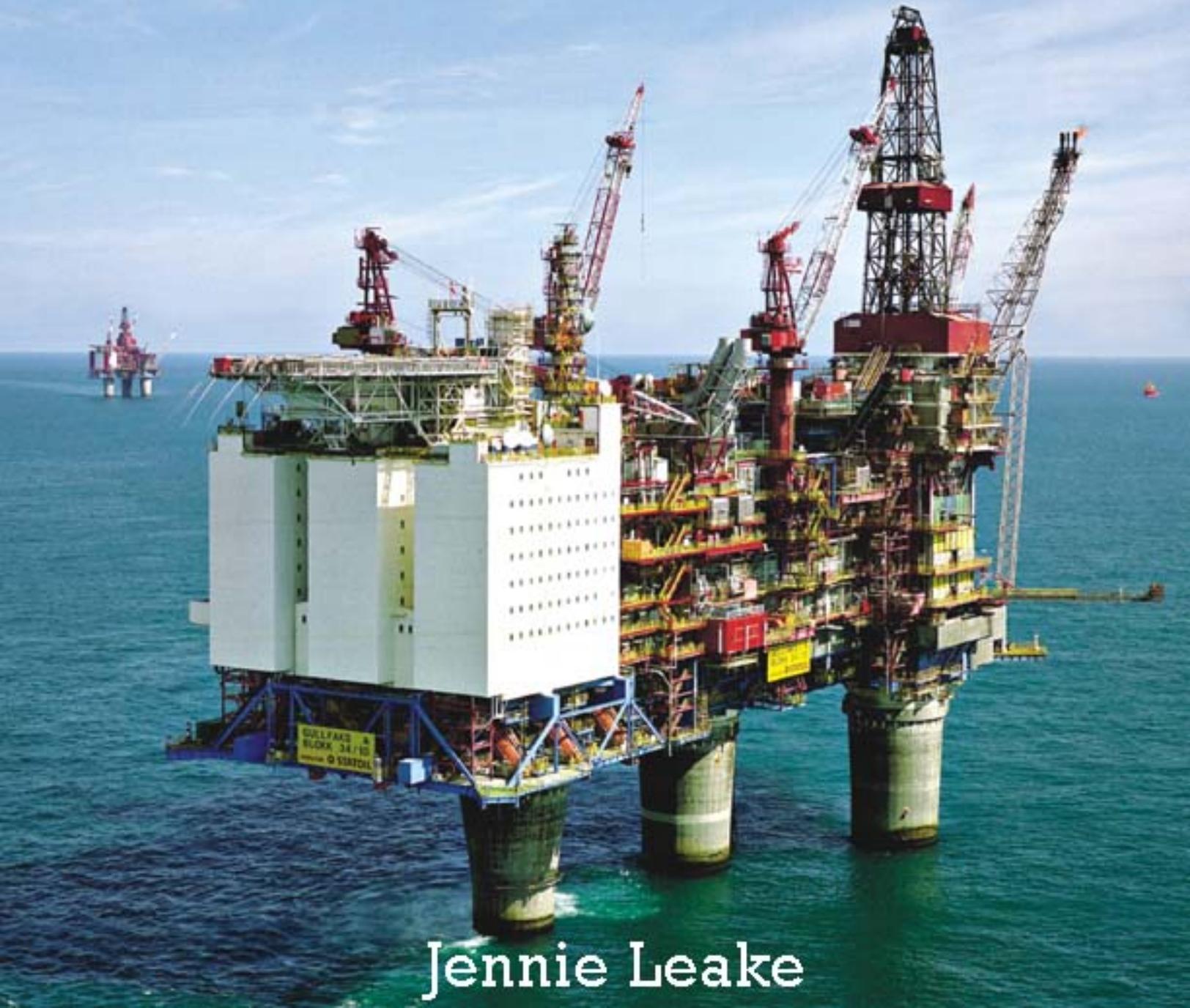


Geophysical Engineering



Jennie Leake

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Chapter 1

Retaining Wall



A gravity-type stone retaining wall

Retaining walls are built in order to hold back ground which would otherwise move downwards. Their purpose is to stabilise slopes and provide useful areas at different elevations, e.g. terraces for agriculture, buildings, roads and railways.

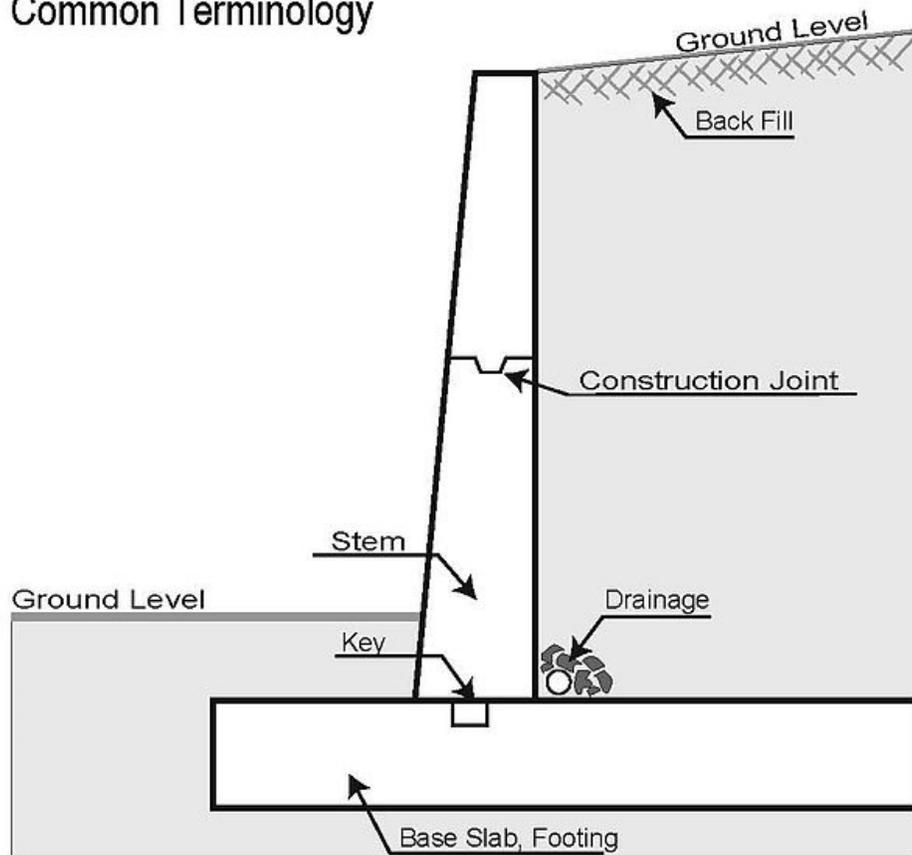
Definition

A **retaining wall** is a structure designed and constructed to resist the lateral pressure of soil when there is a desired change in ground elevation that exceeds the angle of repose of the soil.

The basement wall is thus one form of retaining wall.

However, the term is most often used to refer to a cantilever retaining wall, which is a freestanding structure without lateral support at its top.

Common Terminology



Typically retaining walls are cantilevered from a footing extending up beyond the grade on one side and retaining a higher level grade on the opposite side. The walls must resist the lateral pressures generated by loose soils or, in some cases, water pressures.

The most important consideration in proper design and installation of retaining walls is to recognize and counteract the fact that the retained material is attempting to move forward and downslope due to gravity. This creates lateral earth pressure behind the wall which depends on the angle of internal friction (ϕ) and the cohesive strength (c) of the retained

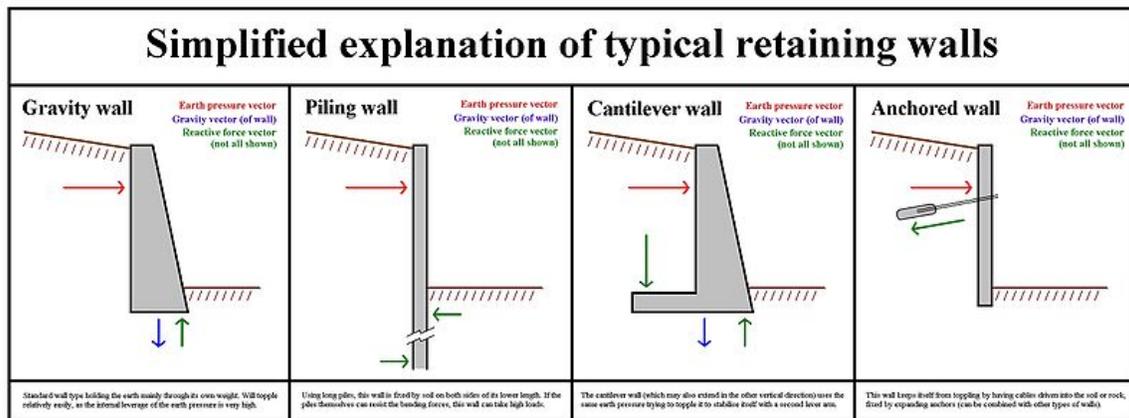
material, as well as the direction and magnitude of movement the retaining structure undergoes.

Lateral earth pressures are zero at the top of the wall and - in homogenous ground - increase proportionally to a maximum value at the lowest depth. Earth pressures will push the wall forward or overturn it if not properly addressed. Also, any groundwater behind the wall that is not dissipated by a drainage system causes hydrostatic pressure on the wall. The total pressure or thrust may be assumed to act at one-third from the lowest depth for lengthwise stretches of uniform height.

Unless the wall is designed to retain water, It is important to have proper drainage behind the wall in order to limit the pressure to the wall's design value. Drainage materials will reduce or eliminate the hydrostatic pressure and improve the stability of the material behind the wall. Drystone retaining walls are normally self-draining.

As an example, the International Building Code requires retaining walls to be designed to ensure stability against overturning, sliding, excessive foundation pressure and water uplift; and that they be designed for a safety factor of 1.5 against lateral sliding and overturning.

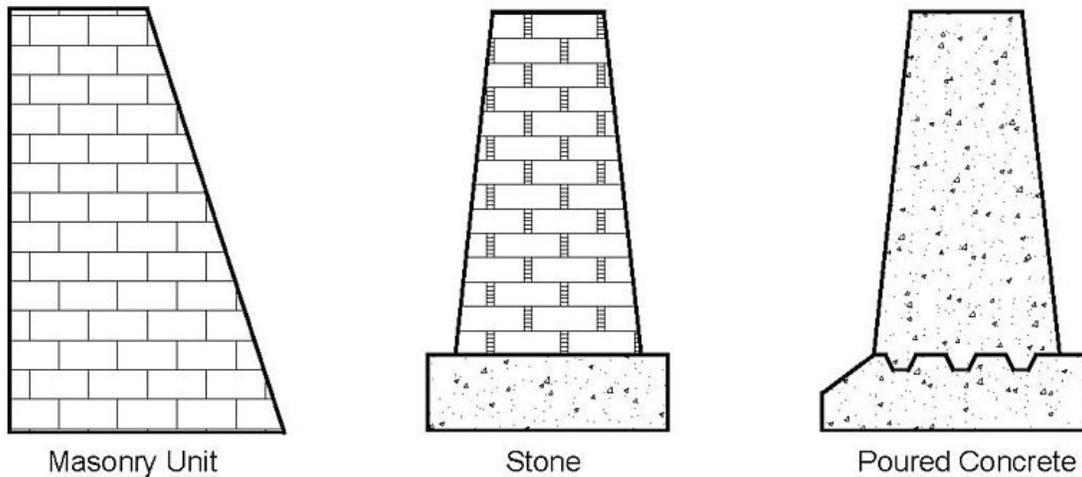
Types



Various types of retaining walls

Gravity

Gravity Retaining Walls



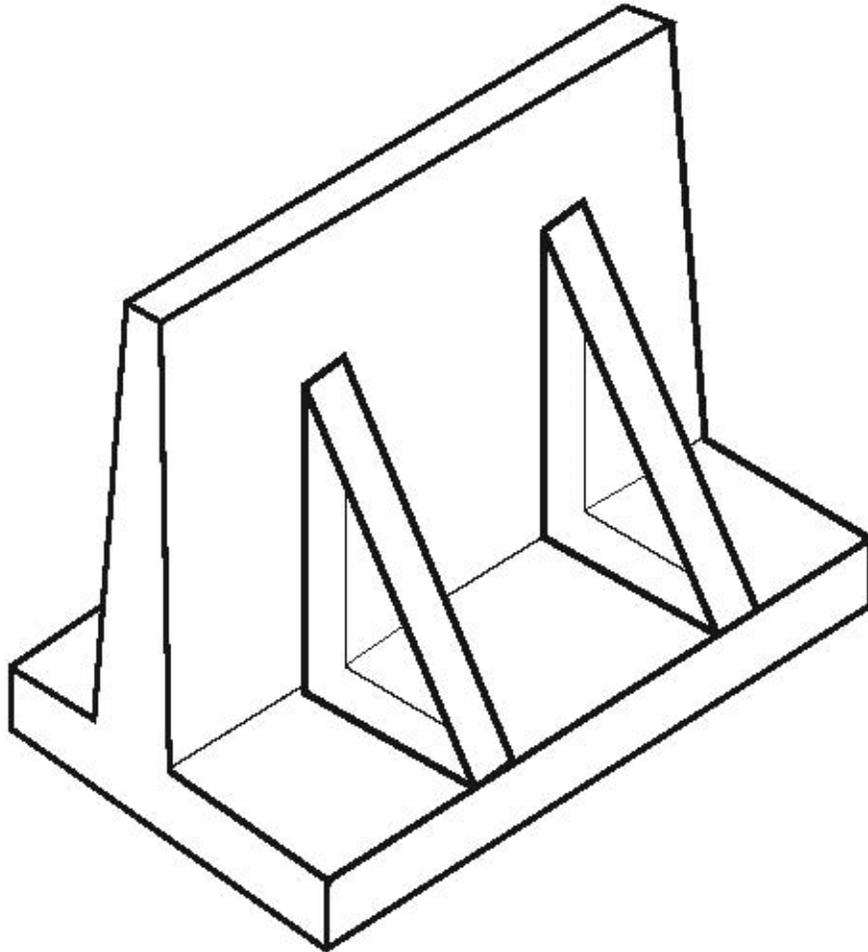
Construction types of gravity retaining walls

Gravity walls depend on the weight of their mass (stone, concrete or other heavy material) to resist pressures from behind and will often have a slight 'batter' setback, to improve stability by leaning back into the retained soil. For short landscaping walls, they are often made from mortarless stone or segmental concrete units (masonry units). Dry-stacked gravity walls are somewhat flexible and do not require a rigid footing in frost areas. Home owners who build larger gravity walls that do require a rigid concrete footing can make use of the services of a professional excavator, which will make digging a trench for the base of the gravity wall much easier.

Earlier in the 20th century, taller retaining walls were often gravity walls made from large masses of concrete or stone. Today, taller retaining walls are increasingly built as composite gravity walls such as: geosynthetic or with precast facing; gabions (stacked steel wire baskets filled with rocks); crib walls (cells built up log cabin style from precast concrete or timber and filled with soil); or soil-nailed walls (soil reinforced in place with steel and concrete rods).

Cantilevered

Counterfort or Buttress Retaining Wall



Counterfort/Buttress on Cantilevered Wall

Cantilevered retaining walls are made from an internal stem of steel-reinforced, cast-in-place concrete or mortared masonry (often in the shape of an inverted T). These walls cantilever loads (like a beam) to a large, structural footing, converting horizontal pressures from behind the wall to vertical pressures on the ground below. Sometimes cantilevered walls are buttressed on the front, or include a counterfort on the back, to improve their strength resisting high loads. Buttresses are short wing walls at right angles to the main trend of the wall. These walls require rigid concrete footings below seasonal frost depth. This type of wall uses much less material than a traditional gravity wall.

Sheet piling



Sheet pile wall

Sheet pile retaining walls are usually used in soft soils and tight spaces. Sheet pile walls are made out of steel, vinyl or wood planks which are driven into the ground. For a quick estimate the material is usually driven 1/3 above ground, 2/3 below ground, but this may be altered depending on the environment. Taller sheet pile walls will need a tie-back anchor, or "dead-man" placed in the soil a distance behind the face of the wall, that is tied to the wall, usually by a cable or a rod. Anchors are placed behind the potential failure plane in the soil.

Anchored

An anchored retaining wall can be constructed in any of the aforementioned styles but also includes additional strength using cables or other stays anchored in the rock or soil behind it. Usually driven into the material with boring, anchors are then expanded at the end of the cable, either by mechanical means or often by injecting pressurized concrete, which expands to form a bulb in the soil. Technically complex, this method is very useful where high loads are expected, or where the wall itself has to be slender and would otherwise be too weak.

Alternative Retaining Techniques

Soil nailing

Soil nailing is a technique in which soil slopes, excavations or retaining walls are reinforced by the insertion of relatively slender elements - normally steel reinforcing bars. The bars are usually installed into a pre-drilled hole and then grouted into place or drilled and grouted simultaneously. They are usually installed untensioned at a slight downward inclination. A rigid or flexible facing (often sprayed concrete) or isolated soil nail heads may be used at the surface.

Soil-strengthened

A number of systems exist that do not simply consist of the wall itself, but reduce the earth pressure acting on the wall itself. These are usually used in combination with one of the other wall types, though some may only use it as facing (i.e. for visual purposes).

Gabion meshes

This type of soil strengthening, often also used without an outside wall, consists of wire mesh 'boxes' into which roughly cut stone or other material is filled. The mesh cages reduce some internal movement/forces, and also reduce erosive forces.

Mechanical stabilization

Mechanically stabilized earth, also called MSE, is soil constructed with artificial reinforcing via layered horizontal mats (geosynthetics) fixed at their ends. These mats provide added internal shear resistance beyond that of simple gravity wall structures. Other options include steel straps, also layered. This type of soil strengthening usually needs outer facing walls (S.R.W.'s - Segmental Retaining Walls) to affix the layers to and vice versa.

The wall face is often of precast concrete units that can tolerate some differential movement. The reinforced soil's mass, along with the facing, then acts as an improved gravity wall. The reinforced mass must be built large enough to retain the pressures from the soil behind it. Gravity walls usually must be a minimum of 50 to 60 percent as deep or thick as the height of the wall, and may have to be larger if there is a slope or surcharge on the wall.

Chapter 2

Tunnel



Underground tunnel for heatpipes between Rigshospitalet and Amagerværket in Denmark.



Underground railway tunnel on the Taipei Metro in Taiwan.

A **tunnel** is an underground passageway, completely enclosed except for openings for egress, commonly at each end.

A tunnel may be for foot or vehicular road traffic, for rail traffic, or for a canal. Some tunnels are aqueducts to supply water for consumption or for hydroelectric stations or are sewers. Other uses include routing power or telecommunication cables, some are to permit wildlife such as European badgers to cross highways. Secret tunnels have given entrance to or escape from an area, such as the Cu Chi Tunnels or the smuggling tunnels in the Gaza Strip which connect it to Egypt. Some tunnels are not for transport at all but rather, are fortifications, for example Mittelwerk and Cheyenne Mountain.

In the United Kingdom, a pedestrian tunnel or other underpass beneath a road is called a underpass subway. In the United States that term now means an underground rapid transit system.

The central part of a rapid transit network is usually built in tunnels. Rail station platforms may be connected by pedestrian tunnels or by foot bridges.

Usage limitations

A tunnel is relatively long and narrow; in general the length is more (usually much more) than twice the diameter. Some hold a tunnel to be at least 0.160 kilometres (0.10 mi) long and call shorter passageways by such terms as an "underpass" or a "chute". For example, the underpass beneath Yahata Station in Kitakyushu, Japan is 0.130 km long (0.081 mi) and so might not be considered a tunnel.

Geotechnical investigation

A tunnel project must start with a comprehensive investigation of ground conditions by collecting samples from boreholes and by other geophysical techniques. An informed choice can then be made of machinery and methods for excavation and ground support, which will reduce the risk of encountering unforeseen ground conditions. In planning the route the horizontal and vertical alignments will make use of the best ground and water conditions.

In some cases conventional desk and site studies yield insufficient information to assess such factors as the blocky nature of rocks, the exact location of fault zones, or the stand-up times of softer ground. This may be a particular concern in large diameter tunnels. To give more information a pilot tunnel, or drift, may be driven ahead of the main drive. This smaller diameter tunnel will be easier to support should unexpected conditions be met, and will be incorporated in the final tunnel. Alternatively, horizontal boreholes may sometimes be drilled ahead of the advancing tunnel face.

Construction



Cut-and-cover constructions of the Paris Métro in France

Tunnels are dug in types of materials varying from soft clay to hard rock. The method of tunnel construction depends on such factors as the ground conditions, the ground water conditions, the length and diameter of the tunnel drive, the depth of the tunnel, the logistics of supporting the tunnel excavation, the final use and shape of the tunnel and appropriate risk management.

There are three basic types of tunnel construction in common use:

- Cut and cover tunnels, constructed in a shallow trench and then covered over.
- Bored tunnels, constructed in situ, without removing the ground above. They are usually of circular or horseshoe cross-section.
- Immersed tube tunnels, sunk into a body of water and sit on, or are buried just under, its bed.

Cut-and-cover

Cut-and-cover is a simple method of construction for shallow tunnels where a trench is excavated and roofed over with an overhead support system strong enough to carry the

load of what is to be built above the tunnel. Two basic forms of cut-and-cover tunnelling are available:

- *Bottom-up method:* A trench is excavated, with ground support as necessary, and the tunnel is constructed in it. The tunnel may be of in situ concrete, precast concrete, precast arches, or corrugated steel arches; in early days brickwork was used. The trench is then carefully back-filled and the surface is reinstated.
- *Top-down method:* Here side support walls and capping beams are constructed from ground level by such methods as slurry walling, or contiguous bored piling. Then a shallow excavation allows making the tunnel roof of precast beams or in situ concrete. The surface is then reinstated except for access openings. This allows early reinstatement of roadways, services and other surface features. Excavation then takes place under the permanent tunnel roof, and the base slab is constructed.

Shallow tunnels are often of the cut-and-cover type (if under water, of the immersed-tube type), while deep tunnels are excavated, often using a tunnelling shield. For intermediate levels, both methods are possible.

Large cut-and-cover boxes are often used for underground metro stations, such as Canary Wharf tube station in London. This construction form generally has two levels, which allows economical arrangements for ticket hall, station platforms, passenger access and emergency egress, ventilation and smoke control, staff rooms, and equipment rooms. The interior of Canary Wharf station has been likened to an underground cathedral, owing to the sheer size of the excavation. This contrasts with most traditional stations on London Underground, where bored tunnels were used for stations and passenger access.

Clay-kicking

Clay-kicking is a specialised method developed in the United Kingdom, of manually digging tunnels in strong clay-based soil structures. Unlike previous manual methods of using mattocks which relied on the soil structure to be hard, clay-kicking was relatively silent and hence did not harm soft clay based structures.

The clay-kicker lies on a plank at a 45degree angle away from the working face, and inserts a tool with a cup-like rounded end with his feet. Turning the tool with his hands, he extracts a section of soil, which is then placed on the waste extract.

Regularly used in Victorian civil engineering, the methods found favour in the renewal of the United Kingdom's then ancient sewerage systems, by not having to remove all property or infrastructure to create an effective small tunnel system. During the First World War, the system was successfully deployed by the Royal Engineer tunnelling companies to deploy large military mines beneath enemy German Empire lines. The method was virtually silent not susceptible to listening methods of detection.

Boring machines



A tunnel boring machine that was used at Yucca Mountain, Nevada, United States

Tunnel boring machines (TBMs) and associated back-up systems are used to highly automate the entire tunneling process, reducing tunneling costs.

Tunnel boring in certain predominantly urban applications, is viewed as quick and cost effective alternative to laying surface rails and roads. Expensive compulsory purchase of buildings and land with potentially lengthy planning inquiries is eliminated.

There are a variety of TBMs that can operate in a variety of conditions, from hard rock to soft water-bearing ground. Some types of TBMs, bentonite slurry and earth-pressure balance machines, have pressurised compartments at the front end, allowing them to be used in difficult conditions below the water table. This pressurizes the ground ahead of the TBM cutter head to balance the water pressure. The operators work in normal air pressure behind the pressurised compartment, but may occasionally have to enter that compartment to renew or repair the cutters. This requires special precautions, such as local ground treatment or halting the TBM at a position free from water. Despite these difficulties, TBMs are now preferred to the older method of tunneling in compressed air, with an air lock/decompression chamber some way back from the TBM, which required operators to work in high pressure and go through decompression procedures at the end of their shifts, much like divers.

In February 2010, Aker Wirth delivered a TBM to Switzerland, for the expansion of Linth Limmern Power Plant in Switzerland. The borehole has a diameter of 8.03 metres (26.3 ft). The TBM used for digging the 57-kilometre (35 mi) Gotthard Base Tunnel, in Switzerland, has a diameter of about 9 metres (30 ft). A larger TBM was built to bore the Green Heart Tunnel (Dutch: Tunnel Groene Hart) as part of the HSL-Zuid in the Netherlands, with a diameter of 14.87 metres (48.8 ft). This in turn was superseded by the Madrid M30 ringroad, Spain, and the Chong Ming tunnels in Shanghai, China. All of these machines were built at least partly by Herrenknecht.

Shafts

A shaft is sometimes necessary for a tunnel project. They are usually circular and go straight down until they reach the level at which the tunnel is going to be built. A shaft normally has concrete walls and is built just like it is going to be permanent. Once they are built the Tunnel Boring Machines are lowered to the bottom and excavation can start. Shafts are the main entrance in and out of the tunnel until the project is completed. Sometimes if a tunnel is going to be long there will be multiple shafts at various locations so that entrance into the tunnel is closer to the unexcavated area.

Other key factors

- Stand-up time is the amount of time a tunnel will support itself without any added structures. Knowing this time allows the engineers to determine how much can be excavated before support is needed. The longer the stand-up time is the faster the excavating will go. Generally certain configurations of rock and clay will have the greatest stand-up time, and sand and fine soils will have a much lower stand-up time.
- Groundwater control is very important in tunnel construction. If there is water leaking into the tunnel stand-up time will be greatly decreased. If there is water leaking into the shaft it will become unstable and will not be safe to work in. To stop this from happening there are a few common methods. One of the most effective is ground freezing. To do this pipes are inserted into the ground surrounding the shaft and are cooled until they freeze. This freezes the ground around each pipe until the whole shaft is surrounded frozen soil, keeping water out. The most common method is to install pipes into the ground and to simply pump the water out. This works for tunnels and shafts.
- Tunnel shape is very important in determining stand-up time. The force from gravity is straight down on a tunnel, so if the tunnel is wider than it is high it will have a harder time supporting itself decreasing its stand-up time. If a tunnel is higher than it is wide the stand up time will increase making the project easier. The hardest shape to support itself is a square or rectangular tunnel. The forces have a harder time being redirected around the tunnel making it extremely hard to support itself. This of course all depends what the material of the ground is.

Sprayed concrete techniques

The **New Austrian Tunneling Method** (NATM) was developed in the 1960s, and is the best known of a number of engineering solutions that use calculated and empirical real-time measurements to provide optimised safe support to the tunnel lining. The main idea of this method is to use the geological stress of the surrounding rock mass to stabilize the tunnel itself, by allowing a measured relaxation and stress reassignment into the surrounding rock to prevent full loads becoming imposed on the introduced support measures. Based on geotechnical measurements, an optimal cross section is computed. The excavation is immediately protected by a layer of sprayed concrete, commonly referred to as shotcrete, after excavation. Other support measures could include steel arches, rockbolts and mesh. Technological developments in sprayed concrete technology have resulted in steel and polypropylene fibres being added to the concrete mix to improve lining strength. This creates a natural load-bearing ring, which minimizes the rock's deformation.



Illowra Battery utility tunnel, Port Kembla. One of many bunkers south of Sydney.

By special monitoring the NATM method is very flexible, even at surprising changes of the geomechanical rock consistency during the tunneling work. The measured rock properties lead to appropriate tools for tunnel strengthening. In the last decades also soft ground excavations up to 10 kilometres (6.2 mi) became usual.

Pipe jacking

Pipe Jacking, also known as **pipejacking** or **pipe-jacking**, is a method of tunnel construction where hydraulic jacks are used to push specially made pipes through the ground behind a tunnel boring machine or shield. This technique is commonly used to

create tunnels under existing structures, such as roads or railways. Tunnels constructed by pipe jacking are normally small diameter tunnels with a maximum size of around 2.4m.

Box jacking

Box jacking is similar to pipe jacking, but instead of jacking tubes, a box shaped tunnel is used. Jacked boxes can be a much larger span than a pipe jack with the span of some box jacks in excess of 20m. A cutting head is normally used at the front of the box being jacked and excavation is normally by excavator from within the box.

Underwater tunnels

There are also several approaches to underwater tunnels, the two most common being bored tunnels or immersed tubes. Submerged floating tunnels are another approach that has not been constructed.

Other

Other tunneling methods include:

- Drilling and blasting
- Slurry-shield machine
- Wall-cover construction method.

Costs and cost overruns of tunnels

Tunnels are costly and generally more costly than bridges. Large cost overruns are common in tunnel construction. Costs and cost overruns are documented in and

Choice of tunnels vs. bridges

For water crossings, a tunnel is generally more costly to construct than a bridge. Navigational considerations may limit the use of high bridges or drawbridge spans intersecting with shipping channels, necessitating a tunnel.

Bridges usually require a larger footprint on each shore than tunnels. There are actually more codes to follow with bridges than with tunnels. In areas with expensive real estate, such as Manhattan and urban Hong Kong, this is a strong factor in tunnels' favor. Boston's Big Dig project replaced elevated roadways with a tunnel system to increase traffic capacity, hide traffic, reclaim land, redecorate, and reunite the city with the waterfront.

The 1934 Queensway Road Tunnel under the River Mersey at Liverpool, was chosen over a massively high bridge for defence reasons. It was feared aircraft could destroy a bridge in times of war. Maintenance costs of a massive bridge to allow the world's largest

ships navigate under was considered higher than a tunnel. Similar conclusions were met for the 1971 Kingsway Tunnel under the River Mersey.



The Queens–Midtown Tunnel in New York City serves as an example of a water-crossing tunnel built instead of a bridge.

Examples of water-crossing tunnels built instead of bridges include the Holland Tunnel, Queens-Midtown Tunnel and Lincoln Tunnel between New Jersey and Manhattan in New York City, and the Elizabeth River tunnels between Norfolk and Portsmouth, Virginia, the 1934 River Mersey road Queensway Tunnel and the Western Scheldt Tunnel, Zeeland, Netherlands.

Other reasons for choosing a tunnel instead of a bridge include avoiding difficulties with tides, weather and shipping during construction (as in the 51.5-kilometre or 32.0 mi Channel Tunnel), aesthetic reasons (preserving the above-ground view, landscape, and scenery), and also for weight capacity reasons (it may be more feasible to build a tunnel than a sufficiently strong bridge).

Some water crossings are a mixture of bridges and tunnels, such as the Denmark to Sweden link and the Chesapeake Bay Bridge-Tunnel in the eastern United States.

There are particular hazards with tunnels, especially from vehicle fires when combustion gases can asphyxiate users, as happened at the Gotthard Road Tunnel in Switzerland in

2001. One of the worst railway disasters ever, the Balvano train disaster, was caused by a train stalling in the Armi tunnel in Italy in 1944, killing 426 passengers.

Variant tunnel types

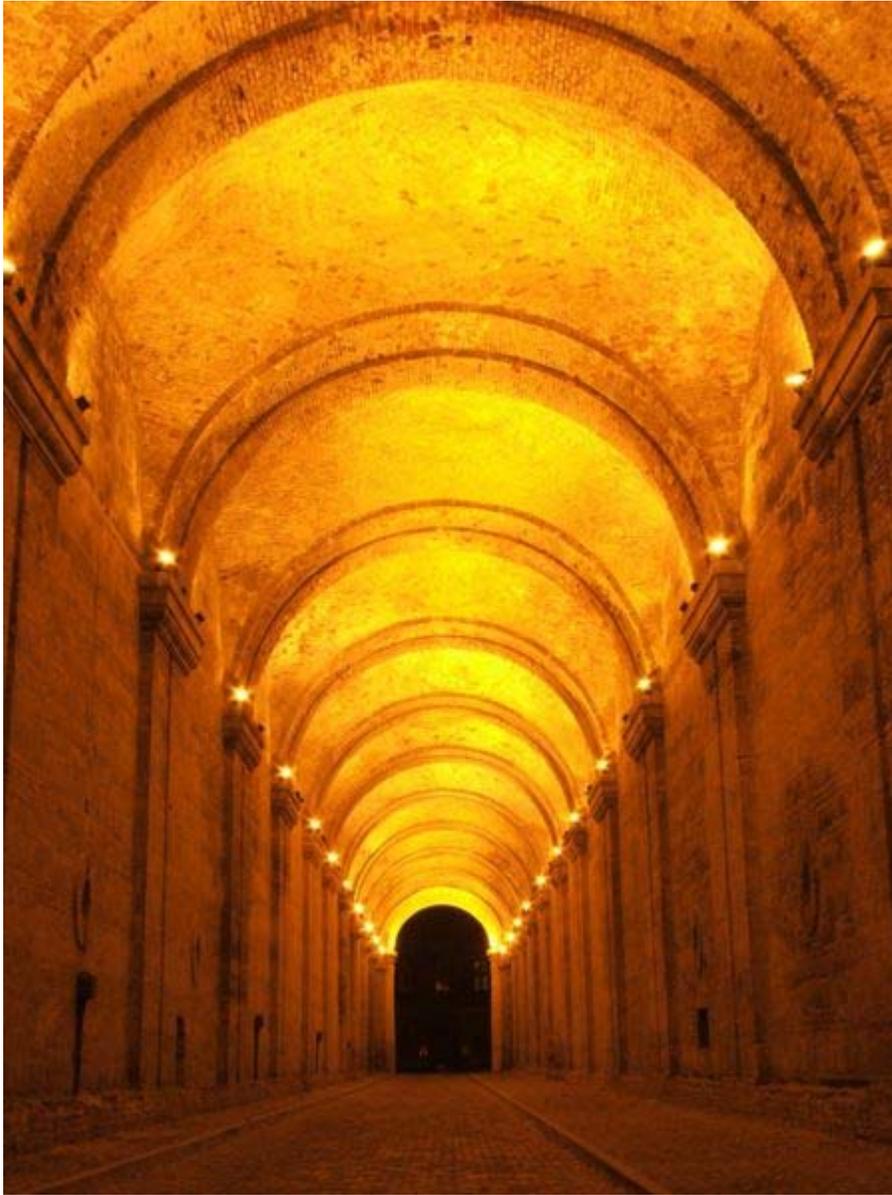
Double-deck tunnel

Some tunnels are double-deck, for example the two major segments of the San Francisco – Oakland Bay Bridge (completed in 1936) are linked by a double-deck tunnel, once the largest diameter tunnel in the world. At construction this was a combination bidirectional rail and truck pathway on the lower deck with automobiles above, now converted to one-way road vehicle traffic on each deck.

A recent double-decker tunnel with both decks for motor vehicles is the Fuxing Road Tunnel in Shanghai, China. Cars travel on the two-lane upper deck and heavier vehicles on the single-lane lower.

Multipurpose tunnels are tunnels that have more than one purpose. The SMART Tunnel in Malaysia is the first multipurpose tunnel in the world, as it is used both to control traffic and flood in Kuala Lumpur.

Artificial tunnels



The 19th century Dark Gate in Esztergom, Hungary.

Overbridges can sometimes be built by covering a road or river or railway with brick or still arches, and then levelling the surface with earth. In railway parlance, a surface-level track which has been built or covered over is normally called a covered way.

Snow sheds are a kind of artificial tunnel built to protect a railway from avalanches of snow. Similarly the Stanwell Park, New South Wales **steel tunnel**, on the South Coast railway line, protects the line from rockfalls.

Common utility ducts are man-made tunnels created to carry two or more utility lines underground. Through co-location of different utilities in one tunnel, organizations are able to reduce the costs of building and maintaining utilities.

Hazards

Owing to the enclosed space of a tunnel, fires can have very serious effects on users. The main dangers are gas and smoke production, with low concentrations of carbon monoxide being highly toxic. Fires killed 11 people in the Gotthard tunnel fire of 2001 for example, all of the victims succumbing to smoke and gas inhalation. Over 400 passengers died in the Balvano train disaster in Italy in 1944, when the locomotive halted in a long tunnel. Carbon monoxide poisoning was the main cause of the horrifying death rate.

Examples of tunnels

In history



A short section remains of the 1836 Edge Hill to Lime Street tunnel in Liverpool. This is the oldest used rail tunnel in the world. A tilting train passes through the tunnel.



Lehigh Tunnel, Pennsylvania

- The World's oldest underwater tunnel is rumored to be the *Terelek kaya tüneli* under Kızıl River, a little south of the towns of Boyabat and Duragan in Turkey. Estimated to have been built more than 2000 years ago (possibly 5000), it is assumed to have had a defence purpose.
- The qanat or karez of Persia is a water management system used to provide a reliable supply of water to human settlements or for irrigation in hot, arid and semi-arid climates. The oldest and largest known qanat is in the Iranian city of Gonabad, which after 2700 years, still provides drinking and agricultural water to nearly 40,000 people. Its main well depth is more than 360 m (1,180 ft), and its length is 45 km (28 mi).
- The Eupalinian aqueduct on the island of Samos (North Aegean, Greece). Built in 520 BC by the ancient Greek engineer Eupalinos of Megara. Eupalinos organised the work so that the tunnel was begun from both sides of mount Kastro. The two teams advanced simultaneously and met in the middle with excellent accuracy, something that was extremely difficult in that time. The aqueduct was of utmost defensive importance, since it ran underground, and it was not easily found by an enemy who could otherwise cut off the water supply to Pythagoreion, the ancient capital of Samos. The tunnel's existence was recorded by Herodotus (as was the mole and harbour, and the third wonder of the island, the great temple to Hera, thought by many to be the largest in the Greek world). The precise location of the

tunnel was only re-established in the 19th century by German archaeologists. The tunnel proper is 1,030 m long (3,380 ft) and visitors can still enter it Eupalinos tunnel.

- The Via Flaminia, an important Roman road, penetrated the Furlo pass in the Apennines through a tunnel which emperor Vespasian had ordered built in 76-77. A modern road, the SS 3 Flaminia, still uses this tunnel, which had a precursor dating back to the 3rd century BC; remnants of this earlier tunnel (one of the first road tunnels) are also still visible.
- Sapperton Canal Tunnel on the Thames and Severn Canal in England, dug through hills, which opened in 1789, was 3.5 km (2.2 mi) long and allowed boat transport of coal and other goods. Above it runs the Sapperton Long Tunnel which carries the "Golden Valley" railway line between Swindon and Gloucester.
- The 1796 Stoddart Tunnel in Chapel-en-le-Frith in Derbyshire is reputed to be the oldest rail tunnel in the world. Rail wagons were horse-drawn.
- The tunnel was created for the first true steam locomotive, from Penydarren to Abercynon. The Penydarren locomotive was built by Richard Trevithick. The locomotive made the historic journey from Penydarren to Abercynon in 1804. Part of this tunnel can still be seen at Pentrebach, Merthyr Tydfil, Wales. This is arguably the oldest railway tunnel in the world, for self-propelled steam engines on rails.
- The Montgomery Bell Tunnel in Tennessee, a 88 m (289 ft), high water diversion tunnel, 4.50-x-2.45 m high (15-x-8.0 ft), to power a water wheel, was built by slave labour in 1819, being the first full-scale tunnel in North America.
- Crown Street Station, Liverpool, 1829. Built by George Stephenson, a single track tunnel 291 yd long (266 m) was bored from Edge Hill to Crown Street to serve the world's first passenger railway station. The station was abandoned in 1836 being too far from Liverpool city centre, with the area converted for freight use. Closed down in 1972, the tunnel is disused. However it is the oldest rail tunnel running under streets in the world.
- The 1.26 mile (2.03 km) 1829 Wapping Tunnel in Liverpool, England, was the first rail tunnel bored under a metropolis. Currently disused since 1972. Having two tracks, the tunnel runs from Edge Hill in the east of the city to the south end Liverpool docks being used only for freight. The tunnel is still in excellent condition and is being considered for reuse by Merseyrail rapid transit rail system, with maybe an underground station cut into the tunnel. The river portal is opposite the new Liverpool Arena being ideal for a serving station. If reused it will be the oldest used underground rail tunnel in the world and oldest part of any underground metro system.
- 1836, Lime St Station tunnel, Liverpool. A two track rail tunnel, 1.13 miles (1,811 m) long was bored under a metropolis from Edge Hill in the east of the city to Lime Street. In the 1880s the tunnel was converted to a deep cutting four tracks wide. The only occurrence of a tunnel being removed. A very short section of the original tunnel still exists at Edge Hill station making this the oldest rail tunnel in the world still in use, and the oldest in use under a street, albeit only one street and one building.

- Box Tunnel in England, which opened in 1841, was the longest railway tunnel in the world at the time of construction. It was dug and has a length of 2.9 km (1.8 mi).
- The 0.75 mile long 1842 Prince of Wales Tunnel, in Shildon near Darlington, England, is the oldest sizable tunnel in the world still in use under a settlement.
- The Thames Tunnel, built by Marc Isambard Brunel and his son Isambard Kingdom Brunel and opened in 1843, was the first underwater tunnel and the first to use a tunnelling shield. Originally used as a foot-tunnel, it was a part of the East London Line of the London Underground until 2007, being the oldest section of the system. From 2010 the tunnel becomes a part of the London Overground system.
- The 2.07 miles (3.34 km) Victoria Tunnel in Liverpool, opened in 1848, was bored under a metropolis. Initially used only for rail freight and later freight and passengers serving the Liverpool ship liner terminal, the tunnel runs from Edge Hill in the east of the city to the north end Liverpool docks. Used until 1972 it is still in excellent condition, being considered for reuse by the Merseyrail rapid transit rail system. Stations being cut into the tunnel are being considered. Also, reuse by a monorail system from the proposed Liverpool Waters redevelopment of Liverpool's Central Docks has been proposed.
- The oldest underground sections of the London Underground were built using the cut-and-cover method in the 1860s. The Metropolitan, Hammersmith & City, Circle and District lines were the first to prove the success of a metro or subway system. Dating from 1863, Baker Street station is the oldest underground station in the world.
- The 1882 Col de Tende Road Tunnel, at 3182 metres long, was one of the first long road tunnels under a pass, running between France and Italy.
- The Mersey Railway tunnel opened in 1886 running from Liverpool to Birkenhead under the River Mersey. The Mersey Railway was the world's first deep-level underground railway. By 1892 the extensions on land from Birkenhead Park station to Liverpool Central Low level station gave a tunnel 3.12 miles (5029 m) in length. The under river section is 0.75 miles in length, being the longest underwater tunnel in world in January 1886.
- The rail Severn Tunnel was opened in late 1886, at 4 miles 624 yd (7,008 m) long, although only 2¼ miles (3.62 km) of the tunnel is actually under the river. The tunnel replaced the Mersey Railway tunnel's longest under water record, which it held for less than a year.
- James Greathead, in constructing the City & South London Railway tunnel beneath the Thames, opened in 1890, brought together three key elements of tunnel construction under water: 1) shield method of excavation; 2) permanent cast iron tunnel lining; 3) construction in a compressed air environment to inhibit water flowing through soft ground material into the tunnel heading.
- St. Clair Tunnel, also opened later in 1890, linked the elements of the Greathead tunnels on a larger scale.
- The 1927 Holland Tunnel was the first underwater tunnel designed for automobiles. This fact required a novel ventilation system.

Longest

- The Delaware Aqueduct in New York USA is the longest tunnel, of any type, in the world at 137 km (85 mi). It is drilled through solid rock.
- The Gotthard Base Tunnel is the longest rail tunnel in the world at 57 km (35 mi). It will be totally completed in 2017.
- The Seikan Tunnel in Japan was the longest rail tunnel in the world at 53.9 km (33.5 mi), of which 23.3 km (14.5 mi) is under the sea.
- The Channel Tunnel between France and the United Kingdom under the English Channel is the second-longest, with a total length of 50 km (31 mi), of which 39 km (24 mi) is under the sea.
- The Lötschberg Base Tunnel opened in June 2007 in Switzerland was the longest land rail tunnel, with a total of 34.5 km (21.4 mi).
- The Lærdal Tunnel in Norway from Lærdal to Aurland is the world's longest road tunnel, intended for cars and similar vehicles, at 24.5 km (15.2 mi).
- The Zhongnanshan Tunnel in People's Republic of China opened in January 2007 is the world's second longest highway tunnel and the longest road tunnel in Asia, at 18 km (11 mi).
- The longest canal tunnel is the Rove Tunnel in France, over 7.12 km (4.42 mi) long.

Notable

- The Lincoln Tunnel between New Jersey and New York is one of the busiest vehicular tunnels in the United States, at 120,000 vehicles/day.
- The Central Artery Tunnel in Boston carries approximately 200,000 vehicles/day.
- The Fredhälls Tunnel in Stockholm, Sweden, and the New Elbe Tunnel in Hamburg, Germany, both with around 150,000 vehicles a day, two of the most trafficked tunnels in the world.
- Gerrards Cross tunnel in Britain is notable in that it is being built over a railway cutting that was dug in the early part of the 20th Century. Thus, arguably, making it the tunnel longest in construction by the cut and cover method. When complete a branch of the Tesco supermarket chain will occupy the space above the railway tunnel.
- Williamson's tunnels in Liverpool, built by a wealthy eccentric are probably the largest underground folly in the world.
- New York City Water Tunnel No. 3, started in 1970, has an expected completion date of 2020.
- The Chicago Deep Tunnel Project is a network of 175 km (109 mi) of tunnels designed to reduce flooding in the Chicago area. Started in the mid 1970s, the project is due to be completed in 2019.
- Moffat Tunnel in Colorado straddles the Continental Divide. The tunnel is 6.2 mi (10.0 km) long and at 9,239 ft (2,816 m) above sea level is the highest railroad tunnel in the United States.
- The Fenghuoshan tunnel on Qinghai-Tibet railway is the world's highest railway tunnel, about 4,905 m (16,093 ft) above sea level.

- The La Linea Tunnel in Colombia, will be (2013) the longest, 8.58 km (5.33 mi), mountain tunnel in South America. It crosses beneath a mountain at 2,500 m (8,202.1 ft) above sea level with six lanes and it has a parallel emergency tunnel. The tunnel is subject to serious groundwater pressure. The tunnel, which is currently under construction, will link Bogotá and its urban area with the coffee-growing region and with the main port on the Colombian Pacific coast.
- The Honningsvåg Tunnel (4.443 km (2.76 mi) long) on European route E69 in Norway is the world's northernmost road tunnel, except for mines (which exist on Svalbard).
- The Eiksund Tunnel on national road Rv 653 in Norway is the world's deepest subsea road tunnel (7,776 m long, with deepest point at -287 metres below the sea level, opened in feb. 2008)

Other uses

Excavation techniques, as well as the construction of underground bunkers and other habitable areas, are often associated with military use during armed conflict, or civilian responses to threat of attack. The use of tunnels for mining is called drift mining. One of the strangest uses of a tunnel was for the storage of chemical weapons .

Natural tunnels

- Lava tubes are partially empty, cave-like conduits underground, formed during volcanic eruptions by flowing and cooling lava.
- Natural Tunnel State Park (Virginia, USA) features an 850-foot (259 m) natural tunnel, really a limestone cave, that has been used as a railroad tunnel since 1890.
- Punarjani Guha Kerala, India. Hindus believe that crawling through the tunnel (which they believe was created by a Hindu god) from one end to the other will wash away all of one's sins and thus attain rebirth, although only men are permitted to crawl through the cave.
- Small "snow tunnels" are created by voles, chipmunks and other rodents for protection and access to food sources.

Temporary way

During construction of a tunnel it is often convenient to install a temporary railway particularly to remove spoil. This temporary railway is often narrow gauge so that it can be double track, which facilitates the operation of empty and loaded trains at the same time. The temporary way is replaced by the permanent way at completion, thus explaining the term Perway.

Enlargement

The vehicles using a tunnel can outgrow it, requiring replacement or enlargement. The original single line Gib Tunnel near Mittagong was replaced with a double line tunnel, with the original tunnel used for growing mushrooms. The Rhyndaston Tunnel was

enlarged using a borrowed Tunnel Boring Machine so as to be able to take ISO containers.

The 1836 Lime Street two track 1 mile tunnel from Edge Hill to Lime Street in Liverpool was totally removed, apart from a short 50 metre section at Edge Hill. Four tracks were required. The tunnel was converted into a very deep 4 track open cutting. However, short larger 4 track tunnels were left in some parts of the run. Train services were not interrupted as the work progressed. Photos of the work in progress: There are other occurrences of tunnels being replaced by open cuts, for example, the Auburn Tunnel.

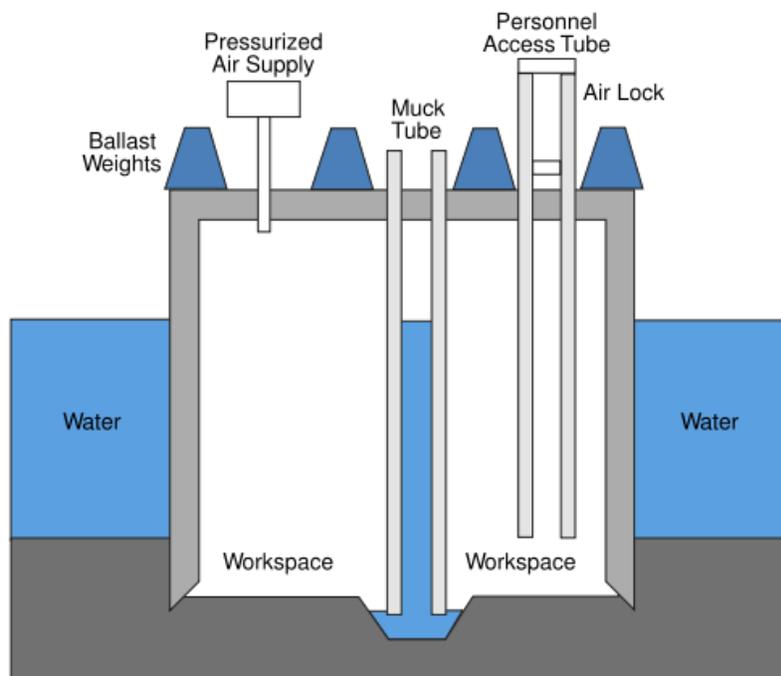
Accidents

- Balvano train disaster
- Gotthard Road Tunnel
- 1996 Channel Tunnel fire
- Bujanov Tunnel
- Harmanec Tunnel

Chapter 3

Caisson (Engineering)

In geotechnical engineering, a **caisson** is a retaining, watertight structure used, for example, to work on the foundations of a bridge pier, for the construction of a concrete dam, or for the repair of ships. These are constructed such that the water can be pumped out, keeping the working environment dry. When piers are to be built using an open caisson and it is not practical to reach suitable soil, friction pilings may be driven to form a suitable sub-foundation. These piles are connected by a foundation pad upon which the column pier is erected.



Schematic cross section of a pressurized caisson

Shallow caissons may be open to the air, whereas **pneumatic caissons**, which penetrate soft mud, are sealed at the top and filled with compressed air to keep water and mud out

at depth. An airlock allows access to the chamber. Workers move mud and rock debris (called *muck*) from the edge of the workspace to a water-filled pit, connected by a tube (called the *muck tube*) to the surface. A crane at the surface removes the soil with a clamshell bucket. The water pressure in the tube balances the air pressure, with excess air escaping up the muck tube. The pressurized air flow must be constant to ensure regular air changes for the workers and prevent excessive inflow of mud or water at the base of the caisson.

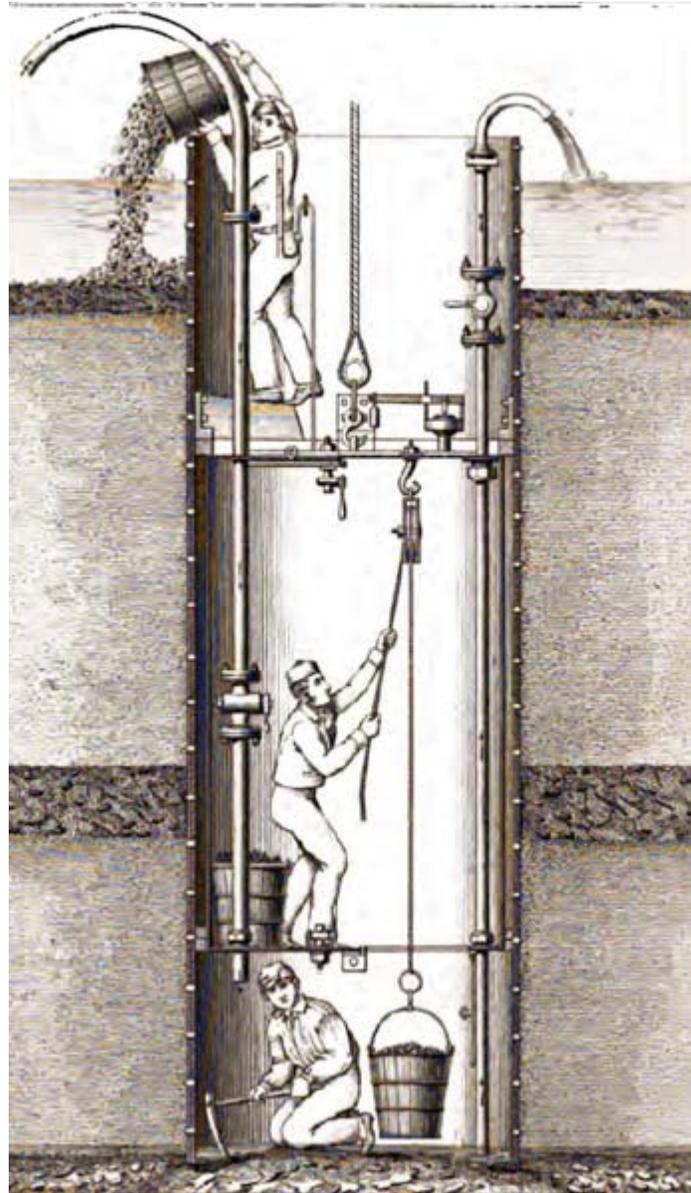
The caisson will be brought down through soft mud until a suitable foundation material is encountered. While bedrock is preferred, a stable, hard mud is sometimes used when bedrock is too deep.

Caisson disease is so named since it appeared in construction workers when they left the compressed atmosphere of the caisson and rapidly reentered normal (decompressed) atmospheric conditions. It is caused by the same processes as decompression sickness in divers. Construction of the Brooklyn Bridge, which was built with the help of caissons, resulted in numerous workers being either killed or permanently injured by caisson disease during its construction, including the designer's son and Chief Engineer of the project, Washington Roebling.

Caissons have also been used in the installation of hydraulic elevators where a single-stage ram is installed below the ground level.

Caissons, codenamed *Phoenix*, were an integral part of the Mulberry harbours used during the World War II Allied invasion of Normandy.

Types



A diagram of an open caisson, dated 1846

The four main types of caisson are *box caisson*, *open caisson*, *compressed-air caisson* and *monolith caisson*.

Box

Box caissons are prefabricated concrete boxes with sides and bottom and are set down on prepared bases. Once in place they will be filled with concrete to become part of the permanent works, for example the foundation for a bridge pier. One problem with box caissons is that hollow concrete structures float and so they must be ballasted or anchored

to prevent this until they can be filled with concrete. Adjustable anchoring systems combined with a GPS survey allow engineers to position a box caisson with pinpoint accuracy. Elaborate anchoring systems may be required in tidal zones.

Open

Open caissons are similar to box caissons except that they do not have a bottom face. They are suitable for use in soft clays (e.g. in some river-beds) but not for where there may be large obstructions in the ground. Open caissons used in soft grounds or high water tables, where open trench excavations are impractical, can also be used to install deep manholes, pump stations and reception/launch pits for micro tunnelling, pipe jacking and other operations. The open caissons may fill with water during sinking. The material is excavated by clamshell excavator bucket on crane. The caissons are sunk by self-weight, concrete or water ballast placed on top, or by hydraulic jacks. The leading edge of the caisson or "cutting shoe" is sloped out at a sharp angle (usually made of steel) to aid sinking in a vertical manner. The shoe is generally wider than the caisson to reduce friction and the leading edge may be supplied with pressurised bentonite slurry (it swells in water to stabilise settlement or fill depressions/voids). The formation level subsoil may still not be suitable for excavation or bearing capacity. The water in the caisson (due to high water table) balances the upthrust forces of the soft soils underneath. If dewatered, the base may "pipe" or "boil" and the caisson sink. To combat this problem piles may be driven from the surface. H-beam sections (typical column sections, due to resistance to bending in all axes) may be driven at angles "raked" to rock or other firmer soils. The H-beams are left extended above the base. A reinforced concrete plug is poured under the water known as a "tremie pour". This will act as a pile cap and resist the upward forces of subsoil once dewatered. The piles will act as bearing (transmitting load to deeper soils or friction along their surface length) and anchorage (resist floatation in the same manner).

Compressed-air

Compressed-air caissons have the advantage of providing dry working conditions which are better for placing concrete. They are also well suited for foundations for which other methods might cause settlement of adjacent structures.

Monolithic

Monoliths are, as their name suggests, larger than the other types but are similar to open caissons. They are often found in quay walls where resistance to impact from ships is required.

Boat lift caissons

The word *caisson* is also used as a synonym for the water-filled trough part of caisson locks, canal lifts and inclines in which boats and ships rest whilst being lifted from one canal elevation to another. This is the opposite of the caissons mentioned earlier; the water is retained on the inside of the caisson, not excluded from the caisson.

Ventilation filtration systems

The word *caisson* is also used as a name for an airtight housing for ventilation filters in facilities that handle hazardous materials. The housing usually has an upstream compartment for a pre-filter element and a downstream compartment for a high-efficiency filter element. It may have multiple sets of compartments. The housing has gasketed access doors to allow for the change out of the filter elements. The housing is usually equipped with connection points used to test the efficiency of the filters and monitor changes in the differential pressure across the filter media.

Chapter 4

Engineering Geology

Engineering Geology is the application of the geologic sciences to engineering practice for the purpose of assuring that the geologic factors affecting the location, design, construction, operation and maintenance of engineering works are recognized and adequately provided for. Engineering geologists investigate and provide geologic and geotechnical recommendations, analysis, and design associated with human development. The realm of the engineering geologist is essentially in the area of earth-structure interactions, or investigation of how the earth or earth processes impact human made structures and human activities.

Engineering geologic studies may be performed during the planning, environmental impact analysis, civil or structural engineering design, value engineering and construction phases of public and private works projects, and during post-construction and forensic phases of projects. Works completed by engineering geologists include; geologic hazards, geotechnical, material properties, landslide and slope stability, erosion, flooding, dewatering, and seismic investigations, etc. Engineering geologic studies are performed by a geologist or engineering geologist that is educated, trained and has obtained experience related to the recognition and interpretation of natural processes, the understanding of how these processes impact man-made structures (and vice versa), and knowledge of methods by which to mitigate for hazards resulting from adverse natural or man-made conditions. The principal objective of the engineering geologist is the protection of life and property against damage caused by geologic conditions.

Engineering geologic practice is also closely related to the practice of geological engineering, geotechnical engineering, soils engineering, environmental geology and economic geology. If there is a difference in the content of the disciplines described, it mainly lies in the training or experience of the practitioner.

History

Although the science of geology has been around since the 18th century, at least in its modern form, the science and practice of engineering geology didn't begin as a recognized discipline until the late 19th and early 20th centuries. The first book entitled

Engineering Geology was published in 1880 by William Penning. In the early 20th century Charles Berkey, an American trained geologist who was considered the first American engineering geologist, worked on a number of water supply projects for New York City, then later worked on the Hoover dam and a multitude of other engineering projects. The first American engineering geology text book was written in 1914 by Ries and Watson. In 1925, Karl Terzaghi, an Austrian trained engineer and geologist, published the first text in Soil Mechanics (in German). Terzaghi is known as the father of soil mechanics, but also had great interest in geology; Terzaghi considered soil mechanics to be a sub-discipline of engineering geology. In 1929, Terzaghi, along with Redlich and Kampe, published their own Engineering Geology text (also in German).

The need for geologist on engineering works gained world wide attention in 1928 with the failure of the St. Francis dam in California and the loss of 426 lives. More engineering failures which occurred the following years also prompted the requirement for engineering geologists to work on large engineering projects.

In 1951, one of the earliest definitions of the "Engineering geologist" or "Professional Engineering Geologist" was provided by the Executive Committee of the Division on Engineering Geology of the Geological Society of America.

The Practice

One of the most important roles of the engineering geologist is the interpretation of landforms and earth processes to identify potential geologic and related man-made hazards that may impact civil structures and human development. Nearly all engineering geologists are initially trained and educated in geology, primarily during their undergraduate education. This background in geology provides the engineering geologist with an understanding of how the earth works, which is crucial in mitigating for earth related hazards. Most engineering geologists also have graduate degrees where they have gained specialized education and training in soil mechanics, rock mechanics, geotechnics, groundwater, hydrology, and civil design. These two aspects of the engineering geologists' education provides them with a unique ability to understand and mitigate for hazards associated with earth-structure interactions.

Scope of Studies

Engineering geologic studies may be performed:

- for residential, commercial and industrial developments;
- for governmental and military installations;
- for public works such as a power plant, wind turbine, transmission line, sewage treatment plant, water treatment plant, pipeline (aqueduct, sewer, outfall), tunnel, trenchless construction, canal, dam, reservoir, building, railroad, transit, highway, bridge, seismic retrofit, airport and park;
- for mine and quarry excavations, mine tailing dam, mine reclamation and mine tunneling;

- for wetland and habitat restoration programs;
- for coastal engineering, sand replenishment, bluff or sea cliff stability, harbor, pier and waterfront development;
- for offshore outfall, drilling platform and sub-sea pipeline, sub-sea cable; and
- for other types of facilities.

Geohazards and adverse geo-conditions

Typical geologic hazards or other adverse conditions evaluated and mitigated by an engineering geologist include:

- fault rupture on seismically active faults ;
- seismic and earthquake hazards (ground shaking, liquefaction, lurching, lateral spreading, tsunami and seiche events);
- landslide, mudflow, rockfall, debris flow, and avalanche hazards ;
- unstable slopes and slope stability;
- erosion;
- slaking and heave of geologic formations;
- ground subsidence (such as due to ground water withdrawal, sinkhole collapse, cave collapse, decomposition of organic soils, and tectonic movement);
- volcanic hazards (volcanic eruptions, hot springs, pyroclastic flows, debris flow, debris avalanche, gas emissions, volcanic earthquakes);
- non-rippable or marginally rippable rock requiring heavy ripping or blasting;
- weak and collapsible soils, foundation bearing failures;
- shallow ground water/seepage; and
- other types of geologic constraints.

An engineering geologist or geophysicist may be called upon to evaluate the excavatability (i.e. rippability) of earth (rock) materials to assess the need for pre-blasting during earthwork construction, as well as associated impacts due to vibration during blasting on projects.

Soil and Rock Mechanics

Soil mechanics is a discipline that applies principles of engineering mechanics, e.g. kinematics, dynamics, fluid mechanics, and mechanics of material, to predict the mechanical behavior of soils. Rock mechanics is the theoretical and applied science of the mechanical behaviour of rock and rock masses; it is that branch of mechanics concerned with the response of rock and rock masses to the force fields of their physical environment. The fundamental processes are all related to the behaviour of porous media. Together, soil and rock mechanics are the basis for solving many engineering geologic problems.

Methods and reporting

The methods used by engineering geologists in their studies include

- geologic field mapping of geologic structures, geologic formations, soil units and hazards;
- the review of geologic literature, geologic maps, geotechnical reports, engineering plans, environmental reports, stereoscopic aerial photographs, remote sensing data, Global Positioning System (GPS) data, topographic maps and satellite imagery;
- the excavation, sampling and logging of earth/rock materials in drilled borings, backhoe test pits and trenches, fault trenching, and bulldozer pits;
- geophysical surveys (such as seismic refraction traverses, resistivity surveys, ground penetrating radar (GPR) surveys, magnetometer surveys, electromagnetic surveys, high-resolution sub-bottom profiling, and other geophysical methods);
- deformation monitoring as the systematic measurement and tracking of the alteration in the shape or dimensions of an object as a result of the application of stress to it manually or with an automatic deformation monitoring system; and
- other methods.

The field work is typically culminated in analysis of the data and the preparation of an engineering geologic report, geotechnical report, fault hazard or seismic hazard report, geophysical report, ground water resource report or hydrogeologic report. The engineering geologic report is often prepared in conjunction with a geotechnical report, but commonly provide geotechnical analysis and design recommendations independent of a geotechnical report. An engineering geologic report describes the objectives, methodology, references cited, tests performed, findings and recommendations for development. Engineering geologists also provide geologic data on topographic maps, aerial photographs, geologic maps, Geographic Information System (GIS) maps, or other map bases.

Chapter 5

Levee Breach



A levee failure during the Great Mississippi Flood of 1927.



A breach in a dike during the North Sea flood of 1953.

A **levee breach** or **levee failure** (the word dike or dyke can also be used instead of levee) is a situation where a levee fails and the water that was retained by that levee is allowed to flood the land behind the levee.

Causes of failure

Man-made levees can fail in a number of ways. The most frequent (and dangerous) form of levee failure is a *breach*. A *levee breach* is when part of the levee actually breaks away, leaving a large opening for water to flood the land protected by the levee.

Subsurface erosion

A breach can be a sudden or gradual failure that is caused either by surface erosion or by a subsurface failure of the levee. Levee breaches are often accompanied by levee boils, or sand boils. A sand boil occurs when the upward pressure of water flowing through soil pores under the levee (underseepage) exceeds the downward pressure from the weight of the soil above it. The underseepage resurfaces on the landside, in the form of a volcano-like cone of sand. Boils signal a condition of incipient instability which may lead to erosion of the levee toe or foundation or result in sinking of the levee into the liquefied foundation below. A sand boil is more threatening when a form of internal erosion called piping occurs. Complete breach of the levee may quickly follow.

Erosion and damage

Surface erosion of the surface of a levee is usually caused by the action of wind and water (waves but also normal flow). Erosion can be worsened by pre-existing or new damage to a levee. Areas with no surface protection are more prone to erosion. A levee grazed by certain types of animals, like sheep, can show trails used by the animals where grass does not grow.

Trees in levees are a special risk. A tree can become unstable after the soil of the levee has become saturated with water. When the tree falls the root system will likely take a chunk of the saturated soil out of the levee. This shallow hole can quickly erode and result in a breach. If the tree falls in the water and floats away it can damage the levee further downstream. Floating trees near levees should be quickly removed by the agency responsible for the maintenance of the levee.

Other forms of damage can be caused by ships or other (large) floating objects or from objects in the levee, like traffic signs or fences that are damaged or completely removed by wind or water. Barbed wire fences can collect large amounts of floating plant material, resulting in a large amount of drag from the water. Whole fences can be dragged away by the water.

Overtopping

Sometimes levees are said to fail when water *overtops* the crest of the levee. *Levee overtopping* can be caused when flood waters simply exceed the lowest crest of the levee system or if high winds begin to generate significant swells (a storm surge) in the ocean or river water to bring waves crashing over the levee. Overtopping can lead to significant landside erosion of the levee or even be the mechanism for complete breach. Often levees are armored or reinforced with rocks or concrete to prevent erosion and failure.



A kolk lake in the Netherlands

Kolk lakes

After a levee breach a kolk lake can often be seen. This is a crater-like depression just behind the breach where soil and other material has been violently removed by the rushing water. After a breach a kolk lake will remain when the water level recedes.

Intentional breaches

In some cases levees are breached intentionally. This can be done to protect other areas or to give back land to nature. In most cases an intentional breach is not without discussion since valuable land is given up. During the Great Mississippi Flood of 1927 a levee was blown up with dynamite to prevent the flooding of New Orleans.

Taking land from the cycle of flooding by putting a dike around it prevents it from being raised by silt left behind after a flooding. At the same time the drained soil consolidates and peat decomposes leading to land subsidence. In this way the difference between the water level on one side and land level on the other side of the dike grew. In some areas reclaimed land is given back to nature by breaching and removing dikes to allow flooding to occur (again). This restores the natural environment in the area. This happened in the Glory River in Iraq

Examples of levee breaches

New Orleans

The words *levee* and *levee breach* were brought heavily into the public consciousness after the levee failures in metro New Orleans on August 29, 2005 when Hurricane Katrina passed east of the city. Levees breached in over 50 different places submerging 80 percent of the city. Most levees failed due to water overtopping them but some failed when water passed underneath the levee foundations causing the levee wall to shift and resulting in catastrophic sudden breaching. The sudden breaching released highly pressured water that moved houses off their foundations and tossed cars into trees. This happened in the Ninth Ward when the Industrial Canal breached and also in the Lakeview neighborhood when the 17th Street Canal breached. Effects of breached levees are discussed further in the article 2005 levee failures in Greater New Orleans, which cites a death toll of 1,464. In New Orleans, the United States Army Corps of Engineers is the Federal agency responsible for levee design and construction as defined in the Flood Control Act of 1965 and subject to local participation requirements, some of which were later waived. Fault has been aimed at the Corps of Engineers, their local contractors, and local levee boards.

North Sea

The St. Elizabeth's flood of 1421 was caused by a surge of seawater being forced upriver during a storm, overflowing the river dikes and submerging approximately 300 square kilometres (100 sq mi) of land in the Netherlands. Estimates of people having died range from 2,000 to 10,000. Parts of the submerged lands have still not been reclaimed resulting in the Biesbosch wetlands.

During the North Sea flood of 1953, in the night of 31 January – 1 February 1953, many dikes in the provinces of Zeeland, Zuid-Holland and Noord-Brabant in the Netherlands were unable to withstand the combination of spring tide and a northwesterly storm. The resulting flood killed 1,835 people. A further 307 people were killed by dike breaches in the United Kingdom, in the counties of Lincolnshire, Norfolk, Suffolk and Essex. In the Netherlands these flood was a main reason for the construction of the Delta Works, probably the most innovative and extensive levee system in the world.

Other breaches

- 1421 - The St. Elizabeth's flood of 1421 in the Netherlands was caused when dikes were breached in a number of places during a heavy storm near the North Sea coast and the lower lying polder land was flooded. A number of villages were swallowed by the flood and were lost, causing between 2,000 and 10,000 casualties.
- 1570 - The All Saints' Flood caused dike breaches on the west coast of the Netherlands. The total number of dead, including in foreign countries, must have been above 20,000, but exact data is not available. Tens of thousands of people

became homeless. Livestock was lost in huge numbers. Winter stocks of food and fodder were destroyed.

- 1651 - During the St. Peter's Flood the city of Amsterdam was flooded after several breaches of the dikes, the coasts of Netherlands and Northern Germany were heavily battered.
- 1686 - The St. Martin's flood flooded large parts of the province of Groningen in the Netherlands. 1558 people, 1387 horses and 7861 cows died. 631 houses were swept away and 616 houses damaged.
- 1703 - The Great Storm of 1703 caused havoc between Wales and Friesland, it was the most severe storm or natural disaster ever recorded in the southern part of Great Britain.. Several dikes were breached in the Netherlands. Between 8,000 - 15,000 lives were lost overall.
- 1717 - The Christmas flood of 1717 was the result of a northwesterly storm, which hit the coast area of the Netherlands, Germany and Scandinavia on Christmas night of 1717. In total, approximately 14,000 people drowned. It was the last large flood in the north of the Netherlands.
- 1809 - When De Biesbosch in the Netherlands froze ice dams caused a rapid rise in waterlevels in the Meuse, Waal and Merwede, which resulted in dike breaches.
- 1820 - The Alblasserwaard in the Netherlands flooded after a dike breach
- 1825 - Parts of Groningen, Friesland and Overijssel in the Netherlands were flooded after dike breaches
- 1855 - Large parts of the central Netherlands were flooded after the Lower Rhine was dammed by ice and dikes were breached
- 1916 - A storm surge on the Zuiderzee coincided with a large volume of water flowing down the Rhine and Meuse rivers causing dozens of dike breaches
- 1927 - The Great Mississippi Flood of 1927 occurred when the Mississippi River breached levees and flooded 27,000 square miles (70,000 km²), killing 246 people in seven states and displacing 700,000 people.
- September 1928: Storm surge from the Okeechobee Hurricane breaches levees surrounding Lake Okeechobee, killing an estimated 2500 people.
- Dec 24, 1955 - Just after midnight, a levee on the west bank of the Feather River collapsed just south of Yuba City, Ca., resulting in the drowning of 38 residents.
- Jan 3, 1976 - A dike failed on the Vliet, a tributary of the Rupel in Belgium. The village of Ruisbroek was flooded to a depth of 3m and over 2000 people had to be evacuated. This disaster prompted the drafting of Belgium's Sigma Plan as a counterpart to the Dutch Delta Plan.
- Feb 20, 1986 - A levee on the south bank of the Yuba River collapsed at the northern Sacramento Valley community of Linda, California in Yuba County, inundating 36 square miles (93 km²) and destroying 600 homes.
- Jan 31, 1995 - 250,000 people were evacuated from central parts of the Netherlands after river dikes had become dangerously unstable. The dikes were not breached after intensive works to stabilize the embankments, aided by military engineers.
- Jan 2, 1997 - A levee on the west bank of the Feather River collapsed at the northern Sacramento Valley community of Arboga, California in Yuba County,

- killing three people. More than 100,000 people in Yuba and Sutter counties were evacuated.
- 26 Aug 2003 - A dike near Wilnis in the Netherlands failed and flooded that town due to the dike not having enough weight to withstand the water pressure of the canal after a long drought. 1,500 inhabitants were evacuated with no loss of life.
 - 3 June 2004 - Jones Tract, an inland island that is protected by a series of levees located in the Sacramento-San Joaquin Delta, failed. Though the exact cause of the levee failure is not known, the breach in the levee allowed water from the Middle River to flood the island.
 - January 5, 2008 - A levee in Fernley, Nevada burst, flooding portions of the town and forcing the evacuations of 3,500 residents.
 - September 14, 2008 - a levee in Munster, Indiana broke on the Little Calumet River resulting in flooding in most of Munster.
 - August 8, 2009 - Levees fail in Southern Taiwan due to Typhoon Morakot causing widespread flooding in many regions.
 - February 26, 2010 - Levees were submerged by wind and a huge tide in Vendée, in Western France because of the Xynthia storm.

Chapter 6

Infill



Kaiser Medical Center in Richmond, California has infilled its employee parking to expand the hospital's emergency services department.

Infill in its broadest meaning is material that fills in an otherwise unoccupied space. The term is commonly used in association with construction techniques such as wattle and daub, and civil engineering activities such as land reclamation.

Construction

When a building is constructed in timber framing, the spaces are filled with non-structural material that is known as infill. The earliest type of infill was wattle and daub. Other materials used for the purpose have been lath and plaster, and brickwork (when it is known as nogging). The infill may be covered by other materials, including plaster, weatherboarding or tiles.

Urban planning

Urban infill



Example of an urban infill site

In the urban planning and development industries, infill is the use of land within a built-up area for further construction, especially as part of a community redevelopment or growth management program or as part of smart growth. It focuses on the reuse and repositioning of obsolete or underutilized buildings and sites. This type of development is essential to renewing blighted neighborhoods and knitting them back together with more prosperous communities. Redevelopment is development that occurs on previously developed land. Infill buildings are constructed on vacant or underutilized property or between existing buildings.

Challenges to urban infill

Although infill is an appealing tool for community redevelopment and growth management, it is often far more costly for developers to develop land within the city than it is to develop on the periphery, in suburban greenfield land. Costs for developers include acquiring land, removing existing structures, and testing for and cleaning up any environmental contamination.

Scholars have argued that infill development is more financially feasible for development when it occurs on a large plot of land (several acres). Large scale development benefits from what economists call economies of scale, and reduces the surrounding negative influences of neighborhood blight, crime, or poor schools. However, large scale infill development is often difficult in a blighted neighborhood for several reasons. These include the difficulties in acquiring land and in gaining community support.

Amassing land is one challenge that infill development poses that greenfield development does not. Neighborhoods that are targets for infill often have parcels of blighted land scattered among places of residence. Developers must be persistent in order to amass land parcel by parcel, and often find resistance from landowners in the target area. One way to approach this problem is for city management to use eminent domain to claim land. This is often unpopular among city management, as well as among neighborhood residents. Developers must deal with regulatory barriers, visit numerous government offices for permitting, interact with city management that is frequently unwilling to use eminent domain to remove current residents, and generally engage in public-private partnerships with local government.

Developers also meet with high social goal barriers in which the local officials and residents are not interested in the same type of development. Although citizen involvement has been found to facilitate the development of brownfields, residents in blighted neighborhoods often want to convert vacant lots to parks or recreational facilities, whereas external actors seek to build apartment complexes, commercial shopping centers, or industrial sites.

Suburban infill

Suburban infill describes the development of land in existing suburban areas that was left vacant during the development of the suburb. It is one of the tenets of the New Urbanism and smart growth trends of urging densification to reduce the need for automobiles, encourage walking, and ultimately save energy. One exception to this is the practice of urban agriculture, in which land in the urban or suburban area is retained to grow food for local consumption.

The Village of Ponderosa in West Des Moines, Iowa is a good example of suburban infill. It was formerly a 9-hole golf course surrounded by suburban West Des Moines businesses and tract homes, but starting in 2006 it was redeveloped into a higher-density mixed-use community with a pedestrian friendly retail center.

Infill housing

Infill housing is the insertion of additional housing units into an already approved subdivision or neighborhood. These can be provided as additional units built on the same lot, by dividing existing homes into multiple units, or by creating new residential lots by further subdivision or lot line adjustments. Units may also be built on vacant lots.

Infill residential development does not require the subdivision of greenfield land, natural areas, or prime agricultural land. Existing infrastructure may in some cases need little expansion for utility and other services.

As with other new construction, structures built as infill may clash architecturally with older, existing buildings.

Infill, a water and aeolian process

Examples of *infills* occur in geology. The Touchet Formation of rhythmite layers located in the Northwestern United States, had intervening periods of aridity. Erosional cracks were later infilled with layers of soil material, especially from aeolian processes. The infilled sections formed vertical inclusions in the horizontally deposited layers of the Touchet Formation, and thus explaining events that intervened in time among the forty-one layers that were deposited.

Chapter 7

Shaft Construction

Shaft construction concerns the building of vertical openings such as Raises and Shafts. Shafts are vertical openings used for supplying equipment, personnel, and support systems to the horizontal tunnel where the pipeline is installed. They can be temporary or permanent, Which need large size excavations.

In this report we will addresses the different construction methods and different applications of shafts and raises, and during that we will also talk about the advantage and disadvantage of each method. In addition, we will talk about their impacts on surrounding infrastructures and environment, resource requirements, appropriate soil conditions, site layout requirements and finally we will have a rough cost estimation.

Definitions, applications, shapes

Raisings

Raisings are driven in the upward direction. They can be vertical or steeply inclined. During raising, gravity assists in drilling and mucking, thereby making the process faster and cheaper. (R. Tatia 2005)

Shafts

Shafts are vertical openings which are driven downward. Decisions about the size, shape and positioning of shafts and raisings are taken based on the purpose they are intended to serve. (R. Tatia 2005)

Usually circular shafts are preferred in almost all situations because they are very stable. Also, when strata should be built, we can use the advantages of rectangular or elliptical shafts and use their cross sectional areas. (R. Tatia 2005)

Applications

According to (R. Tatia 2005) applications of raises and shafts are listed below:

Hydro-electric projects

- surge chamber
- ventilation shaft
- elevator shaft
- pressure shaft
- cable shaft

Water supply

- access or service shaft
- ventilation
- supply riser
- uptake or down-take shaft

Waste water shafts

- drop shafts

Tunnel projects

- ventilation
- accelerators housing
- access

Raise driving techniques

One classification for the raises is based on the application of explosives, that is to say with and without explosives while driving. (R. Tatia 2005)

The line diagram below shows a classification of raising techniques: (R. Tatia 2005)

Conventional methods

- the open rising technique is used in driving short raises which are less than 10 meters.
- Compartment method

Raising by mechanical climbers: Alimak raise climber

Alimak Company introduced this technique in 1957, and even today it is often used in driving blind raises which have long lengths.

The Alimak raise climber is designed to drive raises up to 100 m long, or more. There are several kinds of climbers available: pneumatic, electric and diesel (hydraulic driven).

The following are important features of this technique:

- it makes it possible to drive very long raises, vertical or inclined, straight or curved and mostly rectangular shape.
- The raise climber can be driven into a safe position using backward guardrails.
- Because of its features for blowing air and water at the face after blasting, risks of foul gases are eliminated, and the time required for ventilation is reduced.
- An additional extension piece can be connected to the platform

Blast hole techniques

- Long hole raising
- Drop rising

“Drop rising” technique is the advanced version of the “long hole raising” technique. This technique is based on the vertical carter retreat (VCR) concept. The crater has five holes, one of the holes is at the center and the other four are at the corners. In this method (DTH) drills, drill parallel holes in the raise direction. After that holes are blasted in stages. Raises of longer lengths, up to 150 m, can be drilled using this method.

Raising by application of raise borers

This technique can be used to drive a raise between 2 levels in the ground. Using this technique, Raises have been drilled successfully even in poor ground where the soil condition is not very good. A circular shape is obtained from this technique. In this technique, the machine is set up at the top and drills a hole of 225 to 250 mm diameter, to get to the lower level. After that a large reamer bit is put on at the bottom of the drill rod and then it reams up the raise.

We can execute the reverse procedure by the machine; however, this option is not very popular.

Raise borers can drive in soft ground and hard ground, and such units are useful to drive raises and shafts up to 6 m diameter,

This method has the advantages like, faster rates, better safety for working crews and least disturbance to the rock structure.

By using this method the holes by the following properties is driven before: Shaft length, 1000 m, Diameter .6 to 6 m (R. Tatia 2005)

Shaft sinking

Applications of Shafts: (R. Tatia 2005)

Shafts are usually used for the following purposes: “

- Mining mineral deposits
- Temporary storage and treatment of sewage
- Bridge and other deep foundations
- Hydraulic lift pits
- Wells
- In conjunction with a tunnelling system or network, for the purpose of lifts, escalators, stair and ladder ways, ventilation, conveyance of liquid, carrying pipes and cable in river crossing, drainage and pumping, particularly from sub aqueous tunnels.”

They also can be temporary or permanent,

(R. Tatia 2005) has classified the techniques which are used for sinking shafts:

Activities required for Shaft Sinking

we can divide the operations for sinking a shaft into three parts: (R. Tatia 2005)

1. Reaching up to the rock head
2. Sinking through the rock
3. Sinking through the abnormal difficult ground, if any, using special methods

A sinking cycle includes the following operations: (R. Tatia 2005)

- Drilling
- Blasting
- Mucking and hoisting
- Support or shaft lining
- Auxiliary operations
 - Dewatering
 - Ventilation
 - Lightning or illumination
 - Shaft centering

Drilling

We use sinkers to drill holes of 32–38 mm diameter, The length of the holes vary between 1.5 to 5 meters.

There are three types of cuts

- Wedge cut
- Step cut
- Pyramid cut

1 and 2 are common drilling that are used and in rectangular shafts. Wedge cut is used most of the time. Pyramid cut is often used in the circular ones. Step cut is adopted if water is high and the shaft is of a large cross section.

Blasting

In practice, at the bottom of shaft is usually full of water during sinking. therefore, high density, water-resistant explosives are used.

Lashing and mucking

Lashing is made for the loading of muck into a conveyance for its disposal. This activity is a time consuming activity due to Presence of water, limited space.

Support or shaft lining

There are two types of lining,

- Temporary
- Permanent

The type of water and strength of the rock and soil layer where sinking operation is done determine which option to select. Therefore, in some cases, temporary support is not adopted, while in others it becomes essential to protect the crew and equipment from any side fall.

The permanent lining can be made of bricks, concrete blocks, monolithic concrete, shotcrete and cast iron tubing.

Auxiliary operations

- Dewatering: When the shaft is reached to the water table or beyond it, water inflows inside it, to remove this water usually face or sinking pumps are used.(tatiana) Removing water can also be done by driving deep wells or well point systems around the shaft, that results in lowering the water table around the shaft.(zhou)
- Ventilation: Fresh air, supplied by a forcing fan installed at the surface, which can be provided by rigid ventilation ducts for below 6 m depth or flexible ones for more than 6 m depth.
- Illumination: A pneumatically operated light, is used to provide illumination at the working face during construction work.
- Shaft centering: Using the reference points, which are fixed before, to fix the shaft center. The shaft center is checked from time to time by the use of centering device installed at the surface.

Special methods for shaft sinking.

In the process of shaft sinking, it becomes necessary to adopt a special method if the ground through which the shaft is sunk is loose or unstable such as in sand, mud, gravel, or alluvium, or when an excessive amount of water is encountered, which cannot be dealt with by sinking pumps. In some situations, both sets of these conditions may be encountered. Listed below are special methods that can be used to deal with the situations outlined above:

1. piling system
2. cementation
3. freezing method
4. grouting
5. shotcrete

1. Piling system (Soldier pile):

These piles are driven and after installing the steel beams can be concreted. Piling method and the spaces between piles depend on the soil conditions. (Fangyi Zhou, 2006)

3. Freezing method

”Sometimes when we can’t control the groundwater by pumping, we may use freezing or grouting. This procedure consists of sinking pipes around the area to be excavated and circulating a cold brine solution through the pipes, thereby freezing a wall of soil, this process needs 2 months to complete,” . (Fangyi Zhou, 2006)

4. Grouting:

In this method we drill rows of grout holes around the shaft perimeter, then inject grout into them, but freezing is more reliable comparing to this,

5. Shotcrete:

Shotcrete is sprayed concrete can be applied immediately to freshly excavated rock

Impact on surrounding infrastructures

Shaft sinking can have the following impacts on the infrastructure and environment around it:

- blocking the streets and causing traffic in the area around it
- making noise and dust which can bother the people around the construction area
- bad effects on soil because of making vibrations in the ground while construction
- cutting some trees and clearing the area for construction site

Appropriate soil conditions

The appropriate soil condition For each method is mentioned during the construction method, and if the soil is not strong, we should use piles and temporary linings to take care of that The space between columns depends on the soil conditions and amount of ground water existing, piles can be close to each other or have the appropriate distance.

However, strong and consolidated soil is the most appropriate soil for driving shafts. (class lectures)

Site layout requirements

Tommelein (1989) defines Construction site layout and its benefits as below:

“ identifying the facilities that are temporary needed to support construction operation on a project but that do not form apart of the furnished structure: determining the size and shape of these facilities; positioning them within the boundaries of the available on-site or remote areas”

“the so called temporary facilities usually remain on site for a period ranging from a few days to several months or even years, a time period that ranges from duration of a construction activity to the duration of a major phase of the entire construction period”

“ a well-organized site facilities inventory control, cuts travel times, reduces noise and dust, prevents obstructions and interference, increases safety and security, and improves site access”

According to Fangyi Zhou (2006), considerations affecting the site layout are: Efficiently using site space to accommodate resources throughout a construction project is fundamental to success of a project. So optimizing the construction site layout using physical and computational models is of interest to many researchers. Site Layout has a great effect on project costs, therefore, models are used to simulate the different site layouts and choose the best one.

Resources required: (cost estimation for shaft, City of Edmonton,2005)

Human resources

Equipment operators, labourers and workers, foremen, supervisors

Equipments and machines

- Drill rig, compressor, excavators, explosives
- Cranes, hoists, trucks
- Welding truck

- Lumbers (laggings), liners, ribs, tie rods, support beams, tie wire
- General purpose concrete, concrete forms, concrete pump, rebars
- Water pumps
- Illumination and electrical equipment
- Communication systems
- Personal protective equipment
- Ventilation System
- Instrumentation to determine the concentration of flammable gases

Chapter 8

Shoring

Shoring is a general term used in construction to describe the process of supporting a structure in order to prevent collapse so that construction can proceed. The phrase can also be used as a noun to refer to the materials used in the process.

Buildings- It is used to support the beams and floors in a building while a column or wall is removed. In this situation vertical supports are used as a temporary replacement for the building columns or walls.

Trenches - During excavation, shoring systems provide safety for workers in a trench and speed excavation. In this case, shoring should not be confused with shielding. Shoring is designed to prevent collapse where shielding is only designed to protect workers when collapses occur. Concrete structures shoring, in this case also referred to as falsework, provides temporary support until the concrete becomes hard and achieves the desired strength to support loads.

Ships - It is used onboard when damage has been caused to a vessels integrity, and to hold leak-stopping devices in place to reduce or stop incoming water. Generally consists of timber 100 mm x 100 mm and used in conjunction with wedges, to further jam shoring in place, pad pieces to spread the load and dog's to secure it together. also used onboard is mechanical shoring as a quick, temporary solution, however it isn't favoured due to its inability to move with the vessel.

Shoring Techniques

Buildings

Raking Shore

Raking Shores consist of one or more timbers sloping between the face of the structure to be supported and the ground. The most effective support is given if the raker meets the wall at an angle of 60 to 70 degrees. A wall-plate is typically used to increase the area of support.

Foundations

Shoring is commonly used when installing the foundation of a building. A shoring system such as piles and lagging or shotcrete will support the surrounding loads until the underground levels of the building are constructed.

Trenches

Hydraulic Shoring

Hydraulic shoring is the use of hydraulic pistons that can be pumped outward until they press up against the trench walls. They are typically combined with steel plate or plywood, either being 1-1/8" thick plywood, or special heavy Finland Form (FINFORM) 7/8" thick.

Beam and Plate

Beam and Plate steel I-beams are driven into the ground and steel plates are slid in amongst them. A similar method that uses wood planks is called soldier boarding. Hydraulics tend to be faster and easier; the other methods tend to be used for longer term applications or larger excavations.

Soil Nailing

Soil nailing is a technique in which soil slopes, excavations or retaining walls are reinforced by the insertion of relatively slender elements - normally steel reinforcing bars. The bars are usually installed into a pre-drilled hole and then grouted into place or drilled and grouted simultaneously. They are usually installed untensioned at a slight downward inclination. A rigid or flexible facing (often sprayed concrete) or isolated soil nail heads may be used at the surface.

Continuous Flight Augering

Continuous Flight Augering (CFA) is a method used to create concrete piles to support soil so that excavation can take place nearby. A Continuous Flight Augering drill is used to excavate a hole and concrete is injected through a hollow shaft under pressure as the auger is extracted. This creates a continuous pile without ever leaving an open hole.

Ships

Square Shoring

This consists of a timber member jammed on a pad piece on either the deck or deck head depending on water levels in the compartment and a strong point, this is called the proud. then there is a horizontal timber cut to size to fit between this and what it is shoring up, eg a

splinter box, bulkhead or door. Timber wedges are then used to tighten up the structure if necessary

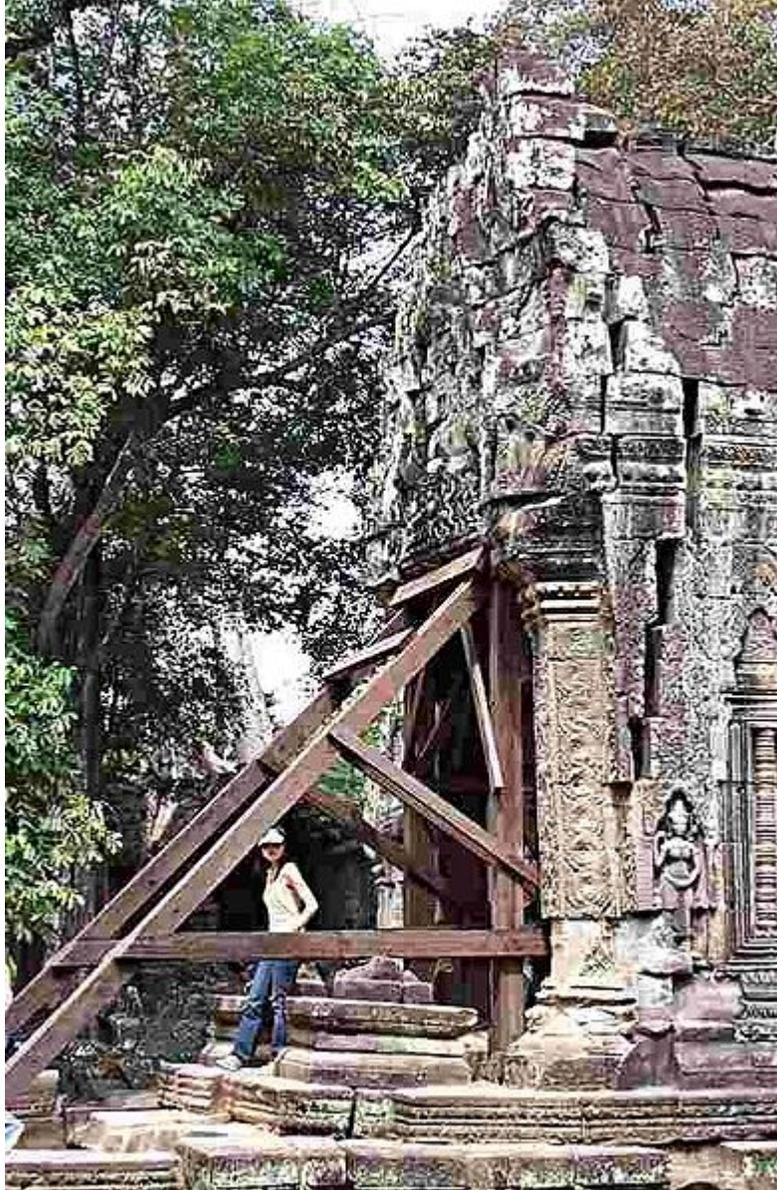
Vertical Shoring This is to support a hatch or splint box on the deck, consisting of a vertical timber between the deck and deck head, with two wedges used opposing each other to tighten it. pad pieces are used to spread the load on weak structures.



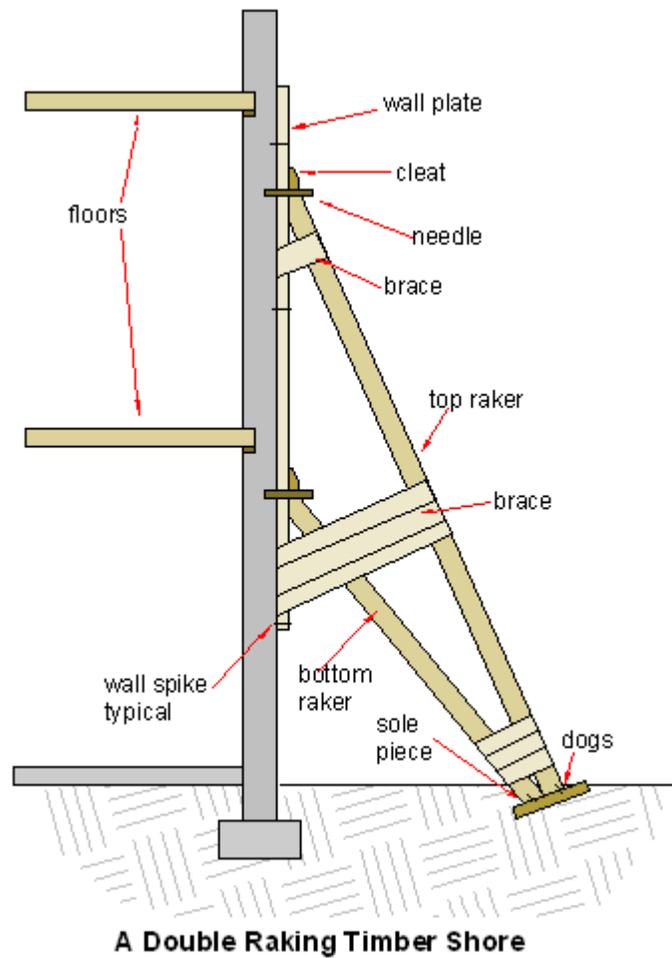
Vertical or dead shore system, typically used in formwork.



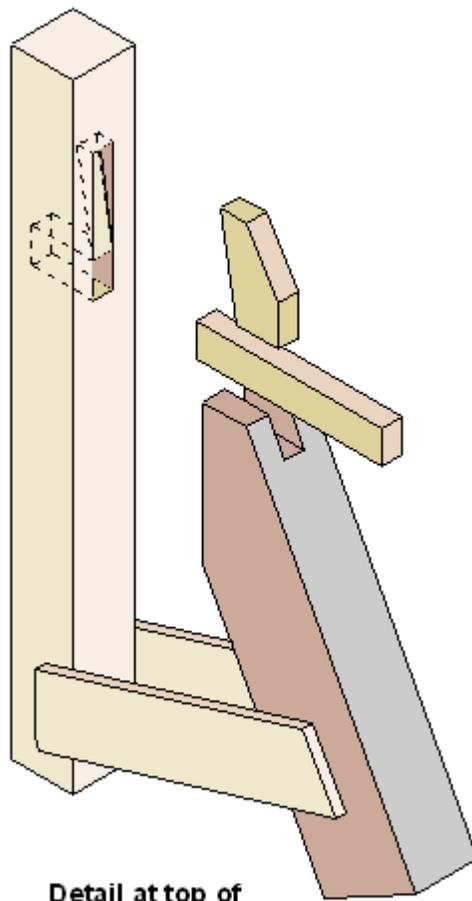
Single steel raking shore system specifically for tilt slab shoring.



Angkor Wat complex, simple combination of timber raking and dead shores.

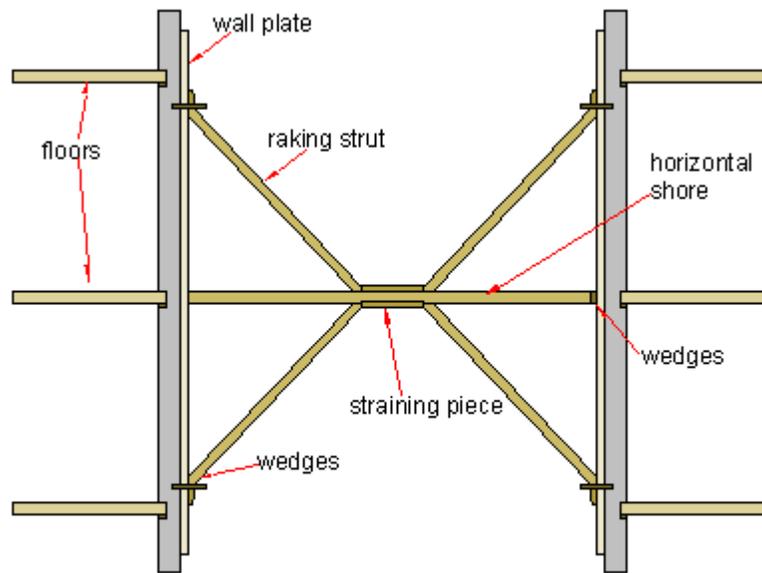


Sketch of a timber double raking shore. Projected centre lines of floors and shores meet.



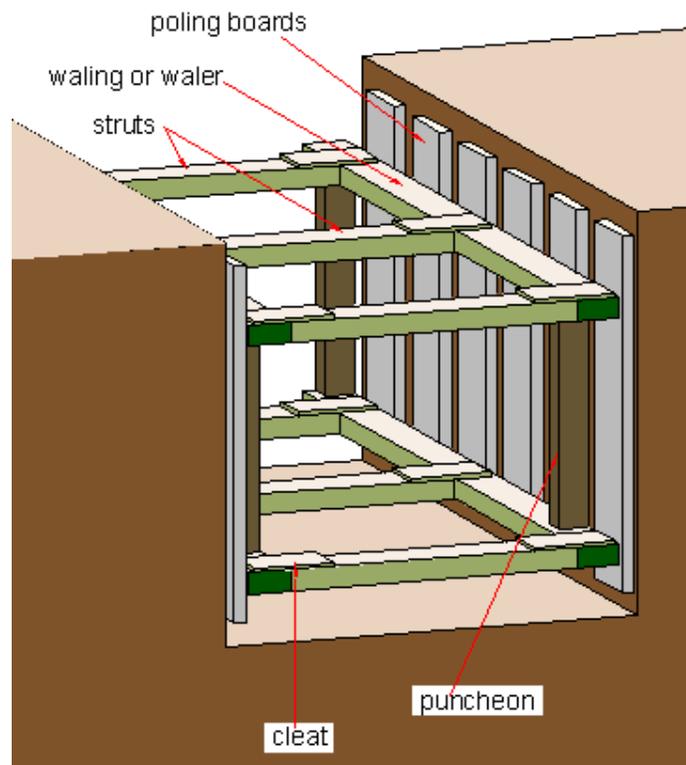
**Detail at top of
raking shore**

Carpentry detail of the joint at the top of a timber raking shore.

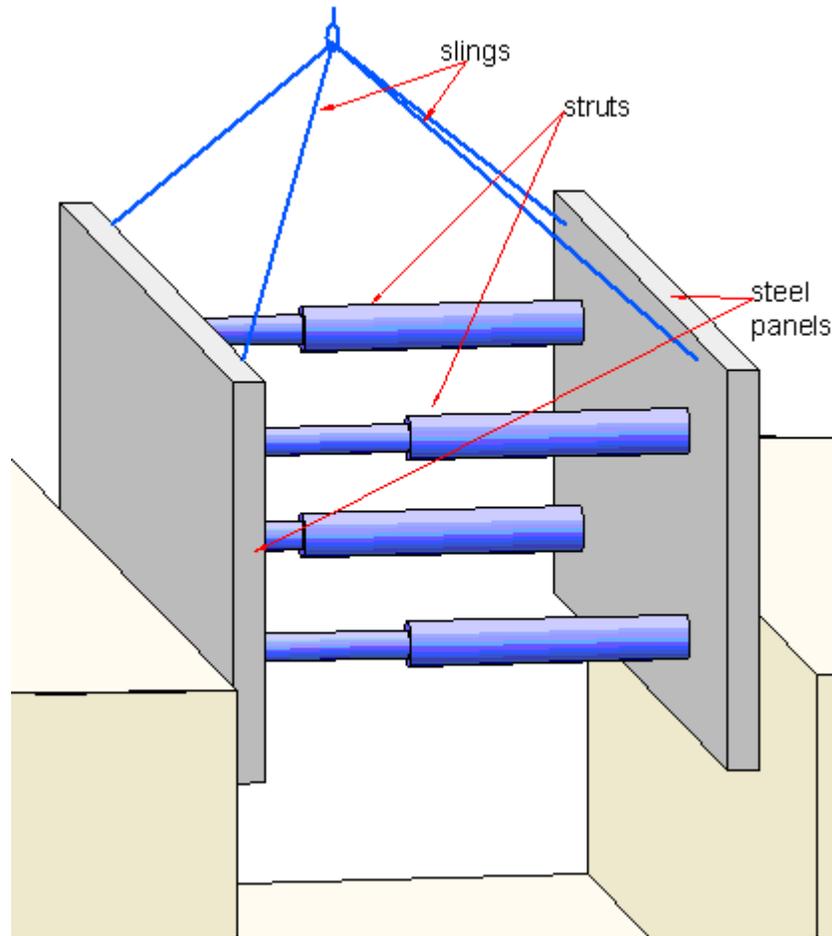


**Part Elevation Through Two Buildings
With A Single Flying Timber Shore**

Sketch of a timber single flying shore between adjacent buildings.



Traditional trench shoring or Timbering.



Schematic sketch of a modern steel trench shore being lowered into a trench.

Chapter 9

Soil Gradation

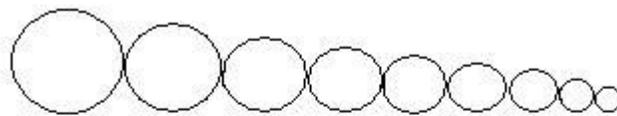


Figure 1. Well Graded

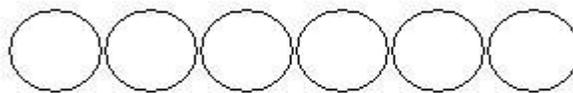


Figure 2. Uniformly-Graded



Figure 3. Gap-Graded

Soil Gradation Categories

Soil gradation is a classification of a coarse-grained soil that ranks the soil based on the different particle sizes contained in the soil. Soil gradation is an important aspect of geotechnical engineering and is an indicator of other engineering properties such as compressibility, shear strength, and hydraulic conductivity. In a design, the gradation of the in situ or on site soil often controls the design and ground water drainage of the site. A poorly graded soil will have better drainage than a well graded soil.

Soil is graded as either well graded or poorly graded. Poorly graded soils are further divided into uniformly-graded or gap-graded soils.

Soil gradation is determined by analyzing the results of a sieve analysis or a hydrometer analysis.

The process for grading a soil is in accordance with either the Unified Soil Classification System or the AASHTO Soil Classification System. Gradation of a soil is determined by reading the grain size distribution curve produced from the results of laboratory tests on the soil. Gradation of a soil can also be determined by calculating the coefficient of uniformity, C_u , and the coefficient of curvature, C_c , of the soil and comparing the calculated values with published gradation limits.

Soil Gradations

Soil gradation is a classification of the particle size distribution of a soil. Coarse-grained soils, mainly gravels or sands, are graded as either well graded or poorly graded. Poorly graded soils are further divided into uniformly-graded or gap-graded soils. Fine-grained soils, mainly silts and clays, are classified according to their Atterberg limits.

Well Graded

A *well graded* soil is a soil that contains particles of a wide range of sizes and has a good representation of all sizes from the No. 4 to No. 200 sieves. A well graded gravel is classified as GW while a well graded sand is classified as SW.

Poorly Graded

A *poorly graded* soil is a soil that does not have a good representation of all sizes of particles from the No. 4 to No. 200 sieve. Poorly graded soils are either uniformly graded or gap-graded. A poorly graded gravel is classified as GP while a poorly graded sand is classified as SP. Poorly graded soils are more susceptible to soil liquefaction than well graded soils.

A *uniformly graded* soil is a soil that has most of its particles at about the same size. An example of a uniformly graded soil is one in which only sand of the No. 20 size is present.

A *gap-graded* soil is a soil that has an excess or deficiency of certain particle sizes or a soil that has at least one particle size missing. An example of a gap-graded soil is one in which sand of the No. 10 and No. 40 sizes are missing, and all the other sizes are present.

Process of Grading a Soil

The process of grading a soil is in accordance with either the Unified Soil Classification System or the AASHTO Soil Classification System. The steps in grading a soil are data collection, calculating coefficients of uniformity and curvature, and grading the soil based on the grading criteria given in the used soil classification system.

Data Collection

Soil gradation is determined by analyzing the results of a sieve analysis or a hydrometer analysis.

In a sieve analysis, a coarse-grained soil sample is shaken through a series of woven-wire square-mesh sieves. Each sieve has successively smaller openings so particles larger than the size of each sieve are retained on the sieve. The percentage of each soil size is measured by weighing the amount retained on each sieve and comparing the weight to the total weight of the sample. The results of a sieve analysis are plotted as a grain size distribution curve, which is then analyzed to determine the soil gradation of the particular soil.

In a hydrometer analysis, a fine-grained soil sample is left to settle in a viscous fluid. This method is used based on Stoke's Law which relates terminal velocity of fall of a particle in a viscous fluid to the grain diameter and density of the grain in suspension. Grain diameter is calculated from a known distance and time of the fall of the particle. This is used to classify fine-grained soils.

Calculating the Coefficients of Uniformity and Curvature

Calculating the coefficients of uniformity and curvature requires grain diameters. The grain diameter can be found for each percent of the soil passing a particular sieve. This means that if 40% of the sample is retained on the No. 20 sieve then there is 60% passing the No. 20 sieve.

The *coefficient of uniformity*, C_u is a crude shape parameter and is calculated using the following equation:

$$C_u = \frac{D_{60}}{D_{10}}$$

where D_{60} is the grain diameter at 60% passing, and D_{10} is the grain diameter at 10% passing

The *coefficient of curvature*, C_c is a shape parameter and is calculated using the following equation:

$$C_c = \frac{(D_{30})^2}{D_{10} * D_{60}}$$

where D_{60} is the grain diameter at 60% passing, D_{30} is the grain diameter at 30% passing, and D_{10} is the grain diameter at 10% passing

Once the coefficient of uniformity and the coefficient of curvature have been calculated, they must be compared to published gradation criteria.

Criteria for Grading Soils

The following criteria are in accordance with the Unified Soil Classification System:

For a gravel to be classified as well graded, the following criteria must be met:

$$C_u > 4 \text{ \& } 1 < C_c < 3$$

If both of these criteria are met, the gravel is classified as well graded or GW. If both of these criteria are not met, the gravel is classified as poorly graded or GP.

For a sand to be classified as well graded, the following criteria must be met:

$$C_u > 6 \text{ \& } 1 < C_c < 3$$

If both of these criteria are met, the sand is classified as well graded or SW. If both of these criteria are not met, the sand is classified as poorly graded or SP.

Importance

Soil gradation is very important to geotechnical engineering. It is an indicator of other engineering properties such as compressibility, shear strength, and hydraulic conductivity.

In a design, the gradation of the in situ or on site soil often controls the design and ground water drainage of the site. A poorly graded soil will have better drainage than a well graded soil because there are more void spaces in a poorly graded soil.

When a fill material is being selected for a project such as a highway embankment or earthen dam, the soil gradation is considered. A well graded soil is able to be compacted more than a poorly graded soil. These types of projects may also have gradation requirements that must be met before the soil to be used is accepted.

When options for ground remediation techniques are being selected, the soil gradation is a controlling factor.

Chapter 10

Suction Excavator

A **suction excavator** or **vacuum excavator** is a construction vehicle that removes earth from a hole on land, or removes heavy debris on land, from various places, by powerful suction through a wide suction pipe which is up to a foot or so diameter. The suction inlet air speed may be up to 100 meters/second = over 200 mph.

The suction nozzle may have two handles for a man to hold it by; those handles may be on a collar which can be rotated to uncover suction-release openings (with grilles over) to release the suction to make the suction nozzle drop anything which it has picked up and is too big to go up the tube.

The end of the tube may be toothed. This helps to cut earth when use for excavating; but when it is used to suck up loose debris and litter, some types of debris items may snag on the teeth.

The earth to be sucked out may be loosened first with a compressed-air lance, or a powerful water jet.

Its construction is somewhat like a gully emptier but with a wider suction hose and a more powerful suction.

Excavating with a suction excavator may called "vacuum excavation", or "hydro excavation" if a water jet is used.

History

RSP GmbH have been making suction excavators and stationary suction units since 1993, but gully emptiers and the old type of suction street cleaner vehicle that could only pick up loose debris have been around for much longer.

Since 1998, the MTS Mobile Tiefbau Saugsysteme GmbH is making a new type of suction excavator. It is said to have a new designed air flow principle, and thus a considerably improved suction performance.

Design and operation

RSP Gmbh

RSP Gmbh in Germany make or made these models:

| model | length | fan capacity | suction negative pressure | maximum suction depth | maximum suction span | spoil tank volume | specifications of carrying truck | | | | info link |
|----------|--------|-------------------------------|---------------------------|-----------------------|----------------------|-------------------|----------------------------------|-------|---------------------|-----------|-----------|
| | | | | | | | power | axles | wheelbase | weight | |
| ESE 18/7 | 7 m | 6.94 – 8.88 m ³ /s | 0.1 - 0.17 bar | 15 m | 70 m | 4 cu.m. | 280 hp | ≥ 2 | 4.2 m = 13 ft 10 in | 18 tonnes | |
| ESE 19/5 | 8 m | 5 - 6.94 m ³ /s | 0.1 - 0.17 bar | 11 m | 50 m | 5 cu.m. | 310 hp | ≥ 2 | 4.5 m = 14 ft 10 in | 19 tonnes | |
| ESE 26/7 | 8.8 m | 5 - 6.94 m ³ /s | 0.1 - 0.17 bar | 11 m | 50 m | 7 cu.m. | 310 hp | ≥ 3 | 4.2 m = 13 ft 10 in | 28 tonnes | |
| ESE 32/7 | 9.8 m | 8.8888 m ³ /s | 0.3 bar | 16 m | 100 m | 7 cu.m. | 400 hp | ≥ 4 | 4.2 m = 13 ft 10 in | 32 tonnes | |

The suction unit is roughly rectangular-block-shaped, about 2.5 meters wide and 3.6 meters high, and is usually mounted and used on the back of a truck, which must have power takeoffs to run the suction unit's air impeller and hydraulics.

When it is emptying its load out, the spoil tank lid (with the hose connection) hinges off to the right, then the spoil tank (with the filters) tips about 90° over to the left to tip its load out.

In the ESE 32/7:

- The suction pipe's internal diameter is 25 cm = 9.8 inches
- The fan produces a maximum pressure reduction of about 30,000 pascals = about 0.3 atmosphere or 4.5 pounds/square inch. Across a circular suction opening 9.8 inches diameter that would give an entry air speed of about 400 mph and a maximum suction power of about 340 pounds = about 3 hundredweight. It can suck up objects up to 25 cm or 9.8 inches across of weight up to 30 kilograms = 66 pounds.
- It is described as able to suck up "earth, stones, vegetable waste, sand, mud, water, pebbles, rubble, asbestos, railway-type ballast"
- Its suction pipe has a detachable extension nozzle narrowing from 10 inches to 4 inches internal diameter, with handles on a rotatable panel to open or close side vents to let the operator let it drop overlarge objects which it has picked up.
- Its expected spoil extraction rates are roughly, in cubic meters per hour:

| material | cu.m./hour | time for 1 cu.m. |
|---|------------|------------------|
| heavy soil with buried cables and pipes | 1.6666 | 36 mins |
| dry heavy soil | 2.5 | 24 mins |
| wet heavy soil or clay | 3 | 20 mins |

| | | |
|--|-------------|----------------|
| moderately heavy soil with buried cables and pipes | 4 | 15 mins |
| muddy soil, gravel, crushed rock | 6 | 10 mins |
| sandy soil | 10 | 6 mins |
| water | 30 | 2 mins |
| <i>heavy soil with buried cables and pipes excavated by hand</i> | <i>0.25</i> | <i>4 hours</i> |



4 views of a suction excavator truck



Cleaning out a sewer manhole



Cleaning a riverbank



Removing building demolition or alteration debris



Trench digging



Removing builder's rubble from a confined area



Removing a ditched truck's load to make the truck light enough to be righted



Emptying a suction excavator's spoil hold into a dump truck



Sortie d'air Filtre fin Container Canal d'air Porte-tuyau flexible d'aspiration



Internal diagram (in French)



Extension nozzle, narrowing from 10 inches to 4 inches internal diameter



Sucking down a hole being dug to work on gas mains, Deansgate, Manchester. The man on the near right is pneumatic drilling.



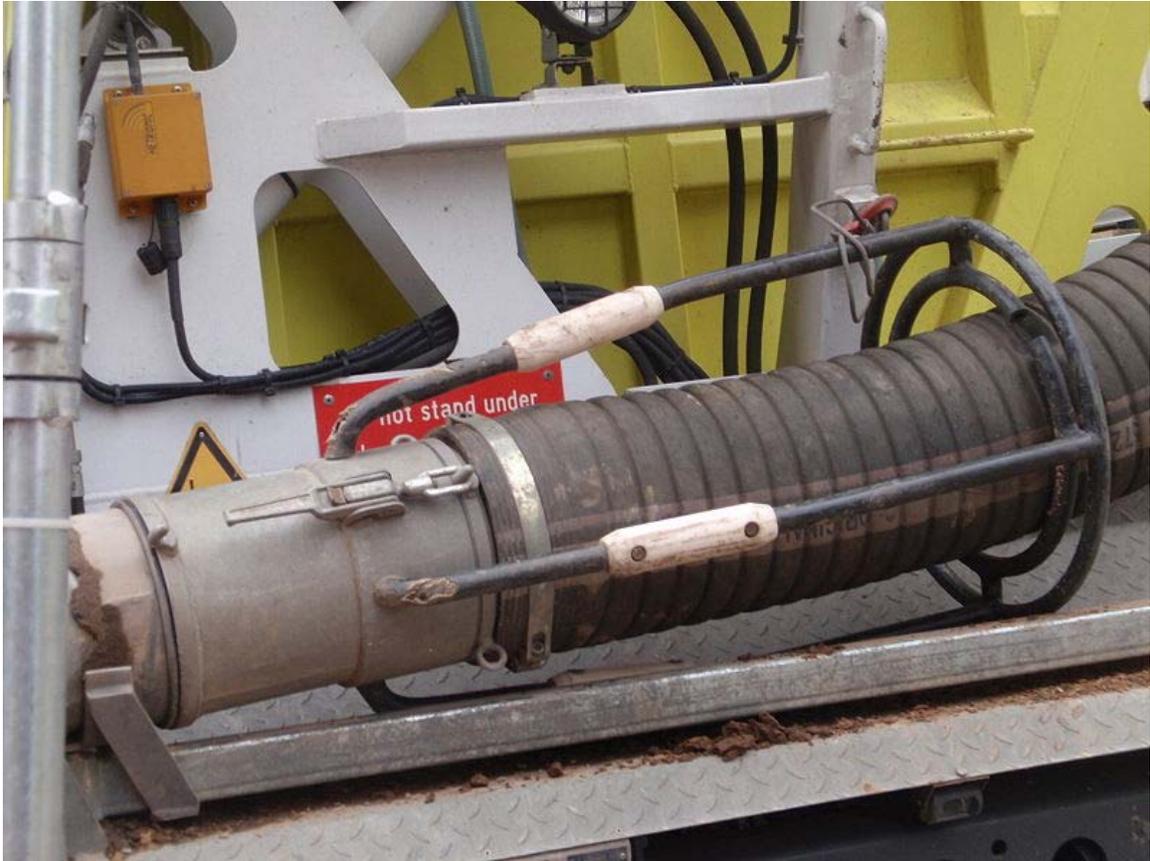
Work in confined space, Deansgate, same site. The man on the right is loosening earth with a compressed air lance.



Work in confined space, Deansgate, same site



View across work site, Deansgate, same site



Suction excavator, close-up of pipe end, stowed away



Back view of suction excavator with kit stowed away

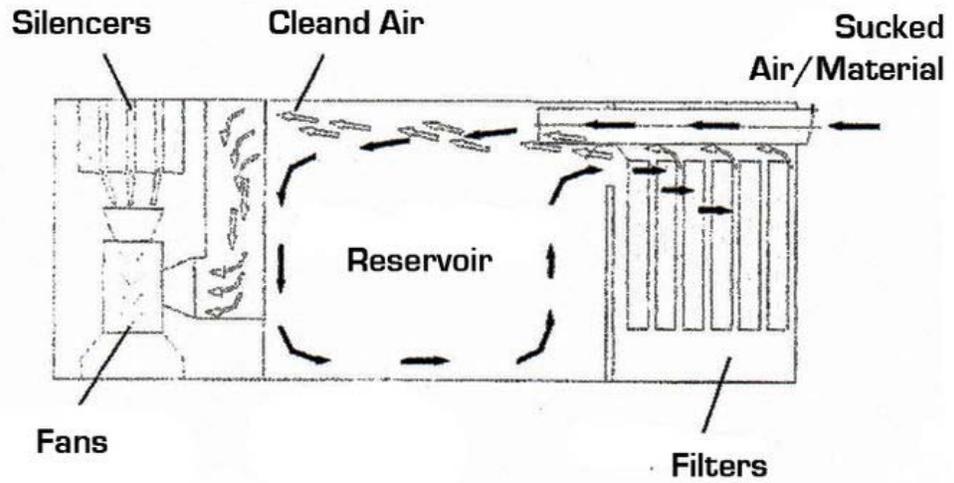
MTS Mobile Tiefbau Saugsysteme GmbH

MTS GmbH in Germersheim, Germany is making since 1998 these types of suction excavators:

| Model | Fan | Air movement | Suction pressure | Spoil capacity | Max. suction depth | Max. suction distance | Suction hose diameter | Info link | Notes |
|-----------------|--------------------------|--------------------------------|------------------|------------------------------------|--------------------|-----------------------|---------------------------------|-----------|--|
| Suction Box SBO | | | | 1-2m ³ | | | 125-200mm = 4.932 - 7.87 inches | | Can be carried by excavators etc. In 22, 32, 42 kW versions. |
| MINI-VAC | Single turbine | 6,944 m ³ /sec | 0.1974 bar | 1,5-2m ³ | 5m | 25m | 200mm = 7.87 inches | | buildup on 7.5 ton truck, compact for difficult-to-reach sites |
| DINO 2-5 | Single or double turbine | 6.944 – 10 m ³ /sec | 0.335 bar | 4m ³ - 12m ³ | 20m+ | 100m+ | 250mm= 9.84 inches | | with telescopic boom or hydraulic boom |
| MEGA-VAC | Quadruple turbine | 10 m ³ /sec | 0.493 bar | 9m ³ | 30m+ | 200m | 250mm = 9.84 inches | | big for big jobs |

With the MEGA-VAC the suction power across a 9.84-inch-wide hose entry would be about half a ton.

The MTS suction excavators are said to have a much easier air routing that leads to a more open spoil-hold design and much better suction performance.



Working principle of a MTS suction excavator



MTS Suction Excavator Mini Vac



MTS suction excavator DINO Tridem



MTS suction excavator Dino 4 in yellow



MTS suction excavator Dino 5 in green



MTS suction excavator Dino on Tridem chassis



MTS suction excavator at work at urban site



MTS Suction excavator while tipping

Saugmaster

Saugmaster make a model similar to the ESE 32/7; it can suck 8 cu.m./second of air, and its suction tube is 9 inches = 23 cm wide inside.

Ditch Witch

The USA firm Ditch Witch makes 4 models of suction excavators: FX20, FX25, FX30, FX60; the number is its approximate horsepower. It is mounted on a semitrailer. It has its own engine (petrol for FX20, the others diesel). Its spoil tank is cylindrical with somewhat rounded ends. Its suction hose is 3 inches diameter inside (but the FX60 can take 4-inch-diameter suction hose). Its spoil tank can be supplied various sizes.

Airex

Airex GB Ltd in the UK make two current models of vacuum excavator: AX-68 and AX-180. Both systems are mounted on the back of rigid 7.5-ton trucks, designed for use in inner-city streets. The smaller design of these trucks gives less impact on their surroundings. The AX-68 uses a 4-inch hose but the AX-180 uses an 8-inch hose which can removing a tonne of earth in six minutes.

Vac-Tron Equipment, LLC

Vac-Tron Equipment, LLC in the U.S. makes more than 50 models of gasoline and diesel vacuum excavators. They offer trailer and skid mounted options, and gasoline and diesel. Spoil tanks come in various sizes and configurations. Low profile increases maneuverability and can be towed by as small as a half-ton pickup truck.

Uses

Suction excavators are useful to remove earth from around existing buried services or tree roots with much less risk of damaging them than using a conventional excavator with a metal scoop.

This type of excavation is held to be a safe and efficient form of excavation. However it is totally unsuitable for archaeological excavation. Using a powerful vacuum and high pressure water, precise holes, trenches and tunnels can be cut to the required size and proportion. Because compressed air or water is used to loosen the earth, the risk of damaging underground utilities is less and contractors can safely find and expose them. Often excavation reveals unknown utilities, saving lives, money and time.

It is also referred to as "daylighting", as the underground utilities are exposed to daylight during the process.

This type of excavating is quickly becoming recognized as a best practice when working in areas with underground utility congestion and frozen ground. Hydro excavation lessens the risk of damaging utilities, which may often be inaccurately mapped and located and marked on the surface.

A suction excavator is useful in bulk excavation in confined areas, where its suction hose can reach in over or through barriers, e.g. digging a swimming pool in a courtyard.

It can be used on railways (perhaps mounted on a railroad car base) to suck old track ballast off the track when re-ballasting the track.

It can be used as a very heavy-duty vacuum cleaner to pick up miscellaneous debris, e. g, rubble, or big accumulations of fallen leaves or litter.

It can suck up liquids, e.g. water from a hollow.

The National Grid (UK) (UK electricity suppliers) has ordered 10 suction excavators.

As at July 2009 in England the North West Gas Alliance has 3 German-made suction excavators.

Specific jobs

Suction excavator jobs in Italy described in RSP Gmbh's publicity include:

- In the old center of Venice:
 - Cleaning deep silt (accumulated over nearly 40 years) out of the Rio Terà San Polo, which was formerly a narrow open canal, but is now a roofed sewer under a busy street. The excavator sucked through a long hose. Access damage to its roof and the street above was limited to four manhole-sized holes, which afterwards were fitted with manhole covers for future access. This avoided a long smelly traffic-obstruction-causing manual job.
 - Cleaning 1.6 meters deep silt out of the Rio Terà San Leonardo (a roofed sewer, 230 m long, 6 to 13 m wide): similarly.
- The south loggia of the Palazzo della Ragione in Padua: Sucking out a big accumulation of rubble and dust and bird droppings. The space is roofed by medieval vaulting through which only one small access hole was allowed. A 150-meter-long suction hose was used. (In the accompanying photographs the rubble seems to be largely plaster removed from the walls.)
- In Siena: removing about 150 cu.m. of rubble left by building restoration works, which had been dumped in old tunnels cut in tuff.

Vacuum excavation

Vacuum excavation is excavating by high-powered vacuum suction machines. This process significantly reduces the risk of loss of property and injury to workers associated with contacting or cutting underground utilities, as often happens if backhoe, auger, hand digging, or other mechanical methods are used.

Portable vacuum excavation equipment such as suction excavators can quickly dig small deep precisely-controlled holes to uncover buried utilities. Soft excavation technology can dig around buried pipe or cable without the risk of damage inherent with backhoes, excavators, or other mechanical tools.

Typically, vacuum excavation loosens the soil with a blunt-nosed high pressure air lance or water source and immediately vacuums away loosened material. Air and water, when used appropriately, are far less likely than sharp-edged tools to damage underground structures.

Depending on the machine used and soil conditions, a 12-inch-square 5-foot-deep pothole can be completed in 20 minutes or less. Most models are capable of digging deeper, but utility potholes seldom need to be more than six feet deep.

Vacuum excavation is best used in conjunction with conventional underground (one-call) locating services. Because of a preponderance of overlapping buried utility lines, locating

devices often incompletely identify all the buried utilities on a site or cannot completely or accurately mark a site.

According to New Mexico One Call 811: *Aligning Change, Locating with Potholing*, "One-call paint marks and flags are the first step in making the process of locating underground utilities safer, the use of vacuum excavation technology adds an additional margin of safety."

Potholing (which here means exposing buried utilities and seeing them to find where and how deep they are) using vacuum, has made it safer to locate underground utilities.

When conventional locating is unworkable due to high densities of buried utilities, potholing can also be used to verify the route of each buried line within the excavation zone. In some cases, the contractor may choose to perform the entire excavation using vacuum methods.

"As vacuum excavation technology and techniques for locating underground utilities has become both readily available and affordable, it's already considered by many municipalities as a Best Practice." Many governmental entities and municipalities no longer allow the use of backhoes for the physical locating of underground utilities, citing the risk of damaging the utility or utilities. Many have implemented policies mandating the use of vacuum excavation.

When conventional locating is unworkable due to high densities of buried utilities, potholing can be used to verify the route of each buried line within the excavation zone. In some cases, the contractor may elect to perform the entire excavation using vacuum methods.

To prevent utility strikes, the use of underground locating services has become the norm, and in most places, is required by law. However, the practice of underground location, while very useful, has its limitations. Locators have been known to incompletely identify all buried utilities or be unable to completely or accurately mark a site because of a preponderance of overlapping buried utility lines.

For these reasons, vacuum excavation techniques can be an effective way to locate, with virtually 100% accuracy, all underground structures in an excavation zone. Vacuum excavation is also typically more cost effective than hand digging.

Through aggressive educational efforts about the safety of vacuum excavation, vacuum excavation is now being mandated in many states and municipalities, and efforts are underway to achieve universal acceptance of vacuum excavation as the preferred technology.

Chapter 11

Well Logging

Well logging, also known as **borehole logging** is the practice of making a detailed record (a *well log*) of the geologic formations penetrated by a borehole. The log may be based either on visual inspection of samples brought to the surface (*geological logs*) or on physical measurements made by instruments lowered into the hole (*geophysical logs*). Well logging is done during all phases of a well's development; drilling, completing, producing and abandoning. Mostly in the oil and gas, groundwater, minerals, geothermal, and for environmental and geotechnical studies.

Electric or geophysical well logs

The oil and gas industry records rock and fluid properties to find hydrocarbon zones in the geological formations intersected by a borehole. The logging procedure consists of lowering a 'logging tool' on the end of a wireline into an oil well (or hole) to measure the rock and fluid properties of the formation. An interpretation of these measurements is then made to locate and quantify potential depth zones containing oil and gas (hydrocarbons). Logging tools developed over the years measure the electrical, acoustic, radioactive, electromagnetic, nuclear magnetic resonance, and other properties of the rocks and their contained fluids. Logging is usually performed as the logging tools are pulled out of the hole. This data is recorded either at surface (real-time mode), or downhole (memory mode) to electronic data format and then either a printed record or electronic presentation called a "well log" provided to the client. Well logging is performed at various intervals during the drilling of the well and when the total depth is drilled, which could range in depths from 150 m to 10668 m (500 ft to 35,000 ft) or more.

Electric line is the common term for the armored, insulated cable used to conduct current to downhole tools used for well logging. Electric line can be subdivided into open hole operations and cased hole operations. Other conveyance methods for logging are logging while drilling (LWD), tractor, coiled tubing (real-time and memory), drill pipe conveyed, and slickline (memory, and with new development, some slickline telemetry capability).

Open hole operations, or reservoir evaluation, involves the deployment of tools into a freshly drilled well. As the toolstring traverses the wellbore, the individual tools gather information about the surrounding formations. A typical open hole log will have

information about the density, porosity, permeability, lithology, presence of hydrocarbons, and oil and water saturation.

Cased hole operations, or production optimization, focuses of the optimization of the completed oil well through mechanical services and logging technologies. At this point in the well's life, the well is encased in steel pipe, cemented into the well bore and may or may not be producing. A typical cased hole log may show cement quality, production information, formation data. Mechanical services uses jet perforating guns, setting tools, and dump bailors to optimize the flow of hydrocarbons.

Wireline tool types

Typically the wireline tools are cylindrical in shape, usually from 1.5 to 5 inches in diameter. "Open hole" tool combinations can extend to over 100 feet long; "cased hole" tool combinations are often limited in length by the height restrictions imposed by constraints of "lubricator" pipe section required to contain the well pressure while deploying cased hole tools. There are many types of logging tools, ranging from common measurements (pressure and temperature) to advanced rock properties and fracture analysis, fluid properties in the wellbore, or formation properties extending several meters into the rock formation.

1. With sensors without excitation

There are units to measure spontaneous potential (SP), which is a voltage difference between a surface electrode and another electrode located in the downhole instrument, other instruments that measure the natural radiation from natural isotopes of potassium, thorium, etc., to measure pressure and temperature, etc.

2. With sources of excitation and sensors

There are sensor systems consistent with a source of excitation and a sensor. In this type we find acoustic (also called sonic), electric, inductive, magnetic resonance, sensing systems, just to name a few.

3. Instruments that produce some mechanical work, or retrieve a sample of fluid or rock to the surface.

Devices to collect samples of rock, samples of fluid extracted from the rock, and some other mechanical devices.

Types of electric/electronic logs

There are many types of electric/electronic logs and they can be categorized either by their function or by the technology that they use. "Open hole logs" are run before the oil or gas well is lined with pipe or cased. "Cased hole logs" are run after the well is lined with casing or production pipe.

Electric/electronic logs can also be divided into two general types based on what physical properties they measure. Resistivity logs measure some aspect of the specific resistance of the geologic formation. There are about 17 types of resistivity logs.

Porosity logs measure the fraction or percentage of pore volume in a volume of rock. Most porosity logs use either acoustic or nuclear technology. Acoustic logs measure characteristics of sound waves propagated through the well-bore environment. Nuclear logs utilize nuclear reactions that take place in the downhole logging instrument or in the formation. Nuclear logs include density logs and neutron logs, as well as gamma ray logs which are used for correlation. The basic principle behind the use of nuclear technology is that a neutron source placed near the formation of which the porosity is required to be measured will result in neutrons being scattered by the hydrogen atoms, largely those present in the formation fluid. Since there is little difference in the neutrons scattered by hydrocarbons or water, the porosity measured gives a figure close to the true physical porosity whereas the figure obtained from electrical resistivity measurements is that due to the conductive formation fluid. The difference between neutron porosity and electrical porosity measurements therefore indicates the presence of hydrocarbons in the formation fluid.

History

Conrad and Marcel Schlumberger, who founded Schlumberger Limited in 1926, are considered the inventors of electric well logging. Conrad developed the Schlumberger array, which was a technique for prospecting for metal ore deposits, and the brothers adopted that surface technique to subsurface applications. On September 5, 1927, a crew working for Schlumberger lowered an electric sonde or tool down a well in Pechelbronn, Alsace, France creating the first well log. In modern terms, the first log was a resistivity log that could be described as 3.5-meter upside-down lateral log.

In 1931, Henri George Doll and G. Dechatre, working for Schlumberger, discovered that the galvanometer wiggled even when no current was being passed through the logging cables down in the well. This led to the discovery of the spontaneous potential (SP) which was as important as the ability to measure resistivity. The SP effect was produced naturally by the borehole mud at the boundaries of permeable beds. By simultaneously recording SP and resistivity, loggers could distinguish between permeable oil-bearing beds and impermeable nonproducing beds .

In 1940, Schlumberger invented the spontaneous potential dipmeter; this instrument allowed the calculation of the dip and direction of the dip of a layer. The basic dipmeter was later enhanced by the resistivity dipmeter (1947) and the continuous resistivity dipmeter (1952).

Oil-based mud (OBM) was first used in Rangely Field, Colorado in 1948. Normal electric logs require a conductive or water-based mud, but OBMs are nonconductive. The solution to this problem was the induction log, developed in the late 1940s.

The introduction of the transistor and integrated circuits in the 1960s made electric logs vastly more reliable. Computerization allowed much faster log processing, and dramatically expanded log data-gathering capacity. The 1970s brought more logs and computers. These included combo type logs where resistivity logs and porosity logs were recorded in one pass in the borehole.

The two types of porosity logs (acoustic logs and nuclear logs) date originally from the 1940s. Sonic logs grew out of technology developed during World War II. Nuclear logging has supplemented acoustic logging, but acoustic or sonic logs are still run on some combination logging tools.

Nuclear logging was initially developed to measure the natural gamma radiation emitted by underground formations. However, the industry quickly moved to logs that actively bombard rocks with nuclear particles. The gamma ray log, measuring the natural radioactivity, was introduced by Well Surveys Inc. in 1939, and the WSI neutron log came in 1941. The gamma ray log is particularly useful as shale beds which often provide a relatively low permeability cap over hydrocarbon reservoirs usually display a higher level of gamma radiation. These logs were important because they can be used in cased wells (wells with production casing). WSI quickly became part of Lane-Wells. During World War II, the US Government gave a near wartime monopoly on open-hole logging to Schlumberger, and a monopoly on cased-hole logging to Lane-Wells. Nuclear logs continued to evolve after the war.

The nuclear magnetic resonance log was developed in 1958 by Borg Warner. Initially the NMR log was a scientific success but an engineering failure. However, the development of a continuous NMR logging tool by Numar (now a subsidiary of Halliburton) is a promising new technology.

Many modern oil and gas wells are drilled directionally. At first, loggers had to run their tools somehow attached to the drill pipe if the well was not vertical. Modern techniques now permit continuous information at the surface. This is known as logging while drilling (LWD) or measurement-while-drilling (MWD). MWD logs use mud pulse technology to transmit data from the tools on the bottom of the drillstring to the processors at the surface.

Logging while drilling

In the 1980s, a new technique, logging while drilling (LWD), was introduced which provided similar information about the well. Instead of sensors being lowered into the well at the end of wireline cable, the sensors are integrated into the drill string and the measurements are made while the well is being drilled. While wireline well logging occurs after the drill string is removed from the well, LWD measures geological parameters while the well is being drilled. However, because there are no wires to the surface, data are recorded downhole and retrieved when the drill string is removed from the hole. A small subset of the measured data can also be transmitted to the surface in real time via pressure pulses in the well's mud fluid column. This mud telemetry method

provides a bandwidth of much less than 100 bits per second, although, as drilling through rock is a fairly slow process, data compression techniques mean that this is an ample bandwidth for real-time delivery of information.

Logging measurement types

Logging measurements are quite sophisticated. The prime target is the measurement of various geophysical properties of the subsurface rock formations. Of particular interest are porosity, permeability, and fluid content. Porosity is the proportion of fluid-filled space found within the rock. It is this space that contains the oil and gas. Permeability is the ability of fluids to flow through the rock. The higher the porosity, the higher the possible oil and gas content of a rock reservoir. The higher the permeability, the easier for the oil and gas to flow toward the wellbore. Logging tools provide measurements that allow for the mathematical interpretation of these quantities.

Beyond just the porosity and permeability, various logging measurements allow the interpretation of what kinds of fluids are in the pores—oil, gas, brine. In addition, the logging measurements are used to determine mechanical properties of the formations. These mechanical properties determine what kind of enhanced recovery methods may be used (tertiary recovery) and what damage to the formation (such as erosion) is to be expected during oil and gas production.

The types of instruments used in well logging are quite broad. The first logging measurements consisted of basic electrical resistivity logs and spontaneous potential (SP) logs, introduced by the Schlumberger brothers in the 1920s. Tools later became available to estimate porosity via sonic velocity and nuclear measurements. Tools are now more specialized and better able to resolve fine details in the formation. Radiofrequency transmission and coupling techniques are used to determine electrical conductivity of fluid (brine is more conductive than oil or gas). Sonic transmission characteristics (pressure waves) determine mechanical integrity. Nuclear magnetic resonance (NMR) can determine the properties of the hydrogen atoms in the pores (surface tension, etc.). Nuclear scattering (radiation scattering), spectrometry and absorption measurements can determine density and elemental analysis or composition. High resolution electrical or acoustical imaging logs are used to visualize the formation, compute formation dip, and analyze thinly-bedded and fractured reservoirs.

In addition to sensor-based measurements above, robotic equipment can sample formation fluids which may then be brought to the surface for laboratory examination. Also, controlled flow measurements can be used to determine in situ viscosity, water and gas cut (percentage), and other fluid and production parameters.

Geological logs

Geological logs use data collected at the surface, rather than by downhole instruments. The geological logs include *drilling time logs*, *core logs*, *sample logs*, and *mud logs*. Mud logs have become the oil industry standard.

Drilling time logs record the time required to drill a given thickness of rock formation. A change in the drilling rate or penetration rate usually means a change in the type of rock penetrated by the bit. The drilling time is expressed as minutes per foot, while the rate of penetration is usually expressed as feet per hour. Therefore, drilling time is the inverse of penetration rate.

Sample logs are made by examining cuttings, which are bits of rock circulated to the surface by the drilling mud in rotary drilling. The cuttings have traveled up the wellbore suspended in the drilling fluid or mud which was pumped into the wellbore via the drill string/pipe and they return to the surface via the annulus, then to the shale shakers via the flow line. Cuttings are then separated from the drilling fluid as they move across the shale shakers and are sampled at regular depth intervals. These rock samples are analyzed and described by the wellsite geologist or mudlogger.

Mud logs are prepared by a mud logging company contracted by the operating company. One parameter a typical mud log displays is the formation gas (gas units or ppm). "The gas recorder usually is scaled in terms of arbitrary gas units, which are defined differently by the various gas-detector manufactures. In practice, significance is placed only on relative changes in the gas concentrations detected." The current industry standard mud log normally includes real-time drilling parameters such as rate of penetration (ROP), lithology, gas hydrocarbons, flow line temperature (temperature of the drilling fluid) and chlorides but may also include mud weight, estimated pore pressure and corrected d-exponent (corrected drilling exponent) for a pressure pack log. Other information that is normally notated on a mud log include lithology descriptions, directional data (deviation surveys), weight on bit, rotary speed, pump pressure, pump rate, viscosity, drill bit info, casing shoe depths, formation tops, mud pump info, to name just a few.

Wireline log

A continuous measurement of formation properties with electrically powered instruments to infer properties and make decisions about drilling and production operations. The record of the measurements, typically a long strip of paper, is also called a log. Measurements include electrical properties (resistivity at various frequencies), sonic properties, active and passive nuclear measurements, dimensional measurements of the wellbore, formation fluid sampling, formation pressure measurement, wireline-conveyed sidewall coring tools, and others. In wireline measurements, the logging tool (or probe) is lowered into the open wellbore on a multiple conductor, contra-helicallly armored wireline. Once lowered to the bottom of the interval of interest, the measurements are taken on the way out of the wellbore. This is done in an attempt to maintain tension on the cable (which stretches) as constant as possible for depth correlation purposes. (The exception to this practice is in certain hostile environments in which the tool electronics might not survive the temperatures on bottom for the amount of time it takes to lower the tool and then record measurements while pulling the tool up the hole. In this case, "down log" measurements might actually be conducted on the way into the well, and repeated on the way out if possible.) Most wireline measurements are recorded continuously even though the probe is moving. Certain fluid sampling and

pressure-measuring tools require that the probe be stopped, increasing the chance that the probe or the cable might become stuck. LWD tools take measurements in much the same way as wireline-logging tools, except that the measurements are taken by a self-contained tool near the bottom of the bottomhole assembly and are recorded downward (as the well is deepened) rather than upward from the bottom of the hole (as wireline logs are recorded).

Memory log

This method of data acquisition involves recording the sensor data into a down hole memory, rather than transmitting "Real Time" to surface. There are some advantages and disadvantages to this memory option.

- The tools can be conveyed into wells where the trajectory is deviated or extended beyond the reach of conventional Electric Wireline cables. This can involve a combination of weight to strength ratio of the electric cable over this extended reach. In such cases the memory tools can be conveyed on Pipe or Coil Tubing.
- The type of sensors are limited in comparison to those used on Electric Line, and tend to be focussed on the cased hole, production stage of the well. Although there are now developed some memory "Open Hole" compact formation evaluation tool combinations. These tools can be deployed and carried downhole concealed internally in drill pipe to protect them from damage while running in the hole, and then "Pumped" out the end at depth to initiate logging. Other basic open hole formation evaluation memory tools are available for use in "Commodity" markets on slickline to reduce costs and operating time.
- In cased hole operation there is normally a "Slick Line" intervention unit. This uses a solid mechanical wire (.82 - .125 inches in OD), to manipulate or otherwise carry out operations in the well bore completion system. Memory operations are often carried out on this Slickline conveyance in preference to mobilizing a full service Electric Wireline unit.
- Since the results are not known until returned to surface, any realtime well dynamic changes cannot be monitored real time. This limits the ability to modify or change the well down hole production conditions accurately during the memory logging by changing the surface production rates. Something that is often done in Electric Line operations.
- Failure during recording is not known until the memory tools are retrieved. This loss of data can be a major issue on large offshore (expensive) locations. On land locations (e.g. South Texas, US) where there is what is called a "Commodity" Oil service sector, where logging often is without the rig infrastructure. this is less problematic, and logs are often run again without issue.

Information use

In the oil industry, the well and mud logs are usually transferred in 'real time' to the operating company, which uses these logs to make operational decisions about the well, to correlate formation depths with surrounding wells, and to make interpretations about

the quantity and quality of hydrocarbons present. Specialists involved in well log interpretation are called log analysts.

Well logging images



Wireline attached to top of Christmas Tree



Oil Well Top of Wireline



Wireline Truck with drum (inside)



Wax being removed off a wireline wax knife



BO shifting tool

Chapter 12

Pile Driver



A crane with a pile driver.

A **pile driver** is a mechanical device used to drive piles into soil to provide foundation support for buildings or other structures. The term is also used in reference to members of the construction crew that work with pile-driving rigs.

One traditional type of pile driver includes a heavy weight placed between guides so that it is able to freely slide up and down in a single line. It is placed upon a pile. The weight is raised, which may involve the use of hydraulics, steam, diesel, or manual labour. When the weight reaches its highest point it is then released and smashes on to the pile in order to drive it into the ground.

History



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

There is a number of claims to the inventor of the pile driver. A mechanically sound drawing of a pile driver appeared as early as 1475 in Francesco di Giorgio Martini's treatise *Trattato di Architettura*. Also, several other prominent inventors — James Nasmyth (son of Alexander Nasmyth), watchmaker James Valoué, Count Giovan Battista Gazzola, and Leonardo da Vinci — have all been credited with inventing the device. However, there is evidence that a comparable device was used in the construction of Crannogs at Oakbank and Loch Tay in Scotland as early as 5000 years ago. Otis Tufts is credited with inventing the steam pile driver in the United States.

Types

Ancient pile driving equipment used manual or animal labor to lift heavy weights, usually by means of pulleys, to drop the weight onto the end of the pile. Modern piledriving equipment uses various methods to raise the weight and guide the pile.

Diesel hammer

A modern diesel pile hammer is a very large two-stroke diesel engine. The weight is the piston, and the apparatus which connects to the top of the pile is the cylinder. Piledriving is started by having the weight raised by auxiliary means — usually a cable from the crane holding the pile driver — which draws air into the cylinder. The weight is dropped, using a quick-release. The weight of the piston compresses the air, heating it to the ignition point of diesel fuel. Diesel fuel is added/injected into the cylinder. The mixture ignites, transferring the energy of the falling weight to the pile head, and driving the weight back up. The rising weight draws in fresh air, and the cycle starts over until the fuel runs out or is stopped by the pile crew.

From an army manual on pile driving hammers:

The initial start up of the hammer requires the piston (ram) to be raised to a point where the trip automatically releases the piston, allowing it to fall by gravity. As the piston falls, it activates the fuel pump, which discharges a metered amount of fuel into the ball pan of the impact block. The falling piston also blocks the exhaust ports, and compression of fuel trapped in the cylinder begins. The compressed air exerts a pre-load force (approx. 44,000 lbs. or 20,000 kg.) to hold the impact block firmly against the drive cap and pile. At the bottom of the compression stroke, the piston strikes the impact block, atomizing the fuel and starting the pile on its downward movement. In the instant after the piston strikes, the atomized fuel ignites, and the resulting explosion exerts an even greater force on the already moving pile, driving it further into the ground. The reaction of the explosion rebounding from the resistance of the pile drives the piston upward. As the piston rises, the exhaust ports open, releasing the gases and force of the explosion into the atmosphere. After the piston stops its upward movement, it again falls by gravity to start another cycle.

Hydraulic hammer

A hydraulic hammer is a modern type of piling hammer used in place of diesel and air hammers for driving steel pipe, precast concrete, and timber piles. Hydraulic hammers are more environmentally acceptable than the older, less efficient hammers as they generate less noise and pollutants.

Hydraulic press-in



A steel sheet pile being hydraulically pressed

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

Such equipment and methods are specified into portions of the internal drainage system in the New Orleans area after Hurricane Katrina as well as many projects around the

world where noise, vibrations and limited access are a concern during the engineering, design and construction phases of the project.

Vibratory pile driver/extractor



A vibratory pile driver on a steel H-pile powered by a diesel engine.

Vibratory pile hammers contain a system of counter-rotating eccentric weights, powered by hydraulic motors, and designed in such a way that horizontal vibrations cancel out, while vertical vibrations are transmitted into the pile. The pile driving machine is lifted and positioned over the pile by means of an excavator or crane, and is fastened to the pile by a clamp and/or bolts. Vibratory hammers can either drive in or extract a pile; extraction is commonly used to recover steel "H" piles used in temporary foundation shoring. Hydraulic fluid is typically supplied to the driver by a diesel engine powered

pump mounted in a trailer or van and connected to the driver head through a set of long hoses. When the pile driver is connected to a dragline excavator, it is powered by the excavator's own diesel engine. Vibratory pile drivers are often chosen to mitigate noise, as when the construction is very close to residence or office buildings, or when there is not enough vertical clearance above the foundation to permit use of a conventional pile hammer (for example when retrofitting additional piles to a bridge column or abutment footing). Hammers are available with several different vibration rates, ranging from about 1200 vibrations per minute to about 2400 VPM; the vibration rate chosen is influenced by soil conditions at the site and other factors such as power requirements and purchase price of the equipment.

Piling rig

A **piling rig** is a construction machine for piling in foundation engineering. It is mainly applied to drill in sandy soil, clay, silty clay, etc. and widely used cast-in-place piles, diaphragm walls, foundation reinforcement and other foundation projects. Its rated power of engine is around 108-450 kW, output torque 60-400 kN•m, maximum pile diameter 1.5–4 m, maximum pile depth 60–90 m. It can meet construction requirement of kinds of foundation engineering projects. It generally applies hydraulic crawler chassis, automatic lift box-type mast, telescopic drill pipe, auto vertical adjustor, depth indicator, etc. Its operation applies hydraulic pilot control, load sensor, thus it is easy and comfortable to control. Main and auxiliary hoisting can meet different requirements in construction sites. The rig can be used on piling construction in dry (short screw), wet soil (rotary bucket) and rock (core drill) by equipping with drilling tool, and can be equipped with long screw drill, diaphragm wall grab, vibratory hammer, etc., to realize many functions. It is mainly used in foundation engineering of municipal construction, expressway, bridge, industrial and civil buildings, diaphragm wall, water conservancy project, Slope protection, etc.

Piling rigs categories

1. small-sized - torque is around 60-100 kN•m, engine power 108 kW, drilling diameter 0.5-1.2m, drilling depth 40m, total quality 40t.
2. middle-sized - torque is around 120-180 kN•m, engine power 125-200 kW, drilling diameter 0.8-1.8m, drilling depth 60m, total quality 42-65t.
3. large-sized - torque is around 240 kN•m, engine power 300 kW, drilling diameter 1-2.5m, drilling depth 80m, total quality 100t.

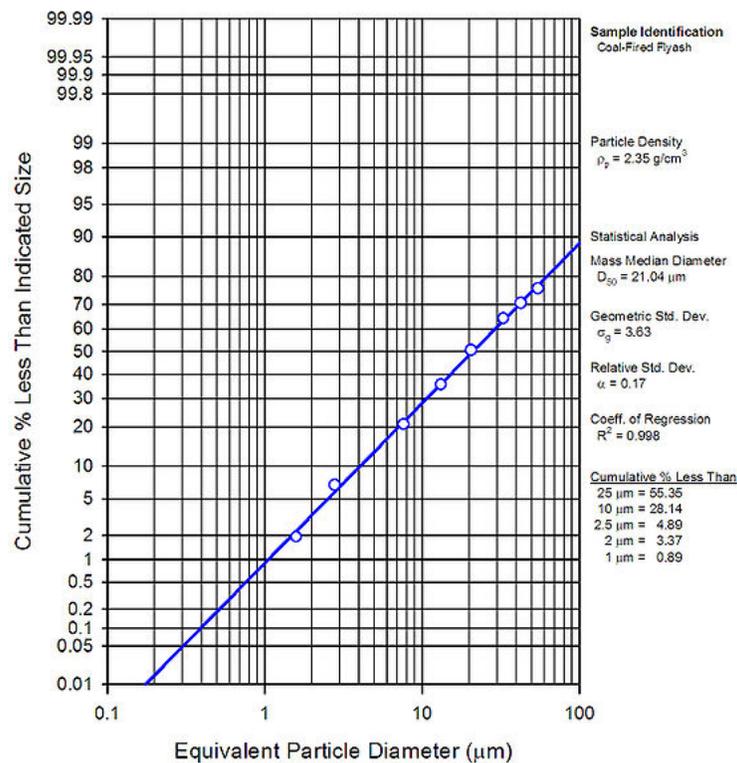
Environmental effects

The underwater sound pressure caused by pile-driving may be deleterious to fish when conducted adjacent to fish-bearing waters. State and local regulatory agencies manage environment issues associated with pile-driving.

Chapter 13

Particle Size Distribution

The **particle size distribution (PSD)** of a powder, or granular material, or particles dispersed in fluid, is a list of values or a mathematical function that defines the relative amounts of particles present, sorted according to size. PSD is also known as **grain size distribution**.



A log-normal distribution of coal-fired Fly Ash.

Significance

The PSD of a material can be important in understanding its physical and chemical properties. It affects the strength and load-bearing properties of rocks and soils. It affects the reactivity of solids participating in chemical reactions, and needs to be tightly controlled in many industrial products such as the manufacture of printer toner and cosmetics.

Significance in the Collection of Particulate Matter

Particle size distribution can greatly affect the efficacy of any collection device.

Settling Chambers will normally only collect very large particles, those that can be separated using sieve trays.

Centrifugal Collectors will normally collect particles down to about 20 μm . Higher efficiency models can collect particles down to 10 μm .

Fabric Filters are one of the most efficient and cost effective types of dust collectors available and can achieve a collection efficiency of more than 99% for very fine particulates.

Wet Scrubbers that use liquid are commonly known as wet scrubbers. In these systems, the scrubbing liquid (usually water) comes into contact with a gas stream containing dust particles. The greater the contact of the gas and liquid streams, the higher the dust removal efficiency.

Electrostatic Precipitators use electrostatic forces to separate dust particles from exhaust gases. They can be very efficient at the collection of very fine particles.

Nomenclature

ρ_p : Actual particle density (g/cm^3)

ρ_g : Gas or sample matrix density (g/cm^3)

r^2 : Least-squares coefficient of determination. The closer this value is to 1.0, the better the data fit to a straight-line.

λ : Gas mean free path (cm)

D_{50} : Mass-median-diameter (MMD). The log-normal distribution mass median diameter. The MMD is considered to be the average particle diameter by mass.

σ_g : Geometric standard deviation. This value is determined mathematically by the equation:

$$\sigma_g = D_{84.13} / D_{50} = D_{50} / D_{15.87}$$

The value of σ_g determines the slope of the least-squares regression curve.

α : Relative standard deviation or degree of polydispersity. This value is also determined mathematically. For values less than 0.1, the particulate sample can be considered to be monodisperse.

$$\alpha = \sigma_g / D_{50}$$

$R_{e(p)}$: Particle Reynolds Number. In contrast to the large numerical values noted for flow Reynolds number, particle Reynolds number for fine particles in gaseous mediums is typically less than 0.1.

R_{ef} : Flow Reynolds number.

K_n : Particle Knudsen number.

Types

The way PSD is expressed is usually defined by the method by which it is determined. The most easily understood method of determination is sieve analysis, where powder is separated on sieves of different sizes. Thus, the PSD is defined in terms of discrete size ranges: e.g. "% of sample between 45 μm and 53 μm ", when sieves of these sizes are used. The PSD is usually determined over a list of size ranges that covers nearly all the sizes present in the sample. Some methods of determination allow much narrower size ranges to be defined than can be obtained by use of sieves, and are applicable to particle sizes outside the range available in sieves. However, the idea of the notional "sieve", that "retains" particles above a certain size, and "passes" particles below that size, is universally used in presenting PSD data of all kinds.

The PSD may be expressed as a "range" analysis, in which the amount in each size range is listed in order. It may also be presented in "cumulative" form, in which the total of all sizes "retained" or "passed" by a single notional "sieve" is given for a range of sizes. Range analysis is suitable when a particular ideal mid-range particle size is being sought, while cumulative analysis is used where the amount of "under-size" or "over-size" must be controlled.

The way in which "size" is expressed is open to a wide range of interpretations. A simple treatment assumes the particles are spheres that will just pass through a square hole in a "sieve". In practice, particles are irregular - often extremely so, for example in the case of fibrous materials - and the way in which such particles are characterized during analysis is very dependent on the method of measurement used.

Sampling

Before PSD can be determined, it is vital that a precisely representative sample is obtained. The material to be analyzed must be carefully blended, and the sample withdrawn using techniques that avoid size segregation. Particular attention must be paid to avoidance of loss of fines during manipulation of the sample.

Measurement techniques

Sieve analysis

This continues to be used for many measurements because of its simplicity, cheapness, and ease of interpretation. Methods may be simple shaking of the sample in sieves until the amount retained becomes more or less constant. Alternatively, the sample may be washed through with a non-reacting liquid (usually water) or blown through with an air current.

Advantages

This technique is well-adapted for bulk materials. A large amount of materials can be readily loaded into 8-inch-diameter (200 mm) sieve trays. Two common uses in the power industry are wet-sieving of milled limestone and dry-sieving of milled coal.

Disadvantages

Many PSDs are concerned with particles too small for separation by sieving to be practical. A very fine sieve, such as 37 μm sieve, is exceedingly fragile, and it is very difficult to get material to pass through it. Another disadvantage is that the amount of energy used to sieve the sample is arbitrarily determined. Over-energetic sieving causes attrition of the particles and thus changes the PSD, while insufficient energy fails to break down loose agglomerates. Although manual sieving procedures can be ineffective, automated sieving technologies using image fragmentation analysis software are available. These technologies can sieve material by capturing and analyzing a photo of material.

Air elutriation analysis

An air elutriator is a simple device which can separate particles into two or more groups. Material may be separated by means of an elutriator, which consists of a vertical tube up which fluid is passed at a controlled velocity. When the particles are introduced, often through a side tube, the smaller particles are carried over in the fluid stream while the large particles settle against the upward current. If we start with low flow rates small less dense particle attain terminal velocities, and flow with the stream, the particle from the stream is collected in overflow and hence will be separated from the feed. Flow rates can be increased to separate higher size ranges. Further size fractions may be collected if the

overflow from the first tube is passed vertically upwards through a second tube of greater cross-section, and any number of such tubes can be arranged in series.

Technique Advantages: A bulk sample is analyzed using centrifugal classification and the technique is non-destructive. Each cut-point can be recovered for future size-respective chemical analyses. This technique has been used for decades in the Air Pollution Control industry (data used for design of control devices). This technique determines particle size as a function of settling velocity in an air stream (as opposed to water, or some other liquid).

Technique Disadvantages: A bulk sample (about ten grams) must be obtained. It is a fairly time-consuming analytical technique. The actual test method has been withdrawn by ASME due to obsolescence. Instrument calibration materials are therefore no longer available.

Photoanalysis

Materials can now be analysed through photoanalysis procedures. Unlike sieve analyses which can be time-consuming and inaccurate, taking a photo of a sample of the materials to be measured and using software to analyze the photo can result in rapid, accurate measurements. Another advantage is that the material can be analyzed without being handled. This is beneficial in the agricultural industry, as handling of food products can lead to contamination. Photoanalysis equipment and software is currently being used in mining, forestry and agricultural industries worldwide.

Optical counting methods

PSDs can be measured microscopically by sizing against a graticule and counting, but for a statistically valid analysis, millions of particles must be measured. This is impossibly arduous when done manually, but automated analysis of electron micrographs is now commercially available. Instruments such as the Retsch Camsizer can perform this analysis on the run using standard camera technology.

Electroresistance counting methods

An example of this is the Coulter counter, which measures the momentary changes in the conductivity of a liquid passing through an orifice that take place when individual non-conducting particles pass through. The particle count is obtained by counting pulses, and the size is dependent on the size of each pulse.

Technique Advantages: Very small sample aliquots can be examined.

Technique Disadvantages: Sample must be dispersed in a liquid medium... some particles may (partially or fully) dissolve in the medium altering the size distribution. The results are only related to the projected cross-sectional area that a particle displaces as it passes

through an orifice. This is a physical diameter, not really related to mathematical descriptions of particles (e.g. terminal settling velocity).

Sedimentation techniques

These are based upon study of the terminal velocity acquired by particles suspended in a viscous liquid. Sedimentation time is longest for the finest particles, so this technique is useful for sizes below 10 μm , but sub-micrometer particles cannot be reliably measured due to the effects of Brownian motion. Typical apparatus disperses the sample in liquid, then measures the density of the column at timed intervals. Other techniques determine the optical density of successive layers using visible light or x-rays.

Technique Advantages: This technique determines particle size as a function of settling velocity.

Technique Disadvantages: Sample must be dispersed in a liquid medium... some particles may (partially or fully) dissolve in the medium altering the size distribution, requiring careful selection of the dispersion media. Density is highly dependent upon fluid temperature remaining constant. X-Rays will not count carbon (organic) particles. Many of these instruments can require a bulk sample (e.g. two to five grams).

Laser diffraction methods

These depend upon analysis of the "halo" of diffracted light produced when a laser beam passes through a dispersion of particles in air or in a liquid. The angle of diffraction increases as particle size decreases, so that this method is particularly good for measuring sizes between 0.1 and 3,000 μm . Advances in sophisticated data processing and automation have allowed this to become the dominant method used in industrial PSD determination. A particular advantage is that the technique can generate a continuous measurement for analyzing process streams.

Acoustic spectroscopy or ultrasound attenuation spectroscopy

Instead of light, this method employs ultrasound for collecting information on the particles that are dispersed in fluid. Dispersed particles absorb and scatter ultrasound similarly to light. This has been known since Lord Rayleigh developed the first theory of *ultrasound scattering* and published a book "The Theory of Sound" in 1878. There have been hundreds of papers studying ultrasound propagation through fluid particulates in the 20th century. It turns out that instead of measuring *scattered energy versus angle*, as with light, in the case of ultrasound, measuring the *transmitted energy versus frequency* is a better choice. The resulting ultrasound attenuation frequency spectra are the raw data for calculating particle size distribution. It can be measured for any fluid system with no dilution or other sample preparation. This is a big advantage of this method. Calculation of particle size distribution is based on theoretical models that are well verified for up to 50% by volume of dispersed particles.

Air pollution emissions measurements

Cascade Impactors – Particulate matter is withdrawn isokinetically from a source and segregated by size in a cascade impactor at the sampling point exhaust conditions of temperature, pressure, etc. Cascade impactors use the principle of inertial separation to size segregate particle samples from a particle laden gas stream. The mass of each size fraction is determined gravimetrically. The California Air Resources Board Method 501 is currently the most widely accepted test method for particle size distribution emissions measurements.

Mathematical models

Probability distributions

- The log-normal distribution is often used to approximate the particle size distribution of aerosols, aquatic particles and pulverized material.
- The Weibull distribution or Rosin Rammler distribution is a useful distribution for representing particle size distributions generated by grinding, milling and crushing operations.
- The log-hyperbolic distribution was proposed by Bagnold and Barndorff-Nielsen to model the particle-size distribution of naturally occurring sediments. This model suffers from having non-unique solutions for a range of probability coefficients.
- The skew log-Laplace model was proposed by Fieller, Gilbertson and Olbricht as a more simple alternative to the log-hyperbolic distribution.

Chapter 14

Fascine



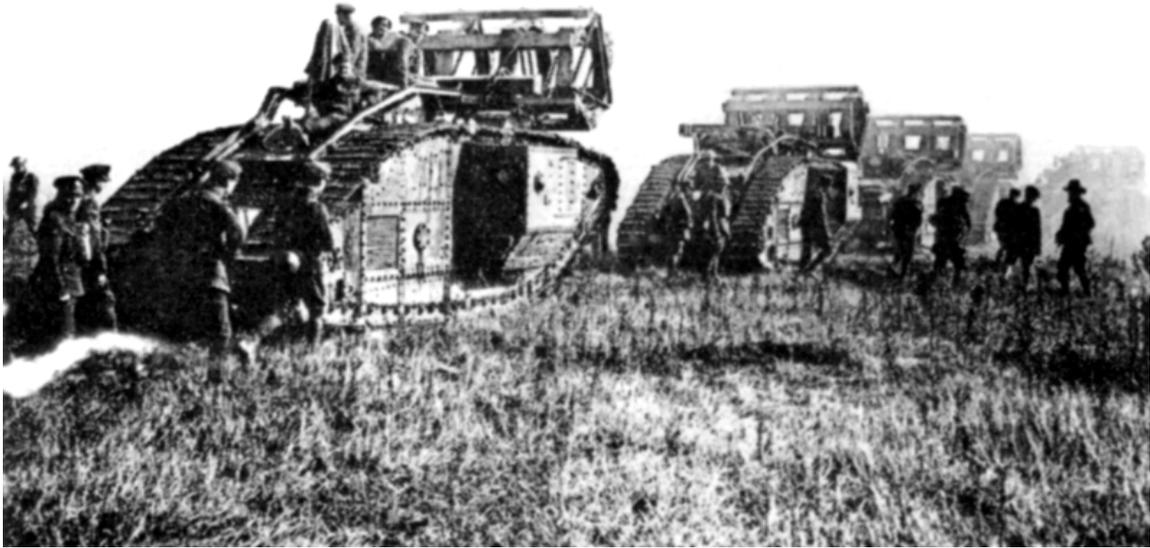
Templin Channel in Templin, Germany. Riverbank strengthened with fascines.

A **fascine** is a rough bundle of brushwood used for strengthening an earthen structure, or making a path across uneven or wet terrain. Typical uses are protecting the banks of streams from erosion, covering marshy ground and so on.

Early military use

Such "fascine" bundles were used in military defences for revetting (shoring up) trenches or ramparts, especially around artillery batteries, or filling in ditches from earliest military actions. Military fascine bridges were used on a regular basis by the Romans to cross obstacles. Subsequently the use of fascines by military engineers continued almost wherever armies were deployed.

Military fascine in WW1 and WW2



British Mark V tanks carrying crib fascines, 1918.



A Churchill AVRE, carrying a fascine, crosses a ditch using an already deployed fascine, 1943.

First World War tanks, namely the British Mark IV, started the practice of carrying fascines on the roof, to be deployed to fill trenches that would otherwise be an obstacle to the tank. These were constructed from the traditional bundles of brushwood used to make fascines since Roman times. Although these were cumbersome to deploy they proved an effective gap crossing device and were used widely by the tanks of the day that weighed up to about 30 tons. In World War II the use of fascines continued as a gap crossing device and within the British Army these were launched from the Churchill AVRE - a Royal Engineer derivative of the standard Churchill tank (40 tons).

Modern military fascine post WW2

The modern pipe fascine was developed in the British Army in the early 1980s to meet the challenges of assuring the mobility of movement in West Germany in the event of a conflict with the Warsaw Pact.

This requirement stemmed from the terrain of West Germany where the majority of obstacles to mobility run north – south and movement by military forces would have been east – west. Thus this terrain naturally presented many obstacles to mobility. The most significant obstacles were those that would block movement of armour; primarily rivers, canals and other gaps in excess of 3m wide and more than 2m deep.

The larger gaps, rivers or canals, were to be crossed using bridges or ferries. The bridges or ferries would be hand assembled on the crossing sites in the areas to the rear of the combat zone. But gaps at the forward edge had to be bridged with armoured vehicles and the bridges launched without exposing the crew. This was achieved using the AVLB (Armoured Vehicle Launched Bridge). These could bridge gaps, from 5 m – 24.5m but, due to their expense, low numbers in service and need for frequent redeployment for use on other large gaps over 10m they could not viably be used on the numerous smaller gaps, from 3 – 10m.

The problem was that within the area of operation of the British Army, near Hannover, there is a significant number of smaller gaps, mainly drainage ditches, streams and small rivers approximately 5-10 m wide and 1.5 – 2.5 m deep that are sufficient to stop armoured vehicles. Given the low number of AVLBs available a solution was needed to bridge these gaps quickly and cheaply and, if required, under fire.

In World War I similar dry gaps, i.e. large trenches, had been bridged using wooden fascines and investigations started on using modern versions of these. However it soon became clear that these were ineffective for use with the much heavier modern vehicles of up to 70 tons, 3 – 4 times heavier than World War I vehicles. The modern vehicles quickly reduced the wood in the fascines to splinters and became ineffective. Further, many of the gaps in Germany had running water in them so wooden fascines were likely to float and not stay in position. The equipment also had to have the capability to be used in rapidly bridging anti tank ditches in assault operations in other operational scenarios.

The Royal Engineers Experimental Establishment at Christchurch did initial tests on the possible use of 9” high density plastic pipes held together with chains as an alternative that would allow water flow and not be damaged with the higher modern vehicle weight.

The further development of this concept was handed over to Lt C Roebuck RE and his troop, 5 Troop, 31 Armoured Engineer Squadron, 32 Armoured Engineer Regiment at Munsterlager, North Germany in 1982. This was the last Centurion Armoured Vehicle Royal Engineers (AVRE) Troop in the British Army with 6 AVREs and thus the unit likely to have to deploy the new equipment first in operations in its role as Assault

Engineers. The Centurion AVRE was a Centurion tank derivative with a bulldozer blade and 165mm demolition gun fitted.



Single fascine launch near Hannover - Centurion AVRE



Subsequent crossing near Hannover - Centurion AVRE



Fascine being mounted on front of AVRE during trials

The Troop built a number of testing prototypes in Germany for development into an effective operational solution that could be accepted into service and used across the Army by both Royal Engineer and other armoured units as required. The fascines were to be launched from with the Combat Engineer Tractor or the Centurion AVRE but also with options for deployment from other vehicles. The front of the AVRE was modified by the addition of a tilting cradle above the drivers compartment to take the fascine.

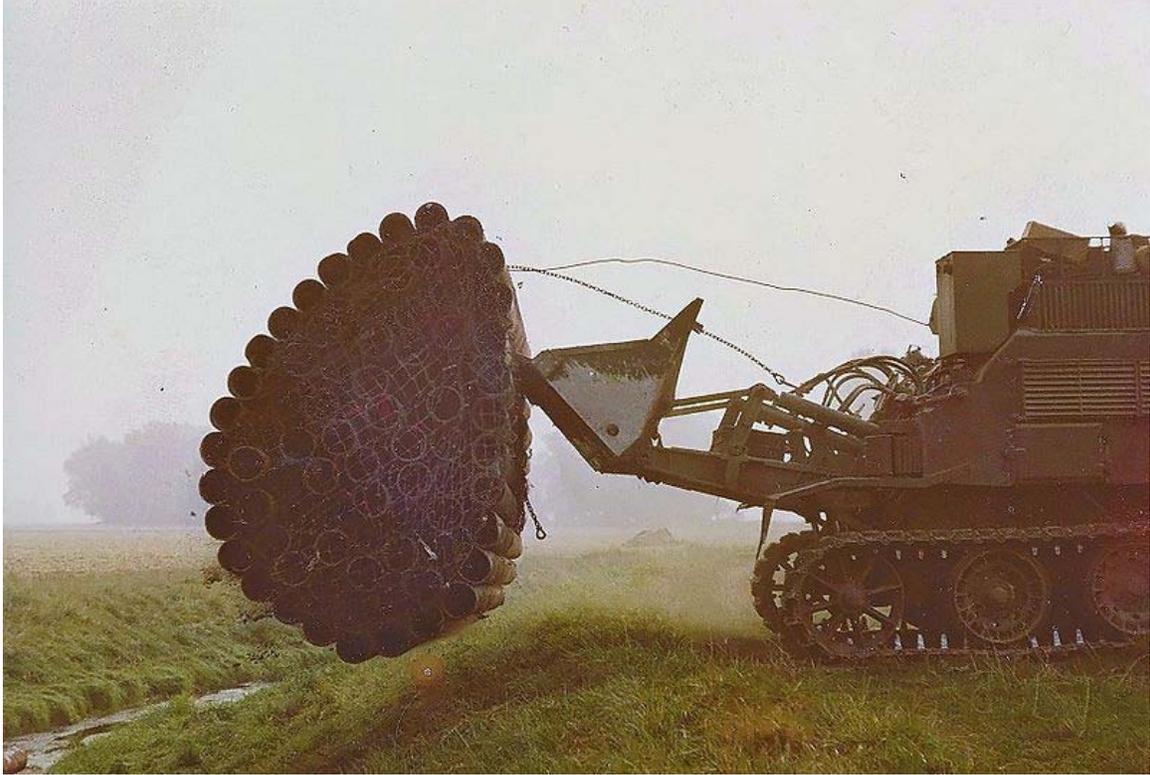
The trials involved a large number of test launches across multiple sites and a wide variety of situations to develop the structure and delivery of the fascine in operations, i.e. to find the optimum number of pipes and chain tension to create an effective level surface for vehicles in gaps, to ensure accurate deployment, rapid recovery and re deployment techniques or to test multiple launches for wider gaps. Vehicles in “shut down” combat mode and night time launches with no lights were also tested to simulate operational conditions. In “wet” gaps differing speeds and volumes of running water in the gap were tested for their impact on the fascines.

The launch technique was to approach the target gap at speed, brake sharply at a marked point and fire the explosive bolts holding the travel hawsers so that the fascine, through inertia, rolled off the AVRE directly into the middle of the gap. When in position the AVRE would then travel over it to level the road surface for other vehicles to cross. This whole process would take less than 1 minute, essential for an assault crossing possibly under fire.



River Fuhse Triple Fascine deployment - Centurion AVRE

Over a number of months the fascine was tested and developed, modifications were made, e.g. inserting splittable shackles in the chain holding the fascine together to allow rapid repair and tensioning, nets on the end of pipes to prevent pipes being pushed out by waterborne debris. The tests showed that with experienced drivers and crew up to 3 fascines could be launched in combination to bridge significant gaps, however this was restricted to 2 for safety reasons when using non ARVE crews. The night time testing of these was the most dangerous part of the trial with the risk of the AVRE tipping off the fascine into the gap, especially where it was a deep water gap.



Combat Engineer Tractor launch

After 6 months of hard work and innovative ideas from all ranks to refine the system the development trial was concluded and the final design, user hand book and acceptance recommendations were submitted by Chris Roebuck in November 1982. The fascine was subsequently accepted into service and used successfully in a number of operational and non operational roles. It was used in combat for the first time during the First Iraq war to breach anti tank ditches using the more recent Chieftain AVRE. It is now in regular use by the British Army and other armies as an effective aid to rapid crossing of small obstacles.

Currently, the British army uses the **ChAVRE** - an engineering vehicle based on the Chieftain tank - to carry and deploy pipe fascines. This is due to be replaced by the Trojan, based on the Challenger 2 tank. Current 32 Armoured Engineer

Chapter 15

Dam



Hoover Dam, a concrete arch-gravity dam in Black Canyon of the Colorado River. Lake Mead in the background is impounded by the dam.



Glen Canyon Dam

A **dam** is a barrier that impounds water or underground streams. Dams generally serve the primary purpose of retaining water, while other structures such as floodgates or levees (also known as dikes) are used to manage or prevent water flow into specific land regions. Hydropower and pumped-storage hydroelectricity are often used in conjunction with dams to generate electricity. A dam can also be used to collect water or for storage of water which can be evenly distributed between locations.

History



The sizable Roman Harbaqa Dam in Syria is 21 m high and 365 m long.



The Roman dam at Cornalvo in Spain has been in use for almost two millennia.



Grand Anicut dam on river Kaveri in Tamil Nadu, South India (19th century on 1st-2nd century foundation)

The word *dam* can be traced back to Middle English, and before that, from Middle Dutch, as seen in the names of many old cities. Early dam building took place in Mesopotamia and the Middle East. Dams were used to control the water level, for Mesopotamia's weather affected the Tigris and Euphrates rivers, and could be quite unpredictable.

The earliest known dam is the Jawa Dam in Jordan, 100 km northeast of the capital Amman. This gravity dam featured a 4.5 m high and 1 m wide stone wall, supported by a 50 m wide earth rampart. The structure is dated to 3000 BC. The Ancient Egyptian Sadd-

el-Kafara Dam at Wadi Al-Garawi, located about 25 kilometers south of Cairo, was 102 m long at its base and 87 m wide. The structure was built around 2800 or 2600 B.C. as a diversion dam for flood control, but was destroyed by heavy rain during construction or shortly afterwards. By the mid-late third century BC, an intricate water-management system within Dholavira, in modern day India, was built. The system included 16 reservoirs, dams and various channels for collecting water and storing it.

Roman dam construction was characterized by "the Romans' ability to plan and organize engineering construction on a grand scale". Roman planners introduced the then novel concept of large reservoir dams which could secure a permanent water supply for urban settlements also over the dry season. Their pioneering use of water-proof hydraulic mortar and particularly Roman concrete allowed for much larger dam structures than previously built, such as the Lake Homs Dam, possibly the largest water barrier to date, and the Harbaqa Dam, both in Roman Syria. The highest Roman dam was the Subiaco Dam near Rome; its record height of 50 m remained unsurpassed until its accidental destruction in 1305.

Roman engineers made routine use of ancient standard designs like embankment dams and masonry gravity dams. Apart from that, they displayed a high degree of inventiveness, introducing most of the other basic dam designs which had been unknown until then. These include arch-gravity dams, arch dams, buttress dams and multiple arch buttress dams, all of which were known and employed by the 2nd century AD. Roman workforces also were the first to build dam bridges, such as the Bridge of Valerian in Iran.

Eflatun Pınar is a Hittite dam and spring temple near Konya, Turkey. It's thought to be the time of the Hittite empire between the 15th and 13th century BC.

The Kallanai is a massive dam of unhewn stone, over 300 meters long, 4.5 meters high and 20 meters (60 ft) wide, across the main stream of the Kaveri river in Tamil Nadu, South India. The basic structure dates to the 1st century AD. and is considered one of the oldest water-diversion or water-regulator structures in the world, which is still in use. The purpose of the dam was to divert the waters of the Kaveri across the fertile Delta region for irrigation via canals. It is considered to be the oldest dam still in use.

Du Jiang Yan is the oldest surviving irrigation system in China that included a dam that directed waterflow. It was finished in 251 B.C. A large earthen dam, made by the Prime Minister of Chu (state), Sunshu Ao, flooded a valley in modern-day northern Anhui province that created an enormous irrigation reservoir (62 miles in circumference), a reservoir that is still present today.

In Iran, bridge dams such as the Band-e Kaisar were used to provide hydropower through water wheels, which often powered water-raising mechanisms. One of the first was the Roman-built dam bridge in Dezful, which could raise 50 cubits of water for the water supply to all houses in the town. Also diversion dams were known. Milling dams were introduced which the Muslim engineers called the *Pul-i-Bulaiti*. The first was built at

Shustar on the River Karun, Iran, and many of these were later built in other parts of the Islamic world. Water was conducted from the back of the dam through a large pipe to drive a water wheel and watermill. In the 10th century, Al-Muqaddasi described several dams in Persia. He reported that one in Ahwaz was more than 3,000 feet long, and that it had many water-wheels raising the water into aqueducts through which it flowed into reservoirs of the city. Another one, the *Band-i-Amir* dam, provided irrigation for 300 villages.

In the Netherlands, a low-lying country, *dams* were often applied to block rivers in order to regulate the water level and to prevent the sea from entering the marsh lands. Such dams often marked the beginning of a town or city because it was easy to cross the river at such a place, and often gave rise to the respective place's names in Dutch. For instance the Dutch capital Amsterdam (old name Amstelredam) started with a *dam* through the river Amstel in the late 12th century, and Rotterdam started with a *dam* through the river Rotte, a minor tributary of the Nieuwe Maas. The central square of Amsterdam, covering the original place of the 800 year old dam, still carries the name *Dam Square* or simply *the Dam*.

The age of hydropower and large dams emerged following the development of the turbine. French engineer Benoît Fourneyron perfected the first water turbine in 1832. The era of mega-dam building was initiated after Hoover Dam was completed on the Colorado River in 1936. By 1997, there were an estimated 800,000 dams worldwide, some 40,000 of them over fifteen meters high.

Types of dams

Dams can be formed by human agency, natural causes, or even by the intervention of wildlife such as beavers. Man-made dams are typically classified according to their size (height), intended purpose or structure.

By structure

Based on structure and material used, dams are classified as timber dams, arch-gravity dams, embankment dams or masonry dams, with several subtypes.

Arch dams



Gordon Dam, Tasmania is an arch dam.

In the arch dam, stability is obtained by a combination of arch and gravity action. If the upstream face is vertical the entire weight of the dam must be carried to the foundation by gravity, while the distribution of the normal hydrostatic pressure between vertical cantilever and arch action will depend upon the stiffness of the dam in a vertical and horizontal direction. When the upstream face is sloped the distribution is more complicated. The normal component of the weight of the arch ring may be taken by the arch action, while the normal hydrostatic pressure will be distributed as described above. For this type of dam, firm reliable supports at the abutments (either buttress or canyon side wall) are more important. The most desirable place for an arch dam is a narrow canyon with steep side walls composed of sound rock. The safety of an arch dam is

dependent on the strength of the side wall abutments, hence not only should the arch be well seated on the side walls but also the character of the rock should be carefully inspected.



Daniel-Johnson Dam, Quebec, is a multiple-arch buttress dam.

Two types of single-arch dams are in use, namely the constant-angle and the constant-radius dam. The constant-radius type employs the same face radius at all elevations of the dam, which means that as the channel grows narrower towards the bottom of the dam the central angle subtended by the face of the dam becomes smaller. Jones Falls Dam, in Canada, is a constant radius dam. In a constant-angle dam, also known as a variable radius dam, this subtended angle is kept a constant and the variation in distance between the abutments at various levels are taken care of by varying the radii. Constant-radius dams are much less common than constant-angle dams. Parker Dam is a constant-angle arch dam.

A similar type is the double-curvature or thin-shell dam. Wildhorse Dam near Mountain City, Nevada in the United States is an example of the type. This method of construction minimizes the amount of concrete necessary for construction but transmits large loads to the foundation and abutments. The appearance is similar to a single-arch dam but with a distinct vertical curvature to it as well lending it the vague appearance of a concave lens as viewed from downstream.

The multiple-arch dam consists of a number of single-arch dams with concrete buttresses as the supporting abutments, as for example the Daniel-Johnson Dam, Québec, Canada. The multiple-arch dam does not require as many buttresses as the hollow gravity type, but requires good rock foundation because the buttress loads are heavy.

Gravity dams



The Grand Coulee Dam is an example of a solid gravity dam.

In a gravity dam, stability is secured by making it of such a size and shape that it will resist overturning, sliding and crushing at the toe. The dam will not overturn provided that the moment around the turning point, caused by the water pressure, is smaller than the moment caused by the weight of the dam. This is the case if the resultant force of water pressure and weight falls within the base of the dam. However, in order to prevent tensile stress at the upstream face and excessive compressive stress at the downstream face, the dam cross section is usually designed so that the resultant falls within the middle at all elevations of the cross section (the core). For this type of dam, impervious foundations with high *bearing* strength are essential.

When situated on a suitable site, gravity dams can prove to be a better alternative to other types of dams. When built on a carefully studied foundation, the gravity dam probably represents the best developed example of dam building. Since the fear of flood is a strong motivator in many regions, gravity dams are being built in some instances where an arch dam would have been more economical.

Gravity dams are classified as "solid" or "hollow" and are generally made of either concrete or masonry. This is called "zoning". The core of the dam is zoned depending on the availability of locally available materials, foundation conditions and the material attributes. The solid form is the more widely used of the two, though the hollow dam is frequently more economical to construct. Gravity dams can also be classified as "overflow" (spillway) and "non-overflow." Grand Coulee Dam is a solid gravity dam and Itaipu Dam is a hollow gravity dam.

Arch-gravity dams



The Hoover Dam is an example of an arch-gravity dam.

A gravity dam can be combined with an arch dam into an arch-gravity dam for areas with massive amounts of water flow but less material available for a purely gravity dam.

Barrages



The Prakasham barrage is an example of a barrage.

A barrage dam is a special kind of dam which consists of a line of large gates that can be opened or closed to control the amount of water passing the dam. The gates are set between flanking piers which are responsible for supporting the water load. They are often used to control and stabilize water flow for irrigation systems.

Barrages that are built at the mouth of rivers or lagoons to prevent tidal incursions or utilize the tidal flow for tidal power are known as tidal barrages.

Embankment dams

Embankment dams are made from compacted earth, and have two main types, rock-fill and earth-fill dams. Embankment dams rely on their weight to hold back the force of water, like the gravity dams made from concrete.

Rock-fill dams

Rock-fill dams are embankments of compacted free-draining granular earth with an impervious zone. The earth utilized often contains a large percentage of large particles hence the term *rock-fill*. The impervious zone may be on the upstream face and made of

masonry, concrete, plastic membrane, steel sheet piles, timber or other material. The impervious zone may also be within the embankment in which case it is referred to as a *core*. In the instances where clay is utilized as the impervious material the dam is referred to as a *composite* dam. To prevent internal erosion of clay into the rock fill due to seepage forces, the core is separated using a filter. Filters are specifically graded soil designed to prevent the migration of fine grain soil particles. When suitable material is at hand, transportation is minimized leading to cost savings during construction. Rock-fill dams are resistant to damage from earthquakes. However, inadequate quality control during construction can lead to poor compaction and sand in the embankment which can lead to liquefaction of the rock-fill during an earthquake. Liquefaction potential can be reduced by keeping susceptible material from being saturated, and by providing adequate compaction during construction. An example of a rock-fill dam is New Melones Dam in California.

Earth-fill dams



The Atatürk Dam in Turkey is an embankment dam.

Earth-fill dams, also called earthen, rolled-earth or simply earth dams, are constructed as a simple embankment of well compacted earth. A *homogeneous* rolled-earth dam is entirely constructed of one type of material but may contain a drain layer to collect *seep* water. A *zoned-earth* dam has distinct parts or *zones* of dissimilar material, typically a locally plentiful *shell* with a watertight clay core. Modern zoned-earth embankments employ filter and drain zones to collect and remove seep water and preserve the integrity of the downstream shell zone. An outdated method of zoned earth dam construction

utilized a hydraulic fill to produce a watertight core. *Rolled-earth* dams may also employ a watertight facing or core in the manner of a rock-fill dam. An interesting type of temporary earth dam occasionally used in high latitudes is the *frozen-core* dam, in which a coolant is circulated through pipes inside the dam to maintain a watertight region of permafrost within it.

Tarbela Dam is a large dam on the Indus River in Pakistan. It is located about 50 km (31 mi) northwest of Islamabad, and a height of 485 ft (148 m) above the river bed and a reservoir size of 95 sq mi (250 km²) makes it the largest earth filled dam in the world. The principal element of the project is an embankment 9,000 feet (2743 meters) long with a maximum height of 465 feet (143 meters). The total volume of earth and rock used for the project is approximately 200 million cubic yards (152.8 million cu. Meters) which makes it the largest man made structure in the world , except for the Great Chinese Wall which consumed somewhat more material.

Because earthen dams can be constructed from materials found on-site or nearby, they can be very cost-effective in regions where the cost of producing or bringing in concrete would be prohibitive.

Asphalt-concrete core

A third type of embankment dam is built with asphalt concrete core. The majority of such dams are built with rock and/or gravel as the main fill material. Almost 100 dams of this design have now been built worldwide since the first such dam was completed in 1962. All asphalt-concrete core dams built so far have an excellent performance record. The type of asphalt used is a viscoelastic-plastic material that can adjust to the movements and deformations imposed on the embankment as a whole, and to settlements in the foundation. The flexible properties of the asphalt make such dams especially suited in earthquake regions.

By size

International standards (including International Commission on Large Dams, **ICOLD**) define *large dams* as higher than 15 meters and *major dams* as over 150 meters in height. The *Report of the World Commission on Dams* also includes in the *large* category, dams, such as Barrages, which are between 5 and 15 meters high with a reservoir capacity of more than 3 million cubic meters.

The tallest dam in the world is the 300-meter-high Nurek Dam in Tajikistan.

By use

Saddle dam

A saddle dam is an auxiliary dam constructed to confine the reservoir created by a primary dam either to permit a higher water elevation and storage or to limit the extent of

a reservoir for increased efficiency. An auxiliary dam is constructed in a low spot or *saddle* through which the reservoir would otherwise escape. On occasion, a reservoir is contained by a similar structure called a dike to prevent inundation of nearby land. Dikes are commonly used for *reclamation* of arable land from a shallow lake. This is similar to a levee, which is a wall or embankment built along a river or stream to protect adjacent land from flooding.

Weir

A weir (also sometimes called an *overflow dam*) is a type of small overflow dam that is often used within a river channel to create an impoundment lake for water abstraction purposes and which can also be used for flow measurement.

Check dam

A check dam is a small dam designed to reduce flow velocity and control soil erosion. Conversely, a *wing dam* is a structure that only partly restricts a waterway, creating a faster channel that resists the accumulation of sediment.

Dry dam

A dry dam is a dam designed to control flooding. It normally holds back no water and allows the channel to flow freely, except during periods of intense flow that would otherwise cause flooding downstream.

Diversionsary dam

A diversionsary dam is a structure designed to divert all or a portion of the flow of a river from its natural course.

By material

Steel dams



Red Ridge steel dam, b. 1905, Michigan.

A steel dam is a type of dam briefly experimented with in around the turn of the 19th-20th Century which uses steel plating (at an angle) and load bearing beams as the structure. Intended as permanent structures, steel dams were an (arguably failed) experiment to determine if a construction technique could be devised that was cheaper than masonry, concrete or earthworks, but sturdier than timber crib dams.

Timber dams



A timber crib dam in Michigan, photographed in 1978.

Timber dams were widely used in the early part of the industrial revolution and in frontier areas due to ease and speed of construction. Rarely built in modern times because of relatively short lifespan and limited height to which they can be built, timber dams must be kept constantly wet in order to maintain their water retention properties and limit deterioration by rot, similar to a barrel. The locations where timber dams are most economical to build are those where timber is plentiful, cement is costly or difficult to transport, and either a low head diversion dam is required or longevity is not an issue. Timber dams were once numerous, especially in the North American west, but most have failed, been hidden under earth embankments or been replaced with entirely new structures. Two common variations of timber dams were the *crib* and the *plank*.

Timber crib dams were erected of heavy timbers or dressed logs in the manner of a log house and the interior filled with earth or rubble. The heavy crib structure supported the dam's face and the weight of the water. Splash dams were timber crib dams used to help float logs downstream in the late 19th and early 20th centuries.

Timber plank dams were more elegant structures that employed a variety of construction methods utilizing heavy timbers to support a water retaining arrangement of planks.

Other types

Cofferdams



A cofferdam during the construction of locks at the Montgomery Point Lock and Dam.

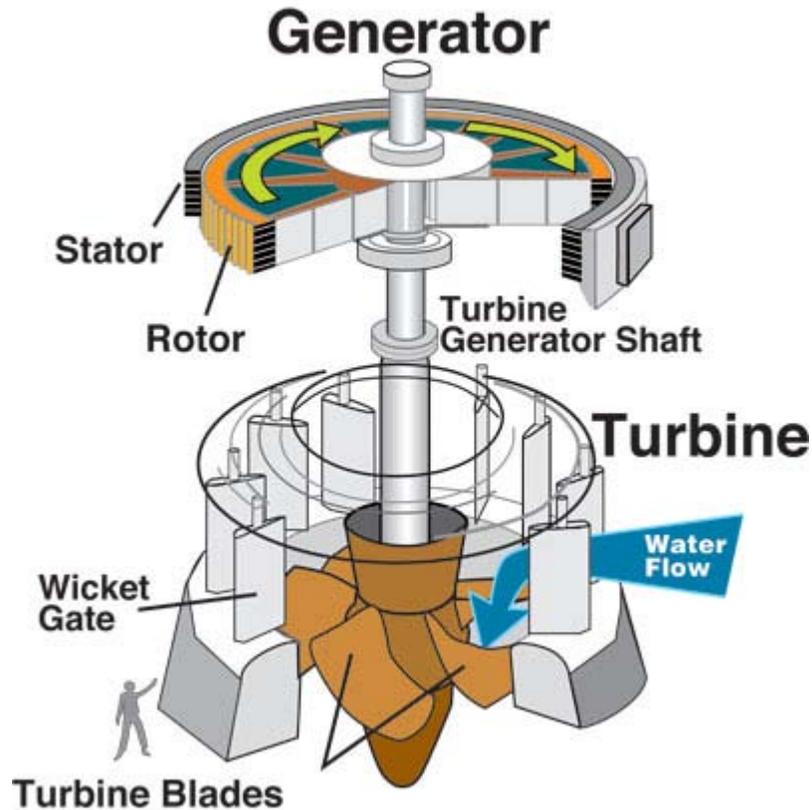
A cofferdam is a (usually temporary) barrier constructed to exclude water from an area that is normally submerged. Made commonly of wood, concrete or steel sheet piling, cofferdams are used to allow construction on the foundation of permanent dams, bridges, and similar structures. When the project is completed, the cofferdam may be demolished or removed. Common uses for cofferdams include construction and repair of off shore oil platforms. In such cases the cofferdam is fabricated from sheet steel and welded into place under water. Air is pumped into the space, displacing the water allowing a dry work environment below the surface. Upon completion the cofferdam is usually deconstructed unless the area requires continuous maintenance.

Beaver dams

Beavers create dams primarily out of mud and sticks to flood a particular habitable area. By flooding a parcel of land, beavers can navigate below or near the surface and remain relatively well hidden or protected from predators. The flooded region also allows beavers access to food, especially during the winter.

Construction elements

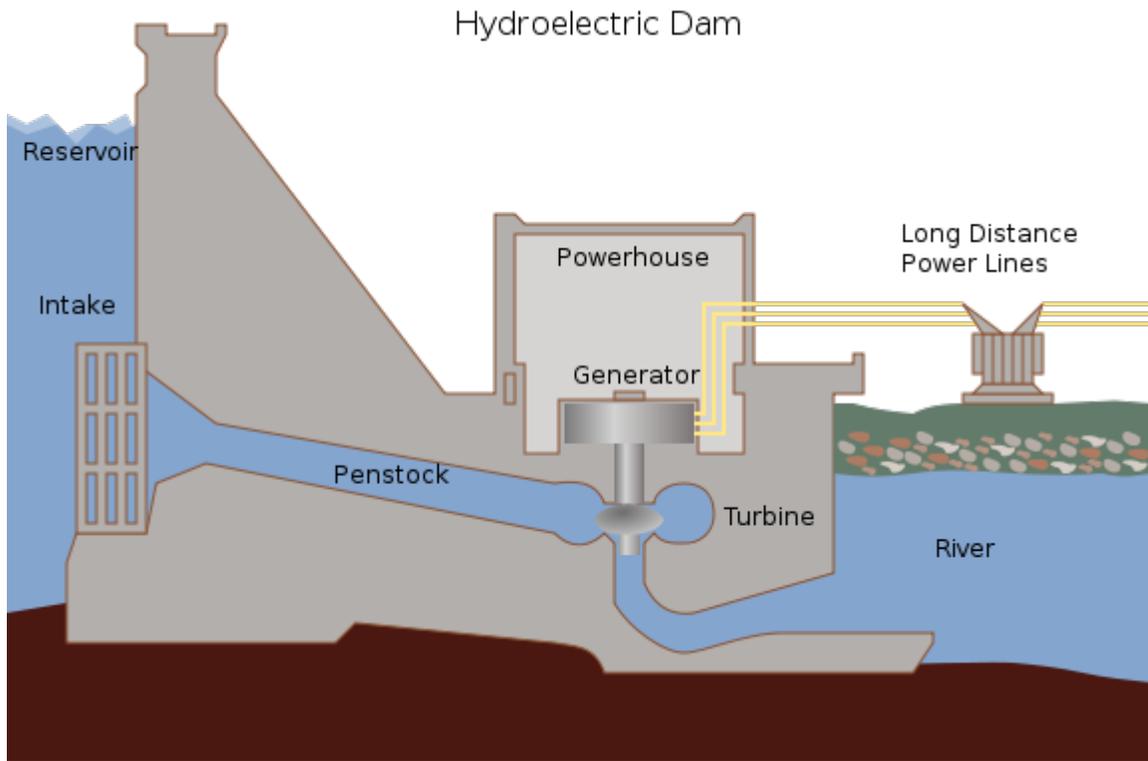
Power generation plant



Hydraulic turbine and electrical generator.

As of 2005, hydroelectric power, mostly from dams, supplies some 19% of the world's electricity, and over 63% of renewable energy. Much of this is generated by large dams, although China uses small scale hydro generation on a wide scale and is responsible for about 50% of world use of this type of power.

Most hydroelectric power comes from the potential energy of dammed water driving a water turbine and generator; to boost the power generation capabilities of a dam, the water may be run through a large pipe called a penstock before the turbine. A variant on this simple model uses pumped storage hydroelectricity to produce electricity to match periods of high and low demand, by moving water between reservoirs at different elevations. At times of low electrical demand, excess generation capacity is used to pump water into the higher reservoir. When there is higher demand, water is released back into the lower reservoir through a turbine.



Hydroelectric dam in cross section.

Spillways



Spillway on Llyn Brianne dam, Wales soon after first fill.

A *spillway* is a section of a dam designed to pass water from the upstream side of a dam to the downstream side. Many spillways have floodgates designed to control the flow through the spillway. Types of spillway include: A *service spillway* or *primary spillway* passes normal flow. An *auxiliary spillway* releases flow in excess of the capacity of the service spillway. An *emergency spillway* is designed for extreme conditions, such as a serious malfunction of the service spillway. A *fuse plug spillway* is a low embankment designed to be over topped and washed away in the event of a large flood. Fusegate elements are independent free-standing block set side by side on the spillway which work without any remote control. They allow to increase the normal pool of the dam without compromising the security of the dam because they are designed to be gradually

evacuated for exceptional events. They work as fixed weir most of the time allowing overspilling for the common floods.

The spillway can be gradually eroded by water flow, including cavitation or turbulence of the water flowing over the spillway, leading to its failure. It was the inadequate design of the spillway which led to the 1889 over-topping of the South Fork Dam in Johnstown, Pennsylvania, resulting in the infamous Johnstown Flood (the "great flood of 1889").

Erosion rates are often monitored, and the risk is ordinarily minimized, by shaping the downstream face of the spillway into a curve that minimizes turbulent flow, such as an ogee curve.

Dam creation

Common purposes

| Function | Example |
|--|--|
| Power generation | Hydroelectric power is a major source of electricity in the world. Many countries that have rivers with adequate water flow, that can be dammed for power generation purposes. For example, the Itaipu Dam on the Paraná River in South America generates 14 GW and supplied 93% of the energy consumed by Paraguay and 20% of that consumed by Brazil as of 2005. |
| Water supply | Many urban areas of the world are supplied with water abstracted from rivers pent up behind low dams or weirs. Examples include London - with water from the River Thames and Chester with water taken from the River Dee. Other major sources include deep upland reservoirs contained by high dams across deep valleys such as the Claerwen series of dams and reservoirs. |
| Stabilize water flow / irrigation | Dams are often used to control and stabilize water <i>flow</i> , often for agricultural purposes and irrigation. Others such as the Berg Strait dam can help to stabilize or restore the water <i>levels</i> of inland lakes and seas, in this case the Aral Sea. |
| Flood prevention | Dams such as the Blackwater dam of Webster, New Hampshire and the Delta Works are created with flood control in mind. |
| Land reclamation | Dams (often called dykes or levees in this context) are used to prevent ingress of water to an area that would otherwise be submerged, allowing its reclamation for human use. |
| Water diversion | A typically small dam used to divert water for irrigation, power generation, or other uses, with usually no other function. Occasionally, they are used to divert water to another drainage or reservoir to increase flow there and improve water use in that particular area. |

Navigation

Dams create deep reservoirs and can also vary the flow of water downstream. This can in return affect upstream and downstream navigation by altering the river's depth. Deeper water increases or creates freedom of movement for water vessels. Large dams can serve this purpose but most often weirs and locks are used.

Recreation and aquatic beauty

Dams built for any of the above purposes may find themselves displaced by time of their original uses. Nevertheless the local community may have come to enjoy the reservoir for recreational and aesthetic reasons. Often the reservoir will be placid and surrounded by greenery, and convey to visitors a natural sense of rest and relaxation.

Location



The discharge of Takato Dam

One of the best places for building a dam is a narrow part of a deep river valley; the valley sides can then act as natural walls. The primary function of the dam's structure is to fill the gap in the natural reservoir line left by the stream channel. The sites are usually those where the gap becomes a minimum for the required storage capacity. The most

economical arrangement is often a composite structure such as a masonry dam flanked by earth embankments. The current use of the land to be flooded should be dispensable.

Significant other engineering and engineering geology considerations when building a dam include:

- permeability of the surrounding rock or soil
- earthquake faults
- landslides and slope stability
- water table
- peak flood flows
- reservoir silting
- environmental impacts on river fisheries, forests and wildlife
- impacts on human habitations
- compensation for land being flooded as well as population resettlement
- removal of toxic materials and buildings from the proposed reservoir area

Impact assessment

Impact is assessed in several ways: the benefits to human society arising from the dam (agriculture, water, damage prevention and power), harm or benefits to nature and wildlife (especially fish and rare species), impact on the geology of an area - whether the change to water flow and levels will increase or decrease stability, and the disruption to human lives (relocation, loss of archeological or cultural matters underwater).

Environmental impact



Wood and garbage accumulated because of a dam

Reservoirs held behind dams affect many ecological aspects of a river. Rivers topography and dynamics depend on a wide range of flows whilst rivers below dams often experience long periods of very stable flow conditions or saw tooth flow patterns caused by releases followed by no releases. Water releases from a reservoir including that exiting a turbine usually contains very little suspended sediment, and this in turn can lead to scouring of river beds and loss of riverbanks; for example, the daily cyclic flow variation caused by the Glen Canyon Dam was a contributor to sand bar erosion.

Older dams often lack a fish ladder, which keeps many fish from moving up stream to their natural breeding grounds, causing failure of breeding cycles or blocking of migration paths. Even the presence of a fish ladder does not always prevent a reduction in fish reaching the spawning grounds upstream. In some areas, young fish ("smolt") are transported downstream by barge during parts of the year. Turbine and power-plant designs that have a lower impact upon aquatic life are an active area of research.

A large dam can cause the loss of entire ecospheres, including endangered and undiscovered species in the area, and the replacement of the original environment by a new inland lake.

Large reservoirs formed behind dams have been indicated in the contribution of seismic activity, due to changes in water load and/or the height of the water table.

Human social impact

The impact on human society is also significant. For example, the Three Gorges Dam on the Yangtze River in China is more than five times the size of the Hoover Dam (U.S.), and will create a reservoir 600 km long to be used for hydro-power generation. Its construction required the loss of over a million people's homes and their mass relocation, the loss of many valuable archaeological and cultural sites, as well as significant ecological change. It is estimated that to date, 40-80 million people worldwide have been physically displaced from their homes as a result of dam construction.

Economics

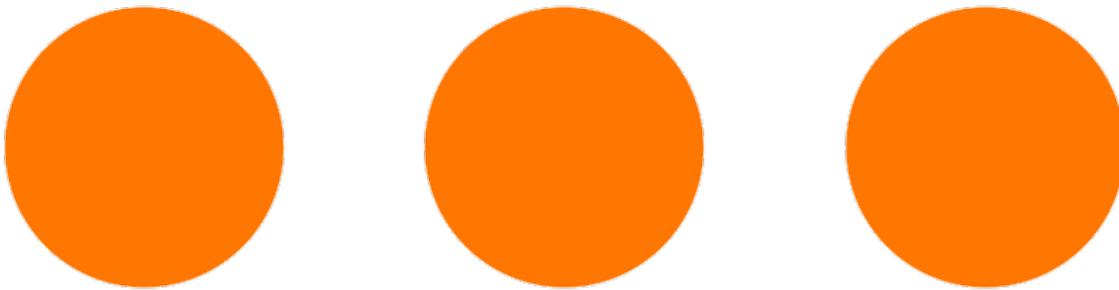
Construction of a hydroelectric plant requires a long lead-time for site studies, hydrological studies, and environmental impact assessment, and are large scale projects by comparison to traditional power generation based upon fossil fuels. The number of sites that can be economically developed for hydroelectric production is limited; new sites tend to be far from population centers and usually require extensive power transmission lines. Hydroelectric generation can be vulnerable to major changes in the climate, including variation of rainfall, ground and surface water levels, and glacial melt, causing additional expenditure for the extra capacity to ensure sufficient power is available in low water years.

Once completed, if it is well designed and maintained, a hydroelectric power source is usually comparatively cheap and reliable. It has no fuel and low escape risk, and as an alternative energy source it is cheaper than both nuclear and wind power. It is more easily regulated to store water as needed and generate high power levels on demand compared to wind power, although dams have life expectancies while renewable energies do not.

Dam failure



The reservoir emptying through the failed Teton Dam.



International special sign for works and installations containing dangerous forces

Dam failures are generally catastrophic if the structure is breached or significantly damaged. Routine deformation monitoring of seepage from drains in and around larger dams is necessary to anticipate any problems and permit remedial action to be taken before structural failure occurs. Most dams incorporate mechanisms to permit the reservoir to be lowered or even drained in the event of such problems. Another solution can be rock grouting - pressure pumping portland cement slurry into weak fractured rock.

During an armed conflict, a dam is to be considered as an "installation containing dangerous forces" due to the massive impact of a possible destruction on the civilian population and the environment. As such, it is protected by the rules of International Humanitarian Law (IHL) and shall not be made the object of attack if that may cause severe losses among the civilian population. To facilitate the identification, a protective sign consisting of three bright orange circles placed on the same axis is defined by the rules of IHL.

The main causes of dam failure include spillway design error (South Fork Dam), geological instability caused by changes to water levels during filling or poor surveying

(Vajont Dam, Malpasset, Testalinden Creek Dam), poor maintenance, especially of outlet pipes (Lawn Lake Dam, Val di Stava Dam collapse), extreme rainfall (Shakidor Dam), and human, computer or design error (Buffalo Creek Flood, Dale Dike Reservoir, Taum Sauk pumped storage plant).

A notable case of deliberate dam failure (prior to the above ruling) was the Royal Air Force 'Dambusters' raid on Germany in World War II (codenamed "*Operation Chastise*"), in which three German dams were selected to be breached in order to have an impact on German infrastructure and manufacturing and power capabilities deriving from the Ruhr and Eder rivers. This raid later became the basis for several films.

Since 2007, the Dutch IJkdijk foundation is developing, with an open innovation model and early warning system for levee/dike failures. As a part of the development effort, full scale dikes are destroyed in the IJkdijk fieldlab. The destruction process is monitored by sensor networks from an international group of companies and scientific institutions.