How Tunnels Work

by William Harris

At its most basic, a tunnel is a tube hollowed through soil or stone. Constructing a tunnel, however, is one of the most compl-ex challenges in the field of civil engineering. Many tunnels are considered technological masterpieces and governments have honored tunnel engineers as heroes. That's not to say, of course, that some tunnel projects haven't encountered major setbacks. The Central Artery/Tunnel Project (the "Big Dig") in Boston, Massachusetts was plagued by massive cost overruns, allegations of corruption, and a partial ceiling collapse that resulted in a fatality. But these challenges haven't stopped engineers from dreaming up even bigger and bolder ideas, such as building a Transatlantic Tunnel to connect New York with London.

In this article, we'll explore what makes tunnels such an attractive solution for railways, roadways, public utilities and telecommunications. We'll look at the defining characteristics of tunnels and examine how tunnels are built. We'll also look at the "Big Dig" in detail to understand the opportunities and challenges inherent to building a tunnel. Finally, we'll look at the future of tunnels.

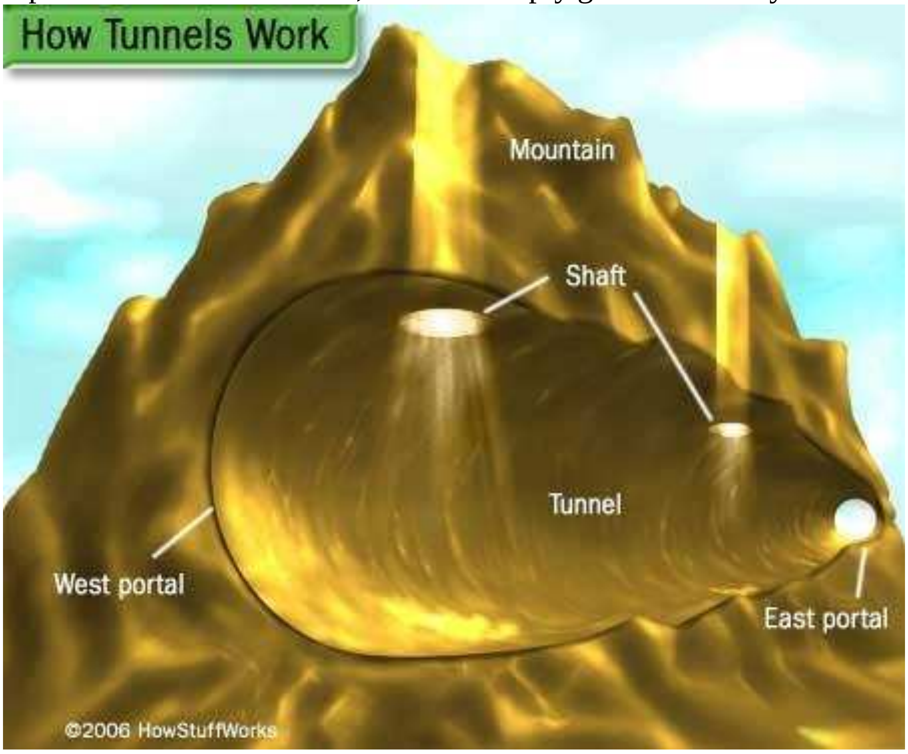
The Gotthard Base Tunnel, a railway tunnel under construction in Switzerland.

Tunnel Basics

A tunnel is a horizontal passageway located underground. While erosion and other forces of nature can form tunnels, in this article we'll talk about man made tunnels -- tunnels created by the process of excavation. There are many different ways to excavate a tunnel, including manual labor, explosives, rapid heating and cooling, tunneling machinery or a combination of these methods.

Some structures may require excavation similar to tunnel excavation, but are not actually tunnels. Shafts, for example, are often hand-dug or dug with boring equipment. But unlike tunnels, shafts are vertical and shorter. Often, shafts are built either as part of a tunnel project to analyze the rock or soil, or in tunnel construction to provide headings, or locations, from which a tunnel can be excavated.

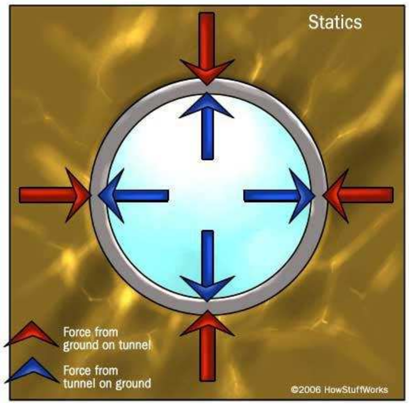
The diagram below shows the relationship between these underground structures in a typical mountain tunnel. The opening of the tunnel is a portal. The "roof" of the tunnel, or the top half of the tube, is the crown. The bottom half is the invert. The basic geometry of the tunnel is a continuous arch. Because tunnels must withstand tremendous pressure from all sides, the arch is an ideal shape. In the case of a tunnel, the arch simply goes all the way around.



Tunnel engineers, like bridge engineers, must be concerned with an area of physics known as statics. Statics describes how the following forces interact to produce equilibrium on structures such as tunnels and bridges:

- **Tension**, which expands, or pulls on, material
- **Compression**, which shortens, or squeezes material
- **Shearing**, which causes parts of a material to slide past one another in opposite directions
- **Torsion**, which twists a material

The tunnel must oppose these forces with strong materials, such as masonry, steel, iron and concrete.



In order to remain static, tunnels must be able to withstand the loads placed on them. **Dead load** refers to the weight of the structure itself, while **live load** refers to the weight of the vehicles and people that move through the tunnel.

Types of Tunnels

There are three broad categories of tunnels: mining, public works and transportation. Let's look briefly at each type.

Mine tunnels are used during ore extraction, enabling laborers or equipment to access mineral and metal deposits deep inside the earth. These tunnels are made using similar techniques as other types of tunnels, but they cost less to build. Mine tunnels are not as safe as tunnels designed for permanent occupation, however.

A coal miner standing on the back of a car in a mine tunnel in the early 1900s. Notice that the sides of the tunnel are shored up with timber.

Public works tunnels carry water, sewage or gas lines across great distances. The earliest tunnels were used to transport water to, and sewage away from, heavily populated regions. Roman engineers used an extensive network of tunnels to help carry water from mountain springs to cities and villages. These tunnels were part of aqueduct systems, which also comprised underground chambers and sloping bridge-like structures supported by a series of arches. By A.D. 97, nine aqueducts carried approximately 85 million gallons of water a day from mountain springs to the city of Rome.

A Roman aqueduct that runs from the Pools of Solomon to Jerusalem

Before there were trains and cars, there were **transportation tunnels** such as **canals** -- artificial waterways used for travel, shipping or irrigation. Just like railways and roadways today, canals usually ran above ground, but many required tunnels to pass efficiently through an obstacle, such as a mountain. Canal construction inspired some of the world's earliest tunnels.

The Underground Canal, located in Lancashire County and Manchester, England, was constructed from the mid- to late-1700s and includes miles of tunnels to house the underground canals. One of America's first tunnels was the Paw Paw Tunnel, built in West Virginia between 1836 and 1850 as part of the Chesapeake and Ohio Canal. Although the canal no longer runs through the Paw Paw, at 3,118 feet long it is still one of the longest canal tunnels in the United States.

Traveling through the Holland Tunnel from Manhattan to New Jersey

By the 20th century, trains and cars had replaced canals as the primary form of transportation, leading to the construction of bigger, longer tunnels. The Holland Tunnel, completed in 1927, was one of the first roadway tunnels and is still one of the world's greatest engineering projects. Named for the engineer who oversaw construction, the tunnel ushers nearly 100,000 vehicles daily between New York City and New Jersey.

Tunnel Planning

Almost every tunnel is a solution to a specific challenge or problem. In many cases, that challenge is an obstacle that a roadway or railway must bypass. They might be bodies of water, mountains or other transportation routes. Even cities, with little open space available for new construction, can be an obstacle that engineers must tunnel beneath to avoid.

In the case of the Holland Tunnel, the challenge was an obsolete ferry system that strained to transport more than 20,000 vehicles a day across the Hudson River. For New York City officials, the solution was clear: Build an automobile tunnel under the river and let commuters drive themselves from New Jersey into the city. The tunnel made an immediate impact. On the opening day alone, 51,694 vehicles made the crossing, with an average trip time of just 8 minutes.

Photo courtesy Japan Railway Public Corporation

Construction of the Seikan Tunnel involved a 24-year struggle to overcome challenges posed by soft rock under the sea.

Sometimes, tunnels offer a safer solution than other structures. The Seikan Tunnel in Japan was built because ferries crossing the Tsugaru Strait often encountered dangerous waters and weather conditions. After a typhoon sank five ferryboats in 1954, the Japanese government considered a variety of solutions. They decided that any bridge safe enough to withstand the severe conditions would be too difficult to build. Finally, they proposed a railway tunnel running almost 800 feet below the sea surface. Ten years later, construction began, and in 1988, the Seikan Tunnel officially opened.

How a tunnel is built depends heavily on the material through which it must pass. Tunneling through soft ground, for instance, requires very different techniques than tunneling through hard rock or soft rock, such as shale, chalk or sandstone. Tunneling underwater, the most challenging of all environments, demands a unique approach that would be impossible or impractical to implement above ground.

That's why planning is so important to a successful tunnel project. Engineers conduct a thorough geologic analysis to determine the type of material they will be tunneling through and assess the relative risks of different locations. They consider many factors, but some of the most important include:

- Soil and rock types
- Weak beds and zones, including **faults** and **shear zones**
- Groundwater, including flow pattern and pressure
- Special hazards, such as heat, gas and fault lines

Often, a single tunnel will pass through more than one type of material or encounter multiple hazards. Good planning allows engineers to plan for these variations right from the beginning, decreasing the likelihood of an unexpected delay in the middle of the project.

Once engineers have analyzed the material that the tunnel will pass through and have developed an overall excavation plan, construction can begin. The tunnel engineers' term for building a tunnel is **driving**, and advancing the passageway can be a long, tedious process that requires blasting, boring and digging by hand.

http://science.howstuffworks.com/engineering/structural/tunnel2.htm