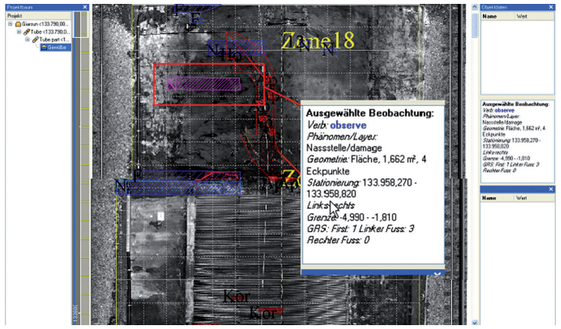

Inspection with tunnel scan data - damage recoring (detail).

Summary of measurements and prospects
The planned scan capacities were achieved. That means 11 night shifts with some deviations (e.g due to necessary constructions on site) in routes; both the contractor and the client were very flexible. Rail traffic was not impaired, nor were there any accidents

Scan data brings the tunnel into the office
The highly detailed, scaled tunnel scan data reduces inspection times. They form the basis for a scaled documentation of damage and allow a visual analysis during follow-up measurements in order to assess damage development. Scanned images considerably speed up the decision-making process when it comes to managing tunnel damage.

Further arguments in favour of digital inspection are:
- complete structure history that can be queried at any time,
- comparably precise data on condition,
- reliable data base for real-cost planning and tendering.

In future, the track management program Toporail 5 from SBB will also permit virtual trips in order to clarify special freight transports.

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Project report Amberg Clearance with GRP 5000

Laser scanning a world cultural heritage Rhaetian Railway

Chur, Switzerland

Thanks to the use of cutting-edge laser scanning technology, it was possible to survey almost all tunnels on the Rhaetian Railway in a short time in 2006 and 2007 (31.2km excluding the Vereina line). The digitalised data opens up new possibilities for selective deployment of resources.

The Rhaetian Railway (RhB) network comprises 384 km . The most well-known sections are operated by Glacier Express (approx. 250,000 passengers p.a.) and Bernina Express (approx. 200,000 passengers p.a., half from Germany in each case). The 114 tunnels (58.6km) account for 15.3% of the total length of track. In addition there are 591 bridges (span > 2.0m) with a total length of 15,553m. This includes 331 brick viaducts, approx. 100 stops and stations (of which approx. 30 manned railway stops / stations and approx. 70 unmanned stops, and 16 service and junction stations).

Special features of the Rhaetian Railway:

- Metre gage. Everywhere with one exception: 3-rail track from Chur to Domat/Ems – mainly for linking up to major industries with normal gage.
- Usually single-track sections
- Seasonal fluctuations. An example: Train travel frequencies to Arosa in 2004 were 30,000 in February, only 7000 in May, 20,000 in August and 6000 passengers in November.
- Gradients. The largest gradient is 70 ‰ (Arosa and Bernina line).

Prime objectives are:

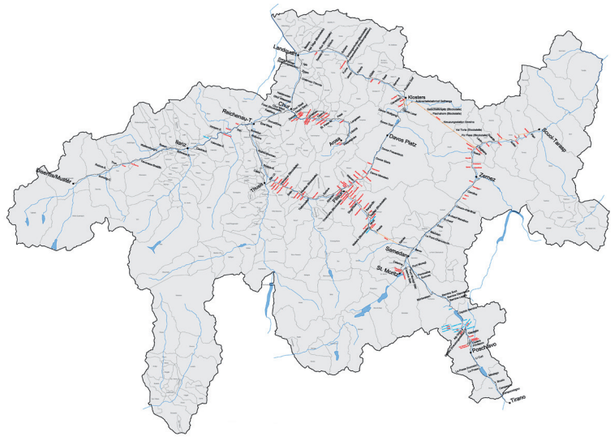
- Maintaining access to regions in the Graubünden canton. Note: RhB runs on a section of approx. 3km on Italian territory.
- Conservation of structures (formulated in SIA norms).

Transporting the system on the flat car.

Condition of the tunnels

The objectives have the following implications for the Rhaetian Railway tunnels:

- Maintaining adequate structural and operational safety,
- Maintaining the economic value of every structure, taking running and maintenance costs into account,
- Safeguarding the utility of every structure,
- Meeting the owner's statutory responsibilities,
- Maintaining the cultural value of the structures (e.g. Unesco).



The 384 km long Rhaetian Railway rail network (the Vereina tunnel in the north-east and the Albula tunnel are hatched)

Most of the structures on the Rhaetian Railway network date from the period of railway construction around 1900 (94% was completed before 1910). Since then, the tunnels have been continuously adapted to changing demands, the track bed optimised for travelling comfort, and damage to the supporting structure repaired.

The major inspection in 2005 led to the assessment in 2007: 61% of tunnels were classified as "out of repair" (grade 3 of 5), and 21% were classified as "poor" (grade 4 of 5). For grade 4 this means: speedy repair or reinforcement (in the next 5 - 10 years) and supplementary safety measures (to gain some leeway with regard to the time of intervention or to restrict the spread of damage, altogether an extensive programme for the next 10 years with a budget of approx. CHF 150 million.

Damage to the approx. 100-year-old structures includes:

- Water leakage (ice build-up),
- Masonry damage (empty mortar joints, weathered mortar),
- Hollows caused by mountain pressure and, as a result, in some cases considerable deformation of the structure gauge.

Structural safety is thus jeopardised by foundation, hydrology, climate and operation. In addition, in some cases there is no drainage.

Measures to optimise tunnel renewal and management:

- Structure gauge analysis (scanning),
- Development of normal construction methods,
- Systematic maintenance of tunnels.

Conditions for tunnel scanning

Various objectives evolved:

- Consistent visualisation of the current condition of the tunnel vault as a basis for major inspection,
- Localisation of facilities, e.g. niches, contact line system, signals, and all other visible elements,
- Monitoring of structure gauge conditions,
- Data recording in national co-ordinates,
- Basis for track optimisation with "Toporail 5", the track planning program from Schweizerische Bundesbahn (SBB).

Special demands to be taken into account:

- The total of 31,234m in 100 tunnels to be surveyed, distributed over 384km of rail network, requires complex logistics,
- Surveying only in the night-time idle times of approx. 7 hours,
- Access to tunnel primarily by rail, in fewer cases by car,
- Partly adverse weather conditions due to snowfall and low temperatures,
- High mountain conditions, e.g. the Bernina Pass is located at 2300m asl,
- In order to ensure safety, it was stipulated that a trained person be present during scanning as head safety officer (private) to assume responsibility with regard to safety.

Evaluation requirements (specifications):

- Structure gauge analysis to RhB scaling,
- Objects of 10mm x 10mm easily recognisable,
- Compress/stretch images,
- Greyscale images,
- Data export to "Toporail 5".

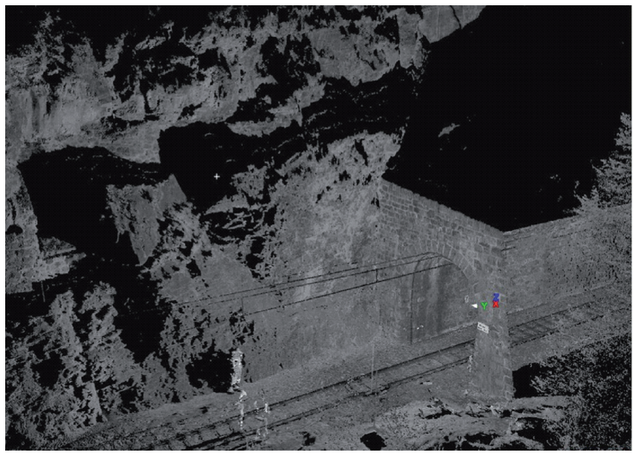
The management of the Rhaetian Railway ultimately decided to have tunnel scanning performed on the entire rail network (with the exception of the Vereina line). Because a cost estimate of between CHF100,000 and 250,000 was to be expected, an invitation procedure was initiated (CH, D). The following placement criteria were defined: Problem assessment, references, personnel deployment, schedule and costs. The order went to Amberg Technologies AG from Regensdorf-Watt, Switzerland.

Between 3 and 17 tunnel per night

First Amberg drew up a measuring plan for eleven nights for two people from Amberg and one tractor/engine driver from RhB (safety officer); due to the logistics involved, three to seventeen tunnels had to be measured per night, i.e. 1200m to 5000m per night. The integration of a motor on the mobile GRP 5000 measuring system ensures high quality images thanks to the constant speed of approx. 2.5kph and allows the operator to concentrate on other tasks during measurement (photos, removing track measurement point marks, documentation of special incidents, e.g. water entry, distinctive damage to tunnel vault).
The following also had to be planned:

- Loading the system onto a flat car and drive with the engine to the tunnels,
- Specification of track closures,
- Import of project data including track centres.

Laser scanner set up on trolley with fixed point for measuring on the tunnel wall.



3D-Scan of one tunnel entry.

The GRP 5000, equipped with a scanner, gauge and superelevation measuring device, was used to scan the tunnels. While the track surveying car is driving through the tunnels at walking speed, the Profiler 5002 laser scanner rotates at 100rpm, recording 5000 (image) pixels per rotation. This creates a three-dimensional set of scanned data of the tunnel lining (profile distance approx. 8mm at a measuring frequency of 100Hz).

The basis for this was a terrestrial fixed point and track survey that already existed for most tunnels of the Rhaetian Railway at the date of scanning. For those tunnels for which no terrestrial measurements were available or were too inaccurate (deformation or track straightening since last surveying), the fixed points and track bed were measured afterwards. The following were also provided:

- Tunnel index,
- Track geometry in Toporail2 format (interface to evaluation system of Amberg Technologies) and in list form (geometry, longitudinal profile, superelevation),
- Stationing/kilometre position of fixed points (track measurement),
- Offset list with deviations of the scanned track points from theoretical track centre.

The scans were used to record the current situation and thus served as a basis for further project developments. Checking and ensuring structure gauge profile is a key concern. On the basis of scans it is possible to perform comparisons of actual/target values and discuss measures to be taken, e.g. vault profiling or track position correction. The effects of a possible track shift can be subjected to computer-assisted verification with "Toporail 5".

In the above process, a greyscale image was created in addition to the scan. The 'digital photo' forms the basis for major tunnel inspections. The high resolution of the image allows detection of wet or moist areas and damaged joints or cracks in the lining. Of course, all technical railway installations such as contact line system, signals, cable lines, etc. are also visible.