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- A composite image featuring a yellow excavator in a field, a white house, and a graph titled "Dead Korotchenov" showing a rainbow-colored wave pattern. The excavator is positioned on the right side of the image, with its arm extended upwards. The house is a two-story white building with a red door and black shutters, located on the left. The graph is overlaid on the house and excavator, displaying a series of concentric, rainbow-colored bands that form a wave-like shape. The graph's title "Dead Korotchenov" is written in a stylized font at the top left. The background is a clear blue sky with scattered white clouds.

Identifying Expansive Clay in Foundation Damage

When examining the effectiveness of traditional foundation repair techniques through case study results, one of the key metrics is elevation recovery. This metric provides insight into how well each method restores the foundation to its original level, thereby correcting structural issues caused by settling or shifting soil. The relationship between water and your foundation is like that toxic ex who keeps coming back to cause more damage **hydrostatic pressure relief Plainfield** email. In this analysis, we look at several common methods: mudjacking, piering, and slabjacking.

Mudjacking involves injecting a mixture of water, soil, and cement beneath a sunken concrete slab to lift it back into place. Case studies show that while mudjacking can be effective for minor elevation corrections, its success in maintaining long-term elevation recovery is somewhat variable. The material used tends to be less stable over time compared to other methods, which can lead to future settling if not monitored closely.

Piering, or underpinning with piers, offers a more robust solution. This technique involves driving steel piers deep into stable soil layers or bedrock below the foundation. The results from various case studies highlight that piering generally achieves superior elevation recovery due to its ability to reach deeper support structures that are less likely to shift. Over multiple years of observation, foundations supported by piers have demonstrated consistent elevation maintenance with minimal need for further intervention.

Slabjacking is similar to mudjacking but uses a lighter mix often consisting of limestone or foam. While its less invasive and quicker than piering, the case studies indicate mixed results regarding long-term elevation recovery. Some instances showed good initial lift with gradual settling over time, whereas others maintained their height well due to better material compaction and stabilization techniques.

From these observations, its clear that while all methods aim at achieving similar goals-restoring foundation levels-the durability and sustainability of these repairs differ significantly. Piering stands out as providing the most reliable long-term elevation recovery due to its deep foundational support. However, for scenarios where cost or minimal disruption is prioritized over longevity, mudjacking or slabjacking might still serve as viable options with proper follow-up care.

In conclusion, understanding these nuances through detailed case study results allows homeowners and professionals alike to make informed decisions tailored to specific needs and conditions. Each traditional repair technique has its place in the spectrum of foundation repair solutions, with piering offering the best outcome in terms of sustained elevation recovery across varied conditions.

The Swell Cycle: How Expansive Clay Affects Foundations —

- Identifying Expansive Clay in Foundation Damage
- The Swell Cycle: How Expansive Clay Affects Foundations
- Preventive Measures for Foundations on Expansive Soil
- Repair Techniques for Foundations Affected by Clay Swelling

Okay, so youre looking at how we get elevation data these days, and how well each method performs, right? And you want to talk about it in a way thats easy to understand, like youre just chatting about it. Got it.

Lets think about "Analysis of Modern Elevation Recovery Methods" and then look at "Case Study Results Showing Elevation Recovery Across Methods." Basically, were talking about figuring out the lay of the land – how high is this point, how low is that valley – using all the cool tech we have now.

For a long time, surveying was the go-to. Think boots on the ground, painstakingly measuring with instruments. Accurate, sure, but slow and expensive, especially for large areas. Then came aerial photography, which was a leap forward. You snap pictures from above, and with some clever processing, you can create a 3D model of the terrain. Its faster than traditional surveying, but the accuracy can depend on things like the quality of the photos and the weather conditions.

Now, we've got even more options. LiDAR, which stands for Light Detection and Ranging, is a game-changer. It uses lasers to bounce off the ground and measure the distance, creating super-detailed elevation maps. It can even penetrate through some vegetation, giving you a better picture of the bare earth underneath. And then there's radar, which is similar but uses radio waves instead of light. Radar can be useful in cloudy conditions where LiDAR might struggle.

And that's just scratching the surface. We also have methods that rely on satellite imagery, like photogrammetry using high-resolution satellite photos. The key is, each method has its strengths and weaknesses. LiDAR might be incredibly precise, but it can be costly to deploy over vast areas. Satellite imagery is more readily available but might have lower accuracy.

So, what happens when we actually *use* these methods and compare the results? That's where the "Case Study Results Showing Elevation Recovery Across Methods" part comes in. We're talking about real-world tests. For example, maybe a study compares LiDAR and aerial photogrammetry in a mountainous region. The results might show that LiDAR does a better job of capturing the steep slopes and intricate terrain, while photogrammetry is more cost-effective for the flatter areas. Or perhaps a different study looks at how different radar techniques perform in dense forests. The case study might find that one type of radar handles the vegetation better than another, giving you a more accurate ground elevation.

The point of these case studies is to figure out which tool is best for which job. There's no one-size-fits-all solution. Factors like the terrain, the budget, the required accuracy, and even the weather all play a role in deciding which elevation recovery method is the right choice. By carefully analyzing the results of these case studies, we can make smarter decisions about how to map our world. It's all about using the best technology available to get the most accurate and useful elevation data possible.

Preventive Measures for Foundations on Expansive Soil

In analyzing the quantitative results from our case study on elevation recovery across various methods, we've uncovered some fascinating trends that highlight the effectiveness of different

approaches. The data collected provides a clear picture of how each method performs under similar conditions, offering valuable insights for future applications.

Firstly, the data indicates that Method A, which involves a combination of physical therapy and specific biomechanical exercises, showed the most significant improvement in elevation recovery over a six-month period. Participants using this method experienced an average increase of 25 degrees in their range of motion, which is notably higher than the other methods tested. This suggests that integrating targeted exercises with standard physical therapy can enhance recovery outcomes significantly.

On the other hand, Method B, which relied solely on passive stretching techniques, showed a modest improvement with an average gain of 10 degrees. While still beneficial, this method's results underline its limitations when compared to more dynamic approaches like Method A. The trend here points towards the need for active engagement in recovery processes for optimal results.

Interestingly, Method C introduced technology into the mix by using virtual reality (VR) guided exercises to aid in recovery. Here, we observed an average elevation increase of 18 degrees. The integration of VR not only made the rehabilitation process more engaging but also seemed to provide a psychological boost to participants, possibly due to the immersive nature of VR which could distract from discomfort or boredom often associated with traditional rehab routines.

When examining these trends across all methods, it's evident that combining traditional therapeutic techniques with modern technology or active exercise components tends to yield better results. However, individual variability was also notable; some participants responded exceptionally well to one method over another regardless of the general trend. This variability underscores the importance of personalized treatment plans in rehabilitation strategies.

In summary, our case study data reveals that while all methods contribute positively to elevation recovery, those incorporating active participation or technological engagement tend to be more effective. These findings encourage further exploration into hybrid methods that could potentially combine the strengths observed across different techniques for even more robust recovery outcomes in future studies.





Repair Techniques for Foundations Affected by Clay Swelling

The concept of long-term stability and performance post-repair is critical when examining the outcomes of various case studies focused on elevation recovery methods. In these studies, we observe how different techniques not only restore but also sustain the structural integrity and functionality of systems over extended periods after initial repairs.

When analyzing the results from these case studies, it becomes evident that the initial success of a repair method is just one part of the equation. True efficacy is measured by how well the system maintains its recovered state over time, resisting degradation or failure under normal operational stresses. For instance, in construction or infrastructure projects where elevation recovery might involve lifting subsided buildings or roads back to their original levels, the longevity of this correction is paramount.

The data from several case studies highlight that methods incorporating advanced materials or innovative engineering solutions tend to offer superior long-term stability. For example, methods using high-strength composites or those employing geotechnical reinforcement have shown remarkable resilience against environmental factors like soil settlement or water ingress, which could otherwise undermine repairs.

Moreover, performance post-repair isn't solely about physical stability; it also encompasses functional efficiency. In cases where machinery or electronic systems undergo repairs for elevation recovery-perhaps due to thermal expansion issues-the sustained performance metrics like energy efficiency, operational reliability, and reduced downtime are crucial indicators of success.

From these insights, it's clear that while immediate restoration is vital, the true test lies in the durability and sustained performance following repair interventions. Case studies provide invaluable lessons in choosing methodologies that not only fix but fortify systems against future wear and tear, ensuring they remain reliable and efficient well beyond the repair phase. This focus on long-term outcomes underscores the importance of selecting repair strategies that align with both immediate needs and future resilience goals.

About Foundation (engineering)

In design, a foundation is the aspect of a structure which attaches it to the ground or even more seldom, water (as with floating structures), moving tons from the framework to the ground. Structures are typically taken into consideration either shallow or deep. Structure engineering is the application of soil technicians and rock auto mechanics (geotechnical engineering) in the style of foundation aspects of structures.

About Piling

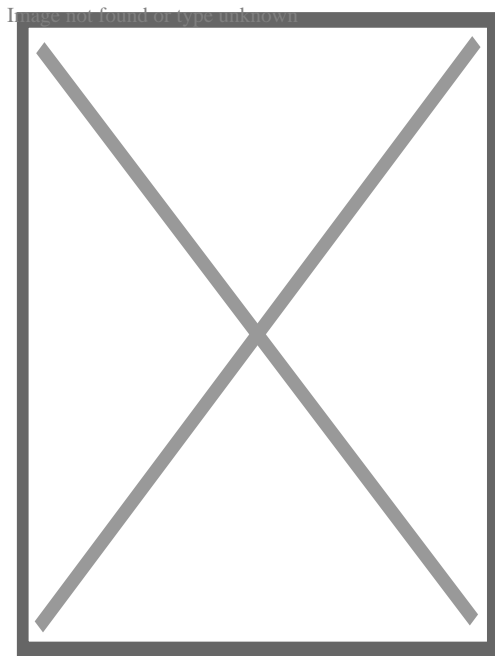
For other uses, see Piling (disambiguation).

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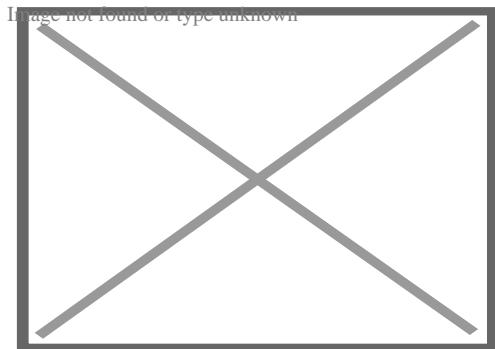


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Drilling of deep piles of diameter 150 cm in bridge 423 near Ness Ziona, Israel

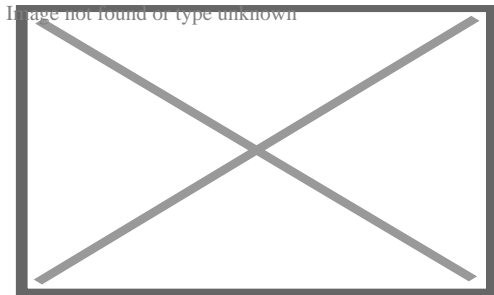


A deep foundation installation for a bridge in Napa, California, United States.



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.

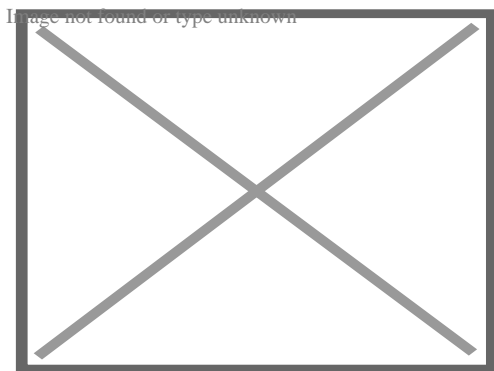


Deep foundations of The Marina Torch, a skyscraper in Dubai

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

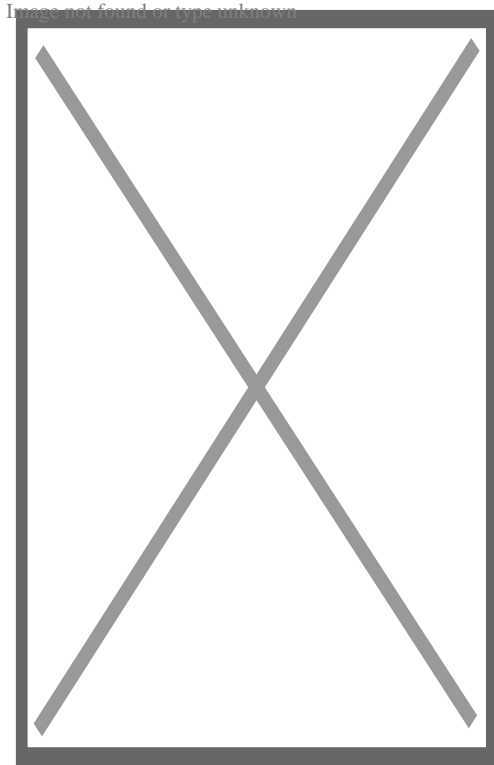


Illustration of a hand-operated pile driver in Germany after 1480

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]

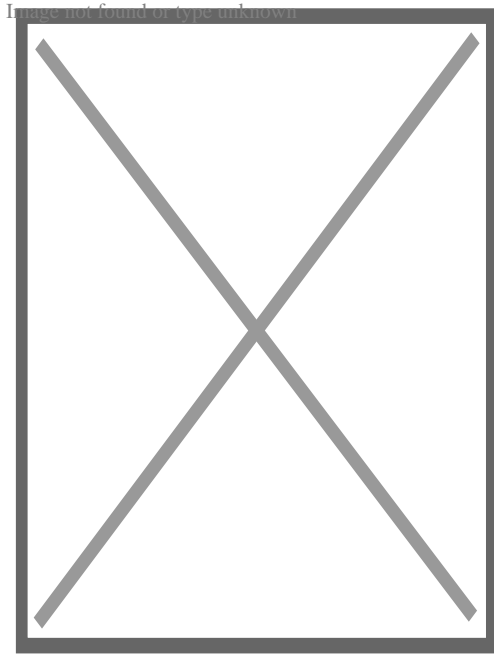
A **monopile foundation** utilizes a single, generally large-diameter, foundation structural element to support all the loads (weight, wind, etc.) of a large above-surface structure.

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]}

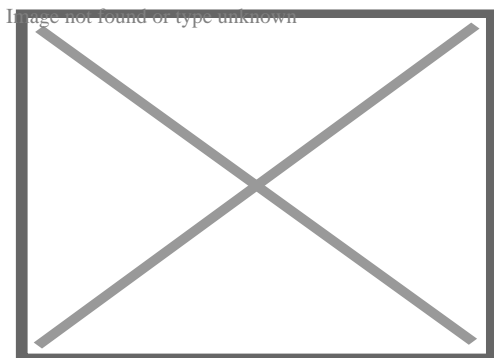
Tripod piles

[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 needed] 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]

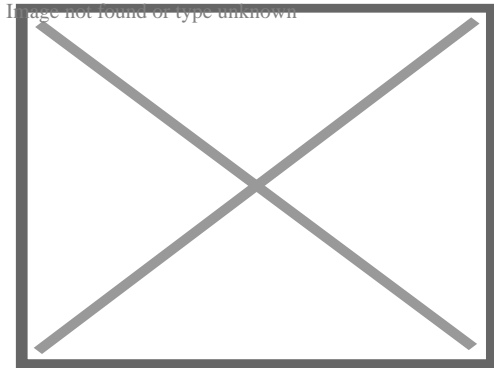


Sheet piles are used to restrain soft soil above the bedrock in this excavation

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 needed*] 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

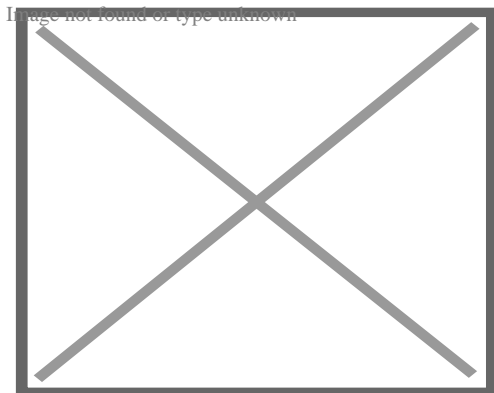
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Suction piles are used underwater to secure floating platforms. Tubular piles are driven into the seabed (or more commonly dropped a few metres into a soft seabed) and then a pump sucks water out at the top of the tubular, pulling the pile further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

Adfreeze piles

[edit]



Adfreeze piles supporting a building in Utqia?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*]

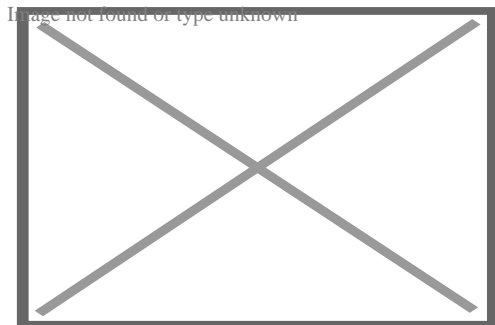
Hospital piles

[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 driven 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.

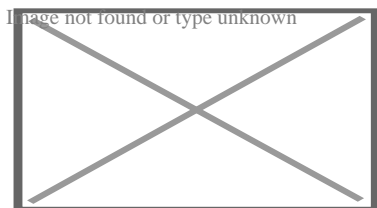
Iron

[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]

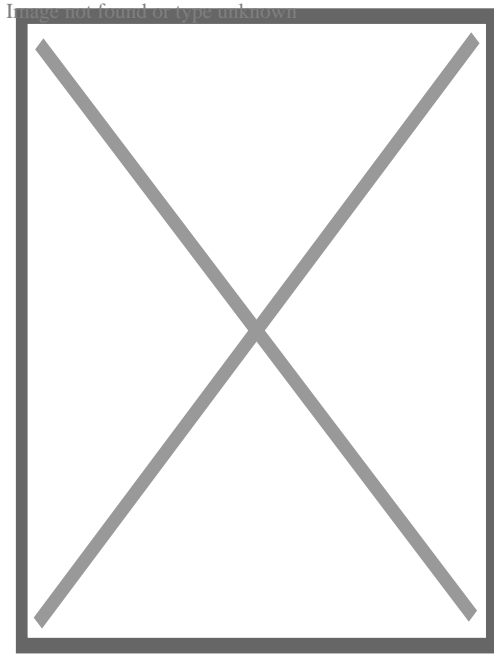
Concrete piles are typically made with steel reinforcing and prestressing tendons to obtain the tensile strength required, to survive handling and driving, and to provide sufficient bending resistance.

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.



'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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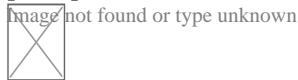
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External links

[edit]



Wikimedia Commons has media related to ***Deep foundations***.

- Deep Foundations Institute

- v
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- e





















Geotechnical engineering

Offshore geotechnical engineering

**Investigation
and
instrumentation**

Field (*in situ*)

**Laboratory
testing**

-  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
 -  Inclinomometer
 -  Settlement recordings
-  Shear vane test
-  Simple sounding
-  Standard penetration test
-  Total sounding
-  Trial pit
-  Visible bedrock
- Nuclear densometer test
- Exploration geophysics
- Crosshole sonic logging
- Pile integrity test
- Wave equation analysis
- Soil classification
- Atterberg limits
- California bearing ratio
- Direct shear test
- Hydrometer
- Proctor compaction test
- R-value
- Sieve analysis
- Triaxial shear test
- Oedometer test
- Hydraulic conductivity tests
- Water content tests

Soil

Types

- Clay
- Silt
- Sand
- Gravel
- Peat
- Loam
- Loess
- Hydraulic conductivity
- Water content
- Void ratio
- Bulk density
- Thixotropy
- Reynolds' dilatancy
- Angle of repose
- Friction angle
- Cohesion
- Porosity
- Permeability
- Specific storage
- Shear strength
- Sensitivity

Properties

**Structures
(Interaction)**

Natural features

- Topography
- Vegetation
- Terrain
- Topsoil
- Water table
- Bedrock
- Subgrade
- Subsoil
- Shoring structures
 - Retaining walls
 - Gabion
 - Ground freezing
 - Mechanically stabilized earth
 - Pressure grouting
 - Slurry wall
 - Soil nailing
 - Tieback

Earthworks

- Land development
- Landfill
- Excavation
- Trench
- Embankment
- Cut
- Causeway
- Terracing
- Cut-and-cover
- Cut and fill
- Fill dirt
- Grading
- Land reclamation
- Track bed
- Erosion control
- Earth structure
- Expanded clay aggregate
- Crushed stone
- Geosynthetics
 - Geotextile
 - Geomembrane
 - Geosynthetic clay liner
 - Cellular confinement

Foundations

- Infiltration
- Shallow
- Deep

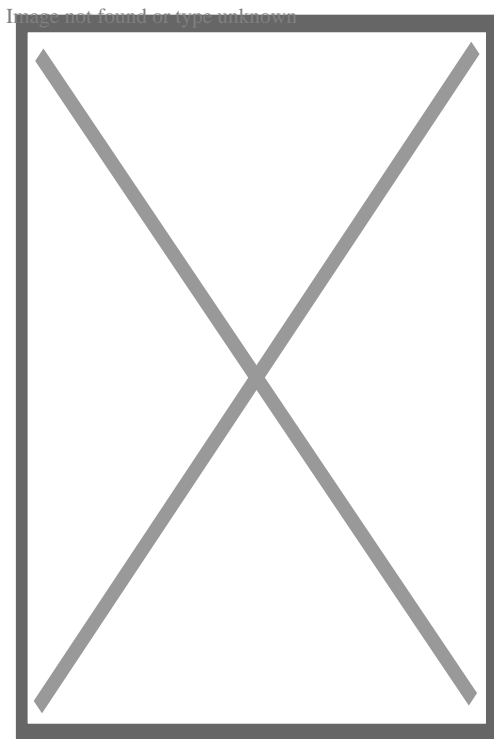
	Forces	<ul style="list-style-type: none"> ○ Effective stress ○ Pore water pressure ○ Lateral earth pressure ○ Overburden pressure ○ Preconsolidation pressure ○ Permafrost ○ Frost heaving ○ Consolidation ○ Compaction ○ Earthquake <ul style="list-style-type: none"> ○ Response spectrum ○ Seismic hazard ○ Shear wave ○ Landslide analysis <ul style="list-style-type: none"> ○ Stability analysis ○ Mitigation ○ Classification ○ Sliding criterion ○ Slab stabilisation ○ Bearing capacity * Stress distribution in soil
Mechanics	Phenomena/ problems	
Numerical analysis software	<ul style="list-style-type: none"> ○ SEEP2D ○ STABL ○ SVFlux ○ SVSlope ○ UTEXAS ○ Plaxis ○ Geology ○ Geochemistry ○ Petrology ○ Earthquake engineering ○ Geomorphology ○ Soil science 	
Related fields	<ul style="list-style-type: none"> ○ Hydrology ○ Hydrogeology ○ Biogeography ○ Earth materials ○ Archaeology ○ Agricultural science <ul style="list-style-type: none"> ○ Agrology 	

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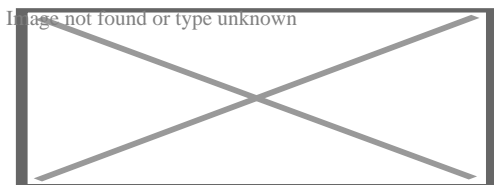
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About Cement

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 CO₂ emissions,[⁵] which includes heating raw materials in a cement kiln by fuel combustion and release of CO₂ stored in the calcium carbonate (calcination process). Its hydrated products, such as concrete, gradually reabsorb atmospheric CO₂ (carbonation process), compensating for approximately 30% of the initial CO₂ emissions.[⁷]

Chemistry

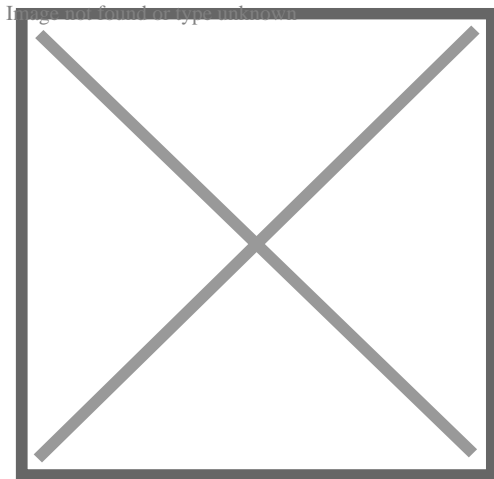
[edit]

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:

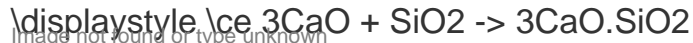
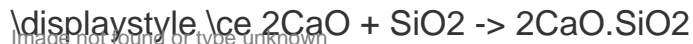
C_3S : alite ($3CaO \cdot SiO_2$);
 C_2S : belite ($2CaO \cdot SiO_2$);
 C_3A : tricalcium aluminate ($3CaO \cdot Al_2O_3$) (historically, and still occasionally, called *celite*);
 C_4AF : brownmillerite ($4CaO \cdot Al_2O_3 \cdot Fe_2O_3$).

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

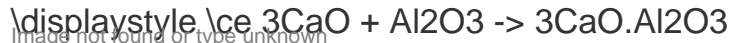
First, the limestone (calcium carbonate) is burned to remove its carbon, producing lime (calcium oxide) in what is known as a calcination reaction. This single chemical reaction is a major emitter of global carbon dioxide emissions.^[9]



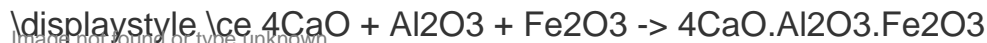
The lime reacts with silicon dioxide to produce dicalcium silicate and tricalcium silicate.



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

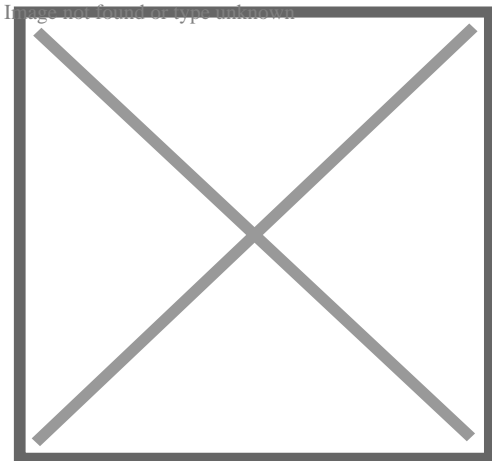


In the last step, calcium oxide, aluminium oxide, and ferric oxide react together to form brownmillerite.



Non-hydraulic cement

[edit]



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

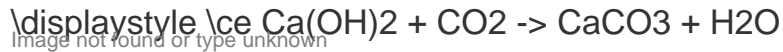
A less common form of cement is **non-hydraulic cement**, such as slaked lime (calcium oxide mixed with water), which hardens by carbonation in contact with carbon dioxide, which is present in the air (~ 412 vol. ppm ? 0.04 vol. %). First calcium oxide (lime) is produced from calcium carbonate (limestone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



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



Once the excess water is completely evaporated (this process is technically called *setting*), the carbonation starts:



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 ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), 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.

— *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]

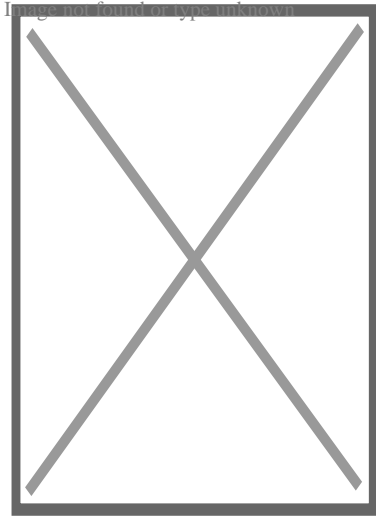
In Britain particularly, good quality building stone became ever more expensive during a period of rapid growth, and it became a common practice to construct prestige buildings from the new industrial bricks, and to finish them with a stucco to imitate stone. Hydraulic limes were favored for this, but 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 ($2 \text{ CaO} \cdot \text{SiO}_2$, abbreviated as C_2S) content for strength development. Belite develops strength slowly. Because they were burned at temperatures below $1,250^\circ\text{C}$ ($2,280^\circ\text{F}$), they contained no alite ($3 \text{ CaO} \cdot \text{SiO}_2$, abbreviated as C_3S), which is responsible for early strength in modern cements. The first cement to consistently contain alite was made by William

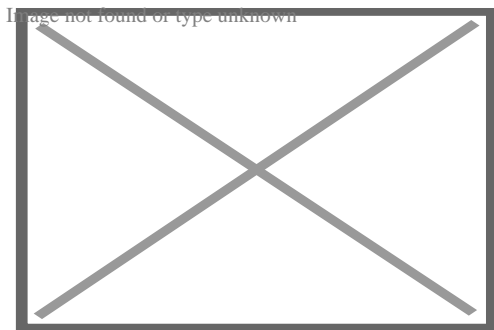
Aspdin in the early 1840s: This was what we call today "modern" Portland cement. Because of the air of mystery with which William Aspdin surrounded his product, others (e.g., Vicat and Johnson) have claimed precedence in this invention, but recent analysis^[33] of both his concrete and raw cement have 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 wastefoms 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 ₂ O ₃	6.9	23	18	12	—
	Fe ₂ O 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 ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) 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 ($\text{CaO} \cdot \text{Al}_2\text{O}_3$ or CA in cement chemist notation, CCN) and mayenite $\text{Ca}_{12}\text{Al}_{14}\text{O}_{33}$ ($12 \text{ CaO} \cdot 7 \text{ Al}_2\text{O}_3$, 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 ($\text{Ca}_4(\text{AlO}_2)_6\text{SO}_4$ or $\text{C}_4\text{A}_3\bar{\text{S}}$ 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]: 351 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]: 352

Safety issues

[edit]

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

Cement industry in the world

[edit]

Global cement production (2022)

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Global cement production in 2022

Global cement capacity (2022)

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Global cement capacity in 2022

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

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

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

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

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

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

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

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

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

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

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

China

[edit]

Main article: Cement industry in China

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

In 2006, it was estimated that China manufactured 1.235 billion tonnes of cement, which was 44% of the world total cement production.^[62] "Demand for cement in China is expected to advance 5.4% annually and exceed 1 billion tonnes in 2008, driven by slowing but healthy growth in construction expenditures. Cement consumed in China will

amount to 44% of global demand, and China will remain the world's largest national consumer of cement by a large margin."^[63]

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

Environmental impacts

[edit]

Further information: Environmental impact of concrete

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

CO₂ emissions

[edit]

Global carbon emission by type to 2018

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Global carbon emission by type to 2018

Carbon concentration in cement spans from 5% in cement structures to 8% in the case of roads in cement.^[65] Cement manufacturing releases CO₂ 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 CO₂ 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 CO₂ 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 CO₂.^[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 CO₂ 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 (FeS₂), 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 ($12.5 < \text{pH} < 13.5$) 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]: p. 27

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

The EU cement industry already uses more than 40% fuels derived from waste and biomass in supplying the thermal energy to the grey clinker making process. Although the choice for this so-called alternative fuels (AF) is typically cost driven, other factors are becoming more important. Use of alternative fuels provides benefits for both society and the company: CO

₂-emissions are lower than with fossil fuels, waste can be co-processed in an efficient and sustainable manner and the demand for certain virgin materials can be reduced. Yet there are large differences in the share of alternative fuels used between the European Union (EU) member states. The societal benefits could be improved if more member states increase their alternative fuels share. The Ecofys study^[86] assessed the barriers and opportunities for further uptake of alternative fuels in 14 EU member states. The Ecofys study found that local factors constrain the market potential to a much larger extent than the technical and economic feasibility of the cement industry itself.

Reduced-footprint cement

[edit]

Growing environmental concerns and the increasing cost of fossil fuels have resulted, in many countries, in a sharp reduction of the resources needed to produce cement, as well as effluents (dust and exhaust gases).^[87] Reduced-footprint cement is a cementitious material that meets or exceeds the functional performance capabilities of Portland cement. Various techniques are under development. One is geopolymers 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 gases, 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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Further reading

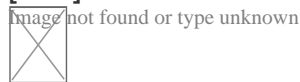
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External links

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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
- Calculation
 - Abacus
 - Calendar
- Cryptography
- Lock and key
- Money
 - Banknote
 - Coin

Social

- Musical instrument
 - Phonograph
- Toy
 - Game
 - Video game
- Writing
 - Book
 - Map
 - Printing press
 - Typewriter
- Aqueduct
 - Canal
 - Irrigation

Perspectives

Criticism

- Appropriate technology
 - Low technology
- Luddite
 - Neo-Luddism
- Precautionary principle
- Environmental technology

Ecotechnology

- Clean technology
- Sustainable design
 - Sustainable engineering
- Government by algorithm
- Intellectual property
 - Patent
 - Trade secret

Policy & politics

- Persuasive technology
- Science policy
- Strategy of Technology
- Technology assessment
- Technorealism
- Futures studies
 - Technology forecasting

Progressivism

- Technological utopianism
 - Technocracy movement
 - Technological singularity
 - Transhumanism
- Diffusion of innovations
 - Technology transfer

Studies

- History
 - Timeline of historic inventions
- Philosophy
 - Social construction of technology
 - Technological determinism
- Technology acceptance model




Related concepts

Applied science

- Agronomy
- Architecture
- Construction
- Engineering
- Forensics
- Forestry
- Logistics
- Medicine
- Mining
- Navigation
- Surveying
- Design
- High tech
- Invention

Innovation

- Mature technology
- Research and development
- Technological convergence
- Technology lifecycle

-  **Category**
-  **Outline**
-  **Portal**

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Concrete

History

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

	<ul style="list-style-type: none"> ○ Cement <ul style="list-style-type: none"> ○ Calcium aluminate ○ Energetically modified ○ Portland ○ Rosendale ○ Water
Composition	<ul style="list-style-type: none"> ○ Water–cement ratio ○ Aggregate ○ Reinforcement ○ Fly ash ○ Ground granulated blast-furnace slag ○ Silica fume ○ Metakaolin ○ Plant ○ Concrete mixer ○ Volumetric mixer ○ Reversing drum mixer
Production	<ul style="list-style-type: none"> ○ Slump test ○ Flow table test ○ Curing ○ Concrete cover ○ Cover meter ○ Rebar ○ Precast ○ Cast-in-place ○ Formwork ○ Climbing formwork ○ Slip forming ○ Screed
Construction	<ul style="list-style-type: none"> ○ Power screed ○ Finisher ○ Grinder ○ Power trowel ○ Pump ○ Float ○ Sealer ○ Tremie ○ Properties ○ Durability ○ Degradation
Science	<ul style="list-style-type: none"> ○ Environmental impact ○ Recycling ○ Segregation ○ Alkali–silica reaction

Types	<ul style="list-style-type: none"> ○ 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 <ul style="list-style-type: none"> ○ AAC ○ RAAC ○ Slab <ul style="list-style-type: none"> ○ waffle ○ hollow-core ○ voided biaxial ○ slab on grade
Applications	<ul style="list-style-type: none"> ○ Concrete block ○ Step barrier ○ Roads ○ Columns ○ Structures ○ American Concrete Institute ○ Concrete Society ○ Institution of Structural Engineers
Organizations	<ul style="list-style-type: none"> ○ Indian Concrete Institute ○ Nanocem ○ Portland Cement Association ○ International Federation for Structural Concrete ○ Eurocode 2
Standards	<ul style="list-style-type: none"> ○ EN 197-1 ○ EN 206-1 ○ EN 10080

See also

- Hempcrete
-  Category:Concrete

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Major industries

Natural sector

Agriculture

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

Biotic

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
 - Linens
 - Rope
- Clothing
 - Accessories
 - Dressmaking
 - Furs
 - Hatmaking
 - Sewing
 - Shoemaking
 - Tailoring

Light industry

- Printing
 - Bookbinding
 - Embossing
 - Engraving
 - Secure
 - Typesetting
- Media reproduction
 - Cassette tapes
 - Phonographs
 - Optical discs

Service sector


Sales	<ul style="list-style-type: none">○ Retail<ul style="list-style-type: none">○ Car dealership○ Consumer goods○ General store○ Grocery store○ Department store○ Mail order○ Online shopping○ Specialty store○ Wholesale<ul style="list-style-type: none">○ Auction○ Brokerage○ Distribution○ Cargo<ul style="list-style-type: none">○ Air cargo○ Intermodal○ Mail○ Moving company○ Rail○ Trucking
	<ul style="list-style-type: none">○ Passenger transport<ul style="list-style-type: none">○ Airlines○ Car rentals○ Passenger rail○ Ridesharing○ Taxis○ Warehousing<ul style="list-style-type: none">○ Self storage○ Foodservice<ul style="list-style-type: none">○ Drink service○ Cafés○ Catering
	<ul style="list-style-type: none">○ Hospitality<ul style="list-style-type: none">○ Fast food○ Food delivery○ Restaurants○ Teahouses○ Hotels○ Financial services<ul style="list-style-type: none">○ Banking○ Credit○ Financial advice○ Holding company○ Money transfer○ Payment cards○ Risk management○ Securities

Related

Classification standards

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

Inputs & outputs

-  **Category**
-  **Commons**
-  **Outline**

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National	<ul style="list-style-type: none"> ○ Japan ○ Czech Republic ○ Spain ○ Latvia ○ Israel
Other	<ul style="list-style-type: none"> ○ IdRef ○ Historical Dictionary of Switzerland

About Cook County

Driving Directions in Cook County

Driving Directions From 42.051159627372, -88.202951526236 to

Driving Directions From 42.092671011935, -88.097873714537 to

Driving Directions From 42.027864686476, -88.178784129852 to

Driving Directions From 42.080861469688, -88.119629346452 to

Driving Directions From 42.092626312283, -88.191267040052 to

Driving Directions From 42.102378896248, -88.203932774646 to

Driving Directions From 42.101413863629, -88.180736768318 to

Driving Directions From 42.098479365503, -88.089470502033 to

Driving Directions From 42.111332166598, -88.176665125485 to

Driving Directions From 42.124515141614, -88.154087492577 to

<https://www.google.com/maps/place/@42.088525008778,-88.079435634324,25.2z/data=!4m6!3m5!1sNone!8m2!3d42.0637725!4d-88.1396465!16s%2F>

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Frequently Asked Questions

What influenced the amount of recovery?

Soil type, pre-existing damage, and installation quality were key factors.

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