), or multi-piece mold, usually made out of aluminum or steel and more recently 3D printed plastic. The mold components are pressed together with the fabric and resin loaded into the inner cavity that ultimately becomes the desired component. The benefit is the speed of the entire process. Some car manufacturers, such as BMW, claimed to be able to cycle a new part every 80 seconds. However, this technique has a very high initial cost since the molds require CNC machining of very high precision.

Filament winding

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For difficult or convoluted shapes, a filament winder can be used to make CFRP parts by winding filaments around a mandrel or a core.

Cutting

[edit]

Carbon fiber-reinforced pre-pregs and dry carbon fiber textiles require precise cutting methods to maintain material integrity and reduce defects such as fiber pull-out, delamination and fraying of the cutting edge. CNC digital cutting systems equipped with drag and oscillating are often used to cut carbon fiber pre-pregs, and rotating knives are commonly used to process carbon fiber fabrics. Ultrasonic cutting is another method to cut CFRP pre-pregs and is particularly effective in reducing delamination by minimizing mechanical stress during the cutting process. Waterjet cutting can be the preferred method for thicker and multilayered polymer composites.[20]

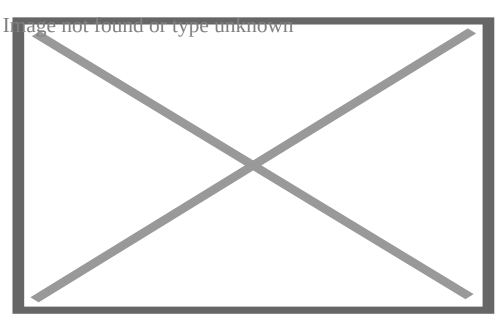
Applications

[edit]

Applications for CFRPs include the following:

Aerospace engineering

[edit]



An Airbus A350 with carbon fiber themed livery. Composite materials are used extensively throughout the A350.

The Airbus A350 XWB is 53% CFRP[21] including wing spars and fuselage components, overtaking the Boeing 787 Dreamliner, for the aircraft with the highest weight ratio for CFRP at 50%.[22] It was one of the first commercial aircraft to have wing spars made from composites. The Airbus A380 was one of the first commercial airliners to have a central wing-box made of CFRP and the first with a smoothly contoured wing cross-section instead of partitioning it span-wise into sections. This flowing, continuous cross section optimises aerodynamic efficiency.[*citation* Moreover, the trailing edge, along with the rear bulkhead, empennage, and un-pressurised fuselage are made of CFRP.[23]

However, delays have pushed order delivery dates back because of manufacturing problems. Many aircraft that use CFRPs have experienced delays with delivery dates due to the relatively new processes used to make CFRP components, whereas metallic structures are better understood. A recurrent problem is the monitoring of structural ageing, for which new methods are required, due to the unusual multi-material and anisotropic[24][25][26] nature of CFRPs.[27]

In 1968 a *Hyfil* carbon-fiber fan assembly was in service on the Rolls-Royce Conways of the Vickers VC10s operated by BOAC.[28]

Specialist aircraft designers and manufacturers Scaled Composites have made extensive use of CFRPs throughout their design range, including the first private crewed spacecraft Spaceship One. CFRPs are widely used in micro air vehicles (MAVs) because of their high strength-to-weight ratio.

Airbus then moved to adopt CFRTP, because it can be reshaped and reprocessed after forming, can be manufactured faster, has higher impact resistance, is recyclable and remoldable, and has lower processing costs.[29]

Automotive engineering

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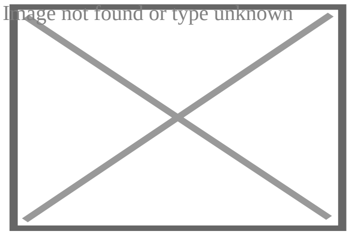
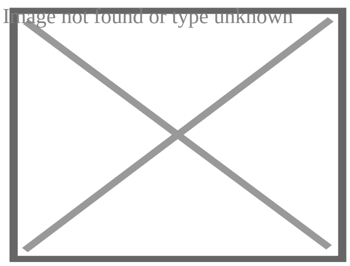
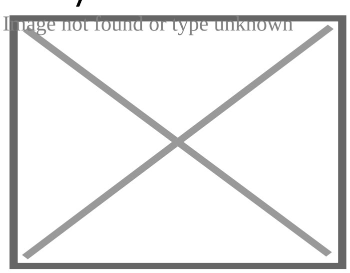


Citroën SM that won 1971 Rally of Morocco with carbon fiber wheels



1996 McLaren F1 – first carbon fiber body shell



McLaren MP4 (MP4/1), first carbon fiber F1 car

CFRPs are extensively used in high-end automobile racing.[30] The high cost of carbon fiber is mitigated by the material's unsurpassed strength-to-weight ratio, and low weight is essential for high-performance automobile racing. Race-car manufacturers have also developed methods to give carbon fiber pieces strength in a certain direction, making it strong in a load-bearing direction, but weak in directions where little or no load would be placed on the member. Conversely, manufacturers developed omnidirectional carbon fiber weaves that apply strength in all directions. This type of carbon fiber assembly is most widely used in the "safety cell" monocoque chassis assembly of high-performance race-cars. The first carbon fiber monocoque chassis was introduced in Formula One by McLaren in the 1981 season. It was designed by John Barnard and was widely copied in the following seasons by other F1 teams due to the extra rigidity provided to the chassis of the cars.[31]

Many supercars over the past few decades have incorporated CFRPs extensively in their manufacture, using it for their monocoque chassis as well as other components.[32] As far back as 1971, the Citroën SM offered optional lightweight carbon fiber wheels.[33][34]

Use of the material has been more readily adopted by low-volume manufacturers who used it primarily for creating body-panels for some of their high-end cars due to its increased strength and decreased weight compared with the glass-reinforced polymer they used for the majority of their products.

Civil engineering

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Further information: Structural applications of FRP

CFRPs have become a notable material in structural engineering applications. Studied in an academic context as to their potential benefits in construction, CFRPs have also proved themselves cost-effective in a number of field applications strengthening concrete, masonry, steel, cast iron, and timber structures. Their use in industry can be either for retrofitting to strengthen an existing structure or as an alternative reinforcing (or prestressing) material instead of steel from the outset of a project.

Retrofitting has become the increasingly dominant use of the material in civil engineering, and applications include increasing the load capacity of old structures (such as bridges, beams, ceilings, columns and walls) that were designed to tolerate far lower service loads than they are experiencing today, seismic retrofitting, and repair of damaged structures. Retrofitting is popular in many instances as the cost of replacing the deficient structure can greatly exceed the cost of strengthening using CFRP.[35]

Applied to reinforced concrete structures for flexure, the use of CFRPs typically has a large impact on strength (doubling or more the strength of the section is not uncommon), but only moderately increases stiffness (as little as 10%). This is because the material used in such applications is typically very strong (e.g., 3 GPa ultimate tensile strength, more than 10 times mild steel) but not particularly stiff (150 to 250 GPa elastic modulus, a little less than steel, is typical). As a consequence, only small cross-sectional areas of the material are used. Small areas of very high strength but moderate stiffness material will significantly increase strength, but not stiffness.

CFRPs can also be used to enhance shear strength of reinforced concrete by wrapping fabrics or fibers around the section to be strengthened. Wrapping around sections (such as bridge or building columns) can also enhance the ductility of the section, greatly increasing the resistance to collapse under dynamic loading. Such 'seismic retrofit' is the major application in earthquake-prone areas, since it is much more economic than alternative methods.

If a column is circular (or nearly so) an increase in axial capacity is also achieved by wrapping. In this application, the confinement of the CFRP wrap enhances the compressive strength of the concrete. However, although large increases are achieved in the ultimate collapse load, the concrete will crack at only slightly enhanced load, meaning that this application is only occasionally used. Specialist ultra-high modulus CFRP (with tensile modulus of 420 GPa or more) is one of the few practical methods of strengthening cast iron beams. In typical use, it is bonded to the tensile flange of the section, both increasing the stiffness of the section and lowering the neutral axis, thus greatly reducing the maximum tensile stress in the cast iron.

In the United States, prestressed concrete cylinder pipes (PCCP) account for a vast majority of water transmission mains. Due to their large diameters, failures of PCCP are usually catastrophic and affect large populations. Approximately 19,000 miles (31,000 km) of PCCP were installed between 1940 and 2006. Corrosion in the form of hydrogen embrittlement has been blamed for the gradual deterioration of the prestressing wires in many PCCP lines. Over the past decade, CFRPs have been used to internally line PCCP, resulting in a fully structural strengthening system. Inside a PCCP line, the CFRP liner acts as a barrier that controls the level of strain experienced by the steel cylinder in the host pipe. The composite liner enables the steel cylinder to perform within its elastic range, to ensure the pipeline's long-term performance is maintained. CFRP liner designs are based on strain compatibility between the liner and host pipe.[36]

CFRPs are more costly materials than commonly used their counterparts in the construction industry, glass fiber-reinforced polymers (GFRPs) and aramid fiber-reinforced polymers (AFRPs), though CFRPs are, in general, regarded as having superior properties. Much research continues to be done on using CFRPs both for retrofitting and as an alternative to steel as reinforcing or prestressing materials. Cost remains an issue and long-term durability questions still remain. Some are concerned about the brittle nature of CFRPs, in contrast to the ductility of steel. Though design codes have been drawn up by institutions such as the American Concrete Institute, there remains some hesitation among the engineering community about implementing these alternative materials. In part, this is due to a lack of standardization and the proprietary nature of the fiber and resin combinations on the market.

Carbon-fiber microelectrodes

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Carbon fibers are used for fabrication of carbon-fiber microelectrodes. In this application typically a single carbon fiber with diameter of 5–7 μm is sealed in a glass capillary.[37] At the tip the capillary is either sealed with epoxy and polished to make carbon-fiber disk microelectrode or the fiber is cut to a length of 75–150 μm to make carbon-fiber cylinder electrode. Carbon-fiber microelectrodes are used either in amperometry or fast-scan cyclic voltammetry for detection of biochemical signalling.

Sports goods

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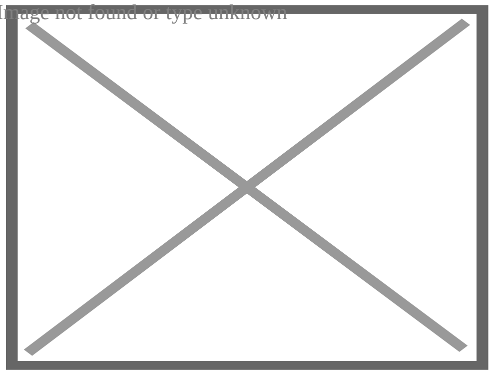

A carbon-fiber and Kevlar canoe (Placid Boatworks Rapidfire at the Adirondack Canoe Classic)

CFRPs are now widely used in sports equipment such as in squash, tennis, and badminton racquets, sport kite spars, high-quality arrow shafts, hockey sticks, fishing rods, surfboards, high end swim fins, and rowing shells. Amputee athletes such as Jonnie Peacock use carbon fiber blades for running. It is used as a shank plate in some basketball sneakers to keep the foot stable, usually running the length of the shoe just above the sole and left exposed in some areas, usually in the arch.

Controversially, in 2006, cricket bats with a thin carbon-fiber layer on the back were introduced and used in competitive matches by high-profile players including Ricky Ponting and Michael Hussey. The carbon fiber was claimed to merely increase the durability of the bats, but it was banned from all first-class matches by the ICC in 2007.[38]

A CFRP bicycle frame weighs less than one of steel, aluminum, or titanium having the same strength. The type and orientation of the carbon-fiber weave can be designed to maximize stiffness in required directions. Frames can be tuned to address different riding styles: sprint events require stiffer frames while endurance events may require more flexible frames for rider comfort over longer periods.[39] The variety of shapes it can be built into has further increased stiffness and also allowed aerodynamic tube sections. CFRP forks including suspension fork crowns and steerers, handlebars, seatposts, and crank arms are becoming more common on medium as well as higher-priced bicycles. CFRP rims remain expensive but their stability compared to aluminium reduces the need to re-true a wheel and the reduced mass reduces the moment of inertia of the wheel. CFRP spokes are rare and most carbon wheelsets retain traditional stainless steel spokes. CFRPs also appear increasingly in other components such as derailleur parts, brake and shifter levers and bodies, cassette sprocket carriers, suspension linkages, disc brake rotors, pedals, shoe soles, and saddle rails. Although strong and light, impact, over-torquing, or improper installation of CFRP components has resulted in cracking and failures, which may be difficult or impossible to repair.[40][41]

Other applications

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Dunlop "Max-Grip" carbon fiber guitar picks. Sizes 1mm and Jazz III.

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Dunlop "Max-Grip" carbon fiber guitar picks. Sizes 1mm and Jazz III.

The fire resistance of polymers and thermo-set composites is significantly improved if a thin layer of carbon fibers is moulded near the surface because a dense, compact layer of carbon fibers efficiently reflects heat.[42]

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Strandberg Boden Plini neck-thru & bolt on versions that both utilize carbon fiber reinforcement strips to maintain rigidity.

CFRPs are being used in an increasing number of high-end products that require stiffness and low weight, these include:

- Musical instruments, including violin bows; guitar picks, guitar necks (fitted with carbon fiber rods), pickguards/scratchplates; drum shells; bagpipe chanters; piano actions; and entire musical instruments such as carbon fiber cellos, violas, and violins, acoustic guitars and ukuleles; also, audio components such as turntables and loudspeakers.
- Firearms use it to replace certain metal, wood, and fiberglass components but many of the internal parts are still limited to metal alloys as current reinforced plastics are unsuitable.
- High-performance drone bodies and other radio-controlled vehicle and aircraft components such as helicopter rotor blades.
- Lightweight poles such as: tripod legs, tent poles, fishing rods, billiards cues, walking sticks, and high-reach poles such as for window cleaning.
- Dentistry, carbon fiber posts are used in restoring root canal treated teeth.
- Railed train bogies for passenger service. This reduces the weight by up to 50% compared to metal bogies, which contributes to energy savings.[43]
- Laptop shells and other high performance cases.
- Carbon woven fabrics.[44][45]
- Archery: carbon fiber arrows and bolts, stock (for crossbows) and riser (for vertical bows), and rail.
- As a filament for the 3D fused deposition modeling printing process,[46] carbon fiber-reinforced plastic (polyamide-carbon filament) is used for the production of sturdy but lightweight tools and parts due to its high strength

and tear length.[47]
  - District heating pipe rehabilitation, using a CIPP method.

Disposal and recycling

[edit]

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The key aspect of recycling fiber-reinforced polymers is preserving their mechanical properties while successfully recovering both the thermoplastic matrix and the reinforcing fibers. CFRPs have a long service lifetime when protected from the sun. When it is time to decommission CFRPs, they cannot be melted down in air like many metals. When free of vinyl (PVC or polyvinyl chloride) and other halogenated polymers, CFRPs recycling processes can be categorized into four main approaches: mechanical, thermal, chemical, and biological. Each method offers distinct advantages in terms of material or energy recovery, contributing to sustainability efforts in composite waste management.

Process	Matrix recovery	Fiber recovery	Degradation of Mechanical Properties	Advantages/Drawbacks

Mechanical	X	X	X	+No use of hazardous chemical substances +No gas emissions +Low-cost energy needed +Big volumes can be recycled -Poor bonding between fiber/matrix -Fibers can damage the equipment
Chemical		X		+Long clean fibers +Retention of mechanical properties +Sometimes there is high recovery of the matrix -Expensive equipment -Possible use of hazardous solvent
Thermal		X	X	+Fiber length retention +No use of hazardous chemical substances +better mechanical properties than mechanical approach +Matrix used to produce energy -Recovered fiber properties highly influenced by process parameters -some processes have no recovery of matrix material

Mechanical Recycling

[edit]

The mechanical process primarily involves grinding, which breaks down composite materials into pulverulent charges and fibrous reinforcements. This method is focused on both the thermoplastic and filler material recovery; however, this process shortens the fibers dramatically. Just as with downcycled paper, the shortened fibers cause the recycled material to be weaker than the original material. There are still many industrial applications that do not need the strength of full-length carbon fiber reinforcement. For example, chopped reclaimed carbon fiber can be used in consumer electronics, such as laptops. It provides excellent reinforcement of the polymers used even if it lacks the strength-to-weight ratio of an aerospace component.[48]

Electro fragmentation

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This method consists in shredding CFRP by pulsed electrical discharges. Initially developed to extract crystals and precious stones from mining rocks, it is now expected to be developed for composites. The material is placed in a vessel containing water and two electrodes. The high voltage electrical pulse generated between the electrodes (50-200 kV) fragments the material into smaller pieces.[49] The inconvenient of this technique is that the energy consumed is 2.6 times the one of a mechanical route making it not economically competitive in terms of energy saving and needs further investigation.

Thermal Recycling

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Thermal processes include several techniques such as incineration, thermolysis, pyrolysis, gasification, fluidized bed processing, and cement plant utilization. This processes imply the recovery of the fibers by the removal of the resin by volatilizing it, leading to by-products such as gases, liquids or inorganic matter.[50]

Oxidation in fluidized bed

[edit]

This technique consists in exposing the composite to a hot and oxygen-rich flow, in which it is combusted (450–550 °C, 840–1,020 °F) . The working temperature is selected in function of the matrix to be decomposed, to limit damages of the fibers. After a shredding step to 6-20 mm size, the composite is introduced into a bed of silica sand, on a metallic mesh, in which the resin will be decomposed into oxidized molecules and fiber filaments. These components will be carried up with the air stream while heavier particles will sink in the bed. This last point is a great advantage for contaminated end-of-life products, with painted surfaces, foam cores or metal insert. A cyclone enables the recovery of fibers of length ranging between 5 and 10 mm and with very little contamination . The matrix is fully oxidized in a second burner operating at approximatively 1,000 °C (1,850 °F) leading to energy recovery and a clean flue gas.[51]

Chemical Recycling

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The chemical recycling of CFRPs involves using a reactive solvent at relatively low temperatures (below 350°C) to break down the resin while leaving the fibers intact for reuse. The solvent degrades the composite matrix into smaller molecular fragments (oligomer), and depending on the chosen solvent system, various processing parameters such as temperature, pressure, and catalysts can be adjusted to optimize the process. The solvent, often combined with co-solvents or catalysts, penetrates the composite and breaks specific chemical bonds, resulting in recovered monomers from the resin and clean, long fibers with preserved mechanical properties. The required temperature and pressure depend on the type of resin, with epoxy resins generally needing higher temperatures than polyester resins. Among the different reactive mediums studied, water is the most commonly used due to its environmental benefits. When combined with alkaline catalysts, it effectively degrades many resins, while acidic catalysts are used for more resistant polymers. Other solvents, such as ethanol, acetone, and their mixtures, have also been explored for this process.

Despite its advantages, this method has some limitations. It requires specialized equipment capable of handling corrosive solvents, hazardous chemicals, and high temperatures or pressures, especially when operating under supercritical conditions. While extensively researched at the laboratory scale, industrial adoption remains limited, with the technology currently reaching a Technology Readiness Level (TRL) of 4 for carbon fiber recycling.[52]

Dissolution Process

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The dissolution process is a method used to recover both the polymer matrix and fibers from thermoplastic composites without breaking chemical bonds. Unlike solvolysis, which involves the chemical degradation of the polymer, dissolution simply dissolves the polymer chains into a solvent, allowing for material recovery in its original form. An energy analysis of the process indicated that dissolution followed by evaporation was more energy-efficient than precipitation. Additionally, avoiding precipitation helped minimize polymer loss, improving overall material recovery efficiency. This method offers a promising approach for sustainable recycling of thermoplastic composites.[53]

Biological Recycling

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The biological process, though still under development, focuses on biodegradation and composting. This method holds promise for bio-based and agro-composites, aiming to create an environmentally friendly end-of-life solution for these materials. As research advances, biological recycling may offer an effective means of reducing plastic composite waste in a sustainable manner.[54]

Carbon nanotube reinforced polymer (CNRP)

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In 2009, Zyvex Technologies introduced carbon nanotube-reinforced epoxy and carbon pre-pregs.[55] Carbon nanotube reinforced polymer (CNRP) is several times stronger and tougher than typical CFRPs and is used in the Lockheed Martin F-35 Lightning II as a structural material for aircraft.[56] CNRP still uses carbon fiber as the primary reinforcement,[57] but the binding matrix is a carbon nanotube-filled epoxy.[58]

See also

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- Carbon fibers – Material fibers about 5–10 μm in diameter composed of carbon
- Composite repair – Composite repair patch preparation and application
- Mechanics of Oscar Pistorius's running blades – Blades used by South African Paralympic runner Oscar Pistorius
- Reinforced carbon–carbon – Graphite-based composite material
- Forged carbon fiber
- Carbon-ceramic
- Carbotanium

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External links

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- Japan Carbon Fiber Manufacturers Association (English)
- Engineers design composite bracing system for injured Hokie running back Cedric Humes
- The New Steel a 1968 *Flight* article on the announcement of carbon fiber
- Carbon Fibres – the First Five Years A 1971 *Flight* article on carbon fiber in the aviation field

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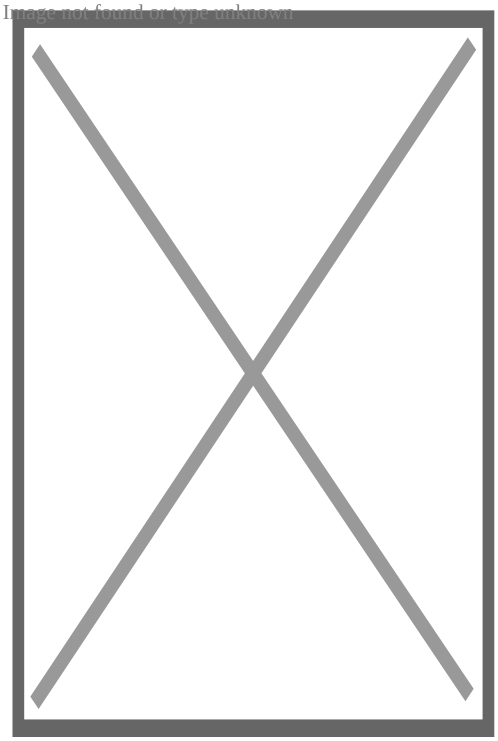
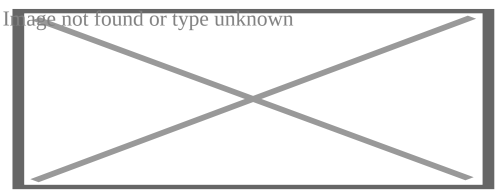
About Cement

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]

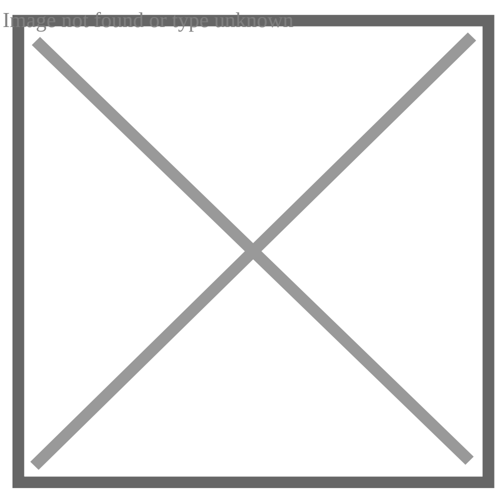
Chemistry

[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

[edit]



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 ($3CaO·SiO_2$);
C_2S: belite ($2CaO·SiO_2$);
C_3A: tricalcium aluminate ($3CaO·Al_2O_3$) (historically, and still occasionally, called *celite*);
C_4AF: brownmillerite ($4CaO·Al_2O_3·Fe_2O_3$).

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.

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

Non-hydraulic cement

[edit]

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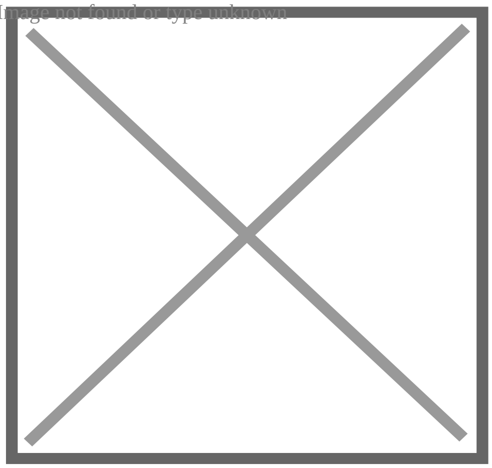

Calcium oxide obtained by thermal decomposition of calcium carbonate at high temperature (above 825 °C).

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 Ã¢â€°Æ’ 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:

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

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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:

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$$\displaystyle \ce{Ca(OH)2 + CO2 -> CaCO3 + H2O}$$

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.
>
> —Ã¢â‚¬Å *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]

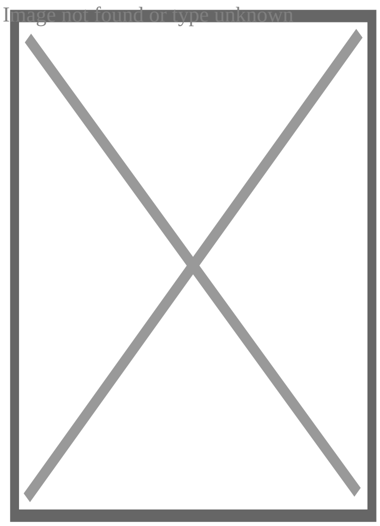
In Britain particularly, good quality building stone became ever more expensive during a period of rapid growth, and it became a common practice to construct prestige buildings from the new industrial bricks, and to finish them with a stucco to imitate stone. Hydraulic limes were favored for this, but 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]



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]

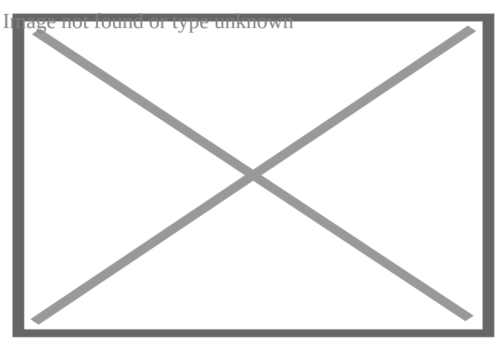
Setting time and "early strength" are important characteristics of cements. Hydraulic limes, "natural" cements, and "artificial" cements all rely on their belite ($2\ CaO \cdot SiO_2$, abbreviated as C_2S) content for strength development. Belite develops strength slowly. Because they were burned at temperatures below 1,250 °C (2,280 °F), they contained no alite ($3\ CaO \cdot SiO_2$, 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 $C_4A_3\bar{S}$ 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]:Ã¢â‚¬Å 351Ã¢â‚¬Å 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]:Ã¢â‚¬Å 352Ã¢â‚¬Å

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 × 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

Image not found or type unknown

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]:Ã¢â‚¬Å p. 27Ã¢â‚¬Å

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

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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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External links

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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

- Accounting

	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

	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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- Image not found or type unknown **Portal**

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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
- Concrete cover
- Cover meter
- Rebar

Construction	◦ 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

<table>
<tr><th>Applications</th><td>

Slab

waffle
hollow-core
voided biaxial
slab on grade

Concrete block
Step barrier
Roads
Columns
Structures

</td></tr>
<tr><th>Organizations</th><td>

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

</td></tr>
<tr><th>Standards</th><td>

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

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<tr><th>See also</th><td>

Hempcrete

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</table>

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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

Industrial sector

- 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

	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

Related	

Classification standards	◦ Production-based
	  ◦ ANZSIC
	  ◦ ***ISIC***
	  ◦ NACE
	  ◦ NAICS
	  ◦ SIC
	  ◦ UKSIC
	◦ Market-based
	  ◦ GICS
	  ◦ ICB
	  ◦ TRBC
	◦ Other
	  ◦ Aftermarket
	  ◦ Generic
	  ◦ OEM

Inputs	◦ Externalities
	  ◦ Community
	  ◦ Crime
	  ◦ Culture
	  ◦ Pollution
	  ◦ Well-being
	◦ Funding
	◦ Goods
	  ◦ Commodities
	  ◦ Final

About waterproofing

Waterproofing is the process of making a things, individual or structure water resistant or water-resistant so that it stays reasonably unaffected by water or resists the ingress of water under specified problems. Such items may be made use of in damp atmospheres or underwater to specified midsts. Waterproof and water-proof often refer to resistance to penetration of water in its fluid state and possibly under stress, whereas wet proof refers to resistance to humidity or dampness. Permeation of water vapour with a material or framework is reported as a moisture vapor transmission rate (MVTR). The hulls of watercrafts and ships were once waterproofed by using tar or pitch. Modern things may be waterproofed by applying water-repellent coatings or by securing joints with gaskets or o-rings. Waterproofing is used of building frameworks (such as cellars, decks, or wet areas), watercraft, canvas, clothing (raincoats or waders), digital gadgets and paper packaging (such as cartons for fluids).

.

About Pier

For other uses, see Pier (disambiguation).

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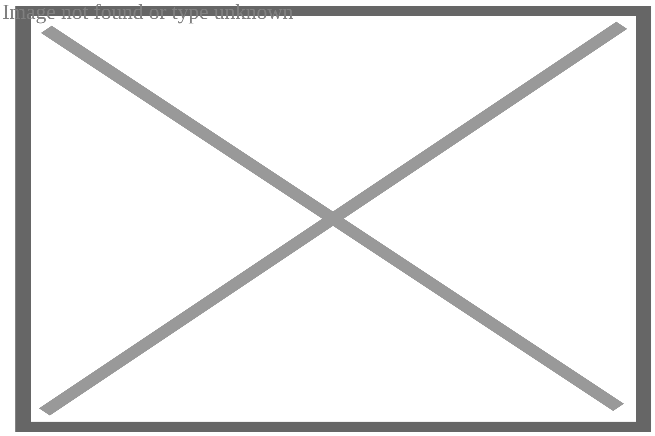


A wooden pier in Corfu, Greece

A **pier** is a raised structure that rises above a body of water and usually juts out from its shore, typically supported by piles or pillars, and provides above-water access to offshore areas. Frequent pier uses include fishing, boat docking and access for both passengers and cargo, and oceanside recreation. Bridges, buildings, and walkways may all be supported by architectural piers. Their open structure allows tides and currents to flow relatively unhindered, whereas the more solid foundations of a quay or the closely spaced piles of a wharf can act as a breakwater, and are consequently more liable to silting. Piers can range in size and complexity from a simple lightweight wooden structure to major structures extended over 1,600 m (5,200 ft). In American English, a pier may be synonymous with a dock.

Piers have been built for several purposes, and because these different purposes have distinct regional variances, the term *pier* tends to have different nuances of meaning in different parts of the world. Thus in North America and Australia, where many ports were, until recently, built on the multiple pier model, the term tends to imply a current or former cargo-handling facility. In contrast, in Europe, where ports more often use basins and river-side quays than piers, the term is principally associated with the image of a Victorian cast iron pleasure pier which emerged in

Great Britain during the early 19th century. However, the earliest piers pre-date the Victorian age.

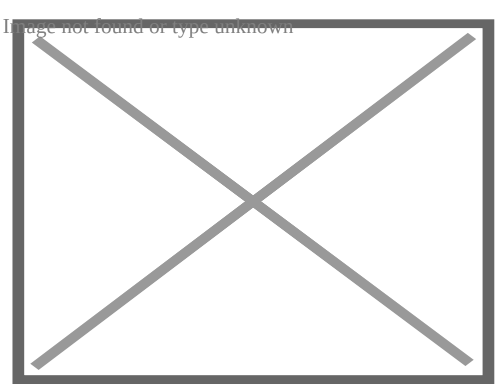
Types

[edit]

Piers can be categorized into different groupings according to the principal purpose.[1] However, there is considerable overlap between these categories. For example, pleasure piers often also allow for the docking of pleasure steamers and other similar craft, while working piers have often been converted to leisure use after being rendered obsolete by advanced developments in cargo-handling technology. Many piers are floating piers, to ensure that the piers raise and lower with the tide along with the boats tied to them. This prevents a situation where lines become overly taut or loose by rising or lowering tides. An overly taut or loose tie-line can damage boats by pulling them out of the water or allowing them so much leeway that they bang forcefully against the sides of the pier.

Working piers

[edit]



Out-of-use industrial bulk cargo Pier, Cook Inlet, Alaska.

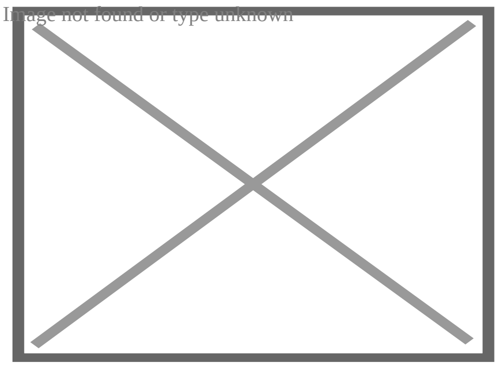
Working piers were built for the handling of passengers and cargo onto and off ships or (as at Wigan Pier) canal boats. Working piers themselves fall into two different groups. Longer individual piers are often found at ports with large tidal ranges, with the pier stretching far enough off shore to reach deep water at low tide. Such piers provided an economical alternative to impounded docks where cargo volumes were low, or where specialist bulk cargo was handled, such as at coal piers. The other form of working pier, often called the finger pier, was built at ports with smaller tidal ranges. Here the principal advantage was to give a greater available quay length for ships to berth against compared to a linear littoral quayside, and such piers are usually much shorter. Typically each pier would carry a single transit shed the length of the pier, with ships berthing bow or stern in to the shore. Some major ports consisted of large numbers of such piers lining the foreshore, classic examples being the Hudson River frontage of New York, or the Embarcadero in San Francisco.

The advent of container shipping, with its need for large container handling spaces adjacent to the shipping berths, has made working piers obsolete for the handling of general cargo, although some still survive for the handling of passenger ships or bulk cargos. One example, is in use in Progreso, Yucatán, where a pier extends more than 4 miles into the Gulf of Mexico, making it the longest pier in the world. The Progreso Pier supplies much of the peninsula with transportation for the fishing and cargo industries and serves as a port for large cruise ships in the area. Many other working piers have been demolished, or remain derelict, but some have been recycled as pleasure piers. The best known example of this is Pier 39 in San Francisco.

At Southport and the Tweed River on the Gold Coast in Australia, there are piers that support equipment for a sand bypassing system that maintains the health of sandy beaches and navigation channels.

Pleasure piers

[edit]



Print of a Victorian pier in Margate in the English county of Kent, 1897

Pleasure piers were first built in Britain during the early 19th century.[2] The earliest structures were Ryde Pier, built in 1813/4, Trinity Chain Pier near Leith, built in 1821, Brighton Chain Pier, built in 1823.[2] and Margate Jetty 1823/24 originally a timber built pier.

Only the oldest of these piers still remains. At that time, the introduction of steamships and railways for the first time permitted mass tourism to dedicated seaside resorts. The large tidal ranges at many such resorts meant that passengers arriving by pleasure steamer could use a pier to disembark safely.[3] Also, for much of the day, the sea was not visible from the shore and the pleasure pier permitted holidaymakers to promenade over and alongside the sea at all times.[4] The world's longest pleasure pier is at Southend-on-Sea, Essex, and extends 1.3 miles (2.1 km) into the Thames Estuary.[2] The longest pier on the West Coast of the US is the Santa Cruz Wharf, with a length of 2,745 feet (837 m).[5]

Providing a walkway out to sea, pleasure piers often include amusements and theatres as part of their attractions.[4] Such a pier may be unroofed, closed, or partly open and partly closed. Sometimes a pier has two decks. Galveston Island Historic Pleasure Pier in Galveston, Texas has a roller coaster, 15 rides, carnival games and souvenir shops.[6]

Early pleasure piers were of complete timber construction, as was with Margate which opened in 1824. The first iron and timber built pleasure pier Margate Jetty, opened in 1855.[7] Margate pier was wrecked by a storm in January 1978 and not repaired.[8][7] The longest iron pleasure pier still remaining is the one at Southend. First opened as a wooden pier in 1829, it was reconstructed in iron and completed in 1889. In a 2006 UK poll, the public voted the seaside pier onto the list of icons of England.[9]

Fishing piers

[edit]

Many piers are built for the purpose of providing boatless anglers access to fishing grounds that are otherwise inaccessible.[10] Many "Free Piers" are available in larger harbors which differ from private piers. Free Piers are often primarily used for fishing. Fishing from a pier presents a set of different circumstances to fishing from the shore or beach, as you do not need to cast out into the deeper water. This being the case there are specific fishing rigs that have been created specifically for pier fishing[11] which allow for the direct access to deeper water.

Piers of the world

[edit]

Main article: List of piers

Belgium

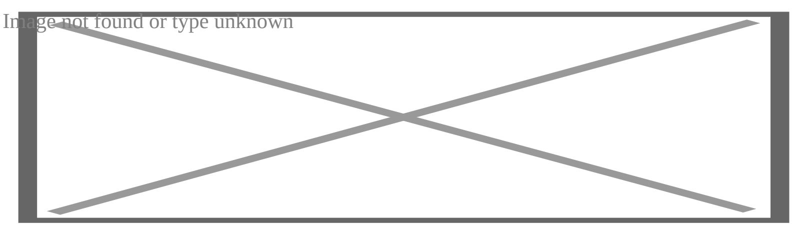
[edit]

In Blankenberge a first pleasure pier was built in 1894. After its destruction in the World War I, a new pier was built in 1933. It remained till the present day, but was partially transformed and modernized in 1999–2004.

In Nieuwpoort, Belgium there is a pleasure pier on both sides of the river IJzer.

Netherlands

[edit]



The Scheveningen Pier

Scheveningen, the coastal resort town of The Hague, boasts the largest pier in the Netherlands, completed in 1961. A crane, built on top of the pier's panorama tower, provides the opportunity to make a 60-metre (200 ft) high bungee jump over the North Sea waves. The present pier is a successor of an earlier pier, which was completed in 1901 but in 1943 destroyed by the German occupation forces.

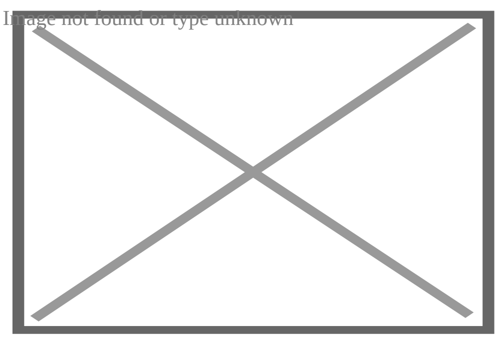
United Kingdom

[edit]

England and Wales

[edit]

The first recorded pier in England was Ryde Pier, opened in 1814 on the Isle of Wight, as a landing stage to allow ferries to and from the mainland to berth. It is still used for this purpose today.[12] It also had a leisure function in the past, with the pier head once containing a pavilion, and there are still refreshment facilities today. The oldest cast iron pier in the world is Town Pier, Gravesend, in Kent, which opened in 1834. However, it is not recognised by the National Piers Society as being a seaside pier.[13]



Brighton Palace Pier (pictured in 2011), opened in 1899

Following the building of the world's first seaside pier at Ryde, the pier became fashionable at seaside resorts in England and Wales during the Victorian era, peaking in the 1860s with 22 being built in that decade.[14] A symbol of the typical British seaside holiday, by 1914, more than 100 pleasure piers were located around the UK coast.[2] Regarded as being among the finest Victorian architecture, there are still a significant number of seaside piers of architectural merit still standing, although some have been lost, including Margate, two at Brighton in East Sussex, one at New Brighton in the Wirral and three at Blackpool in Lancashire.[4] Two piers, Brighton's now derelict West Pier and Clevedon Pier, were Grade 1 listed. The

Birnbeck Pier in Weston-super-Mare is the only pier in the world linked to an island. The National Piers Society gives a figure of 55 surviving seaside piers in England and Wales.[1] In 2017, Brighton Palace Pier was said to be the most visited tourist attraction outside London, with over 4.5 million visitors the previous year.[15]

See also

[edit]

- Boardwalk
- Breakwater
- Dock
- Jetty
- List of piers
- Seaside resort
- Wharf

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[edit]

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[edit]

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About Foundation (engineering)

In design, a structure is the aspect of a structure which connects it to the ground or more seldom, water (just like floating structures), transferring lots from the framework to the ground. Foundations are usually considered either superficial or deep. Foundation engineering is the application of dirt mechanics and rock mechanics (geotechnical engineering) in the style of foundation elements of frameworks.

.

About Shallow foundation

Shallow foundation construction example

A **shallow foundation** is a type of building foundation that transfers structural load to the Earth very near to the surface, rather than to a subsurface layer or a range of depths, as does a deep foundation. Customarily, a shallow foundation is considered as such when the width of the entire foundation is greater than its depth.[1] In comparison to deep foundations, shallow foundations are less technical, thus making them more economical and the most widely used for relatively light structures.

Types

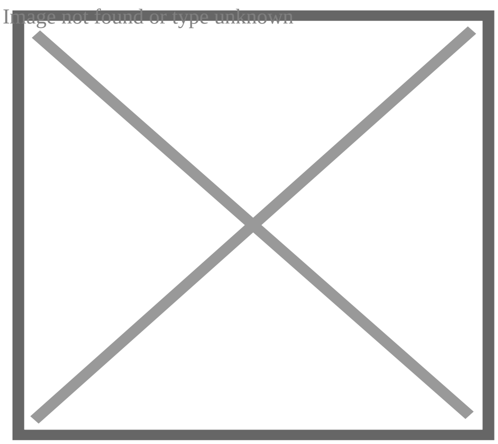
[edit]

Footings are always wider than the members that they support. Structural loads from a column or wall are usually greater than 1,000 kPa, while the soil's bearing capacity is commonly less than that (typically less than 400 kPa). By possessing a larger bearing area, the foundation distributes the pressure to the soil, decreasing the bearing pressure to within allowable values.[2] A structure is not limited to one footing. Multiple types of footings may be used in a construction project.

Wall footing

[edit]

Also called *strip footing*, a wall footing is a continuous strip that supports structural and non-structural load-bearing walls. Found directly under the wall, Its width is commonly 2-3 times wider than the wall above it.[3]



Detail Section of a strip footing and its wall.

Isolated footing

[edit]

Also called *single-column footing*, an isolated footing is a square, rectangular, or circular slab that supports the structural members individually. Generally, each column is set on an individual footing to transmit and distribute the load of the structure to the soil underneath. Sometimes, an isolated footing can be sloped or stepped at the base to spread greater loads. This type of footing is used when the structural load is relatively low, columns are widely spaced, and the soil's bearing capacity is adequate at a shallow depth.

Combined footing

[edit]

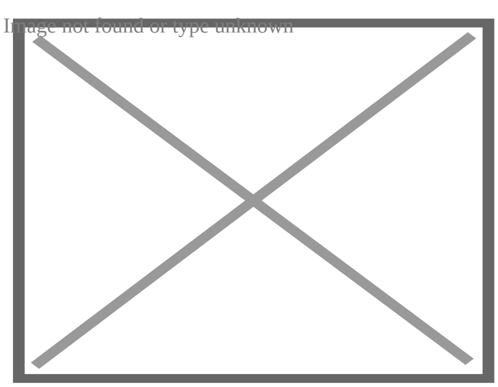
When more than one column shares the same footing, it is called a *combined footing*. A combined footing is typically utilized when the spacing of the columns is too restricted such that if isolated footing were used, they would overlap one another. Also, when property lines make isolated footings eccentrically loaded, combined footings are preferred.

When the load among the columns is equal, the combined footing may be rectangular. Conversely, when the load among the columns is unequal, the combined footing should be trapezoidal.

Strap footing

[edit]

A strap footing connects individual columns with the use of a strap beam. The general purpose of a strap footing is alike to those of a combined footing, where the spacing is possibly limited and/or the columns are adjacent to the property lines.



Mat foundation with its concrete undergoing curing.

Mat foundation

[edit]

Also called *raft* foundation, a mat foundation is a single continuous slab that covers the entirety of the base of a building. Mat foundations support all the loads of the structure and transmit them to the ground evenly. Soil conditions may prevent other footings from being used. Since this type of foundation distributes the load coming from the building uniformly over a considerably large area, it is favored when individual footings are unfeasible due to the low bearing capacity of the soil.

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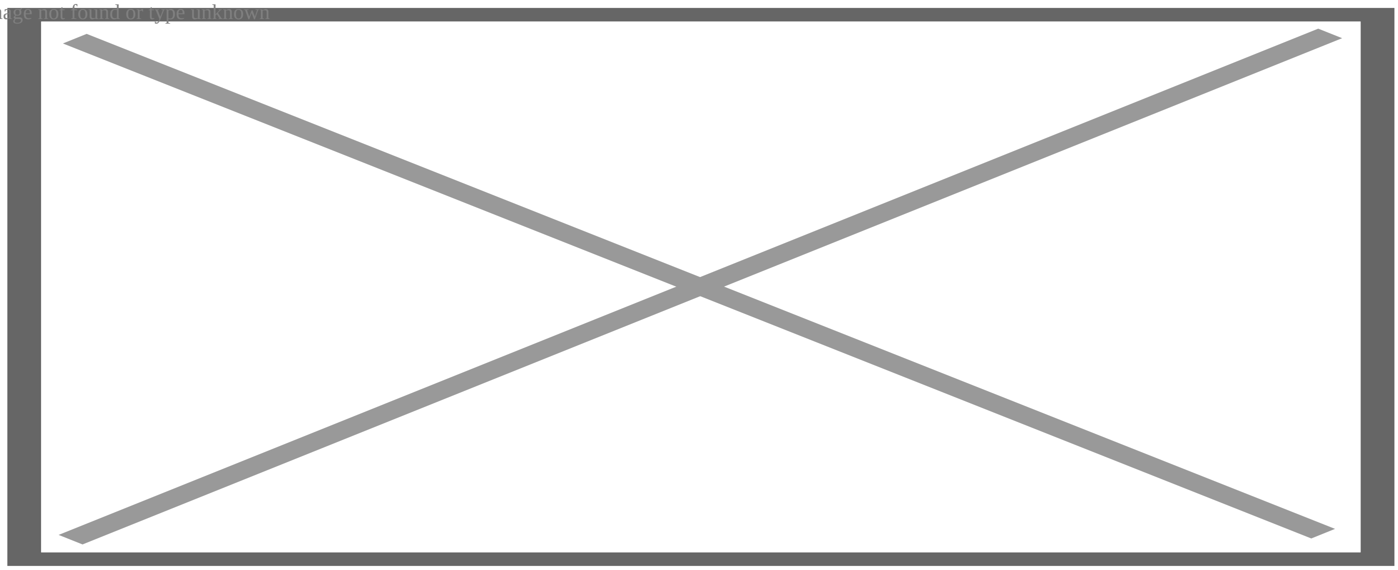

Diagrams of the types of shallow foundations.

Slab-on-grade foundation

[edit]

"Floating foundation" redirects here. For Floating raft system, see Floating raft system.

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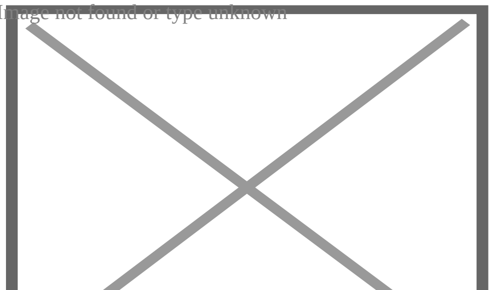

Pouring a slab-on-grade foundation

Slab-on-grade or *floating slab* foundations are a structural engineering practice whereby the reinforced concrete slab that is to serve as the foundation for the structure is formed from formwork set into the ground. The concrete is then poured into the formwork, leaving no space between the ground and the structure. This type of construction is most often seen in warmer climates, where ground freezing and thawing is less of a concern and where there is no need for heat ducting underneath the floor. Frost Protected Shallow Foundations (or FPSF) which are used in areas of potential frost heave, are a form of slab-on-grade foundation.[4]

Remodeling or extending such a structure may be more difficult. Over the long term, ground settling (or subsidence) may be a problem, as a slab foundation cannot be readily jacked up to compensate; proper soil compaction prior to pour can minimize this. The slab can be decoupled from ground temperatures by insulation, with the concrete poured directly over insulation (for example, extruded polystyrene foam panels), or heating provisions (such as hydronic heating) can be built into the slab.

Slab-on-grade foundations should not be used in areas with expansive clay soil. While elevated structural slabs actually perform better on expansive clays, it is generally accepted by the engineering community that slab-on-grade foundations offer the greatest cost-to-performance ratio for tract homes. Elevated structural slabs are generally only found on custom homes or homes with basements.

Copper piping, commonly used to carry natural gas and water, reacts with concrete over a long period, slowly degrading until the pipe fails. This can lead to what is commonly referred to as slab leaks. These occur when pipes begin to leak from within the slab. Signs of a slab leak range from unexplained dampened carpet spots, to drops in water pressure and wet discoloration on exterior foundation walls. [5] Copper pipes must be *lagged* (that is, *insulated*) or run through a conduit or plumbed into the building above the slab. Electrical conduits through the slab must be water-tight, as they extend below ground level and can potentially expose wiring to groundwater.

See also

[edit]

- Argillipedoturbation
- Building construction
- Construction engineering
- Fiber reinforced concrete
- Grade beam
- Precast concrete
- Prestressed concrete
- Rebar
- Steel fixer
- Tie rod

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[edit]

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- Raft or Mat Foundations

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Geotechnical engineering

Offshore geotechnical engineering

- Core drill
- Cone penetration test
- Geo-electrical sounding
- Permeability test
- Load test
  - Static
  - Dynamic
  - Statnamic
- Pore pressure measurement
  - Piezometer
  - Well
- Ram sounding
- Rock control drilling
- Rotary-pressure sounding
- Rotary weight sounding
- Sample series
- Screw plate test
- Deformation monitoring
  - Inclinometer
  - Settlement recordings
- Shear vane test

Field (*in situ*)

Investigation

and

Soil

Types

- Clay
- Silt
- Sand
- Gravel
- Peat
- Loam
- Loess

Properties

- Hydraulic conductivity
- Water content
- Void ratio
- Bulk density
- Thixotropy
- Reynolds' dilatancy
- Angle of repose
- Friction angle
- Cohesion
- Porosity
- Permeability
- Specific storage
- Shear strength
- Sensitivity

Natural features

- Topography
- Vegetation
- Terrain
- Topsoil
- Water table
- Bedrock
- Subgrade
- Subsoil

Structures

(Interaction)

Earthworks

- Shoring structures
  - Retaining walls
  - Gabion
  - Ground freezing
  - Mechanically stabilized earth
  - Pressure grouting
  - Slurry wall
  - Soil nailing
  - Tieback
- Land development
- Landfill
- Excavation
- Trench
- Embankment
- Cut
- Causeway
- Terracing
- Cut-and-cover
- Cut and fill

Mechanics

Forces

- Effective stress
- Pore water pressure
- Lateral earth pressure
- Overburden pressure
- Preconsolidation pressure

Phenomena/ problems

- Permafrost
- Frost heaving
- Consolidation
- Compaction
- Earthquake
    - Response spectrum
    - Seismic hazard
    - Shear wave
- Landslide analysis
    - Stability analysis
    - Mitigation
    - Classification
    - Sliding criterion
    - Slab stabilisation
- Bearing capacity * Stress distribution in soil

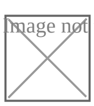
Numerical analysis software

- SEEP2D
- STABL
- SVFlux
- SVSlope
- UTEXAS
- Plaxis

Related fields

- Geology
- Geochemistry
- Petrology
- Earthquake engineering
- Geomorphology
- Soil science
- Hydrology
- Hydrogeology
- Biogeography
- Earth materials
- Archaeology
- Agricultural science
    - Agrology

About Pump



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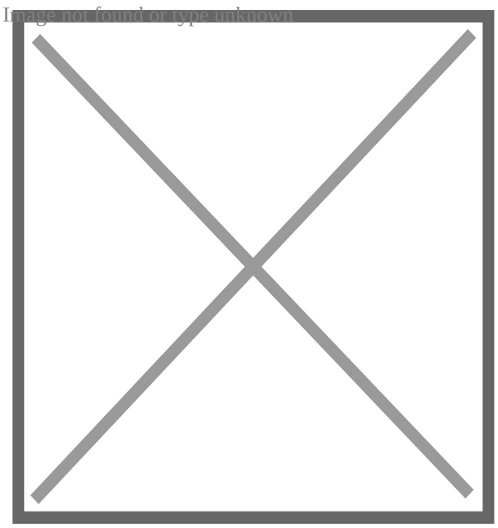
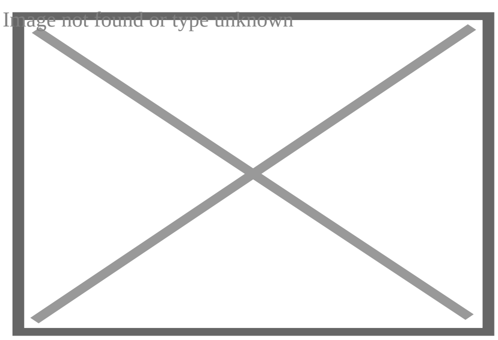
"Water Pump" redirects here. For the community in Pakistan, see Water Pump, Karachi.
For other uses of "pump" or "pumps", see Pump (disambiguation).



A small, electrically powered pump



A large, electrically driven pump for waterworks near the Hengsteysee, Germany

A **pump** is a device that moves fluids (liquids or gases), or sometimes slurries,[1] by mechanical action, typically converted from electrical energy into hydraulic or pneumatic energy.

Mechanical pumps serve in a wide range of applications such as pumping water from wells, aquarium filtering, pond filtering and aeration, in the car industry for water-cooling and fuel injection, in the energy industry for pumping oil and natural gas or for operating cooling towers and other components of heating, ventilation and air conditioning systems. In the medical industry, pumps are used for biochemical processes in developing and manufacturing medicine, and as artificial replacements for body parts, in particular the artificial heart and penile prosthesis.

When a pump contains two or more pump mechanisms with fluid being directed to flow through them in series, it is called a *multi-stage pump*. Terms such as *two-stage* or *double-stage* may be used to specifically describe the number of stages. A pump that does not fit this description is simply a *single-stage pump* in contrast.

In biology, many different types of chemical and biomechanical pumps have evolved; biomimicry is sometimes used in developing new types of mechanical pumps.

Types

[edit]

Mechanical pumps may be **submerged** in the fluid they are pumping or be placed **external** to the fluid.

Pumps can be classified by their method of displacement into electromagnetic pumps, positive-displacement pumps, impulse pumps, velocity pumps, gravity pumps, steam pumps and valveless pumps. There are three basic types of pumps: positive-displacement, centrifugal and axial-flow pumps. In centrifugal pumps the direction of flow of the fluid changes by ninety degrees as it flows over an impeller, while in axial flow pumps the direction of flow is unchanged.[2][3]

See also: Vacuum pump

Electromagnetic pump

[edit]

This section is an excerpt from Electromagnetic pump.[edit]

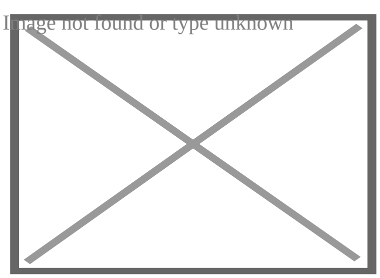
An electromagnetic pump is a pump that moves liquid metal, molten salt, brine, or other electrically conductive liquid using electromagnetism.

A magnetic field is set at right angles to the direction the liquid moves in, and a current is passed through it. This causes an electromagnetic force that moves the liquid.

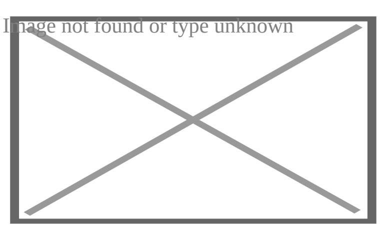
Applications include pumping molten solder in many wave soldering machines, pumping liquid-metal coolant, and magnetohydrodynamic drive.

Positive-displacement pumps

[edit]



Lobe pump internals



Lobe pump internals

A positive-displacement pump makes a fluid move by trapping a fixed amount and forcing (displacing) that trapped volume into the discharge pipe.

Some positive-displacement pumps use an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pump as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is constant through each cycle of operation.

Positive-displacement pump behavior and safety

[edit]

Positive-displacement pumps, unlike centrifugal, can theoretically produce the same flow at a given rotational speed no matter what the discharge pressure. Thus, positive-displacement pumps are *constant flow machines*. However, a slight increase in internal leakage as the pressure increases prevents a truly constant flow rate.

A positive-displacement pump must not operate against a closed valve on the discharge side of the pump, because it has no shutoff head like centrifugal pumps. A positive-displacement pump operating against a closed discharge valve continues to produce flow and the pressure in the discharge line increases until the line bursts, the pump is severely damaged, or both.

A relief or safety valve on the discharge side of the positive-displacement pump is therefore necessary. The relief valve can be internal or external. The pump manufacturer normally has the option to supply internal relief or safety valves. The internal valve is usually used only as a safety precaution. An external relief valve in the discharge line, with a return line back to the suction line or supply tank, provides increased safety.

Positive-displacement types

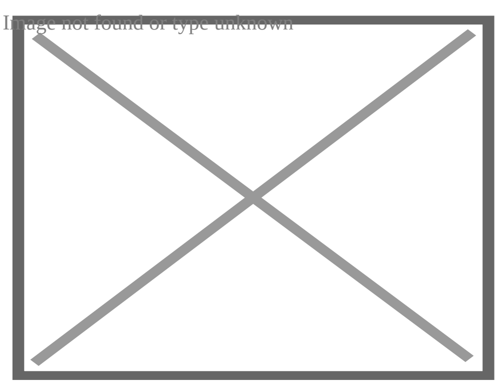
[edit]

A positive-displacement pump can be further classified according to the mechanism used to move the fluid:

- *Rotary-type* positive displacement: internal and external gear pump, screw pump, lobe pump, shuttle block, flexible vane and sliding vane, circumferential piston, flexible impeller, helical twisted roots (e.g. the Wendelkolben pump) and liquid-ring pumps
- *Reciprocating-type* positive displacement: piston pumps, plunger pumps and diaphragm pumps
- *Linear-type* positive displacement: rope pumps and chain pumps

Rotary positive-displacement pumps

[edit]



Rotary vane pump

These pumps move fluid using a rotating mechanism that creates a vacuum that captures and draws in the liquid.[4]

Advantages: Rotary pumps are very efficient[5] because they can handle highly viscous fluids with higher flow rates as viscosity increases.[6]

Drawbacks: The nature of the pump requires very close clearances between the rotating pump and the outer edge, making it rotate at a slow, steady speed. If rotary pumps are operated at high speeds, the fluids cause erosion, which eventually causes enlarged clearances that liquid can pass through, which reduces efficiency.

Rotary positive-displacement pumps fall into five main types:

- Gear pumps – a simple type of rotary pump where the liquid is pushed around a pair of gears.
- Screw pumps – the shape of the internals of this pump is usually two screws turning against each other to pump the liquid
- Rotary vane pumps
- Hollow disc pumps (also known as eccentric disc pumps or hollow rotary disc pumps), similar to scroll compressors, these have an eccentric cylindrical rotor encased in a circular housing. As the rotor orbits, it traps fluid between the rotor and the casing, drawing the fluid through the pump. It is used for highly viscous fluids like petroleum-derived products, and it can also support high pressures of up to 290 psi.[7][8][9][10][11][12][13]
- Peristaltic pumps have rollers which pinch a section of flexible tubing, forcing the liquid ahead as the rollers advance. Because they are very easy to keep clean, these are popular for dispensing food, medicine, and concrete.

Reciprocating positive-displacement pumps

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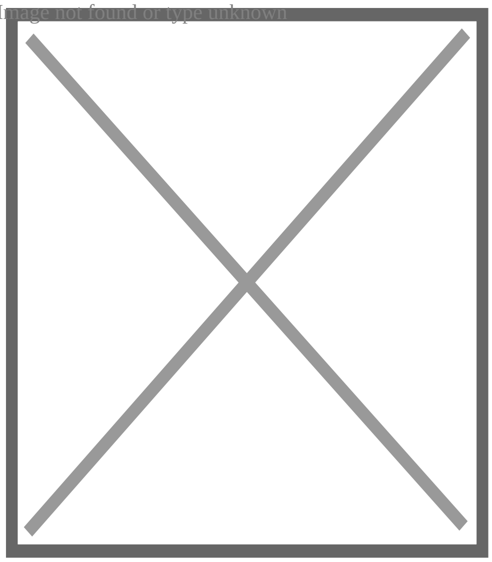

Simple hand pump

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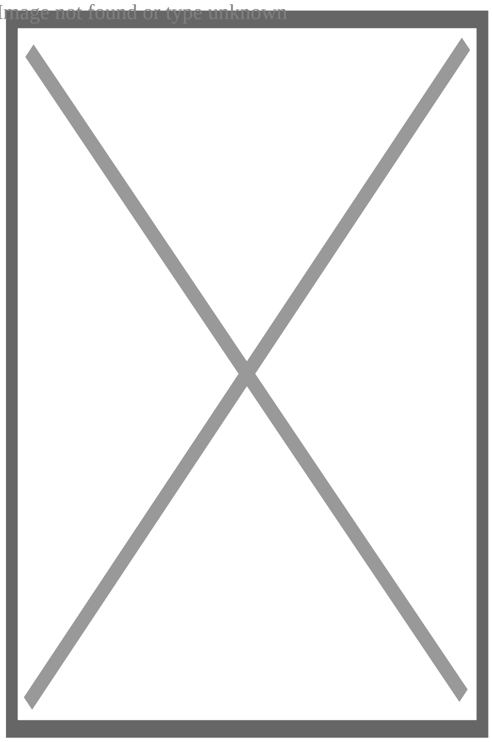


Antique "pitcher" pump (c. 1924) at the Colored School in Alapaha, Georgia, US

See also: Reciprocating pump

Reciprocating pumps move the fluid using one or more oscillating pistons, plungers, or membranes (diaphragms), while valves restrict fluid motion to the desired direction. In order for suction to take place, the pump must first pull the plunger in an outward motion to decrease pressure in the chamber. Once the plunger pushes back, it will increase the chamber pressure and the inward pressure of the plunger will then open the discharge valve and release the fluid into the delivery pipe at constant flow rate and increased pressure.

Pumps in this category range from *simplex*, with one cylinder, to in some cases *quad* (four) cylinders, or more. Many reciprocating-type pumps are *duplex* (two) or *triplex* (three) cylinder. They can be either *single-acting* with suction during one direction of piston motion and discharge on the other, or *double-acting* with suction and discharge in both directions. The pumps can be powered manually, by air or steam, or by a belt driven by an engine. This type of pump was used extensively in the 19th century—in the early days of steam propulsion—as boiler feed water pumps. Now reciprocating pumps typically pump highly viscous fluids like concrete and heavy oils, and serve in special applications that demand low flow rates against high resistance. Reciprocating hand pumps were widely used to pump water from wells. Common bicycle pumps and foot pumps for inflation use reciprocating action.

These positive-displacement pumps have an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pumps as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is constant given each cycle of operation and the pump's volumetric efficiency can be achieved through routine maintenance and inspection of its valves.[14]

Typical reciprocating pumps are:

- *Plunger pump* – a reciprocating plunger pushes the fluid through one or two open valves, closed by suction on the way back.
- *Diaphragm pump* – similar to plunger pumps, where the plunger pressurizes hydraulic oil which is used to flex a diaphragm in the pumping cylinder. Diaphragm valves are used to pump hazardous and toxic fluids.
- *Piston pump* displacement pumps – *usually simple devices for pumping small amounts of liquid or gel manually. The common hand soap dispenser is such a pump.*
- *Radial piston pump* – a form of hydraulic pump where pistons extend in a radial direction.
- Vibratory pump or vibration pump – a particularly low-cost form of plunger pump, popular in low-cost espresso machines.[15][16] The only moving part is a spring-loaded piston, the armature of a solenoid. Driven by half-wave rectified alternating current, the piston is forced forward while energized, and is retracted by the spring during the other half cycle. Due to their inefficiency, vibratory pumps typically cannot be operated for more than one minute without overheating, so are limited to intermittent duty.

Various positive-displacement pumps

[edit]

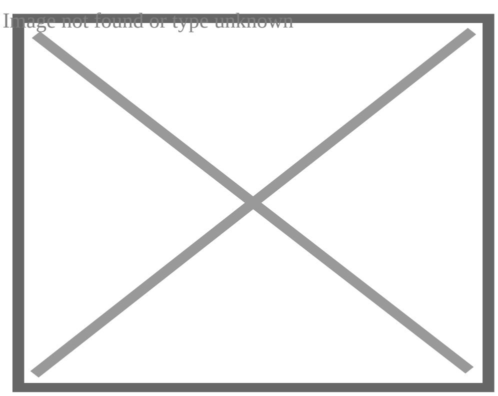
The positive-displacement principle applies in these pumps:

- Rotary lobe pump
- Progressing cavity pump
- Rotary gear pump
- Piston pump
- Diaphragm pump

- Screw pump
- Gear pump
- Hydraulic pump
- Rotary vane pump
- Peristaltic pump
- Rope pump
- Flexible impeller pump

Gear pump

[edit]



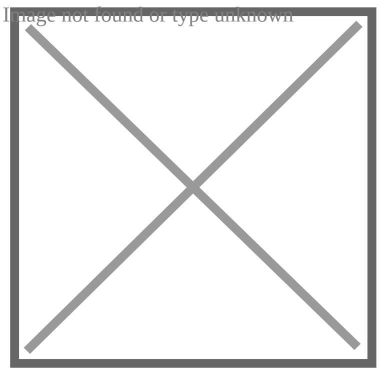
Gear pump

Main article: Gear pump

This is the simplest form of rotary positive-displacement pumps. It consists of two meshed gears that rotate in a closely fitted casing. The tooth spaces trap fluid and force it around the outer periphery. The fluid does not travel back on the meshed part, because the teeth mesh closely in the center. Gear pumps see wide use in car engine oil pumps and in various hydraulic power packs.

Screw pump

[edit]



Screw pump

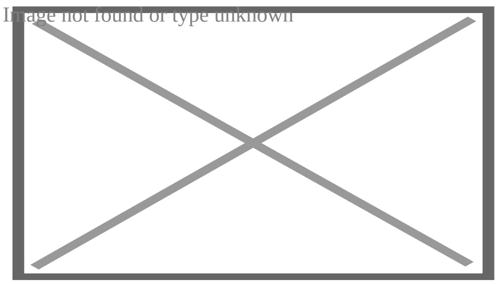
Main article: Screw pump

A screw pump is a more complicated type of rotary pump that uses two or three screws with opposing thread — e.g., one screw turns clockwise and the other counterclockwise. The screws are mounted on parallel shafts that often have gears that mesh so the shafts turn together and everything stays in place. In some cases the driven screw drives the secondary screw, without gears, often using the fluid to limit abrasion. The screws turn on the shafts and drive fluid through the pump. As with other forms of rotary pumps, the clearance between moving parts and the pump's casing is minimal.

Progressing cavity pump

[edit]

Main article: Progressing cavity pump

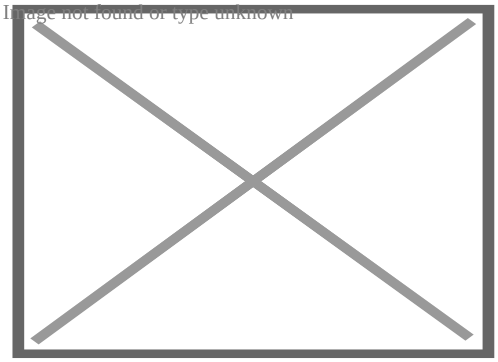


Progressing cavity pump

Widely used for pumping difficult materials, such as sewage sludge contaminated with large particles, a progressing cavity pump consists of a helical rotor, about ten times as long as its width, and a stator, mainly made out of rubber. This can be visualized as a central core of diameter *x* with, typically, a curved spiral wound around of thickness half *x*, though in reality it is manufactured in a single lobe. This shaft fits inside a heavy-duty rubber sleeve or stator, of wall thickness also typically *x*. As the shaft rotates inside the stator, the rotor gradually forces fluid up the rubber cavity. Such pumps can develop very high pressure at low volumes at a rate of 90 PSI per stage on water for standard configurations.

Roots-type pump

[edit]



A Roots lobe pump

Main article: Roots-type supercharger

Named after the Roots brothers who invented it, this lobe pump displaces the fluid trapped between two long helical rotors, each fitted into the other when perpendicular at 90°, rotating inside a triangular shaped sealing line configuration, both at the point of suction and at the point of discharge. This design produces a continuous flow with equal volume and no vortex. It can work at low pulsation rates, and offers gentle performance that some applications require.

Applications include:

- High capacity industrial air compressors.
- Roots superchargers on internal combustion engines.
- A brand of civil defense siren, the Federal Signal Corporation's Thunderbolt.

Peristaltic pump

[edit]

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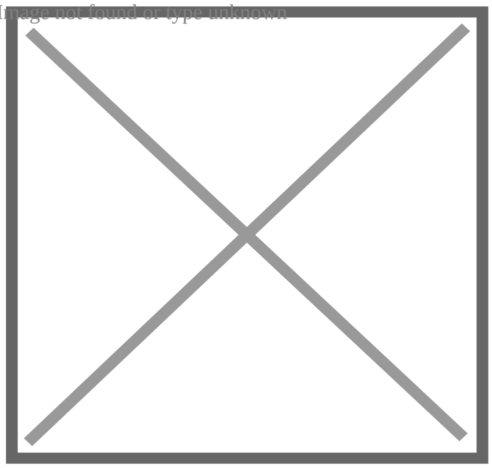

360º peristaltic pump

Main article: Peristaltic pump

A *peristaltic pump* is a type of positive-displacement pump. It contains fluid within a flexible tube fitted inside a circular pump casing (though linear peristaltic pumps have been made). A number of *rollers*, *shoes*, or *wipers* attached to a rotor compress the flexible tube. As the rotor turns, the part of the tube under compression closes (or *occludes*), forcing the fluid through the tube. Additionally, when the tube opens to its natural state after the passing of the cam it draws (*restitution*) fluid into the pump. This process is called *peristalsis* and is used in many biological systems such as the gastrointestinal tract.

Plunger pumps

[edit]

Main article: Plunger pump

Plunger pumps are reciprocating positive-displacement pumps.

These consist of a cylinder with a reciprocating plunger. The suction and discharge valves are mounted in the head of the cylinder. In the suction stroke, the plunger retracts and the suction valves open causing suction of fluid into the cylinder. In the forward stroke, the plunger pushes the liquid out of the discharge valve. Efficiency and common problems: With only one cylinder in plunger pumps, the fluid flow varies between maximum flow when the plunger moves through the middle positions, and zero flow when the plunger is at the end positions. A lot of energy is wasted when the fluid is accelerated in the piping system. Vibration and *water hammer* may be a serious problem. In general, the problems are compensated for by using two or more cylinders not working in phase with each other. Centrifugal pumps are also susceptible to water hammer. Surge analysis, a specialized study, helps evaluate this risk in such systems.

Triplex-style plunger pump

[edit]

Triplex plunger pumps use three plungers, which reduces the pulsation relative to single reciprocating plunger pumps. Adding a pulsation dampener on the pump outlet can further smooth the *pump ripple*, or ripple graph of a pump transducer. The dynamic relationship of the high-pressure fluid and plunger generally requires high-quality plunger seals. Plunger pumps with a larger number of plungers have the benefit of increased flow, or smoother flow without a pulsation damper. The increase in moving parts and crankshaft load is one drawback.

Car washes often use these triplex-style plunger pumps (perhaps without pulsation dampers). In 1968, William Bruggeman reduced the size of the triplex pump and increased the lifespan so that car washes could use equipment with smaller footprints. Durable high-pressure seals, low-pressure seals and oil seals, hardened crankshafts, hardened connecting rods, thick ceramic plungers and heavier duty ball and roller bearings improve reliability in triplex pumps. Triplex pumps now are in a myriad of markets across the world.

Triplex pumps with shorter lifetimes are commonplace to the home user. A person who uses a home pressure washer for 10 hours a year may be satisfied with a pump that lasts 100 hours between rebuilds. Industrial-grade or continuous duty triplex pumps on the other end of the quality spectrum may run for as much as 2,080 hours a year.[17]

The oil and gas drilling industry uses massive semi-trailer-transported triplex pumps called mud pumps to pump drilling mud, which cools the drill bit and carries the cuttings back to the surface.[18] Drillers use triplex or even quintuplex pumps to inject water and solvents deep into shale in the extraction process called *fracking*.[19]

Diaphragm pump

[edit]

Typically run on electricity compressed air, diaphragm pumps are relatively inexpensive and can perform a wide variety of duties, from pumping air into an aquarium, to liquids through a filter press. Double-diaphragm pumps can handle viscous fluids and abrasive materials with a gentle pumping process ideal for transporting shear-sensitive media.[20]

Rope pump

[edit]

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Rope pump schematic

Main article: Rope pump

Devised in China as chain pumps over 1000 years ago, these pumps can be made from very simple materials: A rope, a wheel and a pipe are sufficient to make a simple rope pump. Rope pump efficiency has been studied by grassroots organizations and the techniques for making and running them have been continuously improved.[21]

Impulse pump

[edit]

Impulse pumps use pressure created by gas (usually air). In some impulse pumps the gas trapped in the liquid (usually water), is released and accumulated somewhere in the pump, creating a pressure that can push part of the liquid upwards.

Conventional impulse pumps include:

- *Hydraulic ram pumps* – kinetic energy of a low-head water supply is stored temporarily in an air-bubble hydraulic accumulator, then used to drive water to a higher head.
- *Pulser pumps* – run with natural resources, by kinetic energy only.
- *Airlift pumps* – run on air inserted into pipe, which pushes the water up when bubbles move upward

Instead of a gas accumulation and releasing cycle, the pressure can be created by burning of hydrocarbons. Such combustion driven pumps directly transmit the impulse from a combustion event through the actuation membrane to the pump fluid. In order to allow this direct transmission, the pump needs to be almost entirely made of an elastomer (e.g. silicone rubber). Hence, the combustion causes the membrane to expand and thereby pumps the fluid out of the adjacent pumping chamber. The first combustion-driven soft pump was developed by ETH Zurich.[22]

Hydraulic ram pump

[edit]

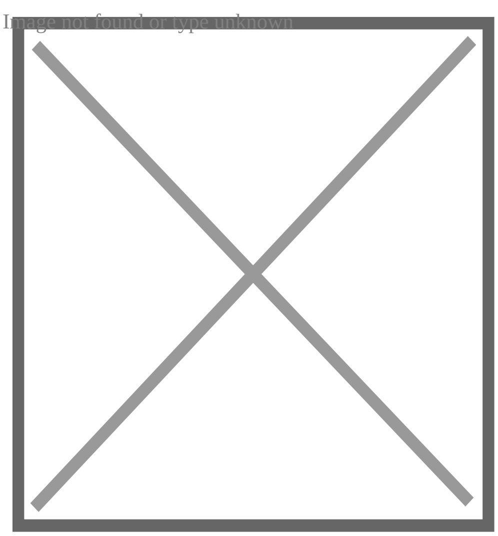
A hydraulic ram is a water pump powered by hydropower.[23]

It takes in water at relatively low pressure and high flow-rate and outputs water at a higher hydraulic-head and lower flow-rate. The device uses the water hammer effect to develop pressure that lifts a portion of the input water that powers the pump to a point higher than where the water started.

The hydraulic ram is sometimes used in remote areas, where there is both a source of low-head hydropower, and a need for pumping water to a destination higher in elevation than the source. In this situation, the ram is often useful, since it requires no outside source of power other than the kinetic energy of flowing water.

Velocity pumps

[edit]



A centrifugal pump uses an impeller with backward-swept arms

Rotodynamic pumps (or dynamic pumps) are a type of velocity pump in which kinetic energy is added to the fluid by increasing the flow velocity. This increase in energy is converted to a gain in potential energy (pressure) when the velocity is reduced prior to or as the flow exits the pump into the discharge pipe. This conversion of kinetic energy to pressure is explained by the *First law of* *thermodynamics*, or more specifically by *Bernoulli's principle*.

Dynamic pumps can be further subdivided according to the means in which the velocity gain is achieved.[24]

These types of pumps have a number of characteristics:

1. Continuous energy
2. Conversion of added energy to increase in kinetic energy (increase in velocity)
3. Conversion of increased velocity (kinetic energy) to an increase in pressure head

A practical difference between dynamic and positive-displacement pumps is how they operate under closed valve conditions. Positive-displacement pumps physically displace fluid, so closing a valve downstream of a positive-displacement pump produces a continual pressure build up that can cause mechanical failure of pipeline or pump. Dynamic pumps differ in that they can be safely operated under closed valve conditions (for short periods of time).

Radial-flow pump

[edit]

Such a pump is also referred to as a *centrifugal pump*. The fluid enters along the axis or center, is accelerated by the impeller and exits at right angles to the shaft (radially); an example is the centrifugal fan, which is commonly used to implement a vacuum cleaner. Another type of radial-flow pump is a vortex pump. The liquid in them moves in tangential direction around the working wheel. The conversion from the mechanical energy of motor into the potential energy of flow comes by means of multiple whirls, which are excited by the impeller in the working channel of the pump. Generally, a radial-flow pump operates at higher pressures and lower flow rates than an axial- or a mixed-flow pump.

Axial-flow pump

[edit]

Main article: Axial-flow pump

These are also referred to as *all-fluid pumps*. The fluid is pushed outward or inward to move fluid axially. They operate at much lower pressures and higher flow rates than radial-flow (centrifugal) pumps. Axial-flow pumps cannot be run up to speed without special precaution. If at a low flow rate, the total head rise and high torque associated with this pipe would mean that the starting torque would have to become a function of acceleration for the whole mass of liquid in the pipe system.[25]

Mixed-flow pumps function as a compromise between radial and axial-flow pumps. The fluid experiences both radial acceleration and lift and exits the impeller somewhere between 0 and 90 degrees from the axial direction. As a consequence mixed-flow pumps operate at higher pressures than axial-flow pumps while delivering higher discharges than radial-flow pumps. The exit angle of the flow dictates the pressure head-discharge characteristic in relation to radial and mixed-flow.

Regenerative turbine pump

[edit]

Regenerative turbine pump animation

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Regenerative turbine pump animation

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Close-up of a Regenerative Turbine Pump Impeller

Also known as **drag**, **friction**, **liquid-ring pump**, **peripheral**, **traction**, **turbulence**, or **vortex** pumps, regenerative turbine pumps are a class of rotodynamic pump that operates at high head pressures, typically 4–20 bars (400–2,000 kPa; 58–290 psi).[26]

The pump has an impeller with a number of vanes or paddles which spins in a cavity. The suction port and pressure ports are located at the perimeter of the cavity and are isolated by a barrier called a **stripper**, which allows only the **tip channel** (fluid between the blades) to recirculate, and forces any fluid in the **side channel** (fluid in the cavity outside of the blades) through the pressure port. In a regenerative turbine pump, as fluid spirals repeatedly from a vane into the side channel and back to the next vane, kinetic energy is imparted to the periphery,[26] thus pressure builds with each spiral, in a manner similar to a regenerative blower.[

[27][28][29]

As regenerative turbine pumps cannot become vapor locked, they are commonly applied to volatile, hot, or cryogenic fluid transport. However, as tolerances are typically tight, they are vulnerable to solids or particles causing jamming or rapid wear. Efficiency is typically low, and pressure and power consumption typically decrease with flow. Additionally, pumping direction can be reversed by reversing direction of spin.[29][27][30]

Side-channel pump

[edit]

A **side-channel** pump has a suction disk, an impeller, and a discharge disk.[31]

Eductor-jet pump

[edit]

Main article: Eductor-jet pump

This uses a jet, often of steam, to create a low pressure. This low pressure sucks in fluid and propels it into a higher-pressure region.

Gravity pumps

[edit]

Gravity pumps include the *syphon* and *Heron's fountain*. The *hydraulic ram* is also sometimes called a gravity pump. In a gravity pump the fluid is lifted by gravitational force.

Steam pump

[edit]

Steam pumps have been for a long time mainly of historical interest. They include any type of pump powered by a steam engine and also pistonless pumps such as Thomas Savery's or the Pulsometer steam pump.

Recently there has been a resurgence of interest in low-power solar steam pumps for use in smallholder irrigation in developing countries. Previously small steam engines have not been viable because of escalating inefficiencies as vapour engines decrease in size. However the use of modern engineering materials coupled with alternative engine configurations has meant that these types of system are now a cost-effective opportunity.

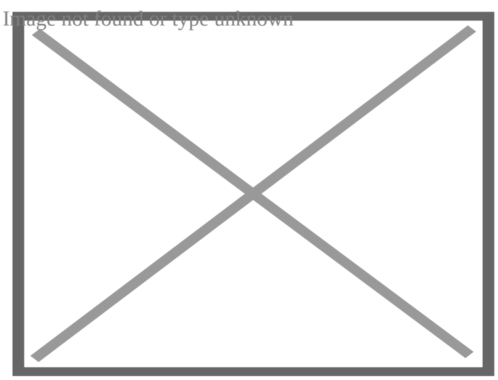
Valveless pumps

[edit]

Valveless pumping assists in fluid transport in various biomedical and engineering systems. In a valveless pumping system, no valves (or physical occlusions) are present to regulate the flow direction. The fluid pumping efficiency of a valveless system, however, is not necessarily lower than that having valves. In fact, many fluid-dynamical systems in nature and engineering more or less rely upon valveless pumping to transport the working fluids therein. For instance, blood circulation in the cardiovascular system is maintained to some extent even when the heart's valves fail. Meanwhile, the embryonic vertebrate heart begins pumping blood long before the development of discernible chambers and valves. Similar to blood circulation in one direction, bird respiratory systems pump air in one direction in rigid lungs, but without any physiological valve. In microfluidics, valveless impedance pumps have been fabricated, and are expected to be particularly suitable for handling sensitive biofluids. Ink jet printers operating on the piezoelectric transducer principle also use valveless pumping. The pump chamber is emptied through the printing jet due to reduced flow impedance in that direction and refilled by capillary action.

Pump repairs

[edit]



Derelict windmill connected to water pump with water storage tank in the foreground

Examining pump repair records and mean time between failures (MTBF) is of great importance to responsible and conscientious pump users. In view of that fact, the preface to the 2006 Pump User's Handbook alludes to "pump failure" statistics. For the sake of convenience, these failure statistics often are translated into MTBF (in this case, installed life before failure).[32]

In early 2005, Gordon Buck, John Crane Inc.'s chief engineer for field operations in Baton Rouge, Louisiana, examined the repair records for a number of refinery and chemical plants to obtain meaningful reliability data for centrifugal pumps. A total of 15 operating plants having nearly 15,000 pumps were included in the survey. The smallest of these plants had about 100 pumps; several plants had over 2000. All facilities were located in the United States. In addition, considered as "new", others as "renewed" and still others as "established". Many of these plants—but not all—had an alliance arrangement with John Crane. In some cases, the alliance contract included having a John Crane Inc. technician or engineer on-site to coordinate various aspects of the program.

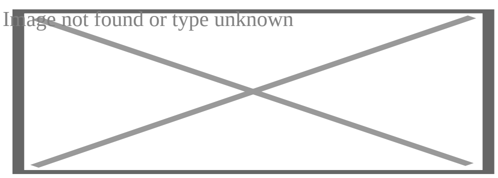
Not all plants are refineries, however, and different results occur elsewhere. In chemical plants, pumps have historically been "throw-away" items as chemical attack limits life. Things have improved in recent years, but the somewhat restricted space available in "old" DIN and ASME-standardized stuffing boxes places limits on the type of seal that fits. Unless the pump user upgrades the seal chamber, the pump only accommodates more compact and simple versions. Without this upgrading, lifetimes in chemical installations are generally around 50 to 60 percent of the refinery values.

Unscheduled maintenance is often one of the most significant costs of ownership, and failures of mechanical seals and bearings are among the major causes. Keep in mind the potential value of selecting pumps that cost more initially, but last much longer between repairs. The MTBF of a better pump may be one to four years longer than that of its non-upgraded counterpart. Consider that published average values of avoided pump failures range from US$2600 to US$12,000. This does not include lost opportunity costs. One pump fire occurs per 1000 failures. Having fewer pump failures means having fewer destructive pump fires.

As has been noted, a typical pump failure, based on actual year 2002 reports, costs US$5,000 on average. This includes costs for material, parts, labor and overhead. Extending a pump's MTBF from 12 to 18 months would save US$1,667 per year — which might be greater than the cost to upgrade the centrifugal pump's reliability.[32][1][33]

Applications

[edit]



Metering pump for gasoline and additives

Pumps are used throughout society for a variety of purposes. Early applications includes the use of the windmill or watermill to pump water. Today, the pump is used for irrigation, water supply, gasoline supply, air conditioning systems, refrigeration (usually called a compressor), chemical movement, sewage movement, flood control, marine services, etc.

Because of the wide variety of applications, pumps have a plethora of shapes and sizes: from very large to very small, from handling gas to handling liquid, from high pressure to low pressure, and from high volume to low volume.

Priming a pump

[edit]

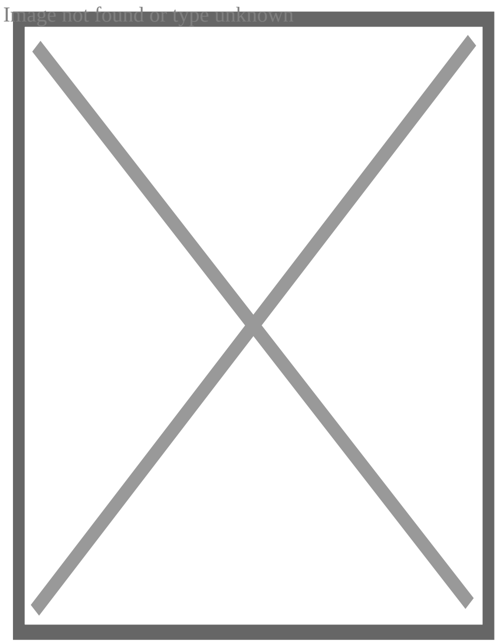
Typically, a liquid pump cannot simply draw air. The feed line of the pump and the internal body surrounding the pumping mechanism must first be filled with the liquid that requires pumping: An operator must introduce liquid into the system to initiate the pumping, known as *priming* the pump. Loss of prime is usually due to ingestion of air into the pump, or evaporation of the working fluid if the pump is used infrequently. Clearances and displacement ratios in pumps for liquids are insufficient for pumping compressible gas, so air or other gasses in the pump can not be evacuated by the pump's action alone. This is the case with most velocity (rotodynamic) pumps — for example, centrifugal pumps. For such pumps, the position of the pump and intake tubing should be lower than the suction point so it is primed by gravity; otherwise the pump should be manually filled with liquid or a secondary pump should be used until all air is removed from the suction line and the pump casing. Liquid ring pumps have a dedicated intake for the priming liquid separate from the intake of the fluid being pumped, as the fluid being pumped may be a gas or mix of gas, liquid, and solids. For these pumps the priming liquid intake must be supplied continuously (either by gravity or pressure), however the intake for the fluid being pumped is capable of drawing a vacuum equivalent to the boiling point of the priming liquid.[34]

Positive–displacement pumps, however, tend to have sufficiently tight sealing between the moving parts and the casing or housing of the pump that they can be described as *self-priming*. Such pumps can also serve as *priming pumps*, so-called when they are used to fulfill that need for other pumps in lieu of action taken by a human operator.

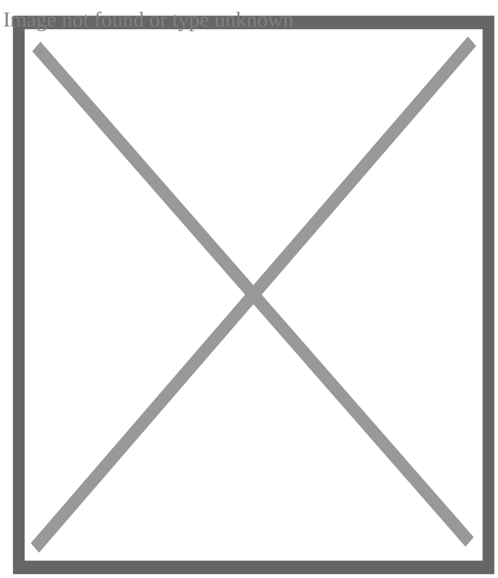
Pumps as public water supplies

[edit]

Main article: Hand pump



Arabic depiction of a piston pump, by Al-Jazari, c. 1206[35][36]



First European depiction of a piston pump, by Taccola, c. 1450[37]

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Irrigation is underway by pump-enabled extraction directly from the Gumti, seen in the background, in Comilla, Bangladesh.

One sort of pump once common worldwide was a hand-powered water pump, or 'pitcher pump'. It was commonly installed over community water wells in the days before piped water supplies.

In parts of the British Isles, it was often called *the parish pump*. Though such community pumps are no longer common, people still used the expression *parish pump* to describe a place or forum where matters of local interest are discussed.[38]

Because water from pitcher pumps is drawn directly from the soil, it is more prone to contamination. If such water is not filtered and purified, consumption of it might lead to gastrointestinal or other water-borne diseases. A notorious case is the 1854 Broad Street cholera outbreak. At the time it was not known how cholera was transmitted, but physician John Snow suspected contaminated water and had the handle of the public pump he suspected removed; the outbreak then subsided.

Modern hand-operated community pumps are considered the most sustainable low-cost option for safe water supply in resource-poor settings, often in rural areas in developing countries. A hand pump opens access to deeper groundwater that is often not polluted and also improves the safety of a well by protecting the water source from contaminated buckets. Pumps such as the Afridev pump are designed to be cheap to build and install, and easy to maintain with simple parts. However, scarcity of spare parts for these type of pumps in some regions of Africa has diminished their utility for these areas.

Sealing multiphase pumping applications

[edit]

Multiphase pumping applications, also referred to as tri-phase, have grown due to increased oil drilling activity. In addition, the economics of multiphase production is attractive to upstream operations as it leads to simpler, smaller in-field installations, reduced equipment costs and improved production rates. In essence, the multiphase pump can accommodate all fluid stream properties with one piece of equipment, which has a smaller footprint. Often, two smaller multiphase pumps are installed in series rather than having just one massive pump.

Types and features of multiphase pumps

[edit]

Helico-axial (centrifugal)

[edit]

A rotodynamic pump with one single shaft that requires two mechanical seals, this pump uses an open-type axial impeller. It is often called a *Poseidon pump*, and can be described as a cross between an axial compressor and a centrifugal pump.

Twin-screw (positive-displacement)

[edit]

The twin-screw pump is constructed of two inter-meshing screws that move the pumped fluid. Twin screw pumps are often used when pumping conditions contain high gas volume fractions and fluctuating inlet conditions. Four mechanical seals are required to seal the two shafts.

Progressive cavity (positive-displacement)

[edit]

Progressive Cavity Pumps are well suited to pump sludge, slurries, viscous, and shear sensitive fluids. [39] Progressive cavity pumps are single-screw types use in surface and downhole oil production.[40] They serve a vast arrange of industries and applications ranging from Wastewater Treatment,[41] Pulp and Paper, oil and gas, mining, and oil and gas.

Electric submersible (centrifugal)

[edit]

These pumps are basically multistage centrifugal pumps and are widely used in oil well applications as a method for artificial lift. These pumps are usually specified when the pumped fluid is mainly liquid.

Buffer tank A buffer tank is often installed upstream of the pump suction nozzle in case of a slug flow. The buffer tank breaks the energy of the liquid slug, smooths any fluctuations in the incoming flow and acts as a sand trap.

As the name indicates, multiphase pumps and their mechanical seals can encounter a large variation in service conditions such as changing process fluid composition, temperature variations, high and low operating pressures and exposure to abrasive/erosive media. The challenge is selecting the appropriate mechanical seal arrangement and support system to ensure maximized seal life and its overall effectiveness.[42][43][44]

Specifications

[edit]

Pumps are commonly rated by horsepower, volumetric flow rate, outlet pressure in metres (or feet) of head, inlet suction in suction feet (or metres) of head. The head can be simplified as the number of feet or metres the pump can raise or lower a column of water at atmospheric pressure.

From an initial design point of view, engineers often use a quantity termed the specific speed to identify the most suitable pump type for a particular combination of flow rate and head. Net Positive Suction Head (NPSH) is crucial for pump performance. It has two key aspects: 1) NPSHr (Required): The Head required for the pump to operate without cavitation issues. 2) NPSHa (Available): The actual pressure provided by the system (e.g., from an overhead tank). For optimal pump operation, NPSHa must always exceed NPSHr. This ensures the pump has enough pressure to prevent cavitation, a damaging condition.

Pumping power

[edit]

Main article: Bernoulli's equation

The power imparted into a fluid increases the energy of the fluid per unit volume. Thus the power relationship is between the conversion of the mechanical energy of the pump mechanism and the fluid elements within the pump. In general, this is governed by a series of simultaneous differential equations, known as the Navier–Stokes equations. However a more simple equation relating only the different energies in the fluid, known as Bernoulli's equation can be used. Hence the power, P, required by the pump:

$$\displaystyle P=\frac{\Delta pQ}{\eta}$$

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where Δp is the change in total pressure between the inlet and outlet (in Pa), and Q, the volume flow-rate of the fluid is given in m^3/s. The total pressure may have gravitational, static pressure and kinetic energy components; i.e. energy is distributed between change in the fluid's gravitational potential energy (going up or down hill), change in velocity, or change in static pressure. η is the pump efficiency, and may be given by the manufacturer's information, such as in the form of a pump curve, and is typically derived from either fluid dynamics simulation (i.e. solutions to the Navier–Stokes for the particular pump geometry), or by testing. The efficiency of the pump depends upon the pump's configuration and operating conditions (such as rotational speed, fluid density and viscosity etc.)

\displaystyle \Delta p=\rho (v_2^2-v_1^2) \over 2+\rho \Delta zg+\Delta p_\math

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For a typical "pumping" configuration, the work is imparted on the fluid, and is thus positive. For the fluid imparting the work on the pump (i.e. a turbine), the work is negative. Power required to drive the pump is determined by dividing the output power by the pump efficiency. Furthermore, this definition encompasses pumps with no moving parts, such as a siphon.

Efficiency

[edit]

Pump efficiency is defined as the ratio of the power imparted on the fluid by the pump in relation to the power supplied to drive the pump. Its value is not fixed for a given pump, efficiency is a function of the discharge and therefore also operating head. For centrifugal pumps, the efficiency tends to increase with flow rate up to a point midway through the operating range (peak efficiency or Best Efficiency Point (BEP)) and then declines as flow rates rise further. Pump performance data such as this is usually supplied by the manufacturer before pump selection. Pump efficiencies tend to decline over time due to wear (e.g. increasing clearances as impellers reduce in size).

When a system includes a centrifugal pump, an important design issue is matching the *head loss-flow characteristic* with the pump so that it operates at or close to the point of its maximum efficiency.

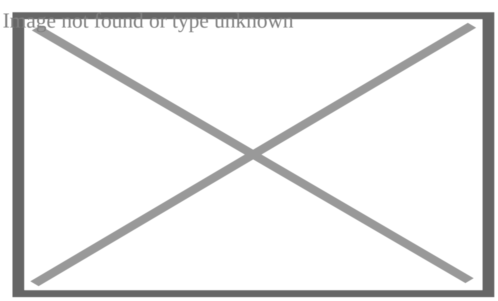
Pump efficiency is an important aspect and pumps should be regularly tested. Thermodynamic pump testing is one method.

Minimum flow protection

[edit]

Most large pumps have a minimum flow requirement below which the pump may be damaged by overheating, impeller wear, vibration, seal failure, drive shaft damage or poor performance.[45] A minimum flow protection system ensures that the pump is not operated below the minimum flow rate. The system protects the pump even if it is shut-in or dead-headed, that is, if the discharge line is completely closed.[46]

The simplest minimum flow system is a pipe running from the pump discharge line back to the suction line. This line is fitted with an orifice plate sized to allow the pump minimum flow to pass.[47] The arrangement ensures that the minimum flow is maintained, although it is wasteful as it recycles fluid even when the flow through the pump exceeds the minimum flow.



Part of a process flow diagram of pump minimum flow protection arrangement

A more sophisticated, but more costly, system (see diagram) comprises a flow measuring device (FE) in the pump discharge which provides a signal into a flow controller (FIC) which actuates a flow control valve (FCV) in the recycle line. If the measured flow exceeds the minimum flow then the FCV is closed. If the measured flow falls below the minimum flow the FCV opens to maintain the minimum flowrate.[45]

As the fluids are recycled the kinetic energy of the pump increases the temperature of the fluid. For many pumps this added heat energy is dissipated through the pipework. However, for large industrial pumps, such as oil pipeline pumps, a recycle cooler is provided in the recycle line to cool the fluids to the normal suction temperature.[48] Alternatively the recycled fluids may be returned to upstream of the export cooler in an oil refinery, oil terminal, or offshore installation.

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Machines

Classical simple machines	Inclined plane Lever Pulley Screw Wedge Wheel and axle
Clocks	Atomic clock Chronometer Pendulum clock Quartz clock

Compressors and pumps	◦ Archimedes' screw ◦ Eductor-jet pump ◦ Hydraulic ram ◦ Pump ◦ Trompe ◦ Vacuum pump
External combustion engines	◦ Steam engine ◦ Stirling engine
Internal combustion engines	◦ Gas turbine ◦ Reciprocating engine ◦ Rotary engine ◦ Nutating disc engine
Linkages	◦ Pantograph ◦ Peaucellier-Lipkin
Turbine	◦ Gas turbine ◦ Jet engine ◦ Steam turbine ◦ Water turbine ◦ Wind generator ◦ Windmill

Aerofoil	○ Sail ○ Wing ○ Rudder ○ Flap ○ Propeller
Electronics	○ Vacuum tube ○ Transistor ○ Diode ○ Resistor ○ Capacitor ○ Inductor
Vehicles	○ Automobile
Miscellaneous	○ Mecha ○ Robot ○ Agricultural ○ Seed-counting machine ○ Vending machine ○ Wind tunnel ○ Check weighing machines ○ Riveting machines
Springs	○ Spring (device)

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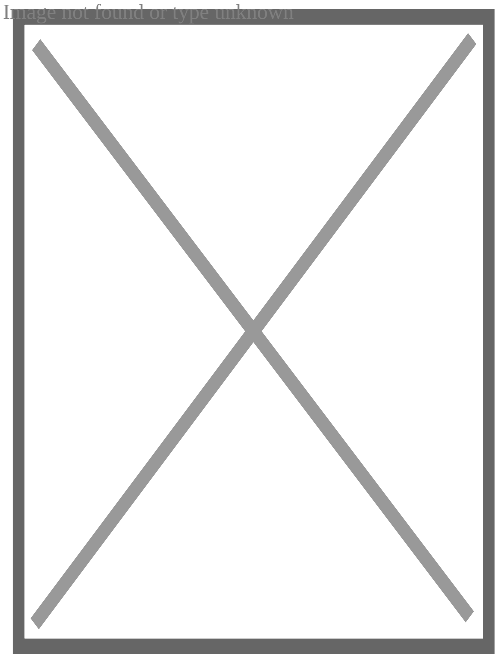
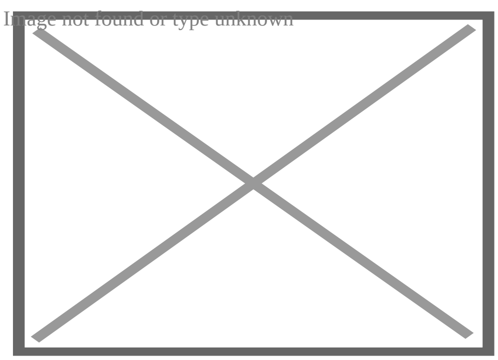
Drilling of deep piles of diameter 150 cm in bridge 423 near Ness Ziona, Israel

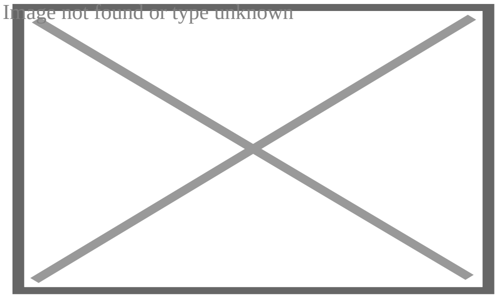


A deep foundation installation for a bridge in Napa, California, United States.



Pile driving operations in the Port of Tampa, Florida.

A **pile** or **piling** is a vertical structural element of a deep foundation, driven or drilled deep into the ground at the building site. A deep foundation is a type of foundation that transfers building loads to the earth farther down from the surface than a shallow foundation does to a subsurface layer or a range of depths.

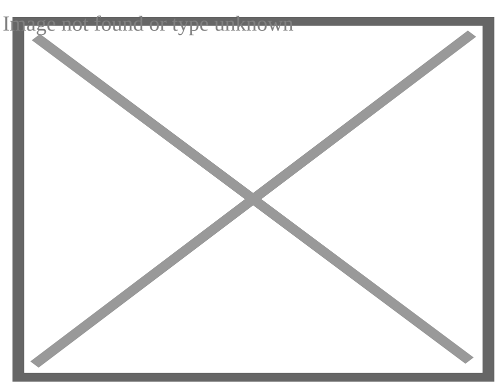


Deep foundations of The Marina Torch, a skyscraper in Dubai

There are many reasons that a geotechnical engineer would recommend a deep foundation over a shallow foundation, such as for a skyscraper. Some of the common reasons are very large design loads, a poor soil at shallow depth, or site constraints like property lines. There are different terms used to describe different types of deep foundations including the pile (which is analogous to a pole), the pier (which is analogous to a column), drilled shafts, and caissons. Piles are generally driven into the ground *in situ*; other deep foundations are typically put in place using excavation and drilling. The naming conventions may vary between engineering disciplines and firms. Deep foundations can be made out of timber, steel, reinforced concrete or prestressed concrete.

Driven foundations

[edit]



Pipe piles being driven into the ground

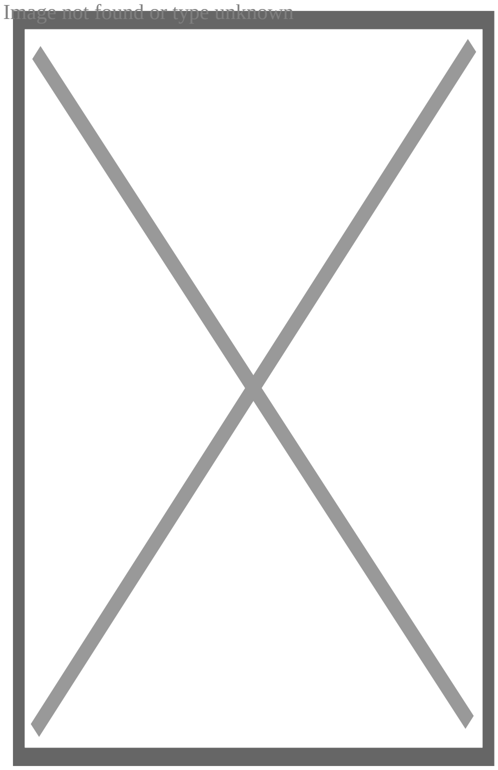


Illustration of a hand-operated pile driver in Germany after 1480

Prefabricated piles are driven into the ground using a pile driver. Driven piles are constructed of wood, reinforced concrete, or steel. Wooden piles are made from the trunks of tall trees. Concrete piles are available in square, octagonal, and round cross-sections (like Franki piles). They are reinforced with rebar and are often prestressed. Steel piles are either pipe piles or some sort of beam section (like an H-pile). Historically, wood piles used splices to join multiple segments end-to-end when the driven depth required was too long for a single pile; today, splicing is common with steel piles, though concrete piles can be spliced with mechanical and other means. Driving piles, as opposed to drilling shafts, is advantageous because the soil displaced by driving the piles compresses the surrounding soil, causing greater friction against the sides of the piles, thus increasing their load-bearing capacity. Driven piles are also considered to be "tested" for weight-bearing ability because of their method of installation.[*citation needed*]

Pile foundation systems

[edit]

Foundations relying on driven piles often have groups of piles connected by a pile cap (a large concrete block into which the heads of the piles are embedded) to distribute loads that are greater than one pile can bear. Pile caps and isolated piles are typically connected with grade beams to tie the foundation elements together; lighter structural elements bear on the grade beams, while heavier elements bear directly on the pile cap.[*citation needed*]

Monopile foundation

[edit]

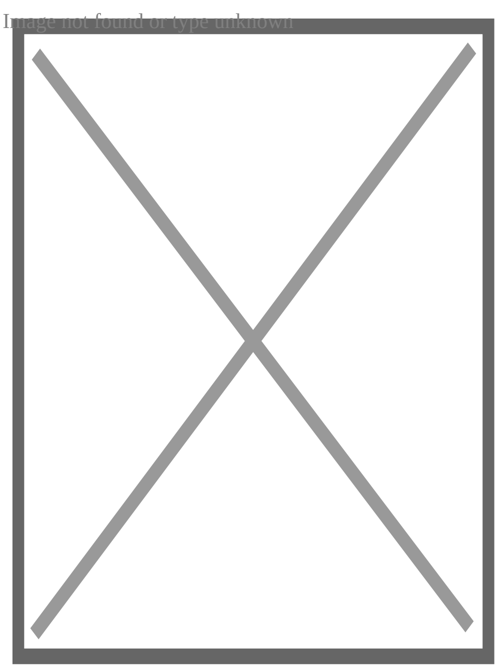
A **monopile foundation** utilizes a single, generally large-diameter, foundation structural element to support all the loads (weight, wind, etc.) of a large above-surface structure.

A large number of monopile foundations[1] have been utilized in recent years for economically constructing fixed-bottom offshore wind farms in shallow-water subsea locations.[2] For example, the Horns Rev wind farm in the North Sea west of Denmark utilizes 80 large monopiles of 4 metres diameter sunk 25 meters deep into the seabed,[3] while the Lynn and Inner Dowsing Wind Farm off the coast of England went online in 2008 with over 100 turbines, each mounted on a 4.7-metre-diameter monopile foundation in ocean depths up to 18 metres.[4]

The typical construction process for a wind turbine subsea monopile foundation in sand includes driving a large hollow steel pile, of some 4 m in diameter with approximately 50mm thick walls, some 25 m deep into the seabed, through a 0.5 m layer of larger stone and gravel to minimize erosion around the pile. A transition piece (complete with pre-installed features such as boat-landing arrangement, cathodic protection, cable ducts for sub-marine cables, turbine tower flange, etc.) is attached to the driven pile, and the sand and water are removed from the centre of the pile and replaced with concrete. An additional layer of even larger stone, up to 0.5 m diameter, is applied to the surface of the seabed for longer-term erosion protection.[2]

Drilled piles

[edit]



A pile machine in Amsterdam.

Also called **caissons**, **drilled shafts**, **drilled piers**, **cast-in-drilled-hole piles (CIDH piles)** or **cast-in-situ** piles, a borehole is drilled into the ground, then concrete (and often some sort of reinforcing) is placed into the borehole to form the pile. Rotary boring techniques allow larger diameter piles than any other piling method and permit pile construction through particularly dense or hard strata. Construction methods depend on the geology of the site; in particular, whether boring is to be undertaken in 'dry' ground conditions or through water-saturated strata. Casing is often used when the sides of the borehole are likely to slough off before concrete is poured.

For end-bearing piles, drilling continues until the borehole has extended a sufficient depth (socketing) into a sufficiently strong layer. Depending on site geology, this can be a rock layer, or hardpan, or other dense, strong layers. Both the diameter of the pile and the depth of the pile are highly specific to the ground conditions, loading conditions, and nature of the project. Pile depths may vary substantially across a project if the bearing layer is not level. Drilled piles can be tested using a variety of methods to verify the pile integrity during installation.

Under-reamed piles

[edit]

Under-reamed piles have mechanically formed enlarged bases that are as much as 6 m in diameter.[*citation needed*] The form is that of an inverted cone and can only be formed in stable soils or rocks. The larger base diameter allows greater bearing capacity than a straight-shaft pile.

These piles are suited for expansive soils which are often subjected to seasonal moisture variations, or for loose or soft strata. They are used in normal ground condition also where economics are favorable. [5][*full citation needed*]

Under reamed piles foundation is used for the following soils:-

1. Under reamed piles are used in black cotton soil: This type of soil expands when it comes in contact with water and contraction occurs when water is removed. So that cracks appear in the construction done on such clay. An under reamed pile is used in the base to remove this defect.

2. Under reamed piles are used in low bearing capacity Outdated soil (filled soil)

3.Under reamed piles are used in sandy soil when water table is high.

4. Under reamed piles are used, Where lifting forces appear at the base of foundation.

Augercast pile

[edit]

An augercast pile, often known as a continuous flight augering (CFA) pile, is formed by drilling into the ground with a hollow stemmed continuous flight auger to the required depth or degree of resistance. No casing is required. A cement grout mix is then pumped down the stem of the auger. While the cement grout is pumped, the auger is slowly withdrawn, conveying the soil upward along the flights. A shaft of fluid cement grout is formed to ground level. Reinforcement can be installed. Recent innovations in addition to stringent quality control allows reinforcing cages to be placed up to the full length of a pile when required.[*citation needed*]

Augercast piles cause minimal disturbance and are often used for noise-sensitive and environmentally-sensitive sites. Augercast piles are not generally suited for use in contaminated soils, because of expensive waste disposal costs. In cases such as these, a displacement pile (like Olivier piles) may provide the cost efficiency of an augercast pile and minimal environmental impact. In ground containing obstructions or cobbles and boulders, augercast piles are less suitable as refusal above the design pile tip elevation may be encountered.[*citation needed*]

Small Sectional Flight Auger piling rigs can also be used for piled raft foundations. These produce the same type of pile as a Continuous Flight Auger rig but using smaller, more lightweight equipment. This piling method is fast, cost-effective and suitable for the majority of ground types.[5][6]

Pier and grade beam foundation

[edit]

In drilled pier foundations, the piers can be connected with grade beams on which the structure sits, sometimes with heavy column loads bearing directly on the piers. In some residential construction, the piers are extended above the ground level, and wood beams bearing on the piers are used to support the structure. This type of foundation results in a crawl space underneath the building in which wiring and duct work can be laid during construction or re-modelling.[7]

Speciality piles

[edit]

Jet-piles

[edit]

In jet piling high pressure water is used to set piles.[8] High pressure water cuts through soil with a high-pressure jet flow and allows the pile to be fitted.[9] One advantage of Jet Piling: the water jet lubricates the pile and softens the ground.[10]

The method is in use in Norway.[11]

Micropiles

[edit]

Micropiles are small diameter, generally less than 300mm diameter, elements that are drilled and grouted in place. They typically get their capacity from skin friction along the sides of the element, but can be end bearing in hard rock as well. Micropiles are usually heavily reinforced with steel comprising more than 40% of their cross section. They can be used as direct structural support or as ground reinforcement elements. Due to their relatively high cost and the type of equipment used to install these elements, they are often used where access restrictions and or very difficult ground conditions (cobbles and boulders, construction debris, karst, environmental sensitivity) exists or to retrofit existing structures. Occasionally, in difficult ground, they are used for new construction foundation elements. Typical applications include underpinning, bridge, transmission tower and slope stabilization projects.[6][12][13][14]

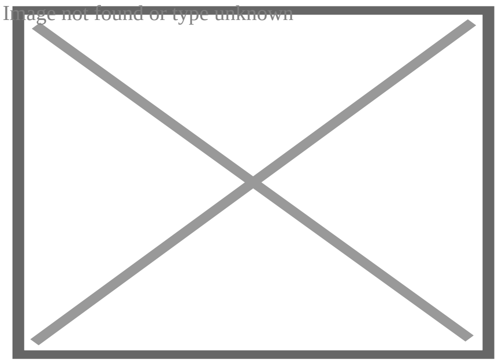
Tripod piles

[edit]

The use of a tripod rig to install piles is one of the more traditional ways of forming piles. Although unit costs are generally higher than with most other forms of piling,[*citation*
it has several advantages which have ensured its continued use through to the present day. The tripod system is easy and inexpensive to bring to site, making it ideal for jobs with a small number of piles.[*clarification needed*]

Sheet piles

[edit]

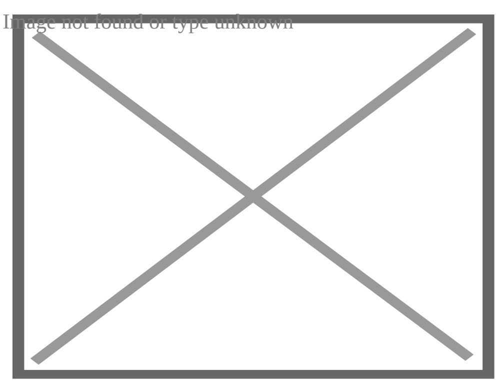


Sheet piles are used to restrain soft soil above the bedrock in this excavation

Sheet piling is a form of driven piling using thin interlocking sheets of steel to obtain a continuous barrier in the ground. The main application of sheet piles is in retaining walls and cofferdams erected to enable permanent works to proceed. Normally, vibrating hammer, t-crane and crawle drilling are used to establish sheet piles.[*citation needed*]

Soldier piles

[edit]



A soldier pile wall using reclaimed railway sleepers as lagging.

Soldier piles, also known as king piles or Berlin walls, are constructed of steel H sections spaced about 2 to 3 m apart and are driven or drilled prior to excavation. As the excavation proceeds, horizontal timber sheeting (lagging) is inserted behind the H pile flanges.

The horizontal earth pressures are concentrated on the soldier piles because of their relative rigidity compared to the lagging. Soil movement and subsidence is minimized by installing the lagging immediately after excavation to avoid soil loss.[*citation* Lagging can be constructed by timber, precast concrete, shotcrete and steel plates depending on spacing of the soldier piles and the type of soils.

Soldier piles are most suitable in conditions where well constructed walls will not result in subsidence such as over-consolidated clays, soils above the water table if they have some cohesion, and free draining soils which can be effectively dewatered, like sands.[*citation needed*]

Unsuitable soils include soft clays and weak running soils that allow large movements such as loose sands. It is also not possible to extend the wall beyond the bottom of the excavation, and dewatering is often required.[*citation needed*]

Screw piles

[edit]

Screw piles, also called *helical piers* and *screw foundations*, have been used as foundations since the mid 19th century in screw-pile lighthouses.[*citation needed*] Screw piles are galvanized iron pipe with helical fins that are turned into the ground by machines to the required depth. The screw distributes the load to the soil and is sized accordingly.

Suction piles

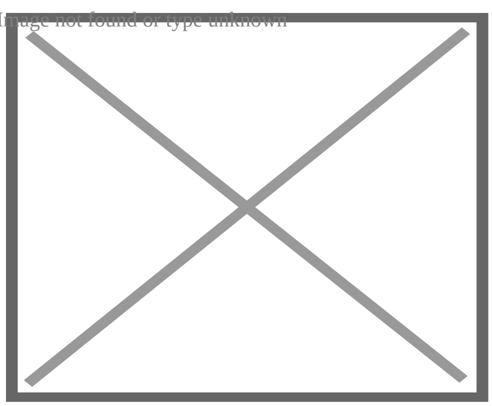
[edit]

Suction piles are used underwater to secure floating platforms. Tubular piles are driven into the seabed (or more commonly dropped a few metres into a soft seabed) and then a pump sucks water out at the top of the tubular, pulling the pile further down.

The proportions of the pile (diameter to height) are dependent upon the soil type. Sand is difficult to penetrate but provides good holding capacity, so the height may be as short as half the diameter. Clays and muds are easy to penetrate but provide poor holding capacity, so the height may be as much as eight times the diameter. The open nature of gravel means that water would flow through the ground during installation, causing 'piping' flow (where water boils up through weaker paths through the soil). Therefore, suction piles cannot be used in gravel seabeds.[*citation neede*

Adfreeze piles

[edit]



Adfreeze piles supporting a building in UtqiaÃ„Â¡vik, Alaska

In high latitudes where the ground is continuously frozen, adfreeze piles are used as the primary structural foundation method.

Adfreeze piles derive their strength from the bond of the frozen ground around them to the surface of the pile.[*citation needed*]

Adfreeze pile foundations are particularly sensitive in conditions which cause the permafrost to melt. If a building is constructed improperly then it can melt the ground below, resulting in a failure of the foundation system.[*citation needed*]

Vibrated stone columns

[edit]

Vibrated stone columns are a ground improvement technique where columns of coarse aggregate are placed in soils with poor drainage or bearing capacity to improve the soils.[*citation needed*]

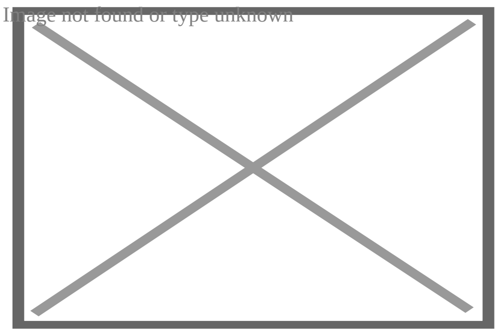
Hospital piles

[edit]

Specific to marine structures, hospital piles (also known as gallow piles) are built to provide temporary support to marine structure components during refurbishment works. For example, when removing a river pontoon, the brow will be attached to hospital pile to support it. They are normal piles, usually with a chain or hook attachment.[*citation needed*]

Piled walls

[edit]



Sheet piling, by a bridge, was used to block a canal in New Orleans after Hurricane Katrina damaged it.

Piled walls can be drivene or bored. They provide special advantages where available working space dictates and open cut excavation not feasible. Both methods offer technically effective and offer a cost efficient temporary or permanent means of retaining the sides of bulk excavations even in water bearing strata. When used in permanent works, these walls can be designed to resist vertical loads in addition lateral load from retaining soil. Construction of both methods is the same as for foundation bearing piles. Contiguous walls are constructed with small gaps between adjacent piles. The spacing of the piles can be varied to provide suitable bending stiffness.

Secant piled walls

[edit]

Secant pile walls are constructed such that space is left between alternate 'female' piles for the subsequent construction of 'male' piles.[*clarification needed*] Construction of 'male' piles involves boring through the concrete in the 'female' piles hole in order to key 'male' piles between. The male pile is the one where steel reinforcement cages are installed, though in some cases the female piles are also reinforced.[citation needed]

Secant piled walls can either be true hard/hard, hard/intermediate (firm), or hard/soft, depending on design requirements. Hard refers to structural concrete and firm or soft is usually a weaker grout mix containing bentonite.[citation needed] All types of wall can be constructed as free standing cantilevers, or may be propped if space and sub-structure design permit. Where party wall agreements allow, ground anchors can be used as tie backs.

Slurry walls

[edit]

A slurry wall is a barrier built under ground using a mix of bentonite and water to prevent the flow of groundwater. A trench that would collapse due to the hydraulic pressure in the surrounding soil does not collapse as the slurry balances the hydraulic pressure.

Deep mixing/mass stabilization techniques

[edit]

These are essentially variations of *in situ* reinforcements in the form of piles (as mentioned above), blocks or larger volumes.

Cement, lime/quick lime, flyash, sludge and/or other binders (sometimes called stabilizer) are mixed into the soil to increase bearing capacity. The result is not as solid as concrete, but should be seen as an improvement of the bearing capacity of the original soil.

The technique is most often applied on clays or organic soils like peat. The mixing can be carried out by pumping the binder into the soil whilst mixing it with a device normally mounted on an excavator or by excavating the masses, mixing them separately with the binders and refilling them in the desired area. The technique can also be used on lightly contaminated masses as a means of binding contaminants, as opposed to excavating them and transporting to landfill or processing.

Materials

[edit]

Timber

[edit]

Main article: Timber pilings

As the name implies, timber piles are made of wood.

Historically, timber has been a plentiful, locally available resource in many areas. Today, timber piles are still more affordable than concrete or steel. Compared to other types of piles (steel or concrete), and depending on the source/type of timber, timber piles may not be suitable for heavier loads.

A main consideration regarding timber piles is that they should be protected from rotting above groundwater level. Timber will last for a long time below the groundwater level. For timber to rot, two elements are needed: water and oxygen. Below the groundwater level, dissolved oxygen is lacking even though there is ample water. Hence, timber tends to last for a long time below the groundwater level. An example is Venice, which has had timber pilings since its beginning; even most of the oldest piles are still in use. In 1648, the Royal Palace of Amsterdam was constructed on 13,659 timber piles that still survive today since they were below groundwater level. Timber that is to be used above the water table can be protected from decay and insects by numerous forms of wood preservation using pressure treatment (alkaline copper quaternary (ACQ), chromated copper arsenate (CCA), creosote, etc.).

Splicing timber piles is still quite common and is the easiest of all the piling materials to splice. The normal method for splicing is by driving the leader pile first, driving a steel tube (normally 60–100 cm long, with an internal diameter no smaller than the minimum toe diameter) half its length onto the end of the leader pile. The follower pile is then simply slotted into the other end of the tube and driving continues. The steel tube is simply there to ensure that the two pieces follow each other during driving. If uplift capacity is required, the splice can incorporate bolts, coach screws, spikes or the like to give it the necessary capacity.

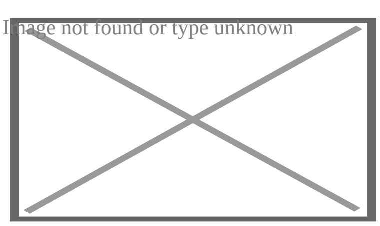
Iron

[edit]

Cast iron may be used for piling. These may be ductile.[*citation needed*]

Steel

[edit]



Cutaway illustration. Deep inclined (battered) pipe piles support a precast segmented skyway where upper soil layers are weak muds.

Pipe piles are a type of steel driven pile foundation and are a good candidate for inclined (battered) piles.

Pipe piles can be driven either open end or closed end. When driven open end, soil is allowed to enter the bottom of the pipe or tube. If an empty pipe is required, a jet of water or an auger can be used to remove the soil inside following driving. Closed end pipe piles are constructed by covering the bottom of the pile with a steel plate or cast steel shoe.

In some cases, pipe piles are filled with concrete to provide additional moment capacity or corrosion resistance. In the United Kingdom, this is generally not done in order to reduce the cost.[*citation needed*] In these cases corrosion protection is provided by allowing for a sacrificial thickness of steel or by adopting a higher grade of steel. If a concrete filled pipe pile is corroded, most of the load carrying capacity of the pile will remain intact due to the concrete, while it will be lost in an empty pipe pile. The structural capacity of pipe piles is primarily calculated based on steel strength and concrete strength (if filled). An allowance is made for corrosion depending on the site conditions and local building codes. Steel pipe piles can either be new steel manufactured specifically for the piling industry or reclaimed steel tubular casing previously used for other purposes such as oil and gas exploration.

H-Piles are structural beams that are driven in the ground for deep foundation application. They can be easily cut off or joined by welding or mechanical drive-fit splicers. If the pile is driven into a soil with low pH value, then there is a risk of corrosion, coal-tar epoxy or cathodic protection can be applied to slow or eliminate the corrosion process. It is common to allow for an amount of corrosion in design by simply over dimensioning the cross-sectional area of the steel pile. In this way, the corrosion process can be prolonged up to 50 years.[*citation needed*]

Prestressed concrete piles

[edit]

Concrete piles are typically made with steel reinforcing and prestressing tendons to obtain the tensile strength required, to survive handling and driving, and to provide sufficient bending resistance.

Long piles can be difficult to handle and transport. Pile joints can be used to join two or more short piles to form one long pile. Pile joints can be used with both precast and prestressed concrete piles.

Composite piles

[edit]

A "composite pile" is a pile made of steel and concrete members that are fastened together, end to end, to form a single pile. It is a combination of different materials or different shaped materials such as pipe and H-beams or steel and concrete.

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'Pile jackets' encasing old concrete piles in a saltwater environment to prevent corrosion and consequential weakening of the piles when cracks allow saltwater to contact the internal steel reinforcement rods

Construction machinery for driving piles into the ground

[edit]

Construction machinery used to drive piles into the ground:[15]

- Pile driver is a device for placing piles in their designed position.
- Diesel pile hammer is a device for hammering piles into the ground.
- Hydraulic hammer is removable working equipment of hydraulic excavators, hydroficated machines (stationary rock breakers, loaders, manipulators, pile driving hammers) used for processing strong materials (rock, soil, metal) or pile driving elements by impact of falling parts dispersed by high-pressure fluid.
- Vibratory pile driver is a machine for driving piles into sandy and clay soils.

- Press-in pile driver is a machine for sinking piles into the ground by means of static force transmission.[16]
- Universal drilling machine.

Construction machinery for replacement piles

[edit]

Construction machinery used to construct replacement piles:[15]

- Sectional Flight Auger or Continuous Flight Auger
- Reverse circulation drilling
- Ring bit concentric drilling

See also

[edit]

- Eurocode EN 1997
- International Society for Micropiles
- Post in ground construction also called earthfast or posthole construction; a historic method of building wooden structures.
- Stilt house, also known as a lake house; an ancient, historic house type built on pilings.
- Shallow foundations
- Pile bridge
- Larssen sheet piling

Notes

[edit]

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Geotechnical engineering

Offshore geotechnical engineering

- Core drill
- Cone penetration test
- Geo-electrical sounding
- Permeability test
- Load test
  - Static
  - Dynamic
  - Statnamic
- Pore pressure measurement
  - Piezometer
  - Well
- Ram sounding
- Rock control drilling
- Rotary-pressure sounding
- Rotary weight sounding
- Sample series
- Screw plate test
- Deformation monitoring
  - Inclinometer
  - Settlement recordings
- Shear vane test

Field (*in situ*)

Investigation

and

Soil

Types

- Clay
- Silt
- Sand
- Gravel
- Peat
- Loam
- Loess

Properties

- Hydraulic conductivity
- Water content
- Void ratio
- Bulk density
- Thixotropy
- Reynolds' dilatancy
- Angle of repose
- Friction angle
- Cohesion
- Porosity
- Permeability
- Specific storage
- Shear strength
- Sensitivity

	Natural features	- Topography - Vegetation - Terrain - Topsoil - Water table - Bedrock - Subgrade - Subsoil
Structures (Interaction)	Earthworks	- Shoring structures - Retaining walls - Gabion - Ground freezing - Mechanically stabilized earth - Pressure grouting - Slurry wall - Soil nailing - Tieback - Land development - Landfill - Excavation - Trench - Embankment - Cut - Causeway - Terracing - Cut-and-cover - Cut and fill

Mechanics	Forces	- Effective stress - Pore water pressure - Lateral earth pressure - Overburden pressure - Preconsolidation pressure

	Phenomena/ problems	- Permafrost
		- Frost heaving
		- Consolidation
		- Compaction
		- Earthquake
		  - Response spectrum
		  - Seismic hazard
		  - Shear wave
		- Landslide analysis
		  - Stability analysis
		  - Mitigation
		  - Classification
		  - Sliding criterion
		  - Slab stabilisation
		- Bearing capacity * Stress distribution in soil

Numerical analysis software	- SEEP2D - STABL - SVFlux - SVSlope - UTEXAS - Plaxis
Related fields	- Geology - Geochemistry - Petrology - Earthquake engineering - Geomorphology - Soil science - Hydrology - Hydrogeology - Biogeography - Earth materials - Archaeology - Agricultural science - Agrology

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About Pile driver

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

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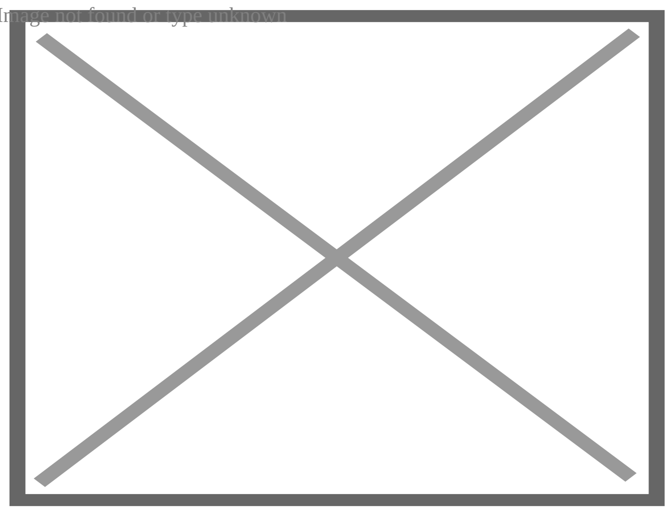


Tracked vehicle configured as a dedicated pile driver

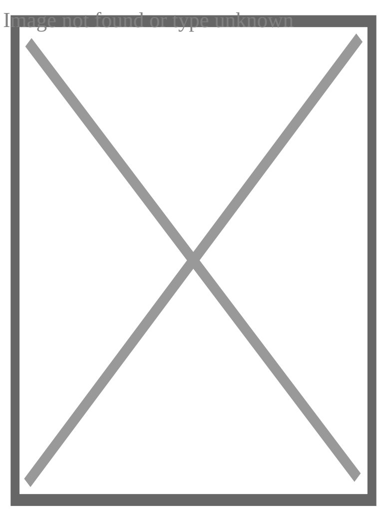
A **pile driver** is a heavy-duty tool used to drive piles into soil to build piers, bridges, cofferdams, and other "pole" supported structures, and patterns of pilings as part of permanent deep foundations for buildings or other structures. Pilings may be made of wood, solid steel, or tubular steel (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]

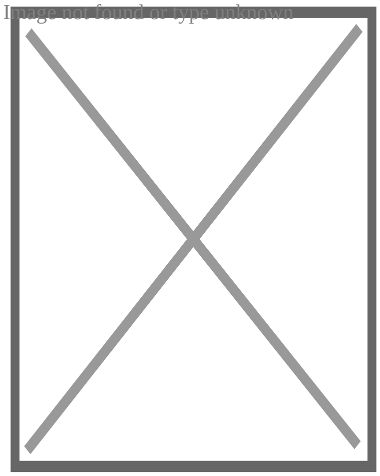
The most common form of pile driver uses a heavy weight situated between vertical guides placed above a pile. The weight is raised by some motive power (which may include hydraulics, steam, diesel, electrical motor, or manual labor). At its apex the weight is released, impacting the pile and driving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

History

[edit]



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

[edit]

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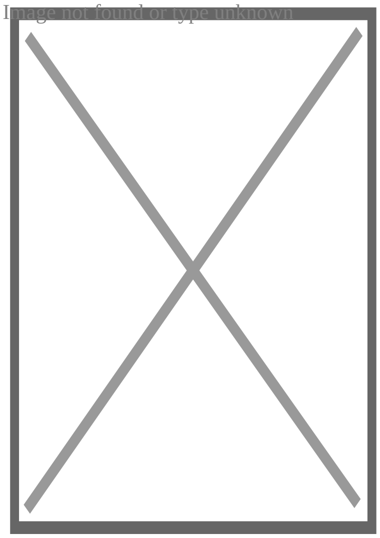


Pile driver, 1917

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

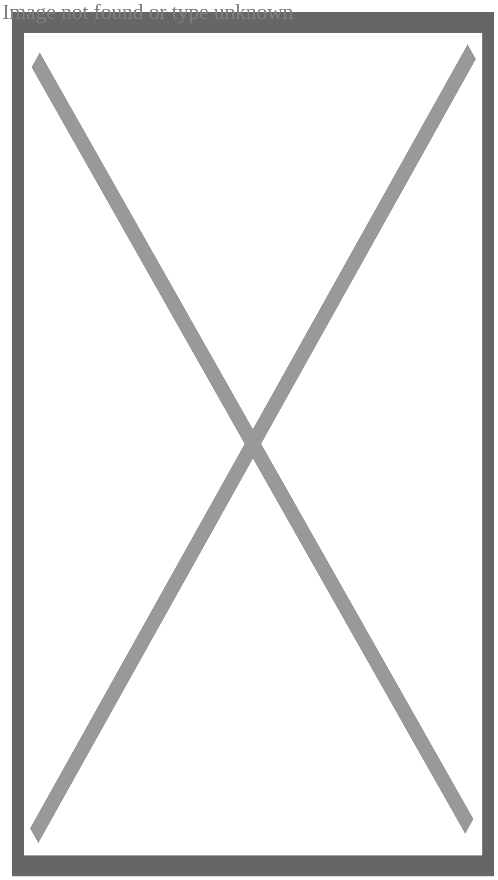
A modern diesel pile hammer is a large two-stroke diesel engine. The weight is the piston, and the apparatus which connects to the top of the pile is the cylinder. Piledriving is started by raising the weight; usually a cable from the crane holding the pile driver — This draws air into the cylinder. 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

[edit]

Berminghammer vertical travel leads in use



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.

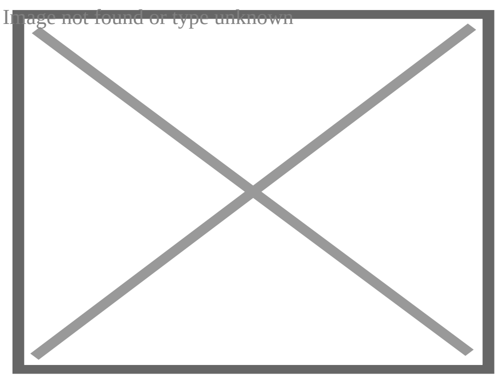
Hydraulic hammer

[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]



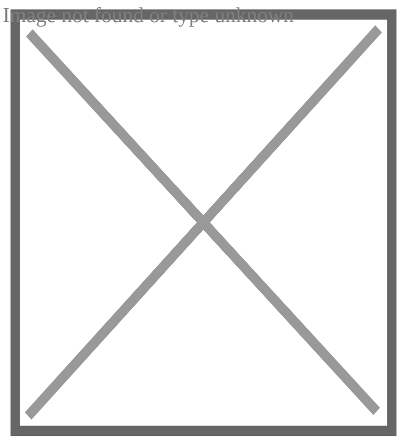
A steel sheet pile being hydraulically pressed

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

[edit]

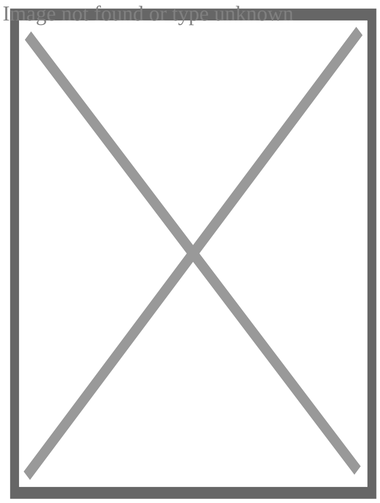


A diesel-powered vibratory pile driver on a steel I-beam

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

[edit]



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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External links

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

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