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GOTTHARD BASE TUNNEL
The Sedrun Shaft Hoisting System

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Gotthard Base Tunnel: The Sedrun Shaft Hoisting Systems

Part 1: Tunnel Construction Phase

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The 57 km long Gotthard Base Tunnel was produced in five contract sections with three intermediate points of attack. The Sedrun intermediate point of attack consists of two blind shafts some 820 m deep, which could only be reached via a roughly one kilometre long access tunnel. The complex, tricky general conditions and the high demands placed on the availability of the shaft hoisting system were and still are a particular challenge for building and operating the facilities. This report in Part 1 deals with constructing and operating the shaft hoisting system in the form of a rock, material and manriding shaft and installations to cool the air in the Faido tunnel section during the excavation phase. Part 2 examines the dismantling and modification of the shafts and the functions of the ultimate hoisting facilities in the Sedrun shafts during the rail tunnel's operational phase.

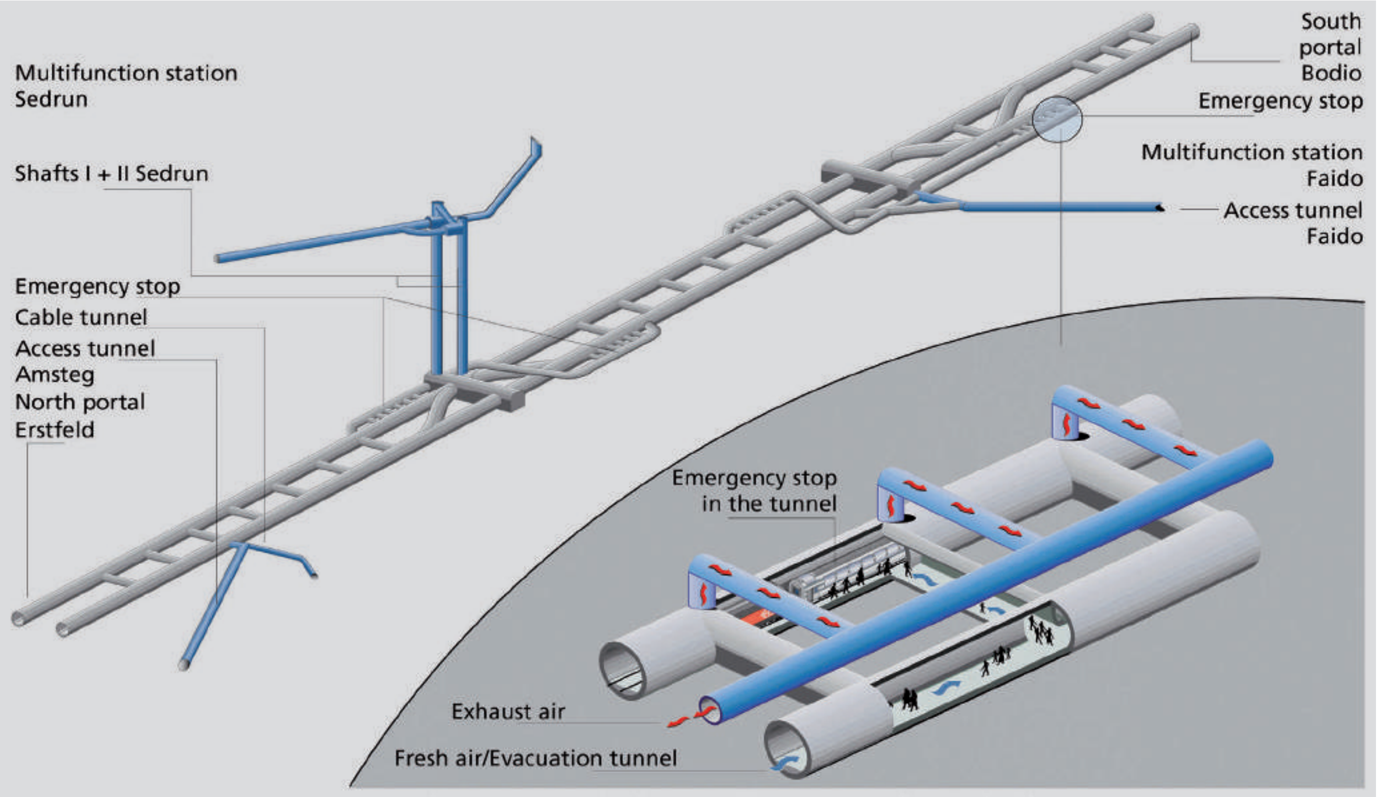
Tunnelling • Shaft construction • Switzerland • Suppliers • Shaft hoisting • Air cooling

1 Introduction

The Gotthard Base Tunnel (GBT) in Switzerland is a project of the century. With its two parallel running single-track tunnel tubes each 57 km in length, it will be the world's longest rail tunnel. This pioneering achievement in tunnelling will result in massive improvements in passenger and freight traffic in the heart of Europe. Passenger trains will be able to travel over the flat and relatively straight route provided by the Gotthard Railway at speeds of up to 250 km/h. This will mean the travel time between Zurich and Milan for instance being cut by about an hour. In addition, by transferring traffic from road to rail, Switzerland will achieve one of the major European environmental protection programmes designed to conserve the mountainous Alpine region. The GBT is scheduled to open in December 2016.

AlpTransit Gotthard AG is responsible for building the new route crossing the Alps – the Gotthard axis with the Base Tunnels at the Gotthard and Ceneri. Set up in 1998, the SBB subsidiary today employs around 160 staff at its Lucerne base and its branches in Altdorf, Sedrun,

Fig. 1: General Layout of the Gotthard Base Tunnel
Source: Alptransit Gotthard AG



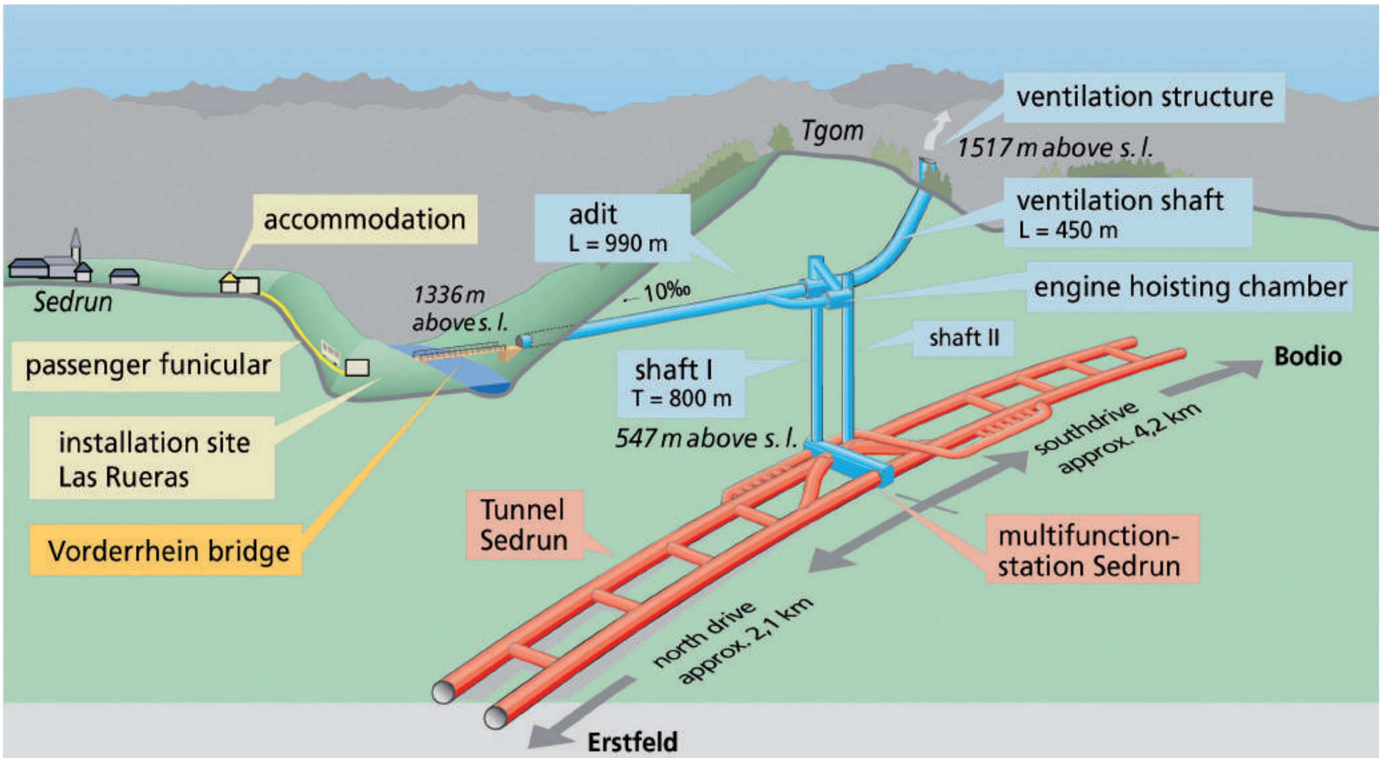


Fig. 2: Intermediate point of attack for the Sedrun part-section
Source: AlpTransit Gotthard AG

Faido and Bellinzona. Siemag Tecberg GmbH was first commissioned to build and operate shaft hoisting system at the Sedrun intermediate point of attack back in 1999. During the tunnel construction phase, an additional mobile shaft winch was supplied for safely operating the Sedrun shafts as well as installations for air conditioning in the tunnel for the Faido intermediate point of attack. For the first time anywhere in the world, hoisting installations with round inspection platforms designed to last 100 years were supplied for future inspection, maintenance and cable assembly purposes. After introducing the Gotthard Base Tunnel project in general and the shafts at the Sedrun intermediate point of attack, this report will explain how the challenges were met given complex general conditions and high demands on the availability of the hoisting system. Part 1 deals with the facilities for the construction phase and Part 2 with converting the shafts and the functions of the newly supplied hoisting installations for the GBT's operating phase.

2 Gotthard Base Tunnel, Multi-Function Stations, Sedrun Shafts

Fig. 1 contains an overall view of the GBT. The Erstfeld portal is located on the northern side of the Alps with the Bodio portal on the southern side. The two tunnel bores for the rail tunnel are connected with one another by cross-passages at 325 m gaps. The tunnel was divided up into five sections, where work forged ahead simultaneously in order to cut down on the construction time needed for the GBT. The tunnel drives were undertaken from both portals as well as from three so-called intermediate points of attack.

Thanks to the two intermediate points of attack Sedrun and Faido the tunnel is divided into three sections of roughly the same length. As a result, entire railway stations were blasted out of the rock at these points, which are called Multi-Function Stations (MFS). In the event of a breakdown or an emergency, trains can park in the emergency bays at the side of the MFS. From these bays, passengers can access the other tube via escapeways and board an evacuation train. Should a fire break out, the operating ventilation system removes the smoke. In addition to the emergency bays, the MFS comprise large caverns, which contain the necessary technical buildings for rail operations and the operating ventilation.

The Faido MFS is ventilated via a 2,700 m long access tunnel and the Sedrun MFS via two roughly 800 m deep vertical shafts as well as a ventilation shaft. The two blind shafts and the shaft hoisting facilities in Sedrun can be reached by means of a roughly 1,000 m long access tunnel (**Fig. 2**). Caverns were excavated to accommodate the shaft hoisting facilities.

The Sedrun intermediate point of attack represented something out of the ordinary as it could only be reached via the shafts, quite apart from actually being an underground construction site in itself. Furthermore, surveying the tunnel via the shafts, the high rock pressure and the soft layers of rock also represented major challenges. It was not possible to apply a tunnel boring machine (TBM) and progress swiftly in the 8.5 km long Sedrun part-section on account of the particular geology prevailing there. The MFS and the four tunnel drives were thus produced by conventional drill+blast and every new metre gained had to be laboriously secured and consolidated.

The AlpTransit Gotthard AG extended each of the two emergency bays in the Sedrun MFS by two departure halls for a possible underground railway station, the so-called “Porta Alpina Sedrun” (PAS). The current level of planning relating to the GBT’s capacity, however, does not foresee the PAS being accomplished and utilized. An alternative use for the existing departure halls for touristic purposes is, however, possible as is producing the PAS sometime in the future.

3 Project Overview

During the GBT project the AlpTransit Gotthard AG commissioned the Siemag Tecberg to fulfil the following contract sections:

- **Part 1:** planning, production, supply, assembly, commissioning and operating installations for shaft conveyance and for tunnel air cooling during the construction phase from 1999 to 2012:
  - In September 1997, a contract to supply, start up and operate the shaft hoisting system for Shaft I (lots 356 and 360)
  - In August 2001, a contract to supply, start-up and operate a mobile shaft winch (lot 372)
  - In 2001, a contract to supply additional installations for handling large mine cars at the shaft head and foot of the shaft hoisting system for Shaft I (the client in this case was the Transco/UN Lot 360 JV)
  - Starting up the shaft hoisting system (lot 356) in accordance with TAS (German technical requirements on shaft and inclined conveyance gear) and BVOS (German mining ordinance for shaft and inclined conveyance gear), in September 2002
  - Operating the fully automatic shaft hoisting system from September 2002 to August 2012 under Siemag Tecberg’s own initiative and responsibility, for serving the construction of the underground rail tunnel and the Multi-Function Station (lot 360)
  - Supplying a Pressure Exchange System (P.E.S.) for cooling the air in the Faido tunnel section in 2002 and 2008
- **Part 2:** modifying the Sedrun shafts and describing the functions of the newly supplied hoisting installations for the rail tunnel operating phase:
  - In November 2011, signing a works contract between the AlpTransit AG and Siemag Tecberg on the installation and operation of new, final hoisting facilities (lot D) for the two 800 m deep vertical shafts in Sedrun
  - In August 2013, starting up of the new hoisting installations, consisting of a double drum winder and a winch, initially for the temporary construction site facilities for enlarging the shaft
  - In March 2014, starting up the new lot D hoisting installations with guided inspection platform for the GBT operating phase
  - At present, integrating the new hoisting installations for the rail tunnel’s control technology and providing training for the maintenance and test personnel

4 Shaft Hoisting System for the Tunnel Construction Phase (Lot 356)

4.1 Generall

Shaft I represented the main artery of the tunnelling site in the Sedrun part-section. During the construction phase, practically all the excavated rock and material was transported through this bottleneck which also provided manriding facilities. In addition the construction sites were supplied with electric power, compressed air, industrial water and consumables via Shaft I. It also catered for drainage control and in particular providing the ventilation system with fresh air. Furthermore, the complete signalling and communications technology was housed in Shaft I.

The shaft hoisting installations in lot 356 had to be available during the excavation and roughwork phase in a 3-shift operation, seven days per week and 340 days per year at maximum power for the following tasks:

- Manriding (personnel rope hoisting facilities)
- Material transports (excavated rock)
- Transporting heavy loads
- Transporting long parts
- Auxiliary manriding (self-propelled manriding)
- Shaft inspections

The complete shaft hoisting system in lot 356 was designed in accordance with the codes of practice of the German mining ordinance for shaft and inclined conveyance gear (BVOS) and the pertinent technical requirements for shaft and inclined conveyance gear (TAS). In addition, the guidelines for shaft transport systems of the Swiss Accident Insurance Agency (SUVA) and further valid Swiss regulations were observed.

Lot 356 for Shaft I largely consisted of the two following shaft hoisting installations (**Fig. 3**):

- Main manriding facility incorporating rope guided fully automatic large cage
- Auxiliary manriding installation with rail guidance

Shaft I also contained additional components such as:

- Shaft head steelwork with sheave wheels
- Crane systems at shaft head and foot
- Shaft bottom steelwork
- Cage loading and unloading installations
- Rope attaching and rope changing installations
- Independent mobile shaft winch (lot 372)

The building materials for the underground caverns, technical buildings and four tunnel driving points were transported by the large cage hoisting facility, which also carried the excavated rock. The large cage hoisting facility designed as the main manriding system comprised a

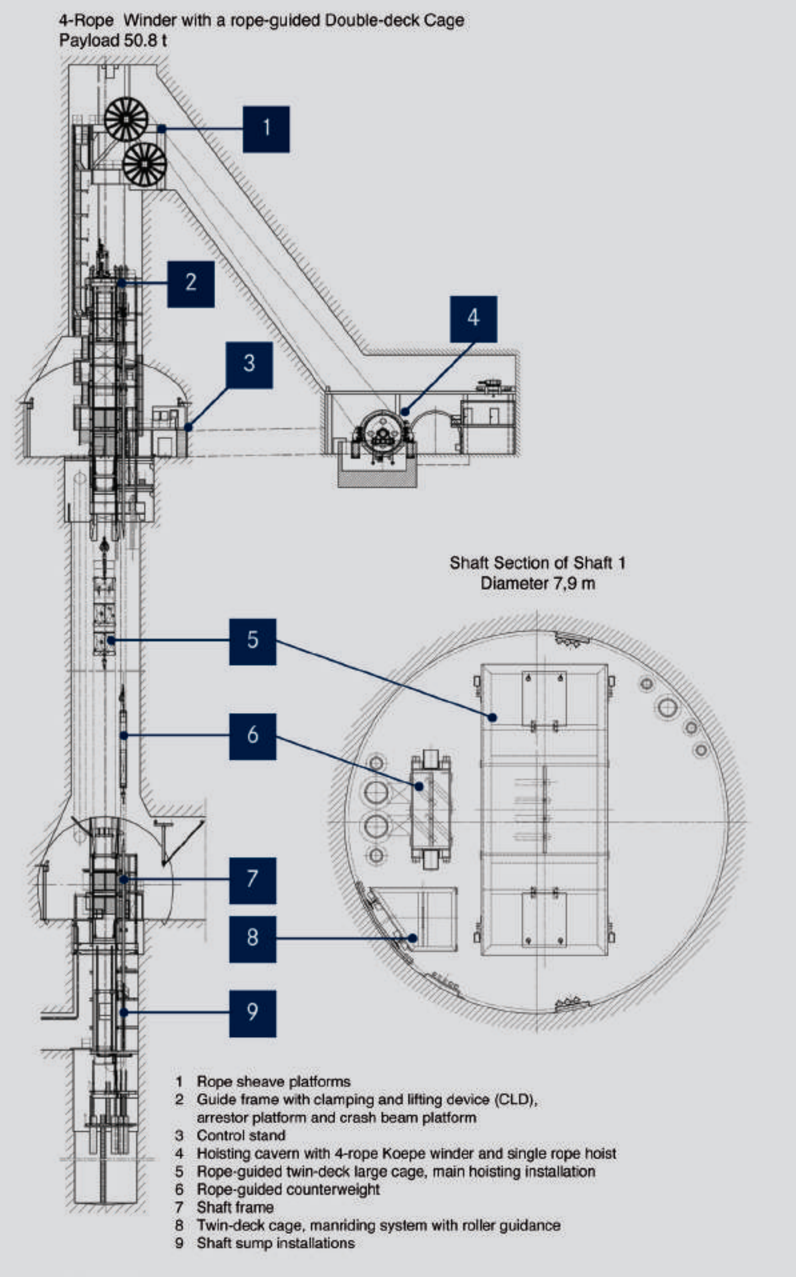


Fig. 3: Shaft hoisting system in Sedrun Shaft I for the tunnel construction phase

double-deck large cage counterweight facility. A haulage car with a capacity of 11 m^3 and a service weight of 19.2 t (gross weight 25.4 t) was transported on each cage deck. Automatic charging devices at the head and bottom of the shaft catered for automated loading and unloading of the large cage. In the event of accidents or breaks in production, additional persons could be carried or evacuated with the double-deck auxiliary manriding installation (MSFA).

The auxiliary manriding installation mainly served as a fully automatic self-propelled transportation unit. The system was used for shaft inspection rides, occasional descents for transporting maintenance and service staff as well as the possible evacuation of persons from the large cage or the tunnel drive. Persons could have been evacuated from the large (double) cage through emergency doors on the western side wall of the double cage. Thankfully, however, they never had to be used.

The shaft hoisting facilities for lot 356 were located, as shown in **Fig. 3**, on the floor in a separate hoisting gear cavern to the west of Shaft I. The 2 sets of 4-rope deflection sheaves with a diameter of 4.8 m were assembled in the shaft porch at the shaft head above the guidance frame on supporting structures – the upper and lower hoisting sheave platform. The rope guidance for the hoisting rope was accomplished from the hoisting gear room by means of an inclined shaft (rope channel) in the shaft porch, in which the ropes were redirected into Shaft I via the hoisting sheave platforms. The 3.2 m diameter hoisting sheave for the auxiliary manriding installation was also set up on the lower hoisting sheave platform with the hoisting sheaves for the counterweight for the main rope hoisting system.

The shaft hoisting system and a part of the additional integrated components will be described more closely in the following chapters. Chapter 4.5 deals with operating the resources during the roughwork phase. The essential technical details for the two hoisting facilities are summed up in **Table 1**. [1]

4.2 Main Manriding Installation

4.2.1 Facility, Friction Sheave and Braking Facilities

The 4-rope Koepe winder (**Fig. 4**) was driven directly via an AC-motor with a capacity of approx. 4.2 MW. The hoisting unit motor was equipped with a water cooling system in order to prevent the hoisting facility area from heating up unnecessarily. The re-cooling system operated in a closed circuit with a heat exchanger. The system's rope working load comprised the 50.8 t payload, the 26 t cage load, the 32 t rope weight and other loads amounting to a total of 7.2 t altogether amounting to 116 t.

The 4.8 m diameter friction sheave possessed two disc brakes. The hydraulic disc braking device, Type SB1, securely brought the hoisting system to a standstill during emergency braking, with fully closed loop controlled retardation. Seen statically, altogether ten Type BE 100 brake calipers retained the maximum overload with at least a triple safety factor. The Koepe winder was equipped with robust plain bearings, which were provided with oil circulating lubrication and hydrostatic start-up aid. A double-groove friction sheave lining ensured it could be re-trimmed easily by means of a turning device. The hoisting unit's friction sheave was designed in two parts to facilitate transport, assembly and disassembly. [1]

4.2.2 Large Cage, Counterweight and Charging Installations

The double-deck large cage with the dimensions 6.0 x 2.6 x 9.5 m was guided on four ropes in Shaft I. The central deck floor of the double cage could be easily dismantled using a sliding platform for transporting large parts. The large cage's head frame was fitted with two chain lifts each capable of lifting 10 t, which made it easier to transport heavy and bulky components. The counterweight frame was equipped with weight plates to provide the necessary ballast or rather to compensate for half the payload. The counterweight was also guided on four ropes.

All transports for the underground construction sites were undertaken using trackbound cars with a permissible maximum weight of roughly 25 t. The excavated rock from the tunnel drives was transported to the surface with the shaft hoisting system and then to the dumping site via locos. In contrast, the tunnel lining material was transported from the installation yard on the surface to the tunnel drives. A specially designed car turnaround cycle (classification yard) at the shaft head and bottom as well as a completely newly developed charging installation ensured that operations ran smoothly (**Fig. 5**). On the tunnel floor and in the access tunnel, the set of cars was driven onto a feeder track, where they were automatically decoupled and moved individually to the shaft. An advance gate and a shaft gate controlled the cars as they moved to their stationery position. The charging installation nonetheless enabled the particularly heavy cars to be pushed into the cage safely and accurately and to remove them from the cage. The cars were guided to their final position by means of pushers or pullers, controlled by coupling claws. A particular challenge involved assuring the fully automatic accelerating, slowing down and exact positioning of the cars with automatic couplings. This was accomplished with the aid of a PLC-based control system (PLC: Programmable Logic Controller) and 30 kW variable frequency AC drives.

The large cage was held in position at both limit stops by means of a cage locking device at floor level. In this way, the cage could be filled horizontally so that no tilting platforms were required to compensate for the rope elongations. Following loading or unloading the load was transferred to the ropes by releasing the cage retention device. [1]

4.2.3 Rope Load Measuring and Braking Facilities

The lot 356 shaft hoisting system was designed in keeping with the safety regulations called for by the German TAS and the BVOS as well as the valid Swiss regulations and in order to ensure that the capacity and availability would be attained. As is customary for modern, safe shaft hoisting systems, the following safety installations were integrated in accordance with the state of the art:

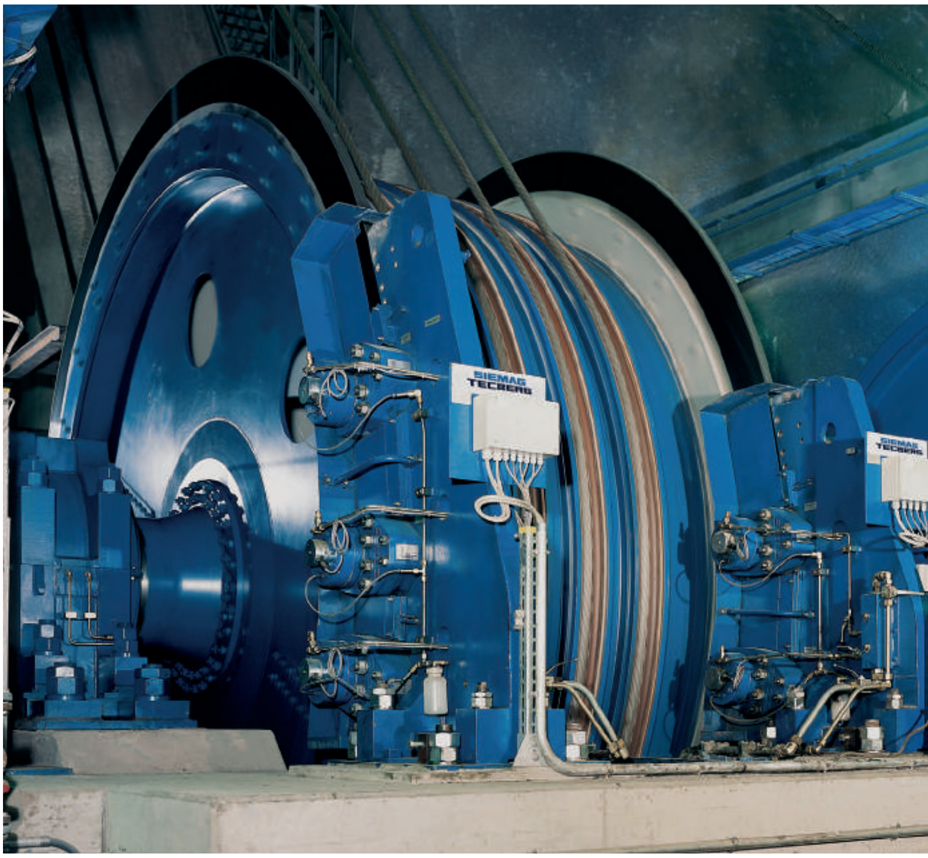
- Rope load measuring installations (SME)
- Siemag Tecberg Safety Arrestor (SSA)

The upper rope attachments – Type ST 320 – at the large cage were equipped with wedge clamps and resetting devices as well as with an integrated electronic rope load measuring installation (SME). The resetting

Table 1: Technical data of the shaft hoisting system in Shaft I for the tunnel construction phase

Description	Main manriding installation	Auxiliary manriding installation
Type of hoist	4-rope Koepe winder	single-drum
Conveying capacity	daily 6,350 t + 50 material units + 960 persons	18 persons/trip
Means of conveyance	double-deck large cage + counterweight	double-deck cage
Type of guidance in shaft	guide ropes	guide rails
Hoisting distance	795 m	795 m
Payload	50.8 t	1.6 t
Conveying speed	18 m/s (material); 12 m/s (manriding)	4 m/s
Type of winder	KW / 4800 / D	SDW / 3000 / G
Drum diameter	4.8 m	3.0 m
Motor capacity	4,176 kW	270 kW
Rope operating load	1,140 kN	60 kN
No. of ropes/Conveyance	4	1
Rope diameter	52 mm	28 mm
Rope breaking load	4 x 1.980 kN	570 kN
Type of brake	disc brake, 2 discs	disk brake,1 disc
No. of brake posts	4	1
No. and type of brake calipers	10 BE 100	3 BE 100
Brake control system	SB1	ST1 SB
Type of emergency braking	fully closed-loop retardation	pressure-controlled brake

Fig. 4: 4-rope Koepe winder, 4,800 mm with direct drive



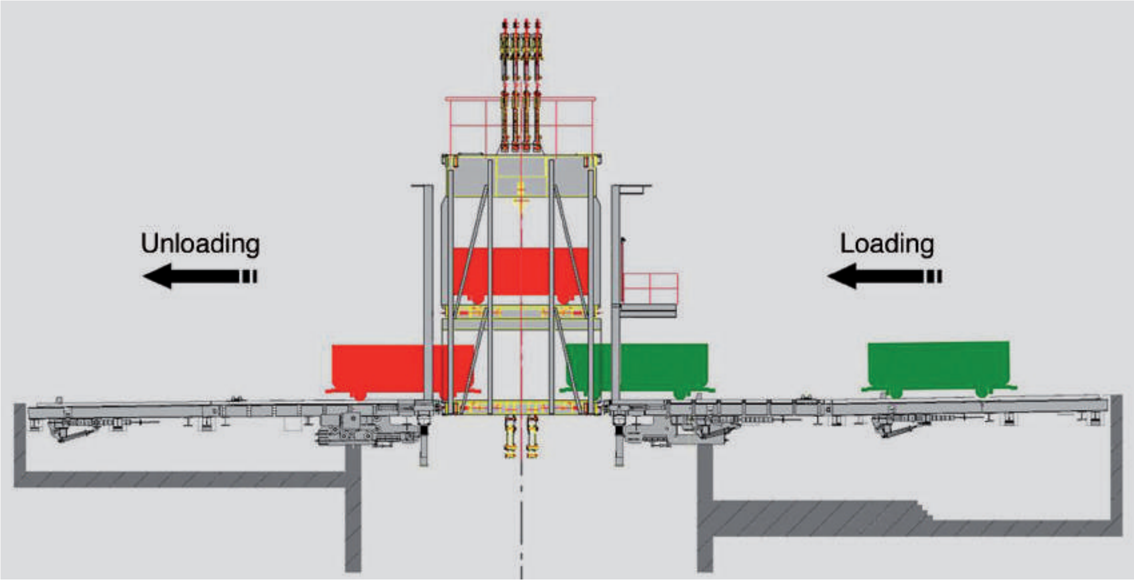


Fig. 5: Charging units for loading and unloading the large cage with controlled guided car

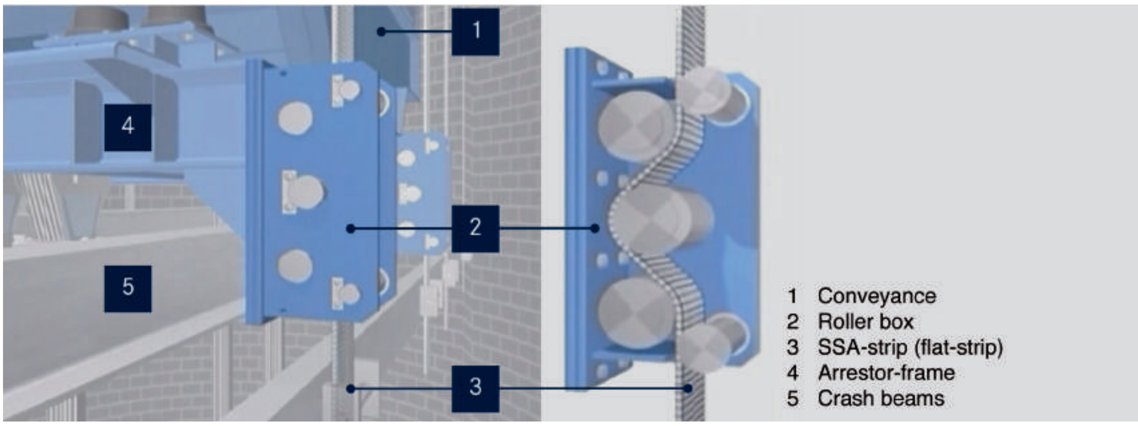
length amounted to 600 mm. The SME rope load measuring device was devised for continuously monitoring the rope loads of multi-rope systems. A load cell was provided for every rope, integrated in the large cage's upper rope attachment to prevent mechanical damage. Precise and reliable load measurements can be carried out and evaluated using a SME.

Siemag Safety Arrestors (SSA) – special overwind braking devices – were installed for the large cage and the counterweight at the shaft head and sump to prevent overrunning. These ensured that the large cage and the counterweight were stopped safely and in a controlled fashion should the shaft limit points be exceeded. The SSA braking devices for the counterweight were assembled in the square hollow profile of the shaft guidances in order to save space. The counterweight was restrained by slings and safely slowed down. The SSA functions by transforming kinetic and potential energy into strain energy and heat. The basic set-up of the SSA braking devices is shown in **Fig. 6**. Generally speaking it comprises an arrestor frame with roller boxes, which are guided via SSA-strips (flat steel strips). The SSA-strips are fixed firmly in the shaft. In the event of the system is overtravelling, the means of conveyance (1) impacts the braking frame (4) and the arrestor strips (3) are deformed plastically by means of the roller blocks (2) in a linear direction. The crash beams (5) are located at the end of the travelway. The braking force is produced by the reciprocal cold forming of the flat steel strips and leads to controlled retardation of the hoisting system. As the SSA braking facilities can be calculated fairly accurately, the corresponding structural parts are not overloaded in the event of an incident occurring. [1, 2, 3]

4.3 Auxiliary Manriding Installation

The auxiliary manriding installation comprised a trackbound double-deck cage, which could hold a maximum of 18 persons or 1.6 t load capacity. The cage was rail-guided in the shaft by spring-loaded guide rollers. The single-rope drum hoist (**Fig. 7**) was driven indirectly via a 270 kW capacity motor by means of a straight bevel gear unit with a maximum conveying speed of 4 m/s. The 3 m diameter drum possessed a disc brake. A hydraulic disc brake unit – Type ST1 SB – safely slowed

Fig. 6: Basic setup of the SSA braking facilities



down the hoisting system if need be with constant braking force until it reached a standstill. [1]

4.4 Mobile Shaft Winch

The safety concept for the Sedrun intermediate point of attack called for an independent mobile shaft winch (**Fig. 8 (a+b)**) to evacuate people at the two Sedrun shafts should for instance, the power supply fail in the hoisting system. In such cases, the mobile shaft winch could be set up and positioned appropriately at the shaft in question. Two evacuation cages of different sizes were available for rescuing people. Should an incident occur an evacuation cage could be attached to the mobile shaft winch's round rope thimble. The evacuation cage could be swivelled over the shaft and lowered down into it with the aid of the rotating, telescopic boom.

The mobile shaft winch's technical data are summarized in **Table 2**. All working functions are driven hydraulically. The power supply is provided via a cable or alternatively by a diesel generator. The maximum rope load amounts to 5 t. The speed can be infinitely adjusted in the 0 to 1.0 m/s range. A cable in the hoisting rope facilitates communication between the winch operator and the crew in the evacuation cage. The winch is mounted on a four-axle truck and corresponds to the mining regulations as approved by the Mining Board. [1, 4]

4.5 Operating Shaft Hoisting System in the Tunnel Construction Phase and Rope-Handling Applications

The fully automatic large cage hoisting gear had to be available from September 2002 till August 2012 on a 3-shift basis, seven days per week and 340 days per year for the Transco-Sedrun JV tunnelling contractor to provide manriding and material transport. Siemag Tecberg GmbH as the operator was obliged to convey the maximum hoisting capacity of 6,350 t of excavated rock per day in addition to 50 units of material. Up to 650 m^3 of concrete gravel per day was utilized for the inner lining.

The main task was thus to assure that the shaft hoisting systems ran without any disturbance. This

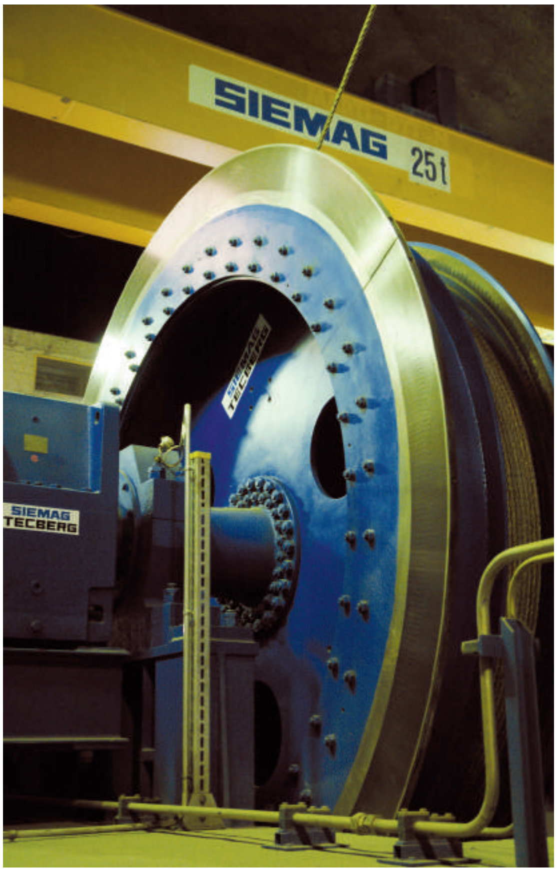


Fig. 7: Single-rope drum hoist for the auxiliary manriding installation

Table 2: Technical data for the mobile shaft winch

Rope capacity	885 m
Payload	5 t
Working radius	7.2 bis 9.7 m
Maximum crane extension height	12.2 m
Swivelling range	360 °
Rope diameter	22 mm
Lifting speed	1 m/s
Drum diameter	1,200 mm

Fig. 8: Mobile shaft winch

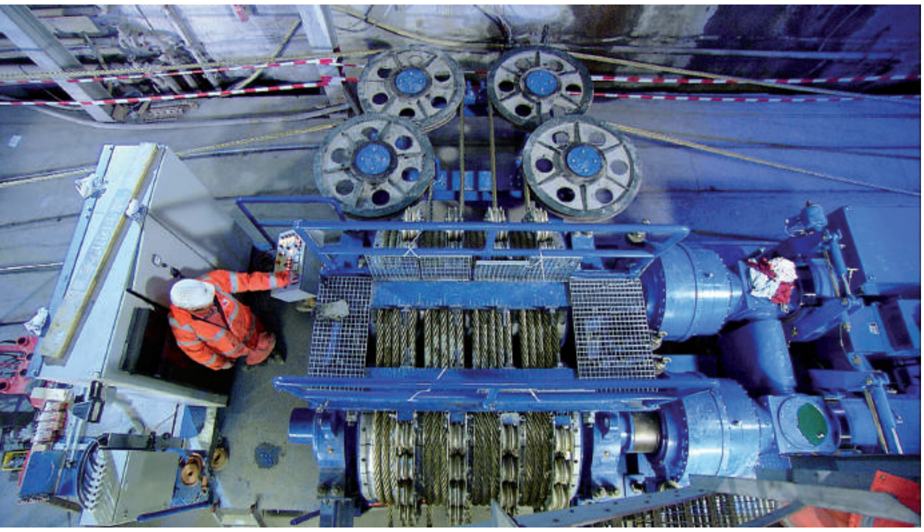


Fig. 9: Mobile friction winch with deflection sheave set

Table 3: Technical data for the mobile friction winch

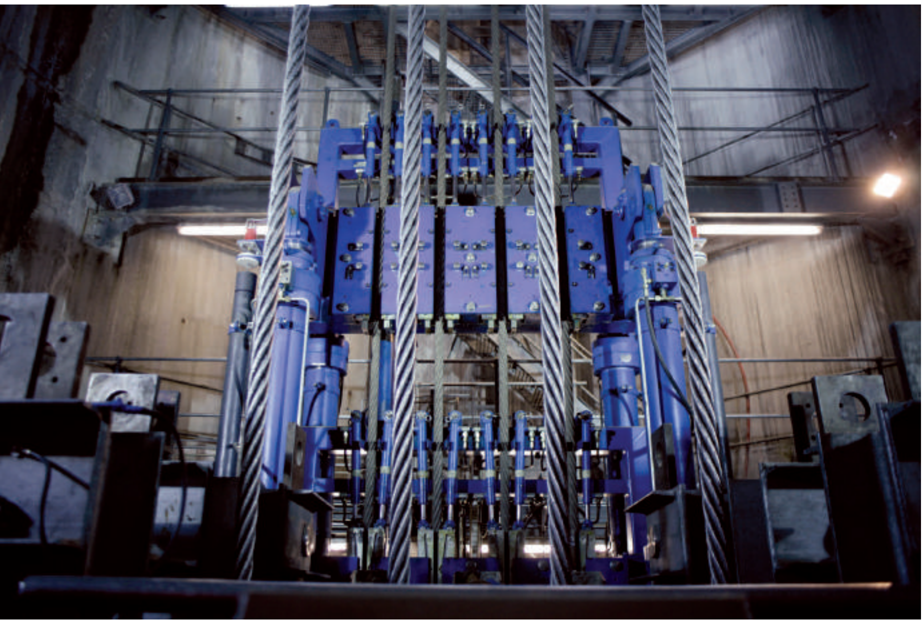
Drum diameter	1,200 mm
Traction force	700 kN
Operating speed	0 bis 0.2 m/s

Table 4: Technical data for the clamping and lifting device (CLD)

Lifting force	1,000 kN
Stroke	1,200 mm

called for targeted measures such as regular servicing or preventive steps to replace worn parts backed up by ensuring spare parts were kept in stock. In order to provide the greatest possible degree of security all available installations relating to safety were housed in the shaft hoisting gear in Shaft I. Furthermore, all necessary inspections prescribed by the Mining Board were executed by service staff during the 3-shift operation. The staff on the spot were provided support if need be by the service and assembly department from their headquarters in Germany. The commercial management for the operational unit was also undertaken from Haiger, Germany.

Fig. 10: Clamping and lifting device (CLD)



Replacing ropes represents a highly relevant task in safety terms and a measure defined by the German TAS and BVOS standards. Ropes must be inspected visually at the shaft hoisting installations by the service personnel on a daily basis. Experts carried out electromagnetic tests on the ropes at least once a year to establish the proper point in time for replacing them. Typical assignments to replace ropes relate to replacing the hoisting ropes, the tail ropes and the associated rope attachments. Generally speaking the ropes for the large cage hoisting system in Shaft I were replaced once every three years.

The members of staff of Siemag Tecberg undertook the assignments to replace the ropes for the Sedrun shaft hoisting resources of their own bat by dint of their know-how as specialists for shaft hoisting technology. Suitable ancillary installations specially designed for the purpose were utilized to minimize costly interruptions to production. The necessary installations were set up at the appropriate points. The following installations were applied in Sedrun for replacing the ropes:

- Mobile friction winch
- Clamping and lifting device (CLD)
- Reeling winch with empty rope drums
    - to wind up the old ropes
    - to suspend new ropes
- Vertical deflecting sheaves at the shaft
- Horizontal deflecting sheaves at the friction winch inlet.

All four ropes could be simultaneously fed into the shaft and removed in reverse operation using the mobile multi-rope friction winch shown in **Fig. 9**. The undercarriages of the friction winch can be lowered hydraulically so that they could be set down and anchored on their intended foundations. **Table 3** contains the technical data for the mobile friction winch.

The clamping and lifting device (CLD) shown in **Fig. 10** was firmly installed on the crash-beam platform beneath the rope sheave platform and could be driven from its parking position into its working position if required. With the help of the CLD at the same time all four hoisting ropes could be clamped and the total load of a hoisting compartment lifted or lowered. In addition to replacing ropes, the CLD can also be used to provide a slack rope for recapping or for changing the hoisting gear. **Table 4** contains the technical data concerning the CLD.

The complicated and dangerous tasks at Shaft I in Sedrun were safely executed with the aid of the mobile friction winch and the CLD. The operator's experienced staff undertook the job of changing the ropes for the 4-rope Koepe winder in around six shifts. It was also necessary to take the fact into consideration that the new hoisting ropes had first to be slowly run in when hoisting operations were restarted. [1, 5, 6, 7, 8, 9]

5 Air-Conditioning in the Faido Part-Section

The same demands are placed on cooling the tunnel as on the shaft hoisting system. Utmost reliability, availability and operational safety must be assured so that repair and maintenance costs are confined to a minimum and standstill and production loss costs avoided if possible.

An air conditioning system was essential on account of the heat produced by the rock and the machines to improve the hot and humid working conditions existing underground. Clear regulations are laid down by the SUVA (Swiss Accident Insurance Agency) with regard to the workplace in order to prevent heat-induced illnesses given eight hours of very hard work. As a result the air temperature must not exceed a dry temperature of 28 °C (given 100 % air humidity) in the areas where the main work is taking place [1]. A Pressure Exchange System (P.E.S.) was supplied in 2002 to cool the Faido part-section. The P.E.S. represents an important link between the primary circuit for producing the cold water and the secondary circuit which enables the cold water to be transferred to the air coolers. As a pressure exchanger it passes the high pressure water caused by the water column in the shaft into the low pressure area for distribution to the remote heat exchangers in the working areas, and takes over the low pressure warm water in the high pressure area to return it back to the cooling plant. A cooling rate of up to 13 MW can be exchanged with a throughput of 800 m^3/h. A temperature loss of around 4 °K ensues in the case of conventional high pressure / low pressure heat exchangers. Alternatively a more efficient P.E.S. can be applied. This results in a temperature loss of less than 0.5 °K. This has a positive effect on the entire remaining system (pumps, pipe diameter, heat exchanger, water quantities etc.) [according to 1, however, with actual data corrected by Siemag Tecberg]. The thermal and energy-related advantages of the P.E.S. enabled an economic application of the temporary tunnel cooling system in Faido.

In 2008, a second P.E.S. was incorporated in the cooling circuit due to an increased need for cooling in the tunnel – caused by rock temperatures that were higher than originally predicted. It was operated as a parallel system within the complete system. [1, 10, 11]

6 Conclusion Part 1

The Gotthard Base Tunnel (GBT) will probably best answer the question itself as from December 2016: “How does one overcome ‘the Alps’ as an obstacle to traffic”?

At the Sedrun intermediate point of attack Siemag Tecberg GmbH, Haiger, Germany, operated a fully automatic shaft hoisting system for transporting excavated rock, building material and manpower during the entire tunnel construction phase. The shaft hoisting system in Shaft I was the site’s main artery. The main task involved ensuring that operations ran without any disturbance. The shaft hoisting system constituted the main manriding installation as well as an auxiliary manriding installation for servicing and emergency purposes, rope-handling applications and a mobile shaft winch to evacuate people. All installations relating to safety were incorporated in the shaft hoisting system from the operator’s own production programme to ensure the highest possible degree of security. The fact that Siemag Tecberg was responsible for operating the Sedrun shaft hoisting system was of decisive advantage. The direct feedback from the company’s own staff led to innovative solutions, improvements in design and further developments of the products concerned.

First of all a P.E.S. (Pressure Exchange System) was ordered for the tunnel drives in the Faido intermediate point of attack for cooling the tunnel. Later a second system of this type was added on account of the rock temperatures, which turned out to be higher than those originally forecast. The underground cooling system could be supplemented in timely fashion thanks to permanent monitoring of the individual parameters of the tunnel climate so that safe working conditions prevailing underground during driving were assured.

The findings derived from the shaft hoisting system and the efficient air cooling facilities have revealed that operating such systems responsibly represents a particular challenge. After all, all eventualities must be covered to ensure that the resources perform properly at all times. The utmost reliability, availability and operating safety must be assured constantly so that servicing and maintenance costs are confined to a minimum and to avoid standstill and production loss costs as well as obstruction costs as far as possible.

The second next part of this report reviews the completion of equipping the Sedrun intermediate point of attack, disassembly and modifying the shafts and the functions of the newly supplied Lot D shaft hoisting systems for the GBT's railway operation phase.

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About Siemag Tecberg GmbH

Siemag Tecberg GmbH with its headquarters at Haiger, Germany, with some 400 employees worldwide, has been supplying the mining industry since 1871. They provide systems on an international basis for mechanical and plant engineering for shaft, inclined and heavy-duty conveying technology, final disposal technology as well as underground and tunnel cooling for the mining, power and infrastructure industries.

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Gotthard Base Tunnel: The Sedrun Shaft Hoisting Systems

Part 2: Conversion and Operating Phase

Michael Flender, Siemag Tecberg GmbH, Haiger, Germany

The 57 km long Gotthard Base Tunnel was produced in five contract sections with three intermediate points of attack. The Sedrun intermediate point of attack consists of two blind shafts some 820 m deep, which could only be reached via a roughly kilometre long access tunnel. The complex, tricky general conditions and the high demands placed on the availability of the shaft hoisting systems were and still are a particular challenge for building and operating the facilities.

This second part of the report concentrates on dismantling and modifying the shafts (Lot 356) and the functions of the ultimate hoisting systems (Lot D) of the Sedrun shafts for the rail tunnel's operating phase. This called for a well harmonized logistics and installation concept.

Part 1 dealt with the building and operation of the shaft hoisting systems as a hoisting, material and man riding shaft and installations for cooling the air in the Faido tunnel section for the tunnel construction phase.

Tunnelling • Shaft construction • Switzerland • Sub-contractors • Shaft hoisting • Automation

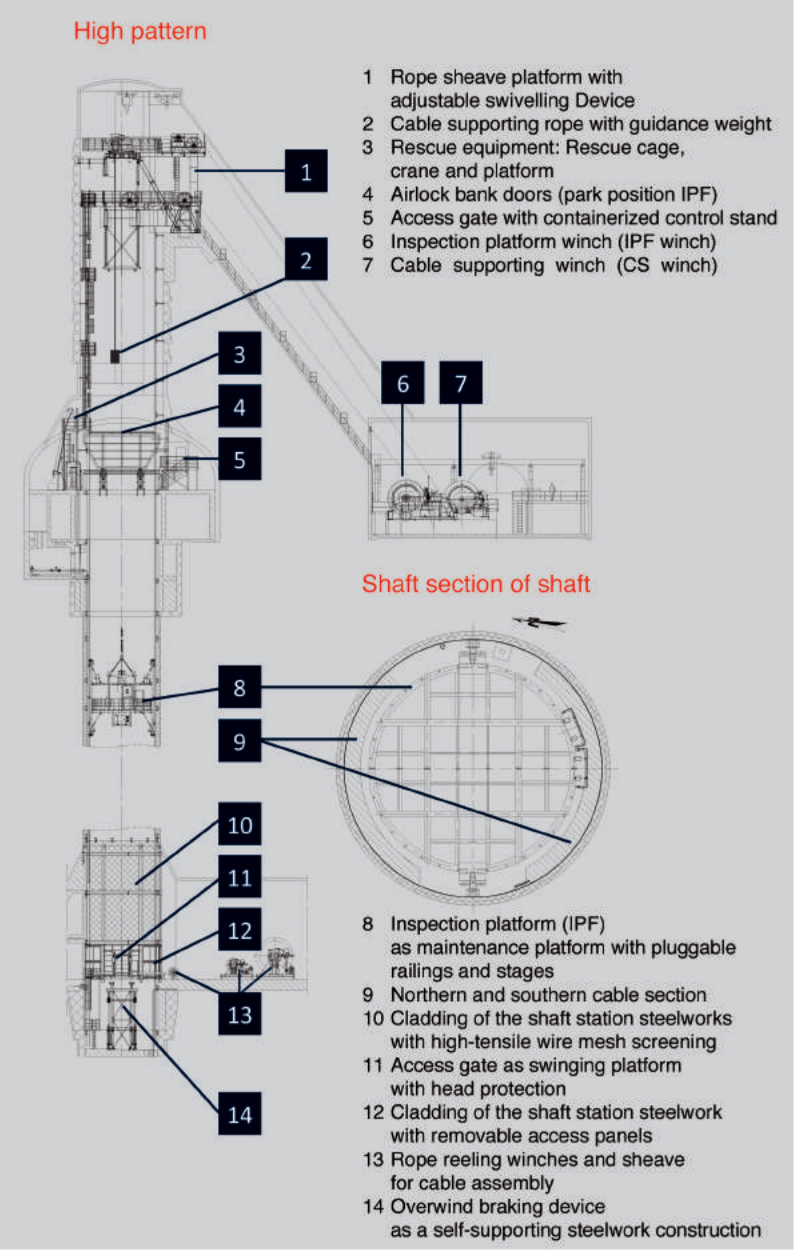


Fig. 1: Shaft hoisting systems in Shaft I at Sedrun for the GBT operating phase
Source: Siemag Tecberg GmbH, unless indicated otherwise

1 Introduction

After dealing with the tunnel construction phase in Part 1 of the report [1, 2], Part 2 examines the concept and functions of the new, ultimate hoisting systems for the Sedrun shafts (Lot D). Towards this end, the dismantling technology (Lot 356) as well as modifying the shaft hoisting facilities will be dealt with. The complex and tricky general conditions posed by the major Sedrun construction site called for well harmonized logistics and installation concept during the conversion phase, which e.g. also had to take into consideration roads kept free of snow for heavy transports. Assurance of high availability for the shaft hoisting facilities being dismantled as well as their replacements represented the determining factors.

2 Classifying the Sedrun Shafts in the GBT Project

Shaft I in Sedrun was described as the tunnel's "lifeline" during the entire construction phase of the GBT. After all the ultimate success of how construction progressed in the Sedrun part-section actually depended on the shaft hoisting systems in Shaft I. Consequently Shaft I exercised a major influence on the overall scheduling process for producing the GBT. Shaft I also took over a key function in the final phase as the GBT was prepared for to become operational – especially when the tunnel opening was brought forward from 2017 to 2016 so that all buffer times were eliminated and a strict timetable for modifying the shaft hoisting systems by spring 2014 had to be adhered to.

The ultimate hoisting systems for the two Sedrun shafts provide for inspection, maintenance and the servicing of the installations located in the shafts during the GBT rail operating phase. The power and data cables in the shaft for supplying the tunnel tubes in general at the shaft head and a water pressure line to provide a constant supply of water at the bottom of the shaft deserve particular mention here. The new Lot D shaft hoisting facilities shown in **Fig. 1** were mainly produced for inspecting Shaft I and further systems such as the supply lines and devised for assembling and replacing cables. However, manriding right to the shaft bottom is also possible so that service staff can be transported. In future, shaft inspections are undertaken by means of a circular inspection platform (IPF) weighing 15 t running on steel guides, which can be operated in Shaft I with a 2 x 560 kW rated 2-rope hoist (IPF winch) at up to 4 m/s. The IPF's payload amounts to 5 t. A 400 kW shaft hoist, the so-called cable supporting winch (CS winch), was installed to ensure that cables could be assembled safely and efficiently. The CS winch's payload amounts to some 15.5 t.

Manriding and inspection of the Shaft II is carried out with an inspection cage, which is operated in the shaft via the mobile shaft winch. The upcast Shaft II was closed with a demountable shaft cover to extract the operating ventilation air.

Siemag Tecberg found itself repeatedly faced with enormous challenges in developing and planning the execution of the systems with regard to production, assembly and operation, which required special designs as a result of the unalterable general conditions and the changing requirements encountered during the construction phase of this extremely large construction site.

Measures to avoid errors, outfalls and impermissible risks of damage were resorted to during planning and development of the new hoisting systems for Lot D. The RAMS process providing a systematic approach and analysis devised for rail systems was applied to cater for the required availability and safety goals for the shaft hoisting systems. RAMS stands for Reliability, Availability, Maintenance and Safety. The RAMS analysis relates to the entire electromechanical installations for the new shaft hoisting systems, such as for example, the electric switch cabinets, transformers and hoisting machines.

The fact that practically all transports to the shaft head, to the shafts and to the bottom of the shaft had to be undertaken via the 1 km long access tunnel in Sedrun was for instance, of decisive logistical and structural significance. As the access tunnel also had to be modified, temporary closures had to be included when planning the schedule to avoid mutual obstructions and standstills on the construction site.

The concepts for the resources and special designs were developed and built in close collaboration with the AlpTransit Gotthard AG and the Ingenieurgemeinschaft Gotthard-Basistunnel Süd (IG GBTS). Well-established and viable relations as well as close and ongoing coordination were essential with the client, the IG GBTS, the Transco Sedrun JV, the Deutsche Montan Technologie GmbH (DMT) and especially the responsible sub-contractors.

3 Conversion Phase for the Shaft Hoisting Systems and Construction Activities in Shaft I

In addition to dismantling the existing shaft hoisting systems in Lot 356 and setting up the Lot D shaft hoisting systems, all other machines located in the shaft and installations from other contract sections had to be dismantled and replaced. The necessary dismantling and assembly activities as well as the required construction work in and around the shaft were undertaken in conjunction with various contract sections. However, these operations were always coordinated and accompanied through Siemag Tecberg's own operating staff. The company deployed around 20 shaft-experienced members of staff for dismantling, assembly and starting up operations.

The basic requirement for carrying out all activities in Shaft I was an approved and operational rescue concept for all phases of disassembly and assembly. The main conversion phases and the application of the shaft hoisting systems in Lots 356 and D are described as follows.

3.1 Dismantling Phase in Lot 356 and Construction Work in Shaft I

In November 2011, the Siemag Tecberg was commissioned by the Transco Sedrun JV to supply new, fold-out working stages for the existing large cage (**Fig. 2**) for the forthcoming disassembly and assembly operations. The existing maintenance platform system on the large cage was extended and started operating in May 2012. Extra fold-out working stages were also added to the central floor and the base frame for concreting operations. In this way, a maintenance platform system with relocatable and extendable working stages as well as corresponding detachable handrails and protective roof structures was available. Thanks to this inspection platform system it was possible to undertake the following operations in the various shaft sectors safely:

- Disassembly and backfilling of the shaft sump
- Disassembly of the shaft installations and backfilling of the pump chambers and water reservoir in the shaft
- Disassembling the hoisting facilities at the shaft station
- Setting up the new shaft station steelwork and the new concrete in the MFS at the shaft bottom
- Disassembling the head frame and hoisting systems, the rope sheave station and API pipelines at the shaft head

The shaft hoisting systems and all shaft installations from Lot 356 were decommissioned in 2012 and dismantled by the end of 2013.

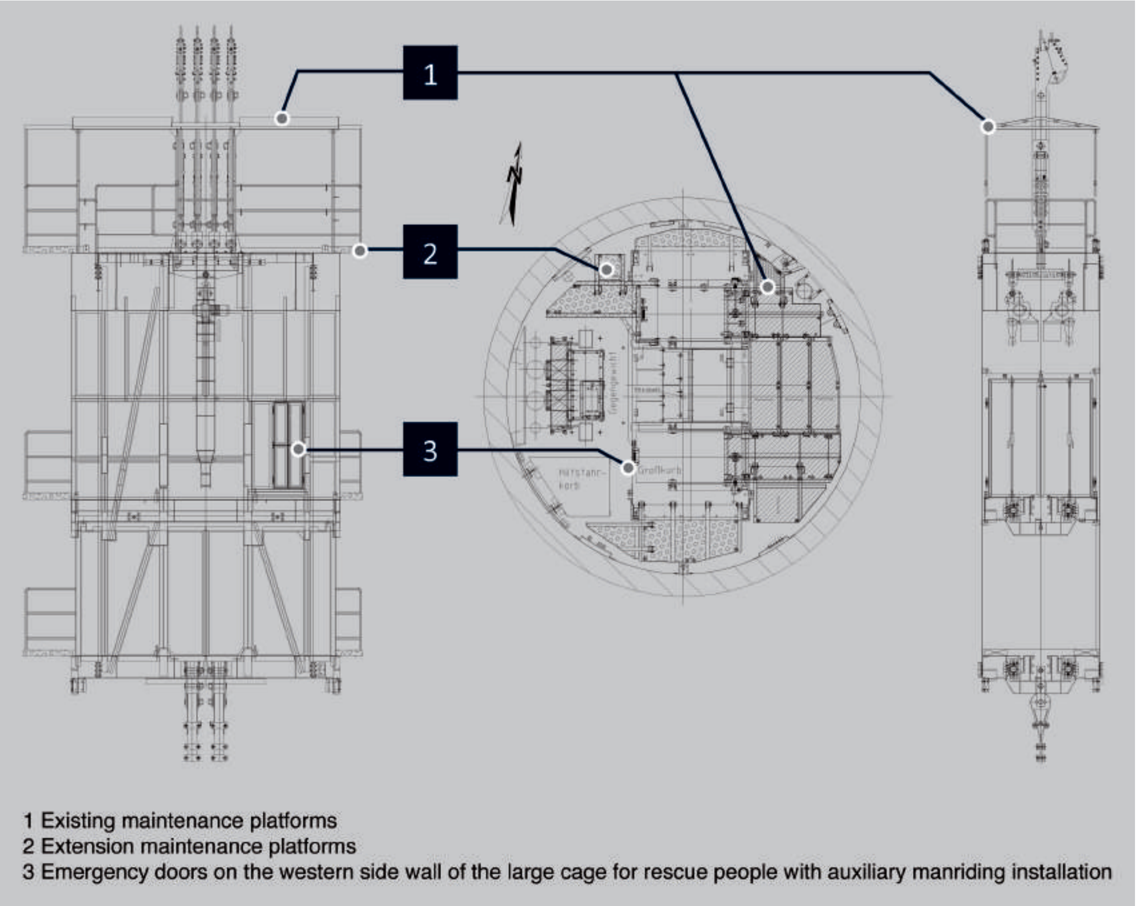


Fig. 2: Extending the maintenance platform system on the large cage Lot 356

3.2 Setting Up the Lot D Shaft Hoisting Systems

In order to ensure that the rescheduled overall deadline plan was adhered to, the logistics and installation concept was concentrated on from the very outset of the project. Thus it was decided in conjunction with the client to do without the planned hoists for the temporary construction site installations for the Lot D assembly phase. Instead of this, the planning, production, supply and assembly of the new shaft hoisting system and the temporary construction site installations for Lot D were preferred as synergy. As a result, the new shaft hoisting system and the lower rope sheave stage for operating the temporary construction site installations (maintenance platform + kibble-hoisting) were thus assembled directly after the dismantling phase. The working stages for setting up the Lot D shaft hoisting system and further contract sections can be summed up as follows with respect to Shaft I:

- Setting up new concrete technical buildings at the shaft head and further technical rooms
- Initiating the operation of the temporary construction site operations with the ultimate shaft hoisting systems for Lot D
- Redeveloping Shaft I and assembly of all shaft installations for the inspection platform
- Disassembling the temporary construction site installations as well as assembly and commissioning the ultimate hoisting inspection platform (IPF) for Lot D

3.2.1 Safety System for Work in Shaft I (Lot D)

In keeping with the Swiss Accident Prevention Regulations (Art. 99 VUV [3]) the interaction of a number of firms on a single site was discussed in advance and agreement reached on the extent of activities and the safety technical requirements. Siemag Tecberg took charge of the safety system for all activities in and around Shaft I as the company with the necessary specialists knowledge during the setting up of the shaft hoisting systems.

The work for completing Shaft I had to be undertaken following all safety requirements for a major construction site into account while lending consideration to the role played by firms lacking mining knowhow. Risk analyses for all operational sequences in the shaft were compiled, which resulted in safety installations designed to protect the workforce being set up at the shaft station at the shaft station steelwork. Temporary no-go zones had to be established at the shaft station for the heavy work at the shaft head or in the shaft, as for instance, assembling steel guides. It had to be assured at all times that no dangers lurked imperiling the safety

Table 1: Classifications and technical requirements posed on shaft hoisting systems after BVOS and TAS

Classifications of the Shaft Hoisting systems Lot D according BVOS and TAS [4, 5]	"medium-sized" Manriding-Hoisting (TDS)	Maintenance Hoisting (TDB)	Stage Hoisting (TDBü)	Shaft winch
IPF Winch	**Operating phase GBT:** Manriding (> 2 m/s, < 4m/s; 11-20 pers./trip), according BVOS § 3 (1), IPF as a medium sized manriding platform (Fig. 4)	**Operating phase GBT:** Shaft inspection (< 4m/s), according BVOS § 2 (3) IPF as a maintenance platform (Fig. 3)	**Assembly phase Lot D:** Shaft installation, according BVOS § 2 (7) Unguided maintenance platform	
CS Winch	**Assembly phase Lot D:** Manriding, according BVOS § 3 (2) rope guided kibble hoisting to maintenance platform	-	-	**Operating phase GBT:** Shaft winch according TAS 10.1.1 for hooking and transportation of material and cable (**Figures 7 and 8**)

of the members of staff at the shaft bottom while these activities were being executed.

The periods for this assembly procedure were always coordinated with the client and all affected firms at an early stage to avoid standstills and mutual obstructions.

3.2.2 Classifying the new Lot D Shaft Hoisting Systems according to Use

The new Lot D hoisting systems in Shaft Sedrun I were designed in accordance with the codes of practice of the German Mine Ordinance for Shaft and inclined Hoisting Systems [4] and the relevant Technical Requirements for Shaft and inclined Shaft Systems [5] just like the shaft hoisting system for the Lot 356 tunnelling phase. The intended use and in turn, the classification of the system in keeping with TAS and BVOS, are determining for the system-specific assessment of shaft hoisting systems. In Germany, shaft hoisting systems are documented according to a standard system of pre-testing and approval. The system's specification is arrived at by means of so-called "Technical Data Sheets" and related documents such as drawings, static calculations, descriptions, functional and switch plans. A distinction is drawn between the Technical Data Sheet for Shaft Maintenance Systems (TDS) and Shaft Inspection Systems (TDB). A shorter form exists for platform systems, the Technical Data Sheet for Stage-Hoisting Systems (TDBü). In keeping with TAS the system classification provides the technical requirements that must be adhered to for designing the hoisting system. The engines for the shaft hoisting systems for Lot D (IPF and CS winches) are devised for speeds of up to 4 m/s and defined as medium-sized manriding hoisting system according to BVOS. These definitions are also derived from the classifications for shaft hoisting systems described in **Table 1** according to BVOS and TAS [6].

During the assembly phase the new shaft hoisting systems were first used in conjunction with the temporary construction site installations consisting of a 3-stage maintenance platform with kibble hoisting *(Please note: the use of the temporary site installations will be dealt with in the article that follows in this edition of GeoResources).*

The IPF winch was operated as a maintenance hoisting system during the assembly phase. During the GBT's operating phase the IPF takes over a twin function in keeping with **Table 1** and can be operated as a medium-sized manriding hoisting or maintenance hoisting system. Use in accordance with higher demands on ensuring the safety of persons is decisive as far as the design is concerned, which in this case relates to the technical requirements for a medium-sized manriding hoisting system [6].

The cable supporting winch (CS winch) was classified as a medium-sized manriding installation for kibble hoisting operations and designed according to the same technical requirements as the IPF winch. During the GBT operating phase on the other hand, the CS winch will be classified according to TAS as a "shaft winch" for fitting cables in that case [6].

4 Shaft Hoisting Systems for the GBT Operating Phase (Lot D)

4.1 Overview

By and large, the services embraced the development, planning of execution, production, assembly and commissioning of the following facilities and parts of facilities presented in **Fig. 1**:

- Conveyances (Chapter 4.3)
  - Inspection platform in Shaft I (Chapter 4.3.1)
  - Rescue cage Shaft I (Chapter 4.3.2)
  - Inspection cage in Shaft II (Chapter 4.3.3)
- Shaft hoisting systems (Chapter 4.4)
  - Inspection platform winch (IPF winch) (Chapter 4.4.2)
  - Cable supporting winch (CS winch) (Chapter 4.4.3)
- Reeling winches and ancillary elements for cable assembly (Chapter 4.5)
- Rope sheave stages at the shaft head (Chapter 4.6)
  - Lower rope sheave platform and limiting beams (Chapter 4.6.1)
  - Upper rope sheave platform with revolving adjustable swivelling platform (Chapter 4.6.2)
- Airlock bank doors Shaft I (Chapter 4.7)

- Control and monitoring units
- Shaft station installations (Chapter 4.8)
    - Shaft station steelwork cover at the shaft bottom (Chapter 4.8.1)
    - Overwind braking device (Chapter 4.8.2)

4.2 New Concept for the Shaft Hoisting Systems – Exploiting Synergies

The parameters of the logistics and installation concept were considered when developing and designing the individual components of the Lot D shaft hoisting systems. The clearance profiles of the access tunnel for example had to be taken into account, as a result of which the machine frame had to consist of multi-sectional welded steel construction for transport reasons then screwed together.

The tender for the new hoisting systems for Lot D permitted the components of the existing shaft hoisting facilities in Lot 356 to be taken over and utilized. The further exploitation of the following components was agreed on with the client as a worthwhile measure during the Lot D conception phase:

- The existing hoisting machine fundament with the securely connected base plates for the old hoisting machines and brake stands were in a very good state and were able to be used for the Lot D shaft hoisting systems.
- The two new hoisting units were set on a massive machine frame, which catered for the safe distribution of force into the existing base plates. Around 184 t of steelwork and engineering was deployed in the hoisting machine room.
- The main beams for the upper and lower rope sheave platforms were reutilized at the shaft inset. These major existing parts first of all served to support the new rope sheave platforms and secondly to safely distribute the force into the rock. In addition, the further utilization of the existing supporting structures simplified the dismantling and assembly of the rope sheave platforms. Around 113 t of steelwork and engineering was involved in the head of blind shaft inset.

The synergy effects that were employed led to a great deal of money and time being saved, something which had a particularly beneficial outcome in ensuring that the narrow timetable was adhered to.

Certain groups of components, such as the adjustable swivelling device, were subjected to thorough scrutiny in their final assembled state at the assembly halls in Haiger prior to being shipped. Subsequently the groups of components were given the green light for being delivered and assembled.

4.3 Conveyances

4.3.1 Inspection Platform in Shaft I

The circular inspection platform (IPF) of the medium-sized manriding installation in Shaft I possesses a diameter of 6.4 m, a height of 8 m and a net weight of around 15 t. The IPF's nominal payload amounts to 5 t, with an off-centre load of up to 3 t (e.g. cable drums) able to be carried on the base frame. The IPF is suspended on two ropes of the single drum blair winder. The suspension device, comprising a seesaw arrangement and a chain sling, compensates for the rope forces as well as static and dynamic changes in rope length during the winding process. The slack rope protection installations are integrated in this suspension device. In the shaft the IPF is operated by roller guides with rubber torsion spring and guide shoes passing through two steel guidances lying opposite one another, with 7 m track gauge. The aggregate located centrally on the base frame caters for the independent supply of power for the lights and to operate the tools.

The gates for the IPF are to be found at the shaft head in the west and the shaft station in the south. Access to the IPF at the shaft head is facilitated by a platform, which also houses the control stand in a container. The gap as danger zone between the access platform and the IPF is bridged by an integrated adjustable platform moved by hand. Should the IPF not be in use, it can be lowered on to the closed airlock bank doors. In this

Fig. 3: Inspection platform (IPF) as maintenance platform with pluggable railings in parked position

Fig. 4: Inspection platform as medium-sized manriding system with pluggable access panels in parked position

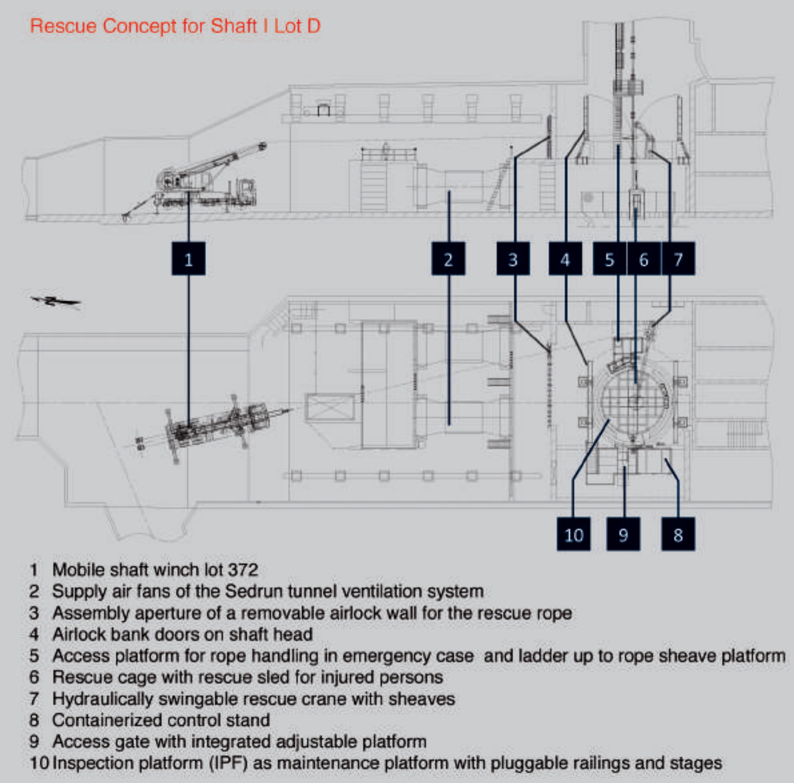


Fig. 5: Rescue concept for Shaft I: arrangement of the installations for rescuing persons at the Sedrun shaft head, sections

case, access is accomplished by means of a ladder via the negotiable closing bank doors from below to reach the parked IPF. The extendable access platform with overhead protection is located at the shaft station to bridge over the gap between the bottom at the shaft station and the IPF.

During the GBT's operating phase, the IPF will be used for shaft inspections to check the shaft's structural state, the installed cables and water lines as well as all shaft maintenance operations that might crop up. **Fig. 3** shows the IPF as maintenance platform with pluggable railings and stages including detachable handrails and stages as well as overhead protection. The IPF is operated with detachable handrails as an inspection unit with a maximum speed of 4 m/s. For ventilation technical reasons it was designed to operate at a gap of 750 mm from the shaft wall. In order to reduce the gap between the IPF and the shaft wall for cable assembly operations, detachable stages with overhead protection can be added to the place where the handrails are positioned.

Descents to the bottom of the shaft are only permitted using manriding hoisting systems in keeping with TAS/BVOS. Hoisting systems complete with closed sidewalls and approved doors have to be employed for manriding. As a result, the IPF is designed in such a way that the detachable handrails, platforms and doors can be replaced by closed sidewalls and two-winged doors. In order to carry out rides to the shaft station, the IPF can easily be converted to a medium-sized manriding hoisting system. In this case, conversion is undertaken on the closed airlock bank doors. **Fig. 4** shows the IPF as medium-sized manriding hoisting system at access level at the shaft head. The IPF can carry a total of 15 persons in this case.

In order to rescue people, a rescue cage can be placed in the middle of the IPF. The interior is accessible via a sliding door. The floor covering of the interior is executed in the form of a honeycomb grating to provide an additional air passage. In incident mode – emergency stop of a train in the Sedrun MFS – the fresh air supply for the underground emergency stops for the passengers is assured at a rate of approx. 120 m^3/s. For safety reasons, shaft inspections and manriding with the IPF is not permitted when the operating ventilation is running. In order to ensure that mishandling of the operating ventilation does not endanger the IPF in case being stuck in the shaft, the IPF's main safety components are devised for the maximum volume flow of 450 m^3/s corresponding to a flow pressure of 0.21 kN/m^2.

4.3.2 Installations for Rescuing Persons

A basic prerequisite for commissioning the new shaft hoisting system in Lot D was functioning safety concepts for the assembly phase of the temporary 3-stage maintenance platform as well as the operating phase of the inspection platform. The evacuation of persons was tried out prior to the hoisting systems being commissioned with the rescue cage and the mobile shaft winch. The safety concepts conform to TAS and can be executed within six hours without any difficulty. The rescue concept (**Fig. 5**) calls for the following main components for evacuating persons:

- Mobile shaft winch (Lot 372)
- Rescue platform to place the rope
- Rescue crane with bracket to be anchored in the concrete floor

- Rescue cage with room for a rescue sled to recover injured persons

The mobile shaft winch is set up in the Sedrun shaft head cavern in a prescribed position. The mobile shaft winch is held at designated attachment points in the roadway floor to accept the horizontal rope tensile forces by use of two 6-t chain hoists. The boom is extended at a height of roughly 7 m. In the process, the rope runs over the supply fans and through a small assembly aperture of a removable airlock wall doors to the rescue crane. The rope is guided to the rescue cage via the rescue crane sheave. The mobile shaft winch raises the attached rescue cage, then swivelled by the rescue crane over the shaft collar into the shaft and lowered into the shaft on to the IPF to rescue persons.

4.3.3 Inspection Cage for Shaft II

The inspection cage (**Fig. 6**) is deployed to undertake shaft inspections in Shaft II, for example to determine deposits, ingressing underground water or other peculiarities. The single-deck cage provides space for a maximum of five people or a maximum payload of 500 kg. The cage is attached to the rope of the mobile shaft winch, swivelled into Shaft II and unguided lowered for inspection purposes. The inspection cage is roughly 2.2 m in diameter. The head and foot frames are both equipped with a handrail with the lower level also provided with an all-round plate up to a height of 1.2 m. Access to the inspection cage is realized by a manually operated swing door at the lower level. The cage has no guidance at the sides. Sliding elements are attached at the sides of the head and foot frames of the annular girders for protection.

The inspection cage is fitted with a special unit for telephoning and signalling purposes (FTS system). The mobile shaft winch with attached inspection cage is only permitted to be run by an appropriately qualified hoist operator. Another qualified professional rides in the inspection cage to ensure that the inspection cage operates properly in the shaft and to communicate with the hoist operator via the FTS unit.

4.4 Shaft Hoisting Systems Lot D

4.4.1 General

The two shaft hoisting systems are shown in **Figs. 7 + 8** from various angles. **Table 2** contains the technical data. The circular inspection platform running on steel guides is operated in the shaft by means of the 2-rope Blair winder. The winch is applied as a shaft hoist together with the revolving adjustable swivelling platform on the upper rope sheave platform and additional reeling winches at the shaft station for the cable assembly concept, in other words, slightly pulling, installing and subsequent replacement of cables (e.g. power supply and data cables).

The Lot D shaft hoisting systems represent something that is unique anywhere in the world. A specially developed multi-axial drive control can operate both hoists separately and synchronously at an accuracy of 0.01 % in the shaft. The system possesses a redundant two-channel control and positioning system.

4.4.2 Inspection Platform Winch (IPF Winch)

The IPF winch is a speed-controlled 2-rope hoist (0.6 to 25 min^{-1}) at the input side and is driven by three-phase current motors (2 x 560 kW) via a bevel helical gear unit.

Fig. 6: Mobile shaft winch with inspection cage for Shaft II

Table 2: Technical data of the shaft hoisting systems in Shaft I Lot D for the GBT operating phase

Description	IPF Winch	CS Winch
Type of hoist	2-rope-drum (Blair-winder)	1-rope-drum
Hoisting capacity	15 pers./trip	-
Means of conveyance	Inspection platform	None / weight
Type of guidance in shaft	Guide rails	Unguided
Hoisting height	ca. 800 m	ca. 800 m
Motor capacity	2 x 560 kW	400 kW
Hoisting speed	3.3 m/s	1.0 m/s
Max. hoisting speed	4 m/s	3.0 m/s
Rope breaking load	1,141 kN	889 kN
Max. static load	15.5 t	19 t
Payload	5.0 t	15.5 t
Drum diameter	ca. 3,2 m	ca. 3.2 m
Max. rope capacity /drum	ca. 950 m	ca. 1,848 m
No. of rope layers	5	6
Rope diameter	32 mm	28 mm
No. of ropes	2	1
Type of brake	Disk brake, 2 disk	Disk brake, 2 disk
No. of brake post	2	2
No. and type of brake calipers	8 BE 125	6 BE 100
Brake control system	SB1	SB1
Type of emergency braking	Fully closed-loop retardation	Fully closed-loop retardation

Fig. 7: View from the rope channel of the shaft hoisting systems for the GBT operating phase

Fig. 8: View of the shaft hoisting systems for Lot D; CS winch in front; IPF at the rear

The drive shafts for the winch each run on dual anti-friction bearings and are connected to each other by means of a tooth coupling. The drive motors and gears are connected via an elastic claw coupling with motor brake.

The braking forces produced by the combined driving and safety brake are distributed over two brake stands each with four pairs of brake elements (totalling 16 × BE 125). These act on a brake disc per drum. The Siemag disc brake control SB 1 with electro-hydraulically regulated safety brake is utilized for load-independent adjustable deceleration values.

The two roughly 840 m long rotation-resistant hoisting ropes possess a nominal diameter of 32 mm and are coiled onto the rope carrier in five layers. Both ropes run overlay.

The medium-sized manriding hoisting system can be used at a maximum speed of 4 m/s as a fully automatic manriding unit for independent rides. The IPF winch was used as a maintenance hoisting for a maintenance platform when the shaft was being developed (comp. **Table 1**).

4.4.3 Cable Supporting Winch (CS Winch)

The cable supporting winch functions as a shaft winch according to TAS. It is applied to install cables and undertake assembly work in the shaft. A prerequisite for the cable assembly concept at the shaft station was that the cable supporting rope had to be twice as long as the shaft. A winch with a steel drum mounted at the shaft station serves to accommodate the cable supporting rope the length of the shaft. As a result, the CS winch's rope carrier has a rope capacity of some 1,850 m, which can be coiled in six layers. The rotation resistant cable supporting rope runs underlay and possesses a nominal diameter of 28 mm.

The speed-controlled (0.16 to 20 min^{-1}) CS winch is driven by a three-phase motor (400 kW) and a bevel helical gear unit. The driving shaft runs on dual anti-friction bearings. The drive motor and the gear unit are connected with each other by an elastic jaw coupling with motor brake.

The braking forces produced by the combined driving and safety brake are distributed over two brake stands each with four pairs of brake elements (totalling 12 x BE 100). These act on one brake disc per drum. The Siemag disc brake control SB 1 with electro-hydraulically regulated safety brake is utilized for load-independent adjustable deceleration values.

During the assembly phase the CS winch was utilized for operating the temporary kibble hoisting system. A guide cradle with kibble was attached to the IPF ropes of the temporary maintance platform. The CS winch was used as a medium-sized manriding hoisting system during this phase and set up in keeping with **Table 1**. The CS winch's driving machine thus was equipped with a reversible gear. The maximum travelling speed for hoisting the kibble amounted to 3 m/s. During the operating phase the winch serves as a shaft winch. In this case, the speed is restricted to 1 m/s for transporting material as well as assembling cables.

4.5 Reeling Winches and ancillary Elements for Cable Assembly

Safe and efficient handling of the ropes and cables is of paramount significance given increasing depth and in turn, increasing loads when cables are being assembled in the shaft. Two electrically operated reeling winches and a guide sheave were supplied for the complicated cable assembly sequences starting from the shaft station at Sedrun. The drives of the two reeling winches operate independently, i. e. they do not depend on the IPF and CS winch control system (**Table 3**). The operators can control the speed and the running direction of the reeling winches via a manual control unit. The double-shoe brake works according to the discharge principle, i. e. the brake gripping force is produced by a group of weights so that the coiled rope or cable can be pulled from the reeling winch with a defined counter-pull force (shown in **Fig. 1**).

Fig. 9 displays the two reeling winches set up at the shaft station, which are operated together with the CS winch at the shaft head. **Table 3** provides the technical data. The reeling winch (**Fig. 9**, at the rear, left) possesses a steel drum with 1.5 m diameter for coiling the cable supporting rope for the CS winch or some other rope.

The second reeling winch serves to accept varying large and wide cable drums produced by different manufacturers. The basic frame of this reeling winch can be correspondingly modified for the various cable drums.

4.6 Rope Sheave Stages at the Shaft Head

The design of the new rope sheave platforms at the shaft head is shown in **Fig. 10** and **Fig. 11** displays a photo of the integrated revolving adjustable swivelling platform. The rope sheave platforms are set up on the main girders taken over from Lot 356 and the concrete foundation located between the hoisting system room and Shaft I to safely transfer forces in the rock. The rope sheaves for the IPF winch are to be found on the lower rope sheave platform. An adjustable swivelling platform rotatable by 360° (revolving platform) is located on the upper rope sheave platform to guide the cable supporting rope into the appropriate cable sectors in Shaft I (**Fig. 11**).

4.6.1 Lower Rope Sheave Platform and limiting Beams

The rope sheaves for the IPF winch are set up on the lower rope sheave platform. During the assembly phase, the CS winch's two vertical rope sheaves for the rope-guided kibble manriding hoisting system are located here.

Contrary to TAS specifications an overwind protection device for the IPF was found unnecessary and therefore was not used in the upper shaft head area. It was established that no upwards directed force can be present when the IPF winch travels upwards – for instance in the event of a power cut. The IPF is brought to a standstill within a sufficiently short distance through gravity. Uncontrolled overrunning at high speed can be precluded as the IPF's travelling speed was restricted to 1 m/s by the hoisting controler in the shaft head area and furthermore there is a free height of 20 m until the arresting devices are reached. As a result of these observations and measures that were undertaken an equivalent safety level was attained. The limiting beams serve as a final overrunning buffer and are mounted below the lower rope sheave stage [6].

Table 3: Technical data for the two reeling winches

Reeler	With steel drum	For cable drums
Drum diameter	1,500 mm	4,000 mm/ 3,200 mm
Torque	11.64 kNm	11.64 kNm
Rope traction force	51 to 35 kN	20 to 10 kN
Rope speed	0 to 0.36 m/s	0 to 1.2 m/s
Gear ratio	79.75 : 1	79.75 : 1
Chain gear	21 / 45	21 / 80
Engine speed	975 rpm	975 rpm
Weight without drum	7,350 kg	9,500 kg
Permissible gross weight	38,000 kg	38,000 kg

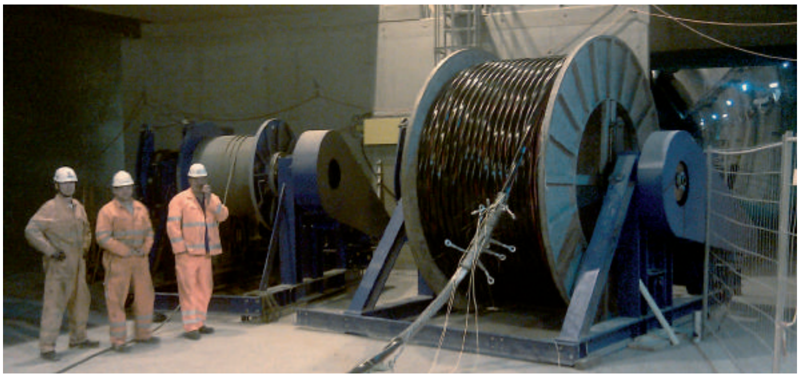
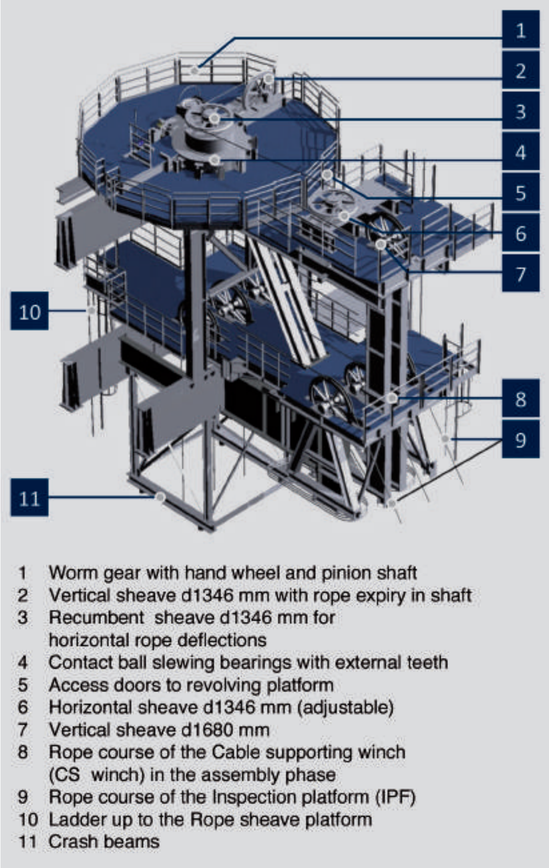


Fig. 9: Set-up of the two reeling winches for assembling cables at the shaft bottom

Fig. 10: Rope sheave platform with integrated revolving adjustable swivelling platform



1 Worm gear with hand wheel and pinion shaft
2 Vertical sheave d1346 mm with rope expiry in shaft
3 Recumbent sheave d1346 mm for horizontal rope deflections
4 Contact ball slewing bearings with external teeth
5 Access doors to revolving platform
6 Horizontal sheave d1346 mm (adjustable)
7 Vertical sheave d1680 mm
8 Rope course of the Cable supporting winch (CS winch) in the assembly phase
9 Rope course of the Inspection platform (IPF)
10 Ladder up to the Rope sheave platform
11 Crash beams

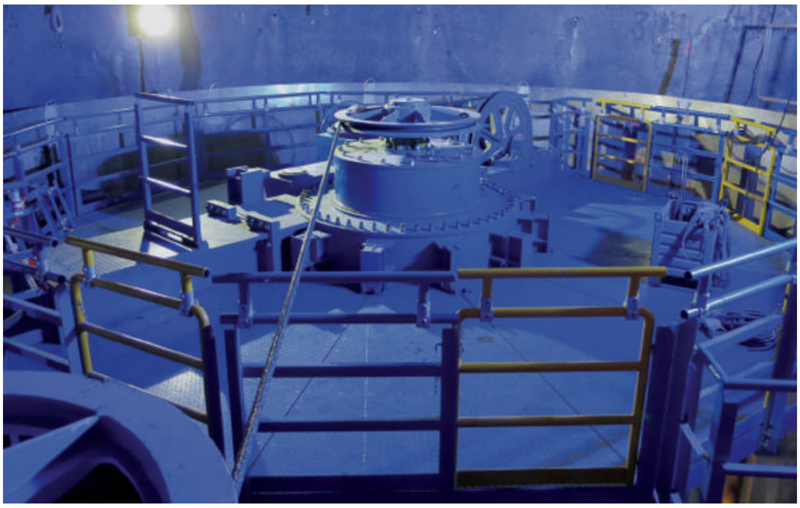
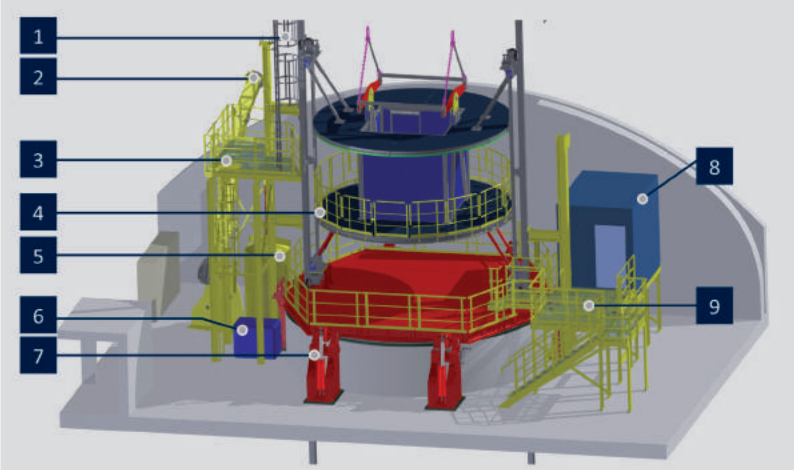


Fig. 11: Revolving adjustable swiveling platform for guiding the cable supporting rope in the Shaft I cable sectors



1 Ladder up to the rope sheave platform
2 Hydraulically swingable rescue crane with sheaves
3 Access platform for rope handling in emergency case and ladder up to the rope sheave platform
4 Inspection platform (IPF) as maintenance platform with puttable stages
5 Rescue cage with rescue sled for injured persons
6 Hydraulic aggregate for the Airlock bank gates and the rescue crane
7 Airlock bank doors (park position IPF)
8 Containerized control stand
9 Assembly aperture of a removable airlock wall for the rescue rope
10 Access gate with integrated adjustable platform

Fig. 12: Installations in the IPF access level at shaft head

4.6.2 Upper Rope Sheave Platform with revolving adjustable Swivelling Platform

The rope run-off point for the cable supporting rope is guided up to the shaft wall by means of the adjustable swivelling device and can be redirected to all shaft areas. The adjustable swivelling device's main functions are thus to exactly position the cable supporting rope between the IPF and the shaft wall. Cable assembly is executed from the IPF.

In order to steer towards the various run-off points in the so-called cable sectors, starting from the CS winch, the cable supporting rope first of all runs over a vertically positioned rope sheave (Pos. 7) as can be seen in **Fig. 10**. Subsequently the cable supporting rope is guided or rather tensioned by two horizontally located rope sheaves (Pos. 3, Pos. 6), prior to the cable supporting rope adopting the desired assembly position in the shaft via a vertically arranged rope sheave (Pos. 2) in the proximity of the shaft wall. The ball bearing slewing ring and the worm gear unit set on the revolving stage with hand wheel (Pos. 1) represent the core of the revolving adjustable swivelling platform. The ball bearing slewing ring (Pos. 4) possesses an external tooth system creating a worm gear unit in conjunction with a pinion shaft. The revolving stage is positioned and arrested via the worm gear unit with hand wheel.

4.7 Airlock Bank Doors in Shaft I

No headframe as required for shaft hoisting systems on the surface was needed for the ultimate hoisting systems. A massive multi-storey concrete building with cellar as shown in **Fig. 5** was set up above Shaft I. **Fig. 12** displays the area above the supply fans, which houses the access level for the inspection platform with control stand, all rescue installations as well as airlock bank doors to protect the shaft.

The airlock bank doors, whose main components are displayed in **Fig. 12**, consist of two rotatable semicircular doors and are set up at access level at the shaft head above the supply fans for the tunnel operating ventilation on an approx. 2.2 m high shaft collar. For transport reasons the roughly 8 t heavy airlock bank doors were devised as multi-part bolted welded steel construction. Each airlock bank door is moved via two hydraulic cylinders. The closed bank doors mainly serve to ensure that Shaft I is closed so that it is pressure proof. In order to facilitate this all-round seals were attached between the airlock bank doors and on the shaft collar. The net weight of the airlock bank doors does not suffice to keep them closed against the operating ventilation's opening pressure forces. As a result, they are mounted in closed state by means of hydraulic door locking devices at the sides.

The closing bank doors also serve to provide a parking position for the roughly 15 t heavy IPF. In order to ensure that the parked IPF is safe to negotiate, safety barriers in the form of detachable handrails are attached to the closing doors. It is only possible to inspect the shaft when these bank doors are open. The open airlock bank doors are secured in place by two locking hooks. The airlock bank doors position is monitored electrically and passed on the to the IPF control system.

4.8 Shaft Station Installations in the Multi-Function Station (MFS)

4.8.1 Shaft Station Steelwork with removable Cover and IPF Access Gate MFS

A shaft station steelwork set up by the JV Transco Sedrun is located at the shaft base. It comprises three annular girders and five support girders. The round shaft station steelwork shown in **Fig. 13** is firmly connected with the western concrete wall acting as an call bell system thus representing an essential component of the shaft hoisting system. A manually operated access platform with overhead protection integrated in the shaft station steelwork permits the IPF facility to be entered and exited in a safe manner.

The safety installations at the shaft station steelwork were devised in the form of safety access panels and high-tensile wire mesh screen for easy removal. It was essential to ensure that the safety cover installations especially in the upper and central sections of the shaft station steelwork allow a sufficient amount of operating ventilation (450 m^3/s) to pass through quite apart from their actual protective function. Furthermore, apertures as well as access possibilities had to be allowed for in the upper shaft station steelwork area for the designated power supply and data cables as well as a water pipeline.

As a consequence, safety mesh screen were hung up as curtains in the upper and central sections of the shaft station steelwork, which were simply opened if required. These safety mesh screens are attached to a continuous steel rope mounted to the shaft wall above the shaft station steelwork.

In the lower section of the shaft station steelwork perforated removable access panels as partitioning safety installations were foreseen as is customary in mining. The supporting steel structure specially devised for the round station steelwork enables the roughly 35 kg heavy perforated plate segments to be dismantled easily and without complications if cables have to be assembled in future.

4.8.2 Overwind Braking Devices in the Shaft Sump

Fig. 14 shows the overwind braking devices – Type Siemag Tecberg Safety Arrestor – subsequently known as the SSA system. The old shaft sump was filled up with material. A massive concrete slab was then positioned to float on the backfilled shaft sump to round things off. As the fill material is unlikely to be seriously affected by settlement, the base slab was not connected to the shaft wall. The introduction of braking forces into the shaft wall, which is customary in mining, had to be avoided.

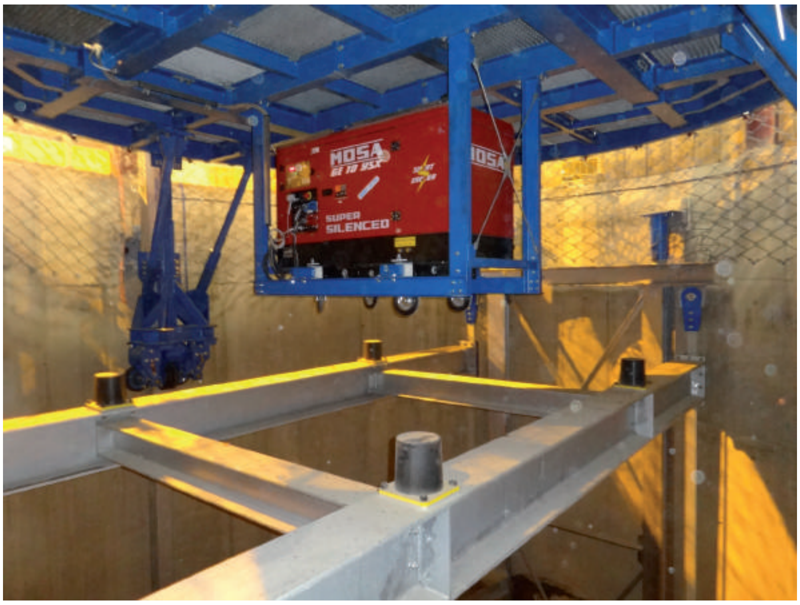
For this reason the SSA system was devised as a self-supporting steel structure, guided by four brackets at the sides to cope with settlement. The braking forces and the SSA system's own weight are supported by the steel structure and transferred to the base slab in a vertical direction. The SSA system is designed to cope with a total weight of 21,000 kg for the IPF and an impact speed of 4 m/s. It operates with a maximum braking path of 2.4 m given full payload. The arrestor frame geometry is devised in such a way that the arrestor aggregate mounted below the IPF platform can dip between the arrestor frames in the event of impact.

Fig. 13: Shaft station steelwork with shaft access gate, call bell system, removable access panels and high-tensile wire mesh screen

5 Summary – Part 2

Shaft I possessed a key function for the conversion phase of the shaft hoisting systems and shafts in Sedrun. It also played an essential role in ensuring that the overall timetable for the Gotthard Base Tunnel (GBT) was adhered to. The amount of time available for the conversion phase called for ongoing optimizations of the

Fig. 14: Overwind braking device Siemag Tecberg Safety Arrestor (SSA) at the shaft bottom frame



logistics and installation concept. The substantial and complex steelwork and engineering components were for example designed as multi-sectional bolted welded steel construction and delivered on-site part-assembled ready for final assembly. The maintenance platform facility for the large cage of the Lot 356 shaft hoisting system was expanded in this way so that as many as possible shaft and concreting operations could be undertaken simultaneously. Synergy effects were attained by the further utilization of existing parts of the system or through speeding up part-deliveries and assemblies. Thus for instance, the temporary maintenance platform with medium-sized rope-guided kibble manriding system intended for developing the shaft was operated with the final shaft hoisting systems for Lot D instead of using temporary winch installations. Reductions in construction work, simplified dismantling and assembly activities led to a considerable amount of time being saved, which had a positive effect on the constricted schedule.

The basic prerequisites for tackling a project successfully and in time were good and sustainable relationships as well as regular consultations with the client and all further companies engaged at the major construction site. Strict adherence to all safety requirements and consideration due to companies experienced in mining had to be observed. Siemag Tecberg also took responsibility for the safety system relating to all activities in and around Shaft I for setting up the ultimate hoisting systems for Lot D.

The two Sedrun shafts mainly serve to ventilate the underground emergency stops in the Multi-Function Stations (MFS) during the Gotthard Base Tunnel's (GBT) future operating phase. The fresh air is supplied via Shaft I and the spent air removed via Shaft II.

Shaft II has no installations and was closed with a demountable airlock bank door at the shaft head for the spent air ventilation system. Shaft inspections to check the structural state and to locate deposits, ingressing underground water or other peculiarities are to be carried out at regular intervals with a newly supplied inspection cage. The inspection cage is to be operated using the reconditioned mobile shaft winch from Lot 372, available at Shaft I and also used for rescuing persons.

Shaft I contains water pipelines for the MFS and power supply and data cables for rail technology for the operating ventilation systems and technical buildings at the shaft head. Siemag Tecberg has developed the Lot D hoisting systems for the assembly or reassembly of the rail technology cables and for periodic checking, service and maintenance purposes. Worthy of mention are on the one hand, the convertible conveyor, the so-called maintenance platform (IPF), which can be operated as an inspection unit as well as a medium-sized manriding system, on the other hand, the hoisting installation specially devised for the assembly of cables. By and large, this constitutes a shaft winch with cable supporting rope, a unique, adjustable swivelling platform rotating 360° for guiding the supporting ropes and assembly ancillary installations consisting of two reeling winches as well as a guide sheave, which ensures that the cables can be safety and unrestrictedly mounted on the shaft wall.

The Lot D shaft hoisting systems represent something unique worldwide in terms of configuration and utilization. A specially developed multi-axial hoisting controler can operate both reeling winches separately and synchronously in the shaft with an accuracy of 0.01 %.

6 Conclusion

The Gotthard Base Tunnel (GBT) is a superlative achievement of the century and in future will be its own best response to the question of how "the Alps" can best be negotiated as an obstacle to transportation. The tunnel is scheduled to open in mid-2016 and train services are due to begin late that year. After completion the 57 km long Gotthard Base Tunnel will be the world's longest rail tunnel. The Sedrun intermediate point of attack represents one of the GBT's most complex tunnelling sites, as it is located some 800 m above the actual tunnel route and the tunnel drives had to be supplied via two shafts with hoisting systems.

The Lot 356 shaft hoisting systems in Shaft I have contributed substantially to the structure of the century – the Gotthard Base Tunnel – over an operational period of almost ten years thanks to their high availability and reliability. The client AlpTransit Gotthard AG once again revealed its faith in Siemag Tecberg products in 2011 with the follow-up commissioning of planning the execution and developing the ultimate hoisting systems for Lot D.

Planning and accomplishing major shaft hoisting systems represents a core competence of the company. The extensive wealth of experience, which was collected during the operation of the company's own shaft hoisting systems at the GBT, led to a thrust in innovation and further development of existing products. The findings obtained guarantee structures based on the latest state of the art when new development projects and complete systems are being planned.

A major advantage was the fact that the concepts for the systems and special structures could be agreed on at an early stage of planning with the client, AlpTransit Gotthard AG, its representatives, experts and in particular, the company's own sub-contractors in a precise manner. Thanks to this approach, it was possible to reduce delays, standstills and obstacles as well as dangers to life and limb for the workforce or the environment to a minimum thus leading to the desired success.

High availability targets and safety functions are to be attained for the future operation of the Gotthard Base Tunnel. These high demands were also posed on the new shaft hoisting systems for Lot D, which could be successfully verified and documented by means of so-called RAMS analyses.

Within the scope of the commissioning phase the hoisting systems for Lot D are currently being integrated in the rail tunnel's control technology. Then Lot D hoisting systems will subsequently be approved during the course of 2016.

7 References

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AlpTransit Gotthard AG

The AlpTransit Gotthard AG is the client for the new Gotthard axis rail route passing through the Alps including the Gotthard and Ceneri Base Tunnels. Founded in 1998, the SBB subsidiary today employs around 160 staff at its Lucerne headquarters and at its branches in Altford, Sedrun, Faido and Bellinzona.

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Gotthard Base Tunnel: The Sedrun Shaft Hoisting Systems Part 1: Tunnel Construction Phase

Gotthard Base Tunnel: The Sedrun Shaft Hoisting Systems Part 2: Conversion and Operating Phase

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