Only with the Ceneri Base Tunnel as continuation of the Gotthard Base Tunnel will the new Gotthard route become a continuous flat route for passenger and goods traffic through the Alps. With a length of 15.4 km, after the Gotthard and Lötschberg base tunnels the Ceneri Base Tunnel is Switzerland’s third-longest railway tunnel. The Ceneri Base Tunnel is scheduled to become operational at the end of 2020.
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With the New Rail Link through the Alps (NRLA), important goals of Switzerland’s transport policy can be implemented: transfer of goods transportation from road to rail and improvements in passenger traffic.

Every year, around one million road trucks cross the Swiss Alps. However, the people of Switzerland want to protect the sensitive Alpine region from the effects of excessive traffic. For this reason, since the 1980s Switzerland has pursued a sustainable transport policy. At its heart is the transfer of as much transalpine traffic as possible from the roads to the railways. Swiss voters have confirmed this policy in several referendums. In 1994 they accepted the Alpine Initiative, according to which heavy traffic through Switzerland should travel by rail. In practical terms, this means that a maximum of 650,000 road trucks per year should cross the Alps.

The new transalpine link
To achieve this ambitious goal, Switzerland has implemented a number of measures. These include a distance-related heavy-vehicle tax (HVT) and financial support for goods traffic on the railways. To increase the capacity of the railways, Switzerland has constructed the NRLA with its three base tunnels through the Lötschberg, the Gotthard and the Ceneri. Ultimately, the NRLA will provide railway goods traffic with a fast and efficient route through Switzerland. For passenger traffic, journey times between centres in the north and south will be substantially reduced. Trains have been travelling through the Lötschberg Base Tunnel since 2007. The Gotthard Base Tunnel became operational at the end of 2016. The Ceneri Base Tunnel is scheduled to become operational at the end of 2020.
Underneath the Gotthard and the Ceneri the first flat route through the Alps is being built. With minimum gradients and curves, it runs from Altdorf to Lugano. The highest point is 550 metres above sea level – the same height as Switzerland’s capital city, Berne.

The Alps present a topographical obstacle to European traffic. To provide more efficient transit routes between northern and southern Europe, Switzerland is investing in the construction of new railway links. At their heart is construction of the NRLA Gotthard axis with its two base tunnels under the Gotthard and the Ceneri.

Benefits for goods and passenger traffic
The gradients and curve-radii of this new north-south axis are comparable to those of railway lines in the plain. Consequently, distances are reduced, maximum speeds are increased, and marshalling of trains becomes unnecessary.

The flat route shortens the distance from Basel to Chiasso by 40 km and has a maximum gradient of only 12.5 per thousand, much less than that of the Gotthard and Ceneri mountain routes, both with maximum gradients of 26 per thousand. With passenger trains travelling at speeds of up to 250 km/h, the new routes cut their journey times substantially. In addition, the elimination of height differences allows more, longer and heavier goods trains to pass, which, because of the shortened distances, also reach their destinations sooner. Furthermore, Switzerland is also upgrading the approach lines on the Gotthard axis so that semi-trailers with a corner-height of four metres can also be carried on trains right across Switzerland and beyond, to the major railway terminals in northern Italy.
The NRLA is a project of the century. The flat route enhances the environmentally compatible transport of goods by rail. And for passenger traffic, the NRLA cuts the total journey time between north and south by up to one hour.

For the increased transfer of goods to the railways to be successful, rail transport must be competitive with road transport. The flat route through the Gotthard and Ceneri will provide a real alternative.

More efficient and more economical goods traffic
For goods traffic, the new Gotthard Tunnel brings increased capacity, faster connections and improved reliability. With trains up to 750 metres long, goods traffic becomes more efficient, more economical and more environmentally-friendly. Since the changeover to the new timetable at the end of 2016, up to five trains per hour can travel in both directions – 30 percent more than formerly. This means that up to 210 goods trains a day can travel through the Gotthard Base Tunnel.

With the Ceneri Base Tunnel and the 4-metre corridor, the competitiveness of the railway on the north-south axis is greatly increased.

Quantum leap for passengers
For passengers, the NRLA through the Gotthard signifies a quantum leap: Zurich and Lugano come within commuting distance. Since the changeover to the new timetable at the end of 2016, the journey time from Zurich to Lugano is up to 25 minutes less than formerly. When the Ceneri Base Tunnel is also operational, Lugano will be reachable from Zurich in less than two hours. From the end of 2020, the time-saving between German-speaking Switzerland and the Ticino will be up to one hour, and the journey time to Milan will be cut to just under three hours.

Not only long-distance traffic but also regional traffic in the Ticino will be substantially improved: from the end of 2020 the connections between Lugano, Bellinzona and Locarno will be expanded and journey times significantly shortened. Thanks to the new direct connection between Locarno and Lugano – the so-called «Bretella» – the train journey will take only 30 minutes instead of 58 minutes.
With construction of the flat route through the Alps, Switzerland is writing transport history. The idea of a flat crossing of the Alps is not new. The first vision of a Gotthard base tunnel was already conceived in 1947. However, the first preparatory work on the Gotthard Base Tunnel only began in the 1990s.

First visions and decisions
In 1947, the engineer Carl Eduard Gruner, of Basel, sketched the visionary idea of a double-deck combined road- and rail-tunnel between Amsteg and Bodio as part of a rapid-transit railway system. In 1963, the Swiss federal government established a committee for a «Railway Tunnel through the Alps». It evaluated various base-tunnel solutions and in 1970 recommended construction of a Gotthard base tunnel from Amsteg to Biasca. In 1989, the federal council decided to implement a so-called «network variant»: a combination of transalpine railway routes through the Gotthard and Lötschberg, along with the Hirzel Tunnel as link to eastern Switzerland.

Pathmaking referendums
In 1992, with a 64% majority, the Swiss electorate accepted the federal government's resolution to construct the Swiss Rail Link through the Alps (the Trans Alpine Resolution). This laid the basis for the planning and construction of the NRLA Gotthard and Lötschberg axes. In a referendum in 1994, the Alpine Initiative was accepted, which incorporates protection of the Alpine region into the Swiss Constitution. And in 1998, with their acceptance of the distance-related heavy vehicle tax (HVT), as well as the federal government’s proposal for construction and financing of public transport infrastructure projects (FinöV), the people of Switzerland gave their final go-ahead for construction of the NRLA.

Driving through the Gotthard and Ceneri
In spring 1999, the Swiss federal government gave its official authorisation for construction of the Gotthard Base Tunnel. In November 1999, with a first blast at Amsteg, driving of the Gotthard Base Tunnel on the north side of the Alps began. In July 2000 at Bodio, the first blast on the south side took place. On October 15, 2010, fourteen years after preparatory work commenced, the final breakthrough of the Gotthard Base Tunnel was achieved. And in 2016, the Gotthard Base Tunnel was opened and put into operation. At 57 kilometres, it is the world’s longest railway tunnel.

Work on the Ceneri Base Tunnel started in 2006. In January 2016, final breakthrough in the west tube of the Ceneri Base Tunnel took place. When the Ceneri Base Tunnel becomes operational at the end of 2020, construction of the NRLA will be complete.
For the purpose of extensively modernising and expanding Switzerland’s railway infrastructure, the federal government created a special financing concept.

BIF replaces FinöV Fund
The money for the NRLA is obtained from special funds. In 1998, to finance the NRLA and three further major railway projects, the FinöV Fund was created. This was financed from the distance-related heavy vehicle tax (HVT), value added tax, and mineral-oil tax. After long political wrangling over how to finance the NRLA, the FinöV Fund brought the breakthrough and the necessary financial stability. It benefited the NRLA and further major railway projects in two ways:

- It assured the financing of the complete project already before construction began, thereby avoiding uncertainty regarding the release of further credit tranches.
- The HVT served not only as the main source of finance for the NRLA. It also created fairer conditions of comparison between rail and road in that the uncovered costs of goods transportation by road were captured and the true costs revealed.

At the start of 2016, the temporary FinöV Fund was replaced by the permanent Railway Infrastructure Fund (BIF). This has additional sources of finance in the form of contributions from the federal government, the cantons and railway passengers, as well as a ceiling on the commuting allowance in the federal income tax. It also obtains relief from increased track charges. The Railway Infrastructure Fund finances not only major projects such as the NRLA but also the entire railway infrastructure, including its operation and maintenance of its substance.

Adherence to final costs
In 2008, the Swiss parliament approved a total credit of 19.1 billion Swiss francs for implementation of the NRLA (at the 1998 price-level, excluding inflation, value added tax and construction interest).

Of this amount, CHF 13.157 billion are earmarked for construction of the Gotthard axis. All indications are that AlpTransit Gotthard Ltd will be able to adhere to this budget. In mid-2017, the forecast final costs for the Gotthard Base Tunnel, including the overground connections to the north and south, lay at around CHF 9.5 billion, and for the Ceneri Base Tunnel at CHF 2.5 billion.

**Die AlpTransit Gotthard Ltd.**

AlpTransit Gotthard Ltd (ATG) was established on May 12, 1998. It is a wholly-owned subsidiary of Swiss Federal Railways (SFR), with headquarters in Lucerne and branch offices in Altdorf, Sedrun and Bellinzona. In 2017, ATG has around 140 employees.

ATG is the constructor of the NRLA Gotthard with base tunnels through the Gotthard and Ceneri. ATG is responsible for the project management and risk management and for ensuring that the built structures are delivered on time, within budget, and in the agreed quality. ATG is purely a management company. It does not plan or build anything itself, but contracts this work to project engineers, construction companies and consortia.
Only with the 15.4-kilometres-long base tunnel under the Ceneri will the continuous flat route from Altdorf to Lugano become reality. After the Gotthard and Lötschberg base tunnels, the Ceneri Base Tunnel is Switzerland’s third-largest railway-tunnel project.

The tunnel system
Like the Gotthard Base Tunnel, the Ceneri Base Tunnel also consists of two single-track tubes around 40 metres apart, which are linked to each other every 325 metres by cross-passages. Because of the tunnel’s shorter length, no track crossovers or multifunction stations are needed.

At the request of the canton of Ticino, to serve regional traffic, the Locarno–Lugano «Bretella» will be implemented. This will provide a direct link between Lugano and Locarno and thereby reduce the journey time from today’s 58 minutes to 30 minutes.

Construction concept
The Ceneri Base Tunnel was excavated entirely by drilling and blasting. The depth of overlying rock is up to 900 m. Most of the excavation was performed in both directions simultaneously from the intermediate heading at Sigirino. To optimise time and costs, inward drives were also cut from the portals at Vigana and Vezia.

Camorino
To link the Ceneri Base Tunnel with the existing railway lines, various structures were built at the Camorino hub, including a new four-lane bridge over the A2 motorway and two single-track railway viaducts over the four-lane cantonal road.

Vigana
The north portal of the Ceneri Base Tunnel is located in the vicinity of Vigana. Here, in loose rock, the tunnel had to pass only nine metres under the A2 motorway. Shortly after the portal in both tubes are underground branch-off caverns which, at a future date, will allow a new connecting line to be built across the Magadino plane.
Sigirino
Starting already in 1997, a 2.7-kilometres-long exploration tunnel was
driven from Sigirino, which provided valuable information about the geology.
In 2008, a tunnel boring machine cut a 2.3-kilometres-long access adit. At the end of this adit are two underground caverns which, from 2010, were the starting points for two drives each running both south and north. The caverns also accommodated construction-site installations for the main drives, including, for example, a concrete-manufacturing plant.

Vezia
At Vezia is the site of the south portal of the Ceneri Base Tunnel. About 2.5 km north of the portal, still inside the mountain, is the underground branchoff at Sarè which will allow a possible future extension of the tunnel southwards to Chiasso and Como. To protect the nearby inhabited areas and buildings – such as the cultural-heritage protected Villa Negroni – special methods were used for driving. Elsewhere, the trackbed of the Ceneri Base Tunnel passes only four meters above the new Vedeggio-Cassarate road tunnel of the Lugano bypass, which also called for protective construction methods. A 200-metres overground section connects the south portal of the Ceneri Base Tunnel with the existing main line.

Final breakthrough of the Ceneri Base Tunnel on January 21, 2016
△ Lining the tunnel in the area of the Sarè branchoff

The Ceneri Base Tunnel was excavated entirely by drilling and blasting. The minimum depth of overlying rock is only a few metres.

Northern Ceneri Zone
The mixed gneisses of this zone present cleavage layers at right-angles to the tunnel axis; also, the Val d’Isone fault zone was 40 m longer than expected in advance.

Central Ceneri Zone
In this zone mixed gneisses and orthogneisses predominate. In the central area, the rock is interspersed with a series of amphibolites. The Val Mara fault zone was explored in advance with a core bore from the surface. In the area of the tunnel it is 145 m long, and therefore almost five times longer than assumed in advance.

Southern Ceneri Zone
The predominant Giumello gneiss consists of alternating layers of twin schist and quartz-rich gneisses. Because of the steeply sloping cleavage layers, there were frequent separations.

Linea Val Colla
This approximately 650-metres-long fault zone consists of crushed and fractured rocks. The rapid transition from compact rock to cohesionless rock, and vice versa, hampered tunnel driving and, in the east tube, caused a roof fall of 150 m³. In parts of this fault zone it was therefore necessary to install the most massive types of support.

Val Colla Zone
The prevailing Stabbiello gneiss varies between quartz-rich gneisses and schists with staurolite and garnet. The main cleavage crosses the tunnel axis almost at right-angles. To the south, the cleavage levels off and is frequently undulating or folded.
The new high-speed route through the Alps makes high demands on the precision of the built structures. Reliable and highly accurate surveying methods guarantee marking-out with millimetre accuracy.

A network of fixed points that are determined by satellite measurement techniques forms the basis for all surveying work. The fixed points provide the link between the project and the terrain, and serve as starting points for marking out the tunnel below ground.

**Surveying the drive**

The access adit at Sigirino played a central role for surveying the drive of the Ceneri Base Tunnel. Almost 95% of the tunnel and adits were marked out from Sigirino by means of traverses, in other words by successive measurement of angles and distances. At regular intervals in the tunnel, surveying points were established which served to control the blasting of the drive. This underground measuring network was continuously updated and checked; the driving direction was optimised using measurements made by gyrotheodolite.

**Continuous checking**

Monitoring and geometrical documentation of the completed built structures, as well as continuous checking of the required constructional tolerances, are part of the surveying work. Verification of the geometry of the tracks to an accuracy of less than one millimetre was the last check to be performed.
Most of the excavation of the Ceneri Base Tunnel was performed simultaneously in both directions from the intermediate heading at Sigirino. Inward drives were also cut from the portals at Vigana and Vezia.

When planning the Ceneri Base Tunnel, attention had to be paid to its closeness to the surface at some points, the densely populated areas near the portals, and the crossings under or over major traffic routes at the portals. This was the reason for driving the tunnel tubes mainly from Sigirino, to the north as well as the south.

Only conventional drilling and blasting

First preparatory work was already performed in 1997 with the 2.7-kilometres-long exploratory tunnel. In 2008, a tunnel boring machine cut the 2.3-kilometres-long access adit. At the end of this adit are two underground caverns which, from 2010, were the starting points for the main drives running south and north. Excavation of the tunnel tubes and the total of 48 cross-passages was performed entirely by conventional drilling and blasting. For logistical supplies to the driving areas, hanging platforms which could be continuously moved forward were installed in all four tunnel tubes. On and under the platforms was room for all the necessary infrastructures. These included fans, dust removers, com-
pressors, emergency generators, containers, driving equipment, crushers, belt conveyors, concrete production systems, and many others. The use of hanging platforms rationalized the work processes, increased productivity and improved safety. This was because such systems allow an optimal interplay of the necessary equipment and provide sufficient space for the construction machines that are used in conventional drill-and-blast driving.

More than one year ahead of schedule
Driving to the south progressed faster than forecast. In the west tube, breakthrough to the inward drive from Vezia already took place on March 17, 2015. This was 13 months ahead of the construction schedule! A decisive contribution to this achievement was the carefully planned and executed blasting in the southernmost zone, where the depth of rock above the tunnel was very small. In this area, the quantity of explosive used was reduced to a minimum by the use of sector detonations. This allowed the vibrations from the blast to be kept under control.

The second breakthrough to the south, in the east tube, took place on March 30, 2015, which was also much earlier than planned. As a result, there was a real lead of 14 months ahead of the construction schedule. AlpTransit Gotthard Ltd therefore contracted acceleration measures with the consortium of the main lot. On January 21, 2016, the miners and many invited guests could celebrate the final breakthrough of the Ceneri Base Tunnel in the west tube. The breakthrough took place with great accuracy: the vertical deviation was less than 2 cm, horizontally it was not even 1 cm. A few days later, the miners also excavated the last metres of rock in the east tube.

Rapid lining
In such a construction project, the permanent lining of the tunnel tubes (invert, vault and kickers) also has to be seamlessly coordinated. Three-hundred to 500 metres behind the driving face, the lining was performed in blocks of 12 metres. Each block, the work began with the invert, with the mixed-water pipeline running in the middle. This was followed by the so-called kicker areas, with the drainage packs on both sides, and then the sealing and concreting of the tunnel vault. The lining work was concluded with construction of the benches.
With construction of the new Gotthard rail link, Switzerland has implemented one of Europe’s largest environmental-protection projects. The flat route contributes to protecting the Alpine environment. Construction also took place as environmentally compatibly as possible.

When constructing the two major tunnels through the Gotthard and the Ceneri, comprehensive measures reduced the effects on people, animals, air and water. The dialogue with environmental authorities and organisations helped in finding workable solutions.

**From excavated rock to concrete**

An excellent example of such a solution was spoil processing. Excavation of the tunnels produced huge quantities of spoil. To conserve natural resources, a large part of the excavated rock was converted into concrete aggregate, which was used for the tunnel lining. The remaining material was used, for example, for landscaping or embankments. Only a small proportion of the material had to be deposited in landfills.

**Recycling of a special kind**

Construction of the Gotthard Base Tunnel produced a total of around 8.6 million tons of excavated material. Around one quarter of this amount could be recycled, for instance for manufacturing shotcrete and other concrete for use inside the tunnel. The remainder was transported by belt-conveyor from the tunnel construction site through the access adit to the permanent spoil deposit at the foot of Monte Ferrino.

When the construction work is complete, the spoil deposit will be contoured so that it blends into the landscape and is not endangered by erosion. It will also be renatured. By means of suitable planting, the spoil deposit will become part of an important wild-animal corridor which continues across the newly constructed wild-animal passage at Dosso di Taverne to the opposite side of the valley.
Following completion of the drive and the lining of the Ceneri Base Tunnel, it is now being fitted out with the mechanical, electrical and ventilation systems without which the tunnel cannot be operated.

Infrastructure in the cross-passages

In order to simplify spare-parts management as well as the acceptance processes, wherever possible in the Ceneri Base Tunnel the same components are being used for the tunnel infrastructure systems as in the Gotthard Base Tunnel. This relates particularly to the doors, the ventilation systems and the technical floors in the 48 cross-passages. The same applies to the special doors of the technical niches and the doors of the cable vaults as well as the covers of the lubrication points. The latter serve as covers for the cable-protection tubes for a possible high-voltage line (132 kV) in the benches.

There are two areas of the tunnel infrastructure systems in which there are major differences from the Gotthard Base Tunnel: one of these is the operational ventilation, the other is the water supply and drainage.

Ventilation in the Ceneri Base Tunnel

In contrast to the Gotthard Base Tunnel, in the Ceneri Base Tunnel no ventilation centre is provided. More than 50 jet fans, which are mounted near the portals and in the middle of the tunnel, provide the necessary ventilation of the tunnel during maintenance and in the event of incidents.

Common pipeline for groundwater and soiled water

In contrast to the Gotthard Base Tunnel, in the Ceneri Base Tunnel the groundwater and soiled water are not drained separately. Here, the much smaller volume of groundwater allows a mixed drainage system. The water-processing systems are located by the north portal at Vigana.
Railway operations in the Ceneri Base Tunnel only become possible with the railway infrastructure systems. They integrate the new track systems into the existing railway network.

The railway infrastructure systems include the track, overhead conductor, electric power supply, cables, telecommunication and radio systems, safety and automation systems, and control systems. In addition to the systems for operation, their installation requires extensive temporary buildings, such as construction-site ventilation, electric power supply and communication, lighting, and access control for installation of the railway infrastructure systems.

Only one installations site
The railway systems installations sites near the portals form the logistical basis for the installation process. In the case of the Gotthard Base Tunnel, the length of 57 km made two installations sites necessary, one in the north at Erstfeld and one in the south at Biasca. For the Ceneri Base Tunnel, a single site in the north is sufficient. On account of its size and position in front of the north portal, the triangle of the traffic hub at Camorino provides ideal conditions for the location of an installations site of around 60,000 square metres, which will be operated between 2016 and 2020. Situated on the site are the control centres, office containers, parking spaces, loading/unloading and marshalling areas, two large halls for the railway systems contractors, and the infrastructure for visitor management.

Coordinated installation
The railway systems are a complex technical system. For this reason, close coordination between the individual areas of the railway infrastructure systems, as well as between the contractors in the areas of the tunnel structure and the tunnel infrastructure systems, is crucial.

Two railway infrastructure buildings
Close to the tunnel portals at both Camorino and Vezia is a railway systems building. These accommodate all of the technical systems that are necessary for control of the tunnel and the railway operations.
Like the Gotthard, the Ceneri Base Tunnel will also have a ballastless railway track. In this system, the sleeper and the rubber shoe are cast directly into the base slab.

The ballastless track and the points of the Ceneri Base Tunnel are constructionally identical to those in the Gotthard Base Tunnel. The principal components are sleeper blocks, rails and Hydrostar points.

High requirements
The railway track is a so-called low-vibration track (LVT). This system consists of concrete monolithic blocks in rubber shoes, which are concreted into unreinforced concrete at intervals of 60 cm.

Overground sections
In the overground sections to the north and south of the Ceneri Base Tunnel, a conventional ballasted track with concrete sleepers is being laid.
The length of the tunnel, the short intervals between trains, and the high availability that is required, make providing the tractive power supply a real challenge also in the Ceneri Base Tunnel.

Tractive power supply
The 16.7 Hz tractive power supply of the Ceneri Base Tunnel comes from the Swiss Federal Railways network. In the north, it is fed in from the frequency converter at Giubiasco and in the south from the new substation at Vezia. To assure the tractive power supply in the event of a fault in a substation, the systems have been designed so that the so-called emergency supply capability can be assured by interconnecting two overhead conductor segments.

Tractive power supply and overhead conductor
Since the Gotthard Base Tunnel was planned, Swiss Federal Railways have updated their standards for overhead conductors in tunnels. Because of this, in both tubes of the Ceneri Base Tunnel, overhead conductor rails are provided. Compared to a conventional overhead wire with catenary, like in the Gotthard Base Tunnel, this system has several advantages:

- With an overhead conductor rail, tensioning devices for the conductor wire and supporting cable are not required. Consequently, simpler and more compact structures with fewer components and less structural height are possible.
- Compared to a catenary, the current-carrying capacity of an overhead rail is higher. Depending on the required current strength, amplification wires are therefore not necessary.
- Overhead rails have a higher short-circuit resistance and are more fire-resistant.
- The permissible wear is greater, so overhead conductor rails have a longer life.

Example of the overhead conductor rail ▲ 15 kV supporting structure for the overhead conductor rail ▼
The safety systems assure seamless control and monitoring of the train traffic. They must fulfill very high requirements for safety and availability.

As in the Gotthard Base Tunnel, the safety systems in the Ceneri Base Tunnel consist of the following main elements:

**Signalling centres:** The latest-generation electronic signalling centres control and monitor track elements such as points and track-release systems (axle counters). They also assure a clear path for the train. In the Ceneri Base Tunnel, an electronic signalling centre is used with the associated external systems.

**Wireless block centre:** The radio block centre (RBC) is the central component of the driver’s cab signalling system. Travel authorisation and the corresponding block information is transmitted from the RBC via wireless interface (GSM-R) direct to the trains. The Gotthard and Ceneri base tunnels each have a separate radio block centre.

**Railway control system:** This is the actual control level and helps the traffic controller to control and monitor operations. The railway control system consists of the ILTIS network-wide control system used by Swiss Federal Railways and the Tunnel Automatic Gotthard (TAG) system, which is used specifically for the Gotthard Base Tunnel.

**Automated railway operations**
The safety systems are operated from the control centre at Pollegio. Inside the tunnel, the decentral systems, such as track-release and points-control, are linked together via a data network. Railway operations are completely automated.

**Driver’s cab signalling system**
The newly constructed sections of the Gotthard and Ceneri are equipped with the modern European Train Control System (ETCS) Level 2 electronic driver’s cab signalling system. The train driver wirelessly receives all information on the display in the driver’s cab. ETCS allows signalling at speeds of more than 160 km/h. It increases safety and allows capacities to be increased by shorter time intervals between trains. Since optical signals are eliminated, the trackside infrastructure is simplified. The signalling system is standardised throughout Europe and therefore assures interoperability and simplified access to networks.

---

**GSM-R**

**GSM-R radio system**

**Pulse encoder**

**Signalling centre**

**RBC**

**Eurobalise**

**reports**

**Position**

**Track vacancy detection**

**Radar**

**Balises**

**antenna**

**GSM-R Antenna**

The ETCS transmits the train’s location and other train data to the Radio Block Centre (RBC).

The train driver reads the signal information from the displays in the driver’s cab.

As the train passes over a balise, the balise transmits the exact position of the train to the ETCS.
The telecommunications systems in the Gotthard and Ceneri base tunnels are necessary for the control of the tunnel infrastructure as well as for the seamless monitoring of the railway traffic. They also allow passengers to use telephone and data services.

Tunnel control systems
With the tunnel control systems, all tunnel-specific installations such as power-supply systems, telecommunication systems, ventilation, doors and lighting are controlled and monitored. Also linked to the control system are further systems that assist the operating personnel for managing incidents or planning maintenance work. Overall control of these systems takes place from the Tunnel Control Centre at Pollegio.

Data network
The data network links the various tunnel systems to the overarching tunnel control system. The networking of locationally distributed components of individual systems also takes place through the data network, so that they can communicate with each other.

Tunnel radio systems
For the largely automated operation of the railway with the electronic train control system a reliable mobile communications network is essential. This is required not only for the operation and maintenance of the tunnel but also in the event of an incident. The following radio networks are available:

1. The train driver receives information which is transmitted into the driver’s cab by the digital radio system for railways (GSM-R).
2. For interventions in the tunnel, emergency services such as police and firefighters use their own digital radio system, POLYCOM.
3. The train passengers use the public radio systems (GSM-P/UMTS/LTE) to access the services of the public mobile radio providers.

As wireless transmission system for the radio, an antenna cable in the tunnel is used. The antenna cable functions similar to an irrigation hose: it has «holes» in its shield, through which radio waves can leave and enter.
Before scheduled train services can travel through the Ceneri Base Tunnel, all of its systems must be thoroughly tested, test kilometres must be completed with trains, and personnel must be trained. Only when everything functions smoothly will Swiss Federal Railways receive authorisation for commercial operations from the Swiss government.

Commissioning of the Ceneri Base Tunnel is highly complex and subdivided into various phases. In sub-tests, each individual component and system is tested for its functionality.

**The test phases**

On completion of installation and successful sub-testing of all components and installations, commissioning proper begins along the entire length of the tunnel. This is subdivided into:

**Overall integration test**

Before test operation begins, it must be ensured that the installed equipment and systems fulfil the requirements, deliver the specified performance, and function faultlessly, under all operating conditions. Within the framework of a so-called overall integration test, the interplay of all components and subsystems, as well as their integration into the overarching control systems and their connection to the rest of the Swiss Federal Railways network, is therefore systematically tested and verified.

**Test operation**

AlpTransit Gotthard Ltd, as constructor, proves the functionality and fulfilment of the safety requirements. In test operation, first of all, detailed measurement data from specific subsystems are recorded and analysed in measurement runs, after which, in further train runs, the interplay of all tunnel components is extensively tested.

**Trial operation**

The subsequent trial operation will take place under the principal responsibility of the future operator, Swiss Federal Railways. Only when it has been demonstrated that operation with passengers and goods trains, as well as personnel deployment and incident management, function perfectly, will the responsible Federal Office of Transport issue the operating permit for commercial operation.
The Gotthard Base Tunnel extends from the north portal at Erstfeld, in the canton of Uri, to the south portal at Bodio, in the canton of Ticino. The main tunnel is 57 km long and consists of two single-track tubes, which are 40 metres apart and connected to each other every 325 metres by a cross-passage. With the addition of all the connecting passages, access adits and shafts, the complete tunnel system measures around 152 km. With a rock overlay of up to 2,300 metres, the Gotthard Base Tunnel is the world's deepest railway tunnel; it also has virtually no gradients, with the highest point lying at 550 metres above sea level.

Two multifunction stations, beneath Faido and Sedrun, divide both tubes into three approximately equally long sections. In these multifunction stations the trains can cross over from one tube into the other and stop in an emergency. For construction purposes, the Gotthard Base Tunnel was divided into five sections. To save time and costs, construction work on the individual sections was coordinated and, for some of the time, proceeded simultaneously.

Driving
To construct the Gotthard Base Tunnel, the miners had to cut through highly diverse rock strata: from hard granite to highly fragmented sediments. Eighty percent of the driving in the main tubes was performed by tunnel boring machines, twenty percent by conventional drilling and blasting. A total of 28.2 million tonnes of excavated rock was transported out of the tunnel. The underground temperature was up to 46 °C. At peak times, around 2,400 people worked on the tunnel construction sites. Construction work took place on a twenty-four-hour, three-shift basis.
World record under the Gotthard
On October 15, 2010, the world record under the Gotthard became reality: 30 kilometres from the south portal and 27 kilometres from the north portal, the final breakthrough of the world’s longest railway tunnel took place. The surveyors also achieved a masterly performance: a deviation of only eight centimetres horizontally and one centimetre vertically. To excavate the entire tunnel, the miners took a total of around eleven years.

Tunnel infrastructure systems and railway systems
However, work operations in the Gotthard Base Tunnel did not end with the final breakthrough. They continued with fitting-out of the two tunnel tubes. The tunnel-infrastructure specialists equipped the tunnel with mechanical and electromechanical systems such as doors, ventilation and drainage. These ensure that the railway tunnel can be safely operated and maintained. Installation of the railway infrastructure systems began in summer 2010. These comprised the track, catenary, electric power supply, cables, telecommunication and radio systems, safety and automation systems, and control systems.

Approach routes to the north and south
Finally, the new tunnel also had to be connected with the existing railway network. For this purpose, in the north as well as in the south, auxiliary structures such as bridges and underpasses were built to provide a link from the existing SFR line to the tunnel.

Commissioning
Before the Gotthard Base Tunnel could be commissioned, in more than 3,500 test runs the interplay of all tunnel components and systems was thoroughly tested. In November 2015 a train travelled for the first time at the maximum test speed of 275 km/h through the world’s longest railway tunnel. In January 2016 the first goods train completed its journey through the new Gotthard Base Tunnel. At the start of June, 2016, the Gotthard Base Tunnel was opened with a large-scale opening ceremony and a public festival for young and old. The construction of the century was put into operation by Swiss Federal Railways with scheduled train services on December 11, 2016.