Renewal of the Alpine San Bernardino Tunnel with Traffic Flowing

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1. TUNNEL PRIOR TO RENEWAL

The San Bernardino road tunnel lies at an altitude of 1600 m. above sea level and is 6.6 km long. On the south side it drops off with a gradient of 0.4 %, on the north side with a gradient of nearly 1 %. The tunnel was officially opened for traffic on December 1, 1967.

Two-way traffic prevails in the tunnel. A single-shell concrete arch supports the rock, and thin-walled concrete lining elements keep seepage water off the roadway. An enterable fresh air duct flanked by utility ducts are arranged under the roadway. The exhaust air duct is located above the traffic space.

In addition to the two ventilation facilities at the north and south portals, the tunnel is ventilated by two underground facilities, Aria and Sasso, which are connected with the surface by inclined shafts. The cross ventilation system is dimensioned for peak traffic of 1500 vehicles per hour. Secondary ducts spaced 5 m apart blow fresh air into the traffic space, and identically spaced openings in the intermediate ceiling extract the exhaust air.

The average daily traffic of nearly 2300 vehicles in 1968 grew to over 6200 vehicles (more than 10% of them trucks) in 2003.

Over 35 years of operation have left their marks on the tunnel. A systematic visual inspection and various investigations have shown that, while the tunnel is still serviceable, progressive damage over the years has jeopardized its operational safety. Consequently, various parts of the basic structure and the electromechanical equipment are badly in need of refurbishment and modernization.

The existing roadway slab has suffered corrosion damage, some of it very severe. Around the joints – every 2.5 m – the bottom layer of reinforcement is in very poor condition. The conditions
here are highly conducive to corrosion. Wherever the concrete coverage is insufficient, heavy rust damage is found. The damage is caused mainly by the practice of spreading de-icing salt in the winter combined with a lack of effective sealing.

The intermediate ceiling is generally in good condition, which indicates that it can be expected to remain sufficiently durable in the future. Only the first 250 meters of intermediate ceiling at the north and south portals have to be renewed to eliminate the damage caused by salt spreading. Except for these portal areas, the mainly unreinforced tunnel crown has suffered only local damage from aggressive ground water.

The following objectives were established for the San Bernardino Tunnel renewal project:

- Safe operation to be ensured at all times.
- Durability and quality of the structural substance to be maintained and secured (service life of at least 50 years without further renovation).
- Electromechanical systems to continue serving operation of the tunnel for 25 years without renovation.
- Closure of the tunnel during the construction work is out of the question for political reasons. So the flow of traffic has to be maintained while the work is done. Other cantons or regions may not be subjected to additional traffic as a result of the project.
- Any traffic obstruction should be restricted to a short period of time. The work in the tunnel’s traffic space is to be limited to just a few years, and no traffic obstruction will be tolerated during the heavy traffic period of summer.
- The renewal project should result in easier operation and servicing of the tunnel equipment, and also in reduced maintenance expenses.

The catastrophic tunnel fires that occurred in France and Austria in the spring of 1999 necessitated a review of the safety concept in the event of a fire. This review produced the following project amendments and modifications:

- Installation of an escape route that employs the two central channels under the roadway as escape and life-saving galleries, and construction of escape exits spaced 350 – 375 m apart on the west side of the tunnel to provide access to the escape gallery.
- Adaptation of the ventilation system, especially the fire ventilation, to the present state of the art in this field.

2. RENEWAL PROJECT
2.1. Lowering of the invert

The tunnel invert around the central channel was lowered by 50 cm. The need to demolish most of the existing concrete base solved the problem of the concrete damage that had occurred over the years. Lowering the invert provided the additional overhead clearance required for future use of the channel as an escape and life-saving gallery.
The cramped conditions necessitated the use of special, extra-compact machines for this work. Mechanical excavation equipment was used to demolish the concrete and excavate the invert rock. Special tractors and cars were used to cart the debris out of the tunnel.

When the new concrete base was poured, it also included a cable conduit installation that includes all of the cable connections required for operation of the tunnel during the construction phase. Formerly, these cables were carried on open racks in the west channel.

2.2. Escape exits

A total of 17 escape exits were built on the west side of the tunnel to connect the traffic space with the escape gallery.

Because the blasting work had to be carried out in the immediate vicinity of the existing structure without interrupting the flow of traffic, some rather drastic restrictions had to be imposed. For one thing the work had to be done during the low-traffic nighttime hours, and for another the charge quantity was limited to 200 g per blast. The excavation work was monitored by means of continuous vibration detection.

2.3. New ventilation system

The ventilation system was converted from transverse air flow to longitudinal air flow with extraction at regularly spaced intervals. If needed, fresh air can be blown into the traffic space at both underground ventilation facilities. Two groups of 6 jet-fans each are needed to regulate the longitudinal air flow.

2.4. Renewal of the roadway

The central element of the refurbishment project is renewal of the roadway. This includes the preliminary work, the actual renewal of the slab, and the roadway finishing work.
The various preparatory jobs included removal of the wall panels and the lighting system installed above the panels on both sides, milling away of the old pavement over the entire roadway width, and demolition of the catwalk on the east side to provide the necessary clearance for traffic during the roadway renewal.

The new roadway consists of a jointless, reinforced slab that is supported across its width by three walls and bears on the vault in both side-walls. Two of the support walls are located at the same points as the existing walls, while the third divides the central channel into the new escape and life-saving galleries.

The finishing operations that complete the roadway renewal comprise:

- **Sealing:** The entire surface of the slab is sealed to protect it against harmful effects from the traffic space. Sealing is achieved by applying a fully bonded web of polymer/bitumen.
- **Catwalk:** The catwalks installed on both sides of the roadway consist essentially of prefabricated concrete elements.
- **Pavement:** Conventional two-layer bridge pavement with 6 cm of HMT B16S topped off by a 3 cm layer of AB 8S.
- **Roadway drainage:** Every 25 m the roadway water exits through drains and flows down into the cast-iron sewer under the roadway slab. Settling/flushing traps are installed every 100 m (or every 50 m near the portals).

The individual worksteps of these finishing operations are carried out in rapid succession, because this work is also done with the traffic flowing and is subject to the same restrictions as the slab renewal work.

2.5. Renewal of the traffic space

The traffic space renewal includes refurbishment of the intermediate ceiling and the crown, plus prefabrication and installation of the wall panels.

3. **SPECIAL ASPECTS OF THE RENEWAL PROJECT**

3.1. Restrictions on working hours

During the construction work, the following restrictions and rules have to be observed.
- Work starts on Sunday at 22.00 hours and stops on Friday at 14.00 hours. Single-lane traffic wherever and whenever work is in progress.
- During weekends, holidays and the 4-week period of heavy traffic in summer, two-lane traffic must be maintained at all times.
- Maximum length of the work site is 800 m, and only one work site is permitted in the tunnel at any given time.
- Maximum 20 minutes of tunnel closure for setting up and clearing the work site. Separation of normal traffic from works traffic.
3.2. Slab renewal in stages

In order to observe these restrictions without impairing work progress, a concept was developed involving step-by-step operations at two mutually independent subsites.

These two subsites, set up in tandem with a traffic crossover in between, cover a total length of 800 m. The first subsite is used for renewing the west side and erecting the new central partition. The east side is then renewed at the second subsite. Work progresses at the same rate at both subsites.

A fixed weekly cycle was defined for renewing the roadway slab at the west and east work sites. Within one week, the following work has to be completed to replace 90 meters of slab:

- Cordonning off of the existing roadway for demolition of one lane with a row of posts in the middle of the existing roadway
- Cutting of the existing slab into transportable sections of concrete
- Removal and carting off of the concrete sections
- Installation of formwork elements, placement of reinforcement, and pouring of concrete for the new slab
- And finally topping off of the concrete surface with an epoxy layer

3.3. Traffic control

It was necessary to develop a safe and efficient traffic control system for the specific purpose of handling the single-lane traffic within the 800 m long work site. The system had to take these factors into consideration:

- In view of the rear-end collision that had occurred in the Tauern Tunnel (Austria), a solution with a red light ahead of the work site with resultant back-ups in the tunnel was out of the question.

- At both portals, the entry of jobsite vehicles via a separate access had to be possible as frequently as necessary.
- These works vehicles had to be able to enter and (more importantly) leave the work site in the tunnel safely and as frequently as possible.
- The truck traffic on the San Bernardino route, which was held back and allowed to pass alternately in one direction only, did not have to be accorded any special treatment by the work site traffic control system.

In spite of these supplementary conditions, the traffic capacity had to be maximized and the the cycle time kept as short as possible.

The traffic control installation VRA02 was developed to meet the above requirements.
Briefly, the traffic control system works this way:

- The traffic lights at the portals are set to operate so that the batch of vehicles released by the green light reaches the single-lane zone at the work site in time to pass through it smoothly.
- Traffic lights are also placed ahead of and following the work site to prevent vehicles arriving too early or too late from entering the single-lane zone.

Besides fulfilling all of the above requirements, this optimized control system keeps the cycle time to about 15 minutes under normal traffic conditions, which is considered tolerable for the drivers.

3.4. Concrete roadway slab

**Early strength**
The need to make the tunnel available for 2-lane traffic on weekends means that the new section of roadway must be able to withstand traffic quite early. The concrete formulation and the formwork design were established with this in mind:

- Early strength of the concrete
  The concrete can be driven on only after 24 hours. At this point its compressive strength must be at least 10 N/mm².

  Because this requirement is mandatory for releasing the roadway for traffic, the slab’s changing strength must be monitored. The concrete’s weighted maturity according to de Vree was prescribed for this measurement. The temperature change of the concrete as a function of time is measured at 6 different points and integrated over time with the help of the so-called maturity computer. As soon as the sum arrived at in preliminary tests has been reached, the concrete has achieved the necessary early strength. Along with this indirect measuring method, the strengths of test cubes are measured regularly after 24 hours.

- Load-bearing formwork design
  Because the concrete’s bearing capacity after 24 hours is not sufficient to withstand the lateral forces around the wall supports with the necessary safety margin, the formwork must be able to absorb the traffic loads and also be exceptionally stiff. The deformations that do occur must be so small that the concrete can absorb them without suffering damage.

**Concrete curing**
Special curing measures are required to suit the young concrete for traffic. The surface is sealed with epoxy resins to prevent drying out and provide additional protection against chloride penetration. Sealing with epoxy has the added advantage that it affords relatively long-term protection of the concrete surface despite the traffic-caused erosion. Because the epoxy coating also serves as substrate for the main seal, it must be compatible with this seal.
800 grams of epoxy and 2.1 kilograms of silica sand per m² are applied to the freshly poured, semi-rigid concrete. The heat produced by the setting concrete helps cure the epoxy, so that it is sufficiently strong by the time the road is released for traffic.

**Frostproofing measures**
Because of the altitude (more than 1600 meters above sea level), the work is carried out in climatic conditions that are sometimes extreme. This necessitates the use of frostproofing measures during the mixing, transport, placement and curing of the concrete.

The following requirements must be met:

- **Production of the concrete**
  The mixing plant must be capable of producing concrete with outside temperatures as low as -20°C. The admixtures must be stored in encased boxes or silos. The fresh concrete temperature must reach 20°C at all times, which means that the mixing water and admixtures must be heated.

- **Transport of the concrete**
  The concrete must have a temperature of at least 15°C when it is poured. Temperature losses during transportation of the concrete should be kept as low as possible (short transit time, preheating of transport vessel, insulation of transport vessel).

- **Shelter**
  A shelter must be built for protection of the concrete pouring location in the traffic space. It protects against drafts and reduces the energy consumed for heating.

- **Heating**
  The concrete work locations have to be kept at a temperature of no less than 15°C. This ensures that the concrete will reach its required early strength. In addition, the channels under the roadway slab and the shelter in the traffic space are heated. Oil burners are used for heating.

4. **CONSTRUCTION PROGRAM AND COSTS**

4.1. Costs

The ultimate total cost of the San Bernardino Tunnel renewal project was CHF 236 million. This figure breaks down as follows:

- Electromechanical systems (hardware and software) about 19 %
- Construction work about 64 %
- General expenses (planning and design, work related to tunnel operation, etc.) about 17 %

4.2. Construction program

The renewal work started in 1998 and was officially completed in 2006 with the reopening. Actually works at the portals have been running until 2008.
Lowering of the invert (Construction Lot 1) had to be carried out first in order to provide the necessary space for the subsequent activities. This work started in mid-1998 and was completed at the end of 2001. Construction Lot 3 with the safety installations started in mid-2001 and was completed at the beginning of 2003, when the roadway renewal work was starting. The main construction phase (Lot 2), including renewal of the roadway, started at the end of 2002 and was completed by 2006. Construction Lot 4, which includes installation of the wall cladding and the electromechanical systems in the traffic space, also were completed in time.

This means that the totally renewed San Bernardino Tunnel is expected to commence normal operation after a construction period of 9 years.

5. Conclusions
5.1. Design and Construction Methods

The most difficult part of the project was the construction method for the lowering of the invert for the escape route underneath the road slab. The free height of less than 2 m was a permanent issue, working was difficult and as a consequence delays to the construction program occurred. In addition the initial excavation method had to be changed and adjusted several times. The problems however, put focus on the escape path and the contractor correctly put a track system into the escape path providing logistics for the rest of the works. This transport system then allowed to finish the slab replacement in time.

The works for the slab replacement progressed as mentioned rather perfect, allowing the complicated operation of the tunnel during weekends and summer peak with full capacity. The traffic light system in the tunnel did work flawless. No major accidents occurred, no traffic jams in the tunnel happened. The system was actually considered also in Austrian tunnel renewal projects later on.

The concrete technology and the structural design worked fine up to today, no actual issues were discovered. During construction a discussion was started however if welded reinforcement could be used in a dynamically loaded transport structure.

Technically the renewal is therefore to be considered a success, despite the difficult technical conditions.

5.2. Costs

The cost for the renewal was however considerable. Many critics would say that for 240 Million CHF a new tunnel could have been build. However this still would have required a renewal of the old tube, just under easier working conditions.

5.3. New for Tunneling

Two new concepts were used, both rather successful: First the tunnel was operated with a traffic management system, using traffic lights inside the tunnel without accident or traffic jams.

Second a road slab was replaced in a tunnel in five working days per cycle starting with removal of the existing slab to curing and reopening for operation, considering the climatic conditions a technology challenge.