HALLANDSÅS TUNNELS

Mid-adit

Hallandsås ringing

TBM erection chamber

Probe hole

06 June 2009

Skanska - Vinci HB
General project information

- Part of the West coast line railway project in South Sweden
- 2 tunnels 8.5 km long with 2 x 5.5 km to be excavated with a TBM (diam. 10.6m) and lined with segmental lining.
General project information - Geology

- Hallandsås ridge is an horst with a long history of tectonic movements. It is quite heterogeneous in terms of fracturation and weathering.
- Rock: gneiss, amphibolite (either massive or dyke) and dolerite.
- Hydrology: presence of long zones with very high permeability. Hydrostatic pressure up to 15 bars.
- Presence of a major difficulty: Möllebäck zone.
First attempt: open type TBM (1993-1995)

- May 93 - KRAFTBYGGARNA started tunnel excavation with the hard rock TBM named HALLBOR (type JARVA MK27).

- July 93 - The TBM is blocked after 16m being excavated. Tunnel excavation resumed with drill and blast technique.

- Dec. 95 - KRAFTBYGGARNA left the project, 3 000 m being excavated.
Second attempt: drill and blast technique (1996-1997)

• Jan. 96 - The project restarted using the drill and blast technique. 4 additional faces were opened (mid-adit).

• June 96/Feb 97 – Excavation was continuing with significant water inflows despite systematic grouting (60 l/s for a contractual flow set at 33 l/s). Ground water lowering was experienced and several wells were dry.

• Sep 97 - The grout material RHoca-GIL, used to seal rock fissures and containing acrylamides is discharged outside, where some animals were poisoned. Some workers were as well intoxicated.

• Oct 97 - The works were stopped. National scandal.

• April 99 - Decontamination works were completed as an in-situ lining in the areas associated with significant water inflows
Third attempt: Project restart

- 8 Nov. 2002 - Contract between BANVERKET and SKANSKA-VINCI signed.
- 15 Mars 2004 - Order to start the works.

Basic principles of the new contract

- Contract: Design and build
- Value: 430 M Euros (Base 2001)
- TBM: Mixshield, specially developed for HALLANDSÅS with HERRENKNECHT.
- Environment - Very strict conditions
  - Control of water inflows: maximum 100 l/s average over 30 days;
    400 l/s instantaneously
  - Control of the discharged water
  - All chemical products on site must be approved
- MBZ fault: Treatment of this fault prior TBM excavation by freezing and grouting.
Original TBM excavation principles

• Three probe holes drilled ahead of the shield in order to get information pertaining to ground water inflows and to rock conditions (fracturation, weathering…)

• In the event ground water inflows are low:
  >> Excavation in open without pre-grouting

• In the event ground water inflows are high:
  >> Pre-grouting and excavation in open mode
  >> Excavation in closed mode.
  >> Pre-grouting and excavation in closed mode.

Pre-grouting from TBM

Face pre-grouting

Peripheral pre-grouting
TBM main technical features

- Hard rock mixshield: Open mode + Closed mode (Cutterhead: power 4 000 kW and torque 2 600 T.m – Thrust: 18 000 T).
- Possibility to work in closed mode up to 8 bars (Slurry circuit).
- Possibility to work excepciónaly in closed mode between 8 and 13 bars over short stretches (faults).
- Segmental lining erected in the tail skin.
- Designed for 15 bars (static)
- Equipped with drilling and grouting facilities:
  1. 3 boomers for drilling through shield/cutterhead
  2. 1 boomer for drilling through cutterhead center

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TBM operation in Open mode

- Originally estimated over 80% of tunnel alignment
- Transport of excavated rock by belt conveyor (1000 T/hr)
- Maximum TBM advance speed 8cm/min
TBM operation in Closed mode

- Originally estimated over 20% of tunnel alignment
- Transport of excavated rock by slurry circuit (1800 m³/hr, increased later to 2000 m³/hr)
- Maximum TBM advance speed 4 cm/min
- Maximum working pressure 8 bars
- Exceptional working pressure 8 to 13 bars

**Technical particularities:**
- Main bearing sealing arrangement designed and tested in factory for 13 bars
- Compensated cutters to permit operation up to 13 bars
- Tail skin sealing arrangement designed and tested for 13 bars
Geological profile and TBM progress (East tunnel)

Total length 5,500m

Excavated

1,362m remaining

Möllebäck Zone

SOUTH

MID ADIT

NORTH

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Main technical problems encountered

Due to very difficult geological conditions:

• Highly heterogeneous rock mass requiring continuous changes in operation parameters
• Bocks instability at the face with the following consequences:
  - damages on the cutterhead
  - damages on the belt conveyors
  - damages on the slurry circuit

• Significant water inflows with the following consequences:
  - extensive pre-grouting
  - construction of barrier to stop water flows along the lining
  - difficulties for backfilling
TBM excavation through blocky ground conditions

Cutterhead action on the blocks: crushing

Large blocks at the outside separation unit after actions of the cutterhead
TBM excavation through blocky ground conditions

Investigation regarding the possible causes of blocks instability focussed on two routes:

- In situ stresses
- Mechanical characteristics of the joints

Involvement of experts Dr Evert Hoek, Prof Paul Marinos, Dr Mark Diederichs. Dr Derek Martin.

Fair gneiss
RC 3-5

Good amphibolite
RC 1-3

Fair gneiss
RC 3-5

Good gneiss
RC 1-2

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Scandinavian rocks formation

1,970 to 1,750 million years

1,750 to 1,275 million years
Scandinavian rocks formation
Horst and dykes conditions in Hallandsås are unique in Sweden

900 to 250 million years

- Rocks formed 900 to 250 million years ago
- Caledonian orogenic belt and meteorite impact sites

Dykes formation in Hallansås horst

250 million years to Quaternary period

- Rocks formed 250 million years ago to the Quaternary period
- Maximum principal stress after c. 12 million years
- Maximum principal stress during the time period 95 to 50 million years

Rotation of stress 12 million years ago

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Typical known stresses conditions:

The vertical stress $\sigma_v$ is equal to the pressure from the overlying soil and rock.

$\sigma_h = 1 \cdot \sigma_v$

(perpendicular to the tunnels)

$\sigma_H = 2 \cdot \sigma_v$

(parallel to the tunnels)
In Situ Stresses

In order to establish the actual regime of in situ stresses:

• Measurement of in situ stresses at various locations in the tunnel

• Modelisation of the Hallandsås ridge and of its formation

Correlation to Geophysical Profile

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In Situ Stresses: comparison model with measurements

Actual stresses conditions in Hallandsås horst:

\[ \sigma_h = (0.7 - 1) \cdot \sigma_v \]
(perpendicular to the tunnels)

\[ \sigma_H = (0.5 - 0.7) \cdot \sigma_v \]
(parallel to the tunnels)

Low stresses conditions
Joint frictional strength

Measurements of joint frictional strength gave significantly lower values with Amphibolite:

- Gneiss: 49 degrees
- Amphibolite: 30 degrees
Blocks stability – Overbreak at face

Modelisation of blocks structure at the tunnel face

Calculation of % of overbreak at face in function of:
- in situ stresses
- Joint frictional strength

Conclusion:
Increase of overbreak with decreasing in situ stresses and decreasing joint frictional strength
Other consequences of low in situ stresses

1. an open jointed rock mass, highly permeable

2. large water inflow
TBM excavation through blocky ground conditions

Measure 1:
Definition of boring classes with specific boring parameters (penetration, cutterhead rotation speed, cutter load...) in relation to the degree of blockiness in order to limit wear and damages on the cutterhead. Cutter load can vary quickly from being almost null to exceeding 20 tons within few meters of tunnel.

Ga Unblocky
Gb Slightly blocky
Gc Highly blocky
TBM excavation through blocky ground conditions

Measure 2:
Frequent inspections of the cutters and scrappers (about every 5m of tunnel)
TBM excavation through blocky ground conditions

Measure 3:
Large cutterhead maintenance every 500 to 1000m for a period of one month. 4 to 5 t of hardox plates and 1000 to 1500 kg of electrodes per large maintenance.
TBM excavation through blocky ground conditions

Measure 3:
Large cutterhead maintenance – Cutters protections refurbishment

Before

Cutter protections worn out

After

Welding of Hardox plates + carbide plates and hard facing to refurbish the cutter protections
TBM excavation through blocky ground conditions

Measure 4:
Installation of a new cutterhead at the mid-adit (after 2500m of tunnel excavation)

**Hallandsas**
S-246 Cutterhead Layout

**Requirements:**
- conventional hard rock with closed mode possibility
- hard and abrasive rock conditions
- occasional blocky rock
- high water inflows
- dual mode operation (center belt - slurry)
- potential soil like ground behaviour in closed mode BC 2D (clogging)
New cutterhead:
- 19” cutters instead of 17” cutters
- Redistribution of cutters
- Additional protection

Cutter 17”

nominal load: 250kN

Cutter 19”

nominal load: 320kN
TBM excavation through blocky ground conditions

Measure 4:
Installation of the new cutterhead at the mid-adit in april/may 2008

Preliminary conclusions relative to the new cutterhead:

• Significant decrease of the amount of cutters damaged by blocks, 19” cutters withstand better impacts associated to blocks.
• Cutters consumption reduced by 50%
• Daily cutterhead maintenance reduced by 50%
Water management: a major constraint

In order to control the ground water inflows within the demands of the Swedish Environmental Court, the following means are used:

• **Pre-grouting** with SH or microfine cement (generally 6 to 14 holes at the face). Drilling in open mode and generally grouting in pressurized condition (to save water and to avoid grout circulation towards the face). Effect of pre-grouting on the water inflows extremely variable (scale 1 to 10) and difficult to be predicted (complexity of the rock mass).

• **Barrier construction** in order reduce the water inflows along the segmental lining. The following technique is used:
  
  • Excavation of 6 rings backfilled with pea-gravel
  • Excavation of 4 rings without backfilling
  • Pressurization of the shield to stop the ground water circulations
  • Backfilling of the empty rings with mortar
  • Cementitious grouting of the pea-gravel matrix
  • De-pressurization of the shield
Water management: TBM advance through water bearing zones

Water inflows reduced by pre-grouting

Water bearing zone

Pre-grouting

TBM

TBM advance (open mode)

Mortar backfilling

Pea gravel backfilling

Water inflows reduced by pre-grouting

Pre-grouting

Residual water inflows reduced by barrier construction

Plug (mortar)

Grouted Pea gravel

Plug (mortar)

Grouted pea gravel

Barrier

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Water management: sequence for barrier construction

1. **TBM excavation in open mode**
   - With residual water inflows up to 300 l/s
   - Four rings without backfilling

2. **Backfilling with mortar, shield being pressurized**
   - Eight to 12 bars
   - Plug (mortar)

3. **TBM excavation in open mode**
   - Six rings backfilled with pea gravel and four rings without backfilling

4. **Backfilling with mortar and grouting of pea gravel matrix, shield being pressurized**
   - Eight to 12 bars
   - Plug (mortar)
   - Gravel pea gravel

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Backfilling behind segmental lining

In open mode, use of pea-gravel and mortar injected through the segmental lining. The pea-gravel matrix is at a later stage injected with a cementitious grout (between barriers where the water circulation is reduced)

3 phases:
- Backfilling with pea-gravel (2/3 inf.) behind the shield
- Backfilling with mortar (1/3 sup.) roughly 20m behind the shield
- Injection of cementitious grout in the pea-gravel matrix
Water management

Daily average flow (South site)

30 days average flow (South site)

30 days average flow (South and North sites)

Decrease of the flow following Barrier construction
Water management: ground water table

Groundwater pressure (m) above centre line of TBM - Bubble pressure TBM (bar)

Barrier construction

Recovery of the water table
Following barrier construction

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Water handling on TBM

• Use of a powerful pumping system (1400 m³/hr) for removing the water from the cutterhead chamber.
• Use of the slurry circuit for flushing continuously the cutterhead and bubble chambers and for maintaining the pumping systems operational.
• Removal of the water inflows transported on the TBM belt conveyor

The TBM can work in open mode with flow up to 300 l/s.
Progress rates (with new cutterhead)

- About 50% of the time spent in dealing with water (ground treatment, barrier...).
- In "dry" zones, average daily progress 11.5 m/day
- In "wet" zones (meaning requiring ground treatment and barriers), 3.7m/day only 1/3 of the time being spent in tunnel excavation.

In the geotechnical and hydrological conditions of the Hallandsås ridge and with the constraints associated to the Environmental Court ruling, the TBM permits progress 5 times faster than with drill and blast technique.
Pre-treatment of Möllebäck Zone

Möllebäck Zone

Details of pre-treatment

Möllebäck zone 300m

NORTH

Freezing
Grouting

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Pre-treatment of Möllebäck Zone: methods

- Construction of a 600m long access tunnel to work as close as possible to the Möllebäck zone.
- Additional exploratory investigations.
- Drilling of 100m long freeze holes (steered drilling).
- Freeze tubes installation (GRI)
- Freezing of the ground
- Excavation of a 5m diameter pilot tunnel, 100m long through the frozen ground.
- Drilling for freezing 30 additional meters of tunnel and for pre-grouting 200m.
- Pre-grouting with microfine cement
- Freezing of the additional 30m of tunnel
- Excavation with the TBM of the pre-grouted part and reaming of the frozen part.
Pre-treatment of Möllebäck Zone: freeze development
Pre-treatment of Möllebäck Zone: pilot tunnel through frozen ground
Pre-treatment of Möllebäck Zone: reaming of the frozen pilot tunnel by the TBM