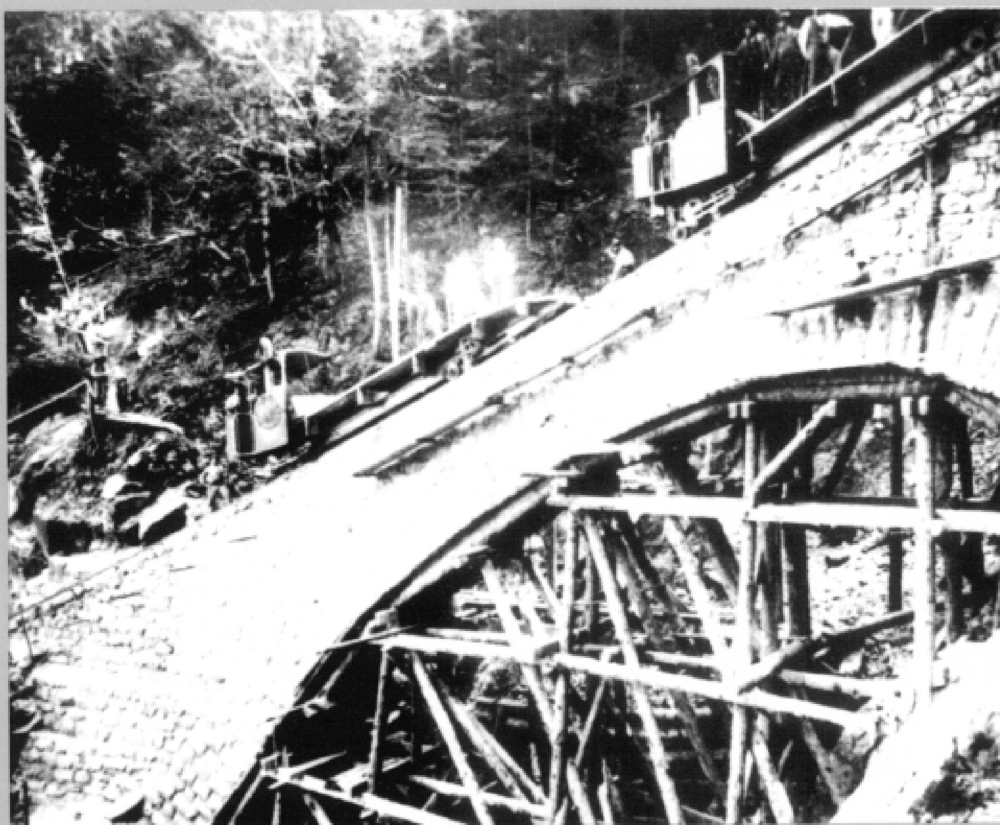
# ★ Pilatusbahn ★

## Historic Mechanical Engineering Landmark

*Designated September 14-15, 2001*

***Mount Pilatus, Switzerland***

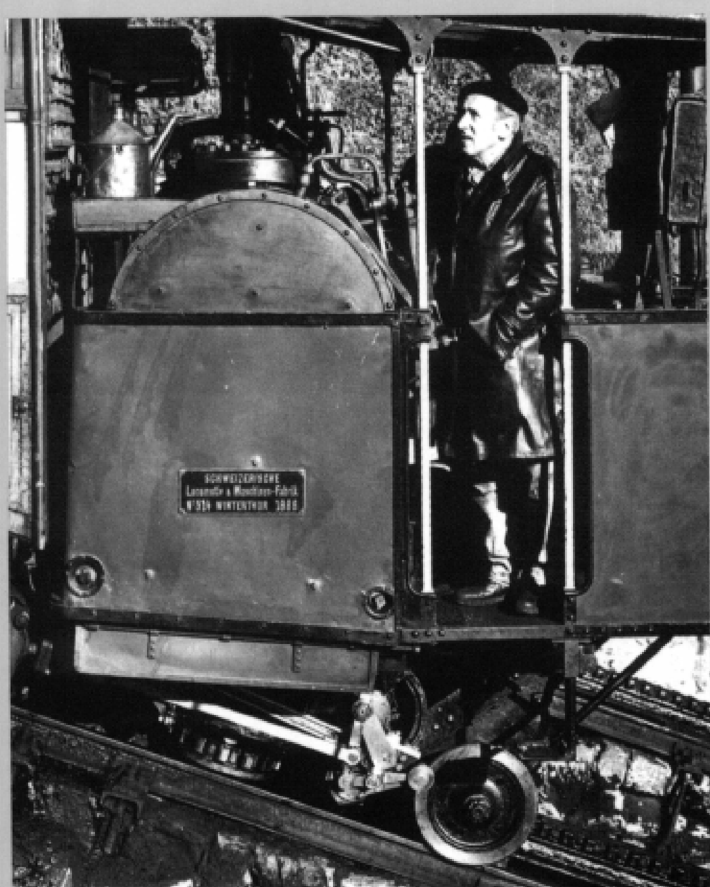
ASME International



*(left)* During construction, cars transported materials and workers.

*(bottom left)* An original steam car on the climb shows one of the propulsion cogwheels.

*(bottom right)* This overview of the mountain station shows limitations posed by the terrian and the need for a unique design for the track switches, or turnouts.



# The Story Begins

Switzerland, with its beautiful mountain scenery in the center of Europe, was recognized early as a tourist paradise, and in the late 19th century attempts were made to ascend to the most beautiful vantage points by "modern" means of transportation. For this, the railway seemed to be ideally suited, but conventional railways, limited to maximum grades of around 6 percent (rarely more than 3.5 percent), cannot climb steep mountainsides (and safely brake on the descent).

About 1870, two pioneers—Sylvester Marsh in the United States and Niklaus Riggenbach in Switzerland (see Facts on Other Cog Railways)—independently solved the problem with rack-and-cogwheel systems. In this, a rack or "ladder" is mounted between the rails. A cogwheel, turning on a horizontal shaft underneath and driven by the locomotive, engages the rack and propels the train up the track. As a consequence, the Mount Washington Railway was built in the United States, and in Switzerland, the Vitznau-Rigi-Bahn. They proved so successful that a number of other mountain railways on these and similar systems were built in the following 10 or 15 years.

On April 22, 1873, a first request was submitted for a concession to build and operate a cogwheel train from the lakeshore of the Vierwaldstädtersee (Lake Lucerne) to the top of Mount Pilatus, using the proven Riggenbach system. On the basis of techno-economic considerations, however, it was recognized that a line built on this system could not be economically viable. The proposal, for a gauge of 1,435 mm (4 feet 8.5 inches), a maximum grade of 25 percent, and a separate passenger car pushed by a locomotive, would have resulted in a railway that was twice as long as the current Pilatusbahn, rolling stock that was too heavy, and curves with radii too great for the topography of Mount Pilatus. The Swiss Federal authorities would not permit a steeper gradient with the conventional rack and cog systems that had been used on a number of mountain railways in both Switzerland and the United States, out of concern that, in the high winds common on Pilatus, the cogwheel would "climb out" of engagement with the rack, eliminating the train's main driving and braking power.

## Locher's Proposal

Then came a proposal from Eduard Locher (1840 - 1910) of Zürich, an engineer with great practical experience obtained in the construction of the St. Gotthard tunnel. His was a concept tailor-made for Mount Pilatus. The track gauge and radii of curves were almost halved (0.8 m or 31.5 inch gauge), and the maximum grade doubled to 48 percent to cut the route length in half. The cars also were much lighter, achieved by combining the propulsion steam engine, boiler, and water and coal storage, with the passenger compartment on one chassis, carried by four wheels.

To ensure positive meshing of the cogwheel and rack and to eliminate the possibility of climb out, a horizontal double rack was placed centrally between the two rails with the rack teeth facing each side. This was engaged by two cogwheels carried on vertical shafts under the car (see photograph of cogwheel display). This arrangement eliminated the tendency of the cogwheels to climb out of the rack, even on the steepest grades. Two horizontal discs (flanges) beneath the cogwheels locked them to the rack and prevented the car from toppling over even under the severest cross winds. The propulsion gear was installed on the downhill end of each car, with twin

The iron ties (of the bow bridge) go through the wall of the bridge.

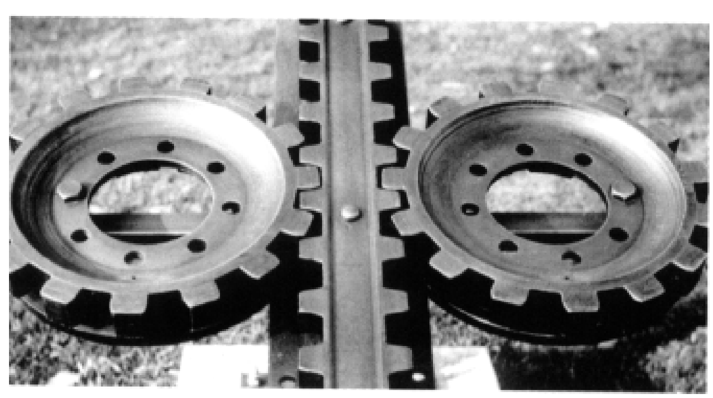
cogwheels for additional braking on the uphill end. To ensure stability of the track, the rails were laid on a solid rock bed, from the valley up to the mountaintop, secured by high-strength iron ties attached to the rock (see photograph of bow bridge), without ballast. A 3-point suspension system (one point on each side of the downhill axle and one point in the center of the uphill axle) ensured that all wheels stayed in contact with the rails under all conditions.

Locher was not only inventor of the line's propulsion system, he was also its promoter. Legally prevented from building an economically viable line using the available Marsh, Riggenbach, or Abt rack designs, Locher developed an entirely new system that addressed the government's safety concerns. And as the government provided no subsidy for its construction, the railway was built entirely with private capital and has remained financially viable throughout its life. The Pilatusbahn's "Locher System" was the engineer's response to the technical, economic, and regulatory conditions of the time. Construction began in April 1886, and operations begun June 4, 1889.

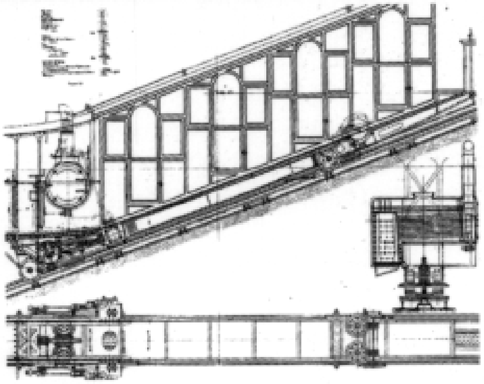
## Unique Solutions

As noted above, a key design feature of the Locher System secures the car against lateral wind forces. Discs (flanges) on the lower side of the horizontal cogwheels roll along both sides of the beam that supports the rack and under the rack itself. This serves two purposes: it guides the car, and it prevents any combination of wind and gravity from lifting the car and disengaging the cogwheels from the rack. In fact, the first Pilatusbahn cars had no flanges on the running wheels at all, though they later were added so that the cars could be maneuvered onto tracks without rack rails for maintenance.

Because the central rack protrudes above the running rails, the design of the turnouts at the stations also is unique:



The horizontal double track rail is mounted on a central beam.

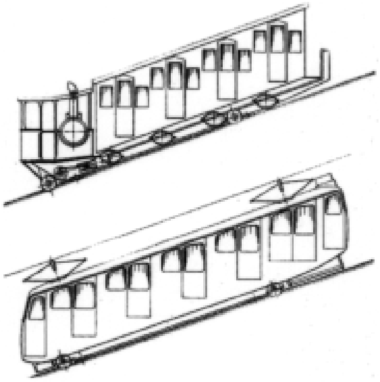


Mechanical details of the original steam cars show the propulsion system in the downhill end of the chassis, with the wooden passenger cabin above.

Where normally rails would cross and a train be shifted from one track to another by moving switch points, Locher's running rails could not cross the center rack. He devised a turnout consisting of a pit spanned by a short bridge that rotates 180 degrees about its lengthwise axis. One side of the bridge has track connecting to the left-hand route, while the other side's track leads to the right-hand route. The bridge is "turned over" to change the route.

All the car components (see drawing of mechanical details), including engine, boiler, and passenger compartment, as well as water tanks and coal bins, were mounted on one 4-wheel chassis. The wooden bodied cars were 11 meters (36 feet) long and weighed 11.6 tons (25,600 pounds) fully loaded. The 2-cylinder engine, which drove one pair of cogwheels, and boiler were mounted in the lower end of the car. To conserve space and ensure that water always covered the firebox crownsheet on the steep grade, the boiler was mounted transversely. A second pair of cogwheels in the upper end of the car furnished guidance and supplemental braking capacity. An emergency brake engaged automatically if a certain critical speed was reached.

Initially, steam-powered cars were delivered with wooden decks in place of passenger bodies. As construction progressed, these cars were used to transport men and materials from Alpnachstad to the work site. In the process, they proved the merits of Locher's unusual design. Although it is not now known for certain, it is likely that these same cars received passenger bodies to serve as the first revenue cars when the line opened to the public.



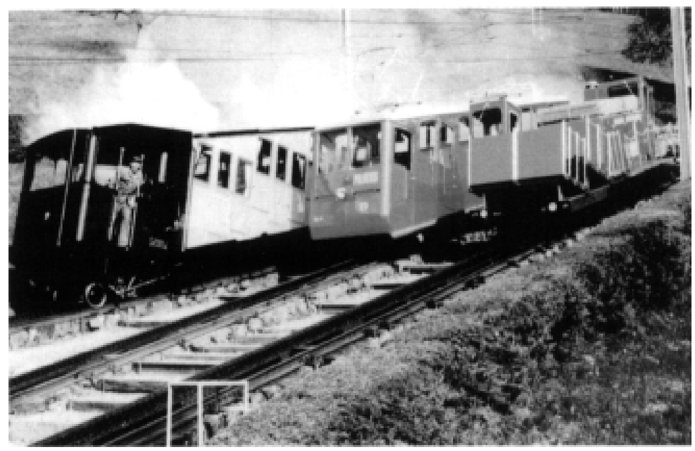
This SLM drawing of the earlier steam car (above) and the modern electric car (below) show basically the same principle of propulsion.

## An Update

The original steam-powered cars were replaced by electric cars in 1937. Additional updates were made in 1954 and 1967, all by SLM. The driving gear principle and basic design remains the same for the electric version as it was for the steam (see comparison in drawing). Today's electric cars feature twin motors that also act as dynamic brakes during descent. In the dynamic braking mode, the motors become generators, resisting motion. The electricity so generated is dissipated as heat through resistance grids. Originally, the steam engines were used as compressors to provide dynamic braking, since the use of friction brakes alone would have caused them to overheat and wear out very rapidly. The running speed was more than doubled following electrification.

After 100 years of operation, the flanges on the cogwheels had significantly worn down the lower sides of the teeth on the rack rails. Simply turning the rails over provided a brand new wearing surface that should be good for another century of service.

Two original steam cars still exist. One is on loan to the Verkehrshaus der Schweiz (Swiss Transportation Museum) in Lucerne, and the other at the Eisenbahnmuseum (Railway Museum) in Munich, Germany. The re-introduction of one of the old steam cars is presently being reconsidered. Pilatus Bahnen at Kriens owns the Pilatusbahn.



One of the original steam cars meets an electric car.

## Facts on Other Cog Railways

World's first cog railway: Mount Washington Railway (New Hampshire, U.S.A.) was built in 1869 by Sylvester Marsh and rises 1,100 meters (3,600 feet), at the mountain top 1,917 meters (6,288 feet) with a maximum slope of 37.41 percent (the second steepest gradient in the world). It was designated an ASME landmark in June 1976.

World's highest cog railway: Manitou & Pike's Peak Railway (Colorado, U.S.A.) was built by SLM for Wilhelm Hildenbrand in 1891 using Roman Abt's system (two parallel, but offset, steel racks with open, upstanding teeth that mesh with the locomotive cogwheels), and it rises to more than 14,000 feet (4,270 meters), climbing grades of 25 percent. It was designated an ASME landmark in May 1976.

Europe's first cog railway: Vitznau-Rigi-Bahn (Vitznau to Rigi Kulm, Switzerland) was built 1871-73, using Niklaus Riggenbach's ladder design.

Europe's highest cog railway: Jungfrau Bahn (Lauterbrunnen to Jungfraujoch, Switzerland) was built in 1896 by Adolf Guyer-Zeller with a design similar to Mount Washington and Vitznau-Rigi-Bahn. It climbs to more than 3,470 meters (11,400 feet) above sea level.

HISTORIC MECHANICAL ENGINEERING LANDMARK

THE PILATUSBAHN

1889

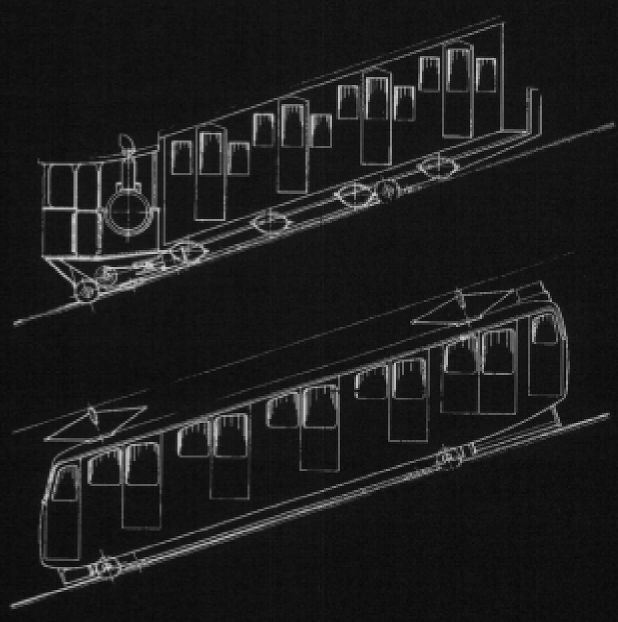
THE PILATUSBAHN IS THE STEEPEST COG, OR RACK, RAILROAD IN THE WORLD, CLIMBING AT A MAXIMUM GRADE OF 48%, OR NEARLY ONE METER RISE IN TWO METERS OF RUN. THIS EXTREME WAS AN ECONOMIC NECESSITY, AS AN EASIER SLOPE WOULD HAVE LENGTHENED THE ROUTE BEYOND THE POSSIBILITY OF ADEQUATE RETURN ON THE INITIAL INVESTMENT.

TO OVERCOME CONCERN THAT AT THIS GRADE A CONVENTIONAL VERTICAL COGWHEEL MIGHT "CLIMB OUT" OF ITS MATCHING RACK RAIL UNDER THE PROPULSION LOAD, ZURICH ENGINEER EDUARD LOCHER (1840-1910) DEVISED A SYSTEM OF TWIN RACKS ENGAGED BY A PAIR OF OPPOSING HORIZONTAL COGWHEELS. ORIGINALLY THIS COMBINATION ALSO GUIDED THE CAR. THE FIRST CARS WERE STEAM PROPELLED, WITH A TRANSVERSE BOILER AND RUNNING GEAR AT THEIR DOWN-HILL END. THE LINE WAS ELECTRIFIED IN 1937.

DIE PILATUSBAHN IST DIE STEILSTE ZAHNRADBAHN DER WELT, MIT EINER MAXIMALEN STEIGUNG VON 48%, ODER FAST 1 METER HÖHENGEWINN IN 2 METER FAHRT. DIESE EXTREME STEIGUNG WAR ERFORDERLICH, WEIL ANSONST DIE FAHRSTRECKE UNZULÄSSIG LANG, UND DADURCH DAS PROJEKT NICHT WIRTSCHAFTLICH GEWORDEN WARE.

UM DIE BERECHTIGTEN BEDENKEN, DASS BEI SOLCH GROSSEN STEIGUNGEN DAS TREIBZAHNRAD UNTER DER GROSSEN ANTRIEBSLAST AUF DIE ZAHNLEITER KLETTERT, ZU BESEITIGEN, ERSANN DER ZÜRCHER INGENIEUR EDUARD LOCHER (1840-1910) EIN WILLINGSZAHNRADSYSTEM MIT HORIZONTALEM EINGRIFF IN EINER DOPPELZAHNSTANGE. URSPRÜNGLICH HATTE DIESE ANORDNUNG DIE TRIEBWAGEN AUCH SEITWÄRTS GEFÜHRT. DIE ERSTEN WAGEN WAREN DAMPFGETRIEBEN, MIT ANTRIEBSEINHEIT UND DAMPFKESSEL AM TALENDE. DIE LINIE WURDE IM JAHR 1937 ELEKTRIFIZIERT.

**THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS – 2001**



## The History and Heritage Program of ASME International

The ASME History and Heritage Recognition Program began in September 1971. To implement and achieve its goals, ASME formed a History and History Committee, composed of mechanical engineers, historians of technology, and the Curator Emeritus of Mechanical and Civil Engineering at the Smithsonian Institution. The Committee provides a public service by examining, noting, recording, and acknowledging mechanical engineering achievements of particular significance. The History and Heritage Committee is part of the ASME Council of Public Affairs and Board on Public Information. For further information, please contact Public Information, the American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016 5990, 212 591-7740: fax 212-591-8676; http://www.asme.org/history/.

An ASME landmark represents a progressive step in the evolution of mechanical engineering. Site designation notes an event or development of clear historical importance to mechanical engineers. Collections mark the contributions of several objects with special significance to the historical development of mechanical engineering.

The ASME History and Heritage Recognition Program illuminates our technological heritage and serves to encourage the presevation of the physical remains of hisorically important works. It provides an annotated roster for engineers, students, educators, hisrotians, and travelers, and helps establish persistent remiders of where we have been and where we are going along the divergent paths of discovery.

## Designation

Since the History and Heritage Program began in 1971, 215 landmarks have been designated as historic mechanical engineering landmarks, heritage collections or heritage sites. Each represents a progressive step in the evolution of mechanical engineering and its significance to society in general. Site designations note an event or development of clear historic importance to mechanical engineers. Collections mark the contributions of a number of objects with special significance to the historical development of mechanical engineering.

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The125,000-member ASME International is a worldwide engineering society focused on technical, educational and research issues. ASME conducts one of the world's largest publishing operations, holds some 30 technical conferences and 200 professional development courses each year, and sets many industrial and manufacturing standards.




**Acknowledgments**

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