

# Lötschberg tunnel disaster, 100 years ago

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## Abstract

**T**he older of Switzerland's Lötschberg tunnels presented a classic case of an engineering geology disaster, which is surprisingly little known. The tunnel heading breached rockhead into a buried valley that had a depth greater than anything perceived as possible at that time. It demonstrates the need for engineers to understand the geological processes behind ground conditions.

The world of tunnelling engineers and geologists has re-focused on the Lötschberg, in the heart of Switzerland, with the recent opening of the 34.6 km base tunnel that takes high-speed trains right through the Bernese Oberland without tortuous climbs up approach valleys. However, the Lötschberg was also the site of one of the greatest disasters of engineering geology, when the earlier rail tunnel broke through rockhead during construction. This was one of the world's classic examples of how engineers can get the geology wrong, but it is surprisingly little known. It happened exactly 100 years ago, and a centenary reflection on the events is still pertinent to the critical interactions between engineering and geology.

Before the Simplon rail tunnel had been opened under the Pennine Alps in early 1906, it was recognized that a Lötschberg tunnel was also needed under the Bernese Oberland, to complete the route in from Bern and the north. Only a footpath crosses the high Lötschen Pass, with massive climbs on each side, but the early railway engineers spotted the potential for tunnelling beneath the crest, where the Kandertal (-tal = valley) on the north side lies close to the Lötschental on the south (Fig. 1). A glacial step up from the Kandertal into the Gasterntal was too high for the railway to climb, so the tunnel portal was opened just south of Kandersteg (Fig. 2). At an altitude of just under 1200 m, the tunnel aimed nearly 14 km through to a bend in the Lötschental.

Late in 1906, excavation started from both ends, using drill-and-blast methods that removed about 1.2 m of rock on each round of holes to advance a pilot heading 2 m high and wide (Fig. 3). This was subsequently enlarged by breaking out the roof and both walls to achieve the full size of the single twin-track tunnel nearly 9 m in diameter.

The insurmountable step and the sharp bend in the valley just above Kandersteg determined the position of the northern portal, and a straight tunnel then had to

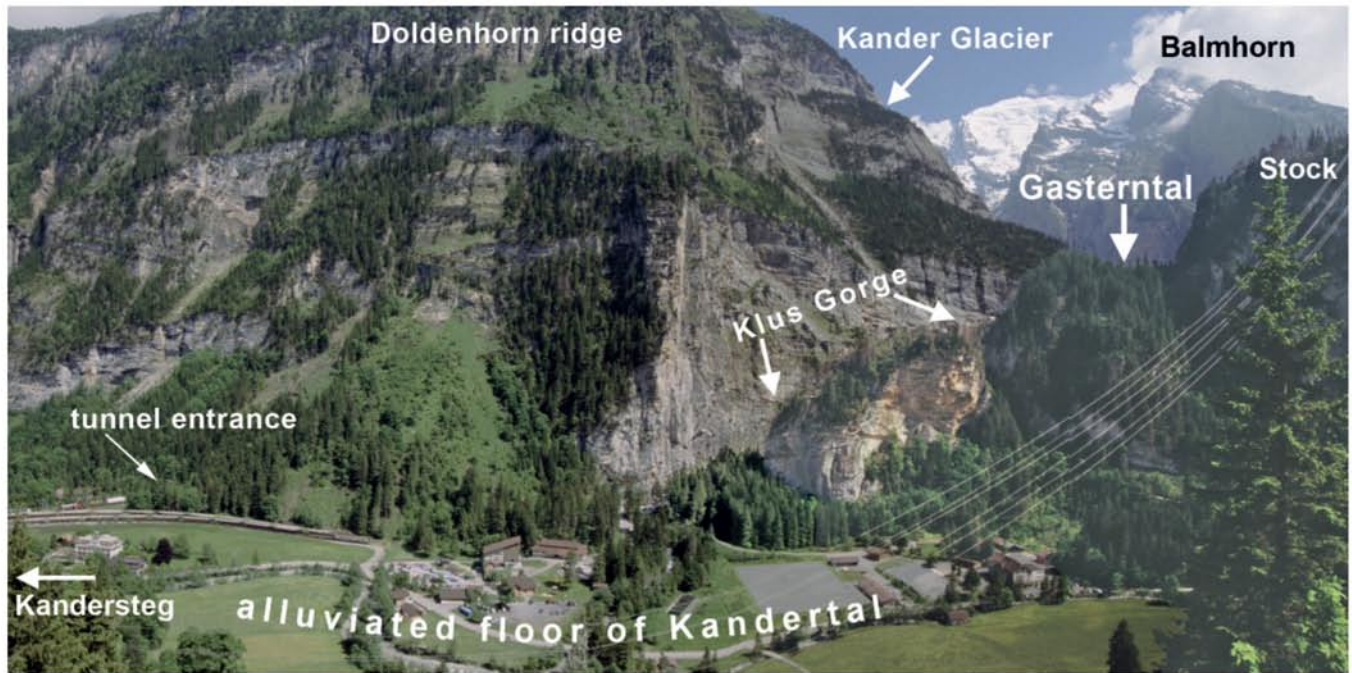
pass deep beneath the Gasterntal (Fig. 4). At the earliest stage in planning, critical questions had been raised concerning the depth of alluvial fill in Gasterntal. But the tunnel lay nearly 180 m below the flat valley floor, so the potential problems were brushed aside. In June 1908, the northern heading passed safely from beneath the shoulder of the Doldenhorn, but disaster struck early in the morning of 24 July.

A round of holes was fired, and an avalanche of sand, gravel, silt, mud, water and rock debris burst through the tunnel face. The heading had broken through into the alluvial fill of the Gasterntal. Saturated sediment ran down the tunnel for 1300 m, and the entire face team of 25 miners was killed. Up above, a sinkhole 80 m across had opened in the right bank of the River Kander where it flows through woodland on the floor of Gasterntal. A whirlpool lake temporarily swallowed the river, but within 3 months it was choked with gravel and lost to sight. The sediment column had failed throughout its



Fig. 1. Old and new tunnel alignments beneath the mountains and glaciers of the Bernese Oberland.





**Fig. 2.** The top end of Kandertal, seen from the west. The power cables on the right rise across the face of the Stock ridge with its stepped profile, which lies in front of the Klus Gorge, with the higher, grey, limestone cliff on its far side. Gasterntal lies beyond the Stock and extends round to the left, in front of the ice ridge of the Balmhorn.



**Fig. 3.** Workmen with hand-held drills excavating hard rock in the Lötschberg tunnel (from Kovari & Fechtig 2000, with permission).

172 m depth, when its rock floor had been blasted away from below.

## Disaster under the Gasterntal

The magnificent glacial trough of the Gasterntal has precipitous walls, mainly of limestone, rising high above a narrow floor with a profile that clearly indicates the presence of a considerable sediment fill (Fig. 5). Aprons of talus and a series of large alluvial fans line the toes of

the valley walls, and interdigitate with alluvial sediments that underlie the gently graded valley floor. There is, however, no indication of the depth to rockhead beneath this major fill. The question of sediment depth did concern the leaders of the Lötschberg tunnel project, who were not happy about their tunnel heading into ground that could be either rock or sediment (the latter being known as soil to engineers), 172 m beneath ground level in the Gasterntal (Fig. 6).

Some of the project engineers and managers dismissed any concern. They cited the bedrock limestone that is exposed in the Klus Gorge, downstream of the tunnel crossing, but they clearly did not understand the concept of glacial over-deepening, where ice is very capable of moving uphill and scouring out a deep basin when pushed ahead by a glacier flowing from a higher source. The long profile of the Kander valley system is marked by conspicuous glacial steps (Waltham 2007), and it is reasonable to expect some degree of over-deepening on each of these steps. Without the proven data on over-deepened valleys that exist today, a commission of three geologists concluded, a century ago, that they anticipated at least 100 m of rock cover over the tunnel, beneath about 70 m of sediments in the Gasterntal. The background of these commission geologists is not recorded, and it may well have been political motivation and simple expediency that drove the project engineers to welcome and follow their advice. An independent geologist echoed earlier worries about much deeper sediments, but his warning was ignored (Sandström 1963).



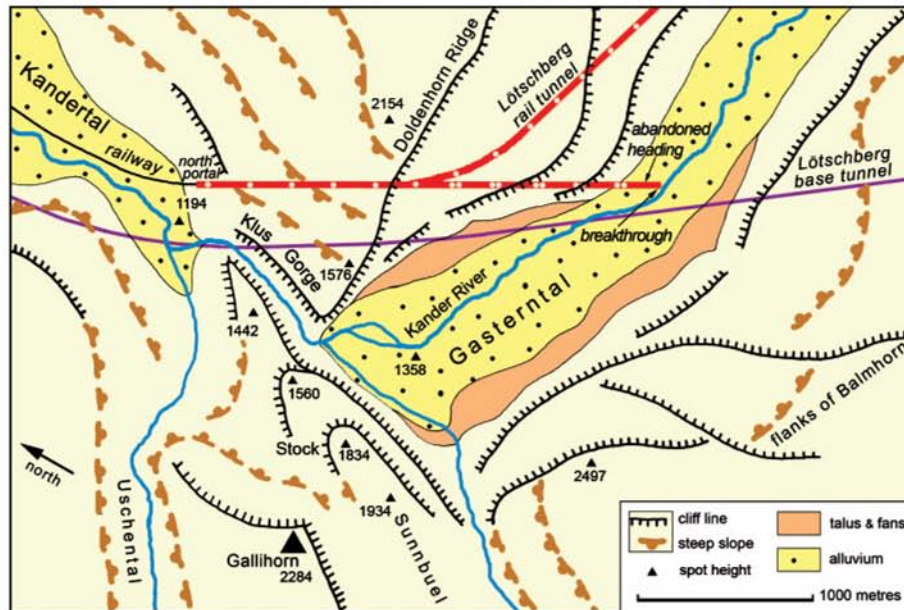


Fig. 4. Plan of the Gasterntal and Klus Gorge above the northern heading of the Lötschberg tunnel.



Fig. 5. The glaciated trough of the Gasterntal, looking up-valley from the Stock hill; the sinkhole over the 1908 tunnel breakthrough was in the woodland just beyond the large meadow.

Unfortunately, where the tunnel eventually broke out of clean dry rock, it did so through a clean valley wall that had been scoured by ice before its burial behind unconsolidated sediments. There is no record of any warning of rock failure, of any sign of rock weathering, or of any water draining from the last round of holes. Even though the last holes to be drilled had not reached the steep rockhead, overbreak from the blasting allowed instant rock failure under the pressure of sediments and water in the Gasterntal fill. If the rockhead position had been just 200 mm either way along the tunnel axis, the disaster may not have happened as any hole drilled through rockhead would probably have created a warning with a powerful jet of water.

The post-event investigation attempted to resolve the causes of the disaster, but released little information. Late in 1908, two boreholes were sunk in the floor of Gasterntal (Fig. 7). One was drilled almost in the centre of the already-choked sinkhole, so that it was close to being above the breakthrough point, and this reached bedrock 220 m down, at 39 m below the tunnel level. The second, 170 m away towards the centre of the Gasterntal, was stopped at the same depth without reaching bedrock. The two sediment profiles reveal little direct correlation; both are variable sequences of sands, clays and coarser beds with limestone debris that may be either till or fanglomerate (unpublished 1909 report by La Commission des Experts Désignés par l'Entreprise Générale du Chemin de Fer des Alpes Bernoises; in Kovari & Fechtig 2000).

The investigation also determined that the best remedial action was to divert the tunnel towards the east. The sediment-filled section was sealed off with a plug of concrete, and became the miners' tomb. The tunnel was then advanced on a new heading that curved away to the east just behind the concrete plug. Crews in



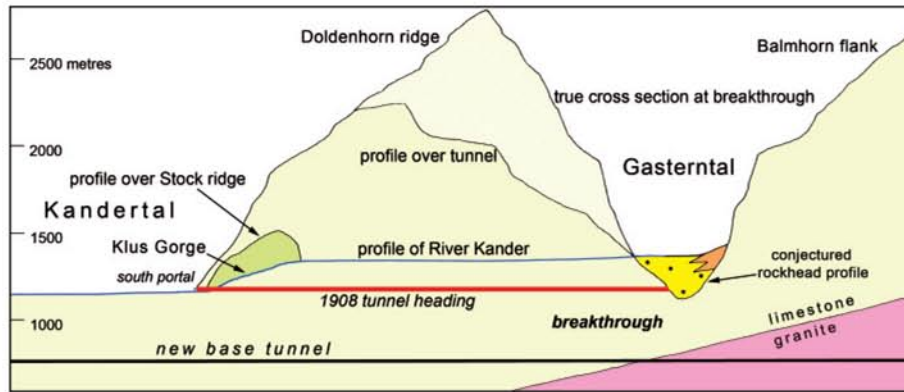


Fig. 6. Profile along the Lötschberg tunnel line as far as the Gasterntal breakthrough.



Fig. 7. Drill housing for the borehole into the Gasterntal sediments soon after the disaster (from Kovari & Fechtig 2000, with permission).

the southern heading also followed a curve to the east, and the tunnel was completed with a reverse curve beneath the upper Gasterntal. At this crossing there was no danger from alluvial fill, as granite bedrock was exposed on the valley floor 230 m above the tunnel.

The two headings met on 31 March 1911, and the tunnel was opened to trains in July 1913. Most of the northern heading had been in the Doldenhorn limestones (which includes some interbedded gypsum and anhydrite), where it had met some significant inflows of cold water. The southern heading had been largely in much harder granite and gneiss, where temperatures rose to over 34°C; zones of heavily kaolinized rock had required extra roof support.

### The over-deepened Gasterntal

The great depth of the Gasterntal valley floor at the tunnel crossing is a result of glacial over-deepening, leaving a trough that was subsequently filled with sedi-

ment up to its overflow level. The Pleistocene Kander Glacier followed an earlier fluvial valley, and was forced round the sharp bend out of the Gasterntal, where it was constricted by the rib of strong limestone forming the Stock spur, before dropping into the Kandertal (Fig. 4). The ice rode up and over this, passing the shoulder at about 1560 m elevation on both sides. Rockhead under Gasterntal has been proven at 1109 m by a borehole over the line of the new base tunnel (and this is unlikely to be its lowest point). A low point over the saddle appears to be close to the 1442 m spot height below the Stock. The floor of the Kander Glacier therefore appears to have risen at least 350 m.

The glacier floor then descended into the Kandertal where another base tunnel borehole has proved it at an elevation of 823 m. Glacial over-deepening of 350–400 m was therefore followed by a glacial step that dropped over 600 m where the glacier was joined by flows from Sunnbél, Uschentäl and other high basins both east and west of Kandertal.



The glacier never went through the Klus Gorge. This is a fluvial feature less than a tenth of the width of the Gasterntal trough. It was probably initiated by subglacial meltwater scouring along fractures in the limestone bedrock, and was then greatly enlarged by proglacial meltwater when the snout of the Kander Glacier stood near the lower end of Gasterntal. With further ice retreat, a proglacial lake would have accumulated until it overflowed through the Klus and thereby deepened the gorge further. The lake was lost when the sediment fills in Gasterntal aggraded to meet the level of the outlet into the Klus.

## Lessons from Lötschberg

Breaching rockhead and opening into unconsolidated sediments is every tunneller's nightmare, but that is exactly what had happened at Lötschberg in 1908. That disaster could have been avoided by an appropriate ground investigation that aimed to identify the rockhead profile along the tunnel line. A deep borehole in the Gasterntal could have proven the depth of the valley sediments. An alternative would have been to drill probing boreholes in advance of the heading, perhaps just in the danger zone about 150 m long where the heading passed out from beneath the rock slopes of the Doldenhorn. Extra costs may have been the reason for abandoning both precautionary measures. Or maybe sediments 172 m deep were beyond the comprehension of the engineers of the day. False security was derived from the great depth and a lack of geological understanding.

After the disaster, all disputes were settled by arbitration, with an agreement not to publish the report, which was deemed to belong to the railway company and therefore not to be public material. This was unfortunate, because a well-publicized report on the geohazard of deep buried valleys on glaciated terrains could have provided a useful lesson for the then-youthful science of engineering geology; it was the year after Herbert Lapworth began giving his lectures on the subject at the Institution of Civil Engineers (Lapworth 1907–1908; de Freitas 2005).

Pre-dating the Lötschberg tunnel, the Gotthard tunnel had been driven beneath Andermatt, 70 km east of Kandersteg, where it lay in solid rock 320 m below the floor of Ursental. Only many years later did a borehole show that it had missed, by less than 30 m, sediments 290 m deep that filled a buried Ursental. If the Gotthard tunnel had breached that deep rockhead, the result would have been disastrous; but would have demonstrated the hazard. One hopes that the engineers on the Lötschberg project, 32 years later, would then have demanded extra ground investigation. However, it does appear that lessons are learned only slowly.

In the 1930s, a failure very similar to that at Lötschberg occurred in Chile, where the Las Raices tunnel, 4.5 km long, was being excavated for a trans-Andes railway (it has since been converted into a road tunnel), with an alignment that passed beneath a high valley (Legget & Hatheway 1988). Problems were not anticipated because bedrock was exposed in the stream bed upstream from the portal and 30 m above tunnel roof level. The tunnel heading did pass intact beneath the valley, beneath a rock cover of unknown and apparently inadequate thickness, but this collapsed when the face had advanced a further 500 m into the mountains. A sinkhole opened in the deep sediments of the valley floor, above an inrush of debris that blocked the tunnel. This trapped 42 men in the heading, but they were all extricated through a rescue tunnel. Again, the engineers had failed to appreciate the possibilities of reverse gradients on bedrock profiles along glaciated valleys; ground investigation had been inadequate, and their tunnel crews were lucky to survive.

Also in the 1930s, the USA had both success and failure. New York's Catskill Aqueduct passed successfully under the Hudson River after an extensive programme of boreholes had established the profile of a buried valley over 200 m deep. At the same time, tunnel contractors in San Francisco encountered major difficulties with the Broadway Tunnels after accepting and not confirming an over-confident report from the client's geologist. Just a few years later in Scotland, tunnels for the Glen Tromie component of the Grampian Hydro-electric Scheme were excavated after ground investigations that included neither boreholes nor geophysics (Anderson 1951). Buried valleys under each flank of the Seilich Valley were masked by till over rockhead with buried relief of more than 50 m, and the tunnel crews found difficult conditions as they worked through lengths of both rock and sediment. Soon after that, the infamous disaster at Knockshinnoch Colliery was also due to breaching rockhead from below after almost no appropriate ground investigation (Bryan 1951).

Modern tunnelling practices include investigations that are a great deal more thorough. Some projects have favoured repeated exploratory probes in advance of the heading. In the 1980s, Norway's excellent tunnelling record was maintained when the Aalesund Fjord tunnels were excavated with two undersea sectors each 7.7 km long and reaching depths of 140 m (Kielland 1988). After a complete seismic survey, alignments were selected to leave 50 m of rock cover beneath the sea bed. Detailed confirmation of rock integrity was then achieved with exploratory drilling after each fifth blast, when arrays of between two and six holes were drilled for 30 m ahead and inclined upwards. In the same decade, the Higo road tunnel in Kyushu, Japan, used advance boring that reached 45 m ahead to identify any hazardous ground, notably in a stretch a kilometre long through limestone (Fujita *et al.* 1988).

The alternative to probes from the tunnel heading is a programme of deep boreholes in advance of construction. This was the approach taken in the 1990s for the Lötschberg Base Tunnel, which, after its opening in 2007, carries trains through the Alps 400 m beneath the original tunnel (Fig. 4). An initial 27 boreholes reached to below tunnel level with depths of as much as 1400 m, including four within the Gasterntal to prove its deeply buried rockhead profile.

Glaciated terrains still offer the greatest risk of encountering deep rockhead in buried valleys, and engineering investigations must be based on properly understanding the relevant geological processes. Deep boreholes are preferred on major tunnel projects where the alignment must be determined ahead of construction. More flexible projects, including most in mine development, can rely on probing ahead, perhaps just where hazardous ground is perceived. Geophysical surveys may also contribute to rockhead identification, especially now that directional techniques can identify buried features that are relatively deep and narrow.

The required investigation techniques do exist in modern ground engineering, but projects still rely on perceptive and receptive leadership. A full-blown catastrophe draws attention to difficult ground conditions on engineering projects, and due reflection is part of the learning curve. The ground is full of surprises, but there should be one less, since those early events

at Lötschberg demonstrated a hazard that had not previously been perceived.

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