Intern rapport
nr. 1910

Long-term behaviour of a 13 m high reinforced steep soil slope. Paper presented at Euro Geo 1 Maastricht.

Oktober 1996

Veglaboratoriet

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Sammendrag

In the summer of 1993 a 13 m high reinforced soil slope was built in the City of Lillehammer as part of a new road system constructed in connection with the 1994 winter olympic games. The reinforced soil slope with an inclination of 60 degrees and a vegetated front was selected as an alternative to a reinforced concrete wall. This proved to be a very cost effective solution. The reinforcement used was a woven polyester geotextile with a characteristic short time tensile strength of 150 kN/m. In-situ materials consisting of silty, gravelly sand were used as backfilling materials. An inclinometer channel and six thermistors were installed in order to meaure horizontal deformations and temperature variations in the structure respectively.

The paper were presented at Euro Geo 1 as a part of a workshop on green faced walls, as an outstanding case history from Scandinavia.

Euro Geo 1 is the First European Geosynthetics Conference and was arranged in Maastricht, Netherlands from September 30 to October 2 1996.

In addition to the paper, this report includes photographs showing the construction procedure and vegetation process.

Emneord: *Reinforced earth, green facing, geosynthetics, instrumentation*

Seksjon: *3520 Geologi- og geoteknikkontoret*
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Dato: *Oktober 1996*

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LONG-TERM BEHAVIOUR OF A 13M HIGH REINFORCED STEEP SOIL SLOPE

Jan Vaslestad, Nils Fjeldheim, Anne Braaten and Tor Helge Johansen.

ABSTRACT: In the summer of 1993 a 13 m high reinforced soil slope was built in the City of Lillehammer as part of a new road system constructed in connection with the 1994 winter olympic games. The reinforced soil slope with an inclination of 60 degrees and a vegetated front was selected as an alternative to a reinforced concrete wall. This proved to be a very cost effective solution. The reinforcement used was a woven polyester geotextile with a characteristic short time tensile strength of 150 kN/m. In-situ materials consisting of silty, gravelly sand were used as backfilling materials. An inclinometer channel and six thermistors were installed in order to measure horizontal deformations and temperature variations in the structure respectively.

1. BACKGROUND

In 1993 a 13 m high reinforced soil slope was built in the city of Lillehammer, The slope was built as a part of the new road system in Lillehammer before the winter olympic games in 1994.

The reinforced soil slope was built as an alternative to a reinforced concrete wall and proved to be a very cost effective solution.

The reinforced slope is situated in the center of Lillehammer with many houses nearby, and reduction of traffic noise was important. A vegetated reinforced slope absorbs in the order of 6 to 8 times as much noise as a reinforced plane concrete wall.

Parts of the reinforced slope were constructed around the opening end of a cut and cover tunnel, and the reinforced earth systems proved flexible in forming curved structural forms.

The total area of the reinforced slope is 1620 m^2. The length of the slope is 120 m and the maximum height is 13 m. The slope angle is 60°.

For aesthetic reasons and trying to lower the effect of the high slope, there is a terrace with a height of 2,5 m in the bottom of the slope. Trees were planted on this terrace for aesthetic reasons.

A plan view of the reinforced soil slope is shown in figure 1.

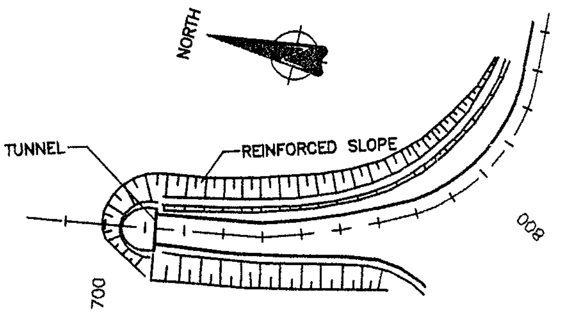

Fig. 1. Plan of the reinforced slope

Owner of the structure is the Public Roads Administration in Oppland and contractor was Veidekke A/S.

The structure was designed by the geotechnical consultant Geo Vita A/S.

A cross section of the reinforced slope is shown in figure 2.

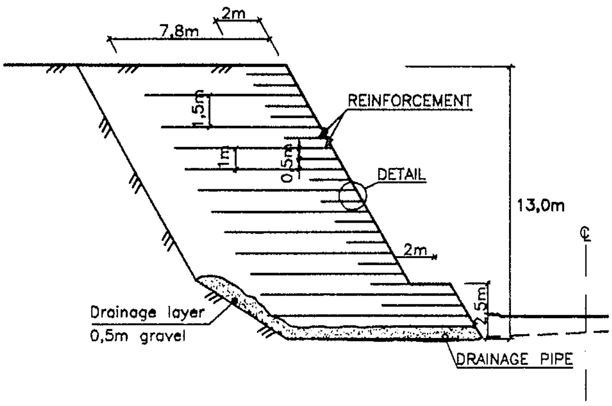

Fig. 2 Cross section of the reinforced slope

Construction control, sieving tests etc. were performed by the Public Roads Administration in Oppland county.

In Norway, all reinforced slopes and walls with heights in excess of more than 5 m must be approved by the Norwegian Road Research Laboratory. This is a design control in order to ensure that the specifications for reinforced earth are followed.

Since reinforced earth were introduced in Norway in 1983, the Public Roads Administration has not experienced any failures. The approval system is one of the reasons for this.

Originally the contractor proposed to use a nonwoven geotextile with a characteristic short time tensile strength of 45 kN/m at a strain of 40 %.

The design guidelines, Public Roads Administration (1990), do not allow more than 5 % strain in the lifetime of reinforced earth structures. The long term allowable design tensile strength, adjusts the serviceability limit load to account for long term durability and construction site damage.

Based on these guidelines the Norwegian Road Research Laboratory could not approve the proposed nonwoven geotextile.

The geotechnical consultant then specified a geotextile with a minimum characteristic short time tensile strength of 150 kN/m.

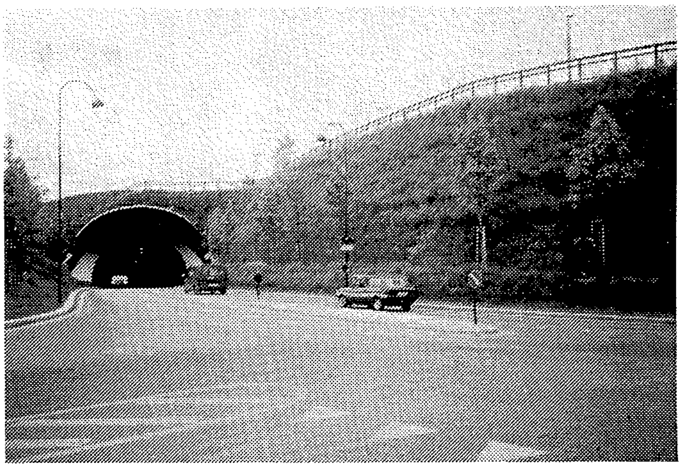

Fig. 3 Finished reinforced slope

A woven multifilament polyester geotextile with a characteristic short time tensile strength of 150 kN/m was chosen for the structure.

In a similar reinforced steep slope in Germany (height 11 m), a high strength woven geotextile (tensile strength 200 kN/m) was used with 1,0 m vertical spacing, Wichter and Nimmesgern (1990). In this structure a nonwoven low strength geotextile were used as secondary reinforcement.

The influence of a low strength nonwoven geotextile and a high strength woven geotextile on the settlement and strain of a reinforced slope are examined by Kharchafi and Dysli (1994).

2. COST

Reinforced soil structures are economically very advantageous compared to conventional reinforced - concrete retaining walls. Moreover, reinforced soil structures provide numerous other indirect savings and conveniences, such as speedy construction methods, graceful appearance, curved structural forms, etc.

In general, the use of reinforced soil can result in savings on the order of 25 percent to 50 percent and possibly more in comparison with reinforced concrete walls, Federal Highway Administration (1990).

It is generally accepted in the literature (Jones 1988, Vaslestad 1993) that reinforced soil walls become more economical with increased height compared to reinforced concrete walls. The total cost of this 13 m high reinforced slope is shown in table 1, compared to other possible options.

Table 1 Cost comparison (total costs)

Wall type	Cost [Nok/m^2]	Relative cost
Reinforced soil	1690,-	0,31
Crib wall	2650,-	0,48
Concrete wall	5500,-	1

This shows that the reinforced soil slope has a cost that is 31 percent of the concrete wall and 64 % percent of the crib wall.

Breakdown of costs, typically shows that the reinforcing materials accounts for some 10 to 20 percent of total costs, Federal Highway Administration (1990).

This shows that using a stronger geotextile or increasing the length to provide on additional factor of safety may not significantly increase the total cost.

3. CONSTRUCTION

The in-situ soil consists of dense sand with layers of silt and gravel.

Triaxial testing showed a characteristic angle of friction $\varphi = 36^\circ$ and cohesion c = 7 kPa. The ground water level was below the bottom of the reinforced slope.

The in-situ soils was used as backfilling material. In the Norwegian specifications for reinforced soil there is a rule requiring that the backfilling materials shall be self-draining.

Horizontal drainage layers with thickness 0,2 m were used and connected with a drainage layer placed in the slope behind the reinforced structure. The backfill was compacted to 95 % Standard Proctor, except for the outer 1 m in the front of the structure that was compacted to 93 % Standard Proctor.

The slope behind the reinforced wall was excavated with a slope gradient of 2:1.

The structure consists of the following elements (see figure 2 and 4).

- Drainage layer of gravel with thickness 0,5 m in the bottom connected with the drainage system for the road.
- Horisontal drainage layers of gravel with thickness 0,2 m and 1,5 m vertical spacing.
- Backfill consisting of in-situ silty and gravelly sand.
- Organic vegetation soil with thickness 0,5 m in the outer layer of the structure. Seeds were included in this fine-graded soil (6 g/m^2).
- Vegetation mat consisting of wool and polyester in the front of the structure.
- Reinforcement. Woven polyester geotextile with tensile strength of 150 kN/m and length 7,8 m as primary reinforcement. Reinforcement spacing was 1,0 m except for the 2 upper layers with spacing 1,5 m. The same geotextile with length 2,0 m and spacing 0,5 m was used as secondary reinforcement.
- Steel mesh. Commercially available lightweight steel mesh with height 0,5 m and 10 mm bars. The mesh was produced in units with length 2,0 m and welded on site. A similar steel mesh was used on a trial steep reinforced slope in Norway in 1987, Fannin and Hermann (1988).
- Hydroseeding consisting of seeds and manure.

The facing is shown in figure 4.

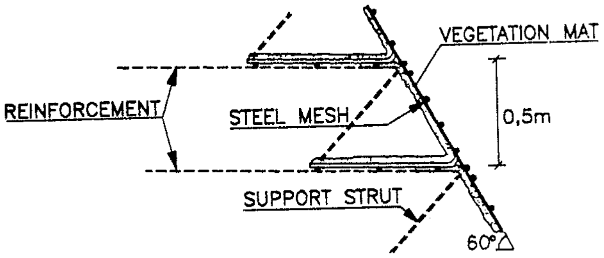

Fig. 4 Detail of wall facing

The backfill was compacted with lift thickness 0,25 m using a 4000 kg vibratory roller and 6 passes. A 1300 kg vibratory roller and a 400 kg vibrating plate were used in the front.

A total of 65 compaction control tests were performed with nuclear density equipment. A mean value of 96,3 % Standard Proctor was obtained. With the planned curvature of the steepened slope geometrycontrol during construction was important.

The quality control of the structure are summarised by Fjeldheim (1993). Quality control of the backfill consisted mainly of compaction control and sieving tests.

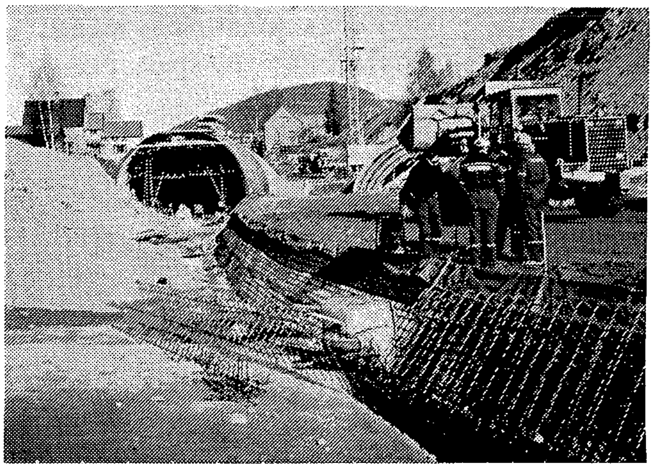

Fig. 5 Construction of the third lift

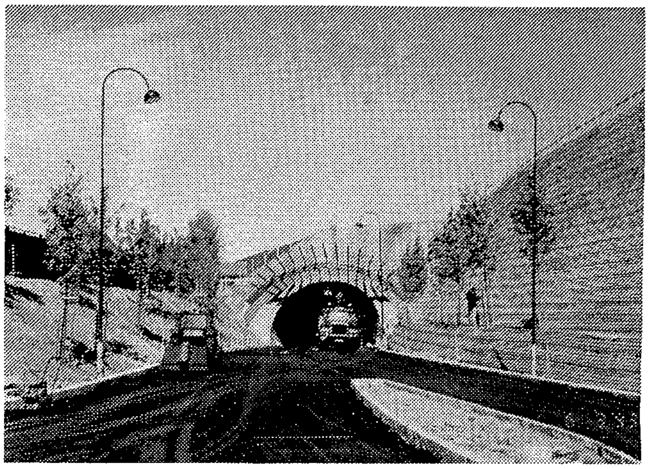

Fig. 6 Finished slope before vegetation

The vegetation in the first 1-2 months after construction consisted mainly of weeds with large parts without vegetation, see figure 7.

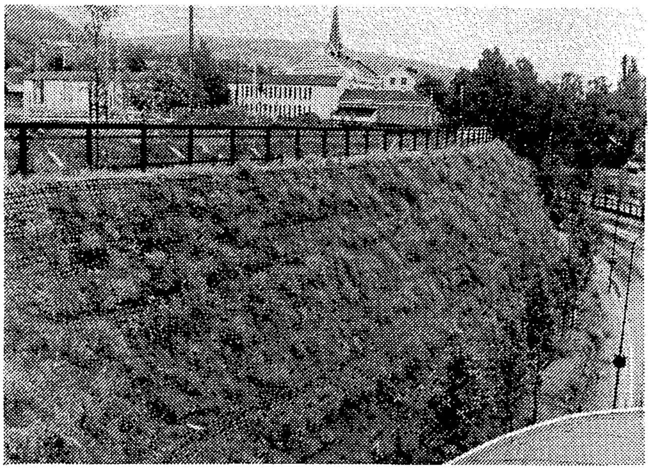

Fig. 7 Spread vegetation in the first 1-2 months.

The weeds were cut and later the vegetation gradually improved and became more even, see figure 8.

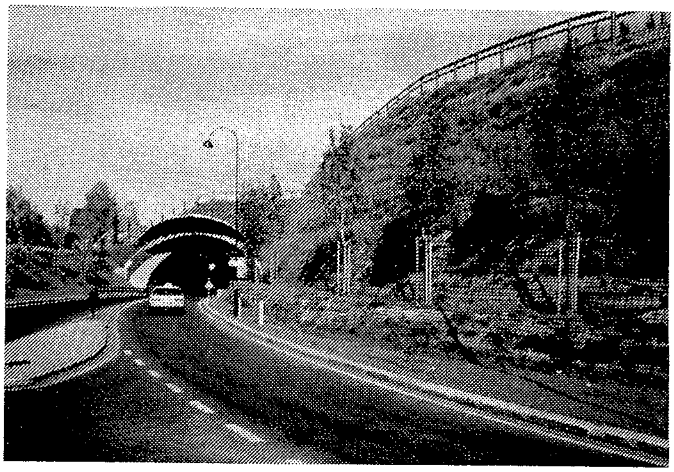

Fig.8 Vegetated slope

4. INSTRUMENTATION

The steep reinforced slope was instrumented with an inclinometer channel to measure horizontal deformation after construction and 6 thermistors to measure the temperature distribution in the front of the structure. The thermistors are placed 5 m below the top of the slope, and with horizontal spacing 0,5 m behind the front. The inclinometer channel is placed 3 m behind the facing of the slope.

4.1 Temperature measurements

The temperature measurements are shown in figure 9. The temperature within the reinforced soil follows an annual cyclical pattern.

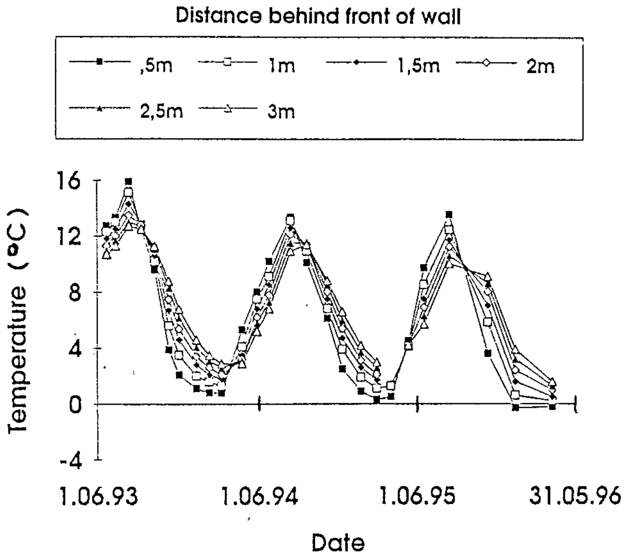

Fig. 9 Temperature measured in the soil in the reinforced structure

Field data has been collected for more than three years.

A maximum temperature of 16°C was measured in the summer 1993 and a minimum temperature of -0,5°C in the winter 1996.

In the summer the difference in temperature is about 4°C from 0,5 m to 3,0 m behind the front. The difference in temperature in the winter is about 3°C from 0,5 m to 3,0 m behind the front.

Long term temperature observations in a period of more than five years, were collected on a 12 m high reinforced soil wall with concrete panel facing, Vaslestad and Johansen (1996).

The temperature measured 0,4 m behind the concrete facing shows variations between -2°C and 16°C. Non-frost succebtible gravel is used in a zone 3 m behind the facing. This wall is situated in Gjøvik wich is in the same county as Lillehammer, with nearly the same air temperature.

Detailed observations of temperature in reinforced soil structures are rarely reported. This may be attributable to the fact that, over the usual temperature range associated with civil engineering structures, the stress-strain properties of steel reinforcements are not significantly affected. To ensure a satisfactory long-term performance of geotextile reinforcement, the properties employed in design must be based on reliable estimates of the temperature to which the material is subjected.

Allen et.al. (1992) published results of tensile tests and creep tests on geotextiles manufactured from polyester and from polypropylene. The tests reported were carried out at two fairly extreme values of temperature of -12°C and 22°C and indicated that the short-term tensile strengths differed by less than 20 percent over this temperature range. However, as regards creep behaviour the effect is much more significant and with some materials the rate of creep strain could be increased by 60 percent or more for a 10°C increase in temperature, Murray and Farrar (1988).

Generally all the polymers used for reinforcement in ground engineering exhibit decreasing ultimate load and increased strain with increased temperature, Murray and Farrar (1988).

4.2 Horizontal deformation

Horizontal deformations after end of construction are shown in figure 10.

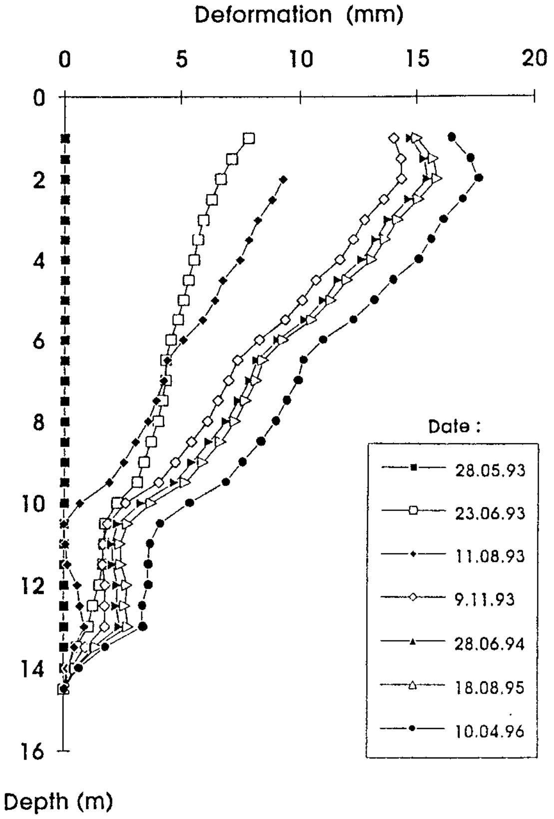

Fig. 10 Horizontal deformation after the end of construction

A maximum horizontal deformation of 18 mm is measured 1 m below the top of the wall.

The major part of the deformations in the top of the wall (14 mm) occur within the first 6 months after the end of construction, see figure 11.

The horizontal deformation also show an annual cyclical pattern as shown on figure 11.

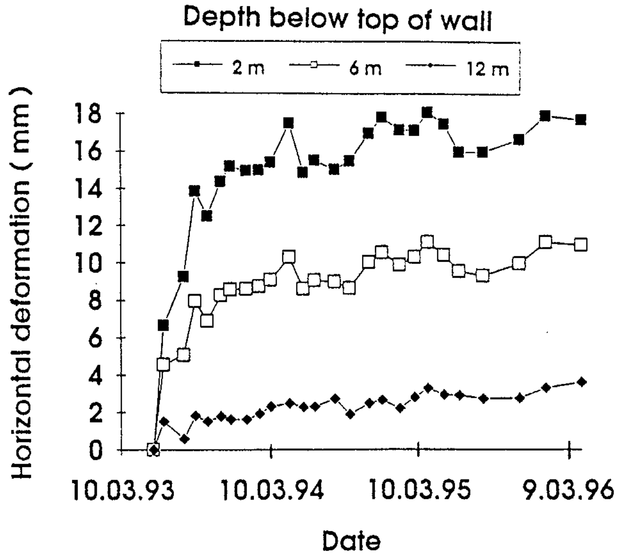

Fig. 11 Horizontal deformations, annual variation

The horisontal deformations are largest in the spring time (the thawing period) and smallest in the summer and autumn.

Earth pressure measurements on a 12 m high reinforced earth walls in the same county, showed increased horizontal earth pressure and decreased vertical earth pressure in the coldest period of the year, Vaslestad and Johansen (1996).

Measurement of long-term post-construction horizontal deformations were made on four reinforced earth walls in Norway, figure 12.

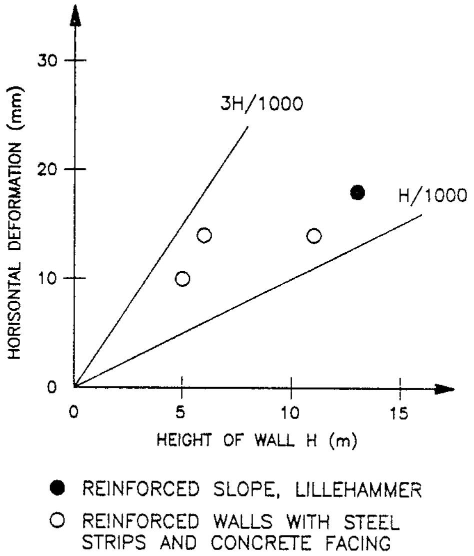

Fig. 12 Long-term post-construction horizontal deformations on reinforced earth walls in Norway

Fig. 12 shows that the long-term deformation of the reinforced slope and walls lies between H/1000 and 3H/1000.

5. CONCLUSIONS

The reinforced soil slope proved to be a very cost effective solution with a green faced, nice appearance and good damping effect regarding traffic noise compared to a concrete wall.

The long-term horizontal deformations are wellwithin acceptable limits.

In Norway we have not experienced any failures with reinforced walls or slopes used for road purposes. This may be attributed to the existing approval system within the Public Roads Administration for such structures.

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PHOTOGRAPHS FROM THE CONSTRUCTION PROCEDURE AND VEGETATION PROCESS

Fig. 1 Drainage layer of gravel before construction

Fig. 2 Steel mesh in the front with vegetation mat. Construction of the third lift

Fig. 3 Compaction of the silty, sandy gravel

Fig. 4 Construction of the 11. lift

Fig. 5 Fine grained vegetation soil including seed in the front (0,5 m thick)

Fig. 6. Terrace (2,5 m high) with trees

Fig. 7 Inclinometer installation on top of the reinforced slope

Fig. 8 Hydroseeding the slope

Fig. 9 Vegetation is coming

Fig. 10 Finished slope and asphalting the road

Fig. 11 Special tunnel portal of wood for the Olympic games, Lillehammer -94

Fig. 12 Vegetation proceeds

Fig. 13 Detail of the facing

Fig. 14 The vegetation process continues

Fig. 15 Green slope finished

Fig. 16 Vegetated green faced slope with yellow flowers