Valtellina 1987, the Val Pola Landslide

Nature and Cause of the Phenomenon, first Emergency Interventions, final Plan of Interventions

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During the summer of 1987, the Central Alps were hit by heavy rainfall that reached record levels in Valtellina, Val Camonica and Bergamo Valleys.

A comparison of these precipitations data with historical data showed that the phenomenon recurred every 100 years (Aquater 1987). Heavy rainfall (15th 19th July) caused floods and disasters along the whole valley; two weeks later (28th July) the Val Pola landslide, described in this paper, occurred. The landslide involved 35 million cubic meters of rock slope killing 27 people and destroying some villages (S. Antonio Morignone, Aquilone); thousands of people living in villages downstream from the slide were evacuated.

Geographical and geomorphological features

The area affected by the landslide is located in the northern part of Valtellina (SO), ten kilometres from the town of Bormio. The large landslide started from the eastern slope of M. Zandila, on the right side of the Adda river next to the Pola River. The body of the landslide covered the main valley from Verzedo to Tola villages along a stretch of more than 2.5 km..

The valley runs north-south and shows features of an alpine glacial valley with overlying fluvial morphology (Azzoni et al., 1992). Average mountain altitude is between 2,500 m. and 3,000 m. with the bottom of the valley at 1,000 m above sea level.

Glacial circles, truncated valleys, rock glaciers and Wurmian moraine deposits shape the landforms in the Val di Pola area (Agostoni et al., 1991). Glacial erosion caNed the valleys, forming steep topographic gradients, that are prone to instability. The recess of the Wurmian glaciers has unloaded the area. Consequent stress relaxation is testified by the „sakung" morphology of mountain ridges. Post-glacial morphology is dominated by talus slopes and stream erosion/deposition.

Mudflows and landslides from the glacial deposits are frequent, rockslides occur particularly in areas of intense tectonic deformation.

Morphological characters caused by an aborted paleoslide had been recognized before the collapse at an elevation of 2,300 m in the Val di Pola area. In particular, a circular crown scarp 700 m long marked by cataclastic rocks had been observed (Presbitero, p.c.).

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Geological Settings

Regional Geology

Upper Valtellina is located in the Austridic Domains and is bounded by the lines of Engadina and Tonale to the North and to the South, respectively.

Three major Ercynic units crop out (Fig. 1) (Agostoni et al., 1991):

- „Cristallino del Tonale" (CT) characterized by paragneiss with insertions of anphibolites, quartzite, ortogneiss and marbles.
- „Cristallino di Grosina " (CG) constituted by gneiss, granitic gneiss, micaceous shales an micaceous schists, paragneiss with levels of marbles (Notarpietro et al., 1978).
- „Gabbro di Sondalo" (GS) with associated gabbrodiorites, diorites (Potenza, 1973).

The landslide mainly involved diorite and gabbro outcrops belonging to the GS formation.

Structures

The lines of Engadina and Tonale strike NE and E. Rigid block tectonics controls the deformation in the area between these tvo structures (Bonsignore, 1969). The CG unit is thrusted over the CT on a low-angle northdipping fault. Cataclastic and mylonitic rocks mark the thrust plane. GS intrudes into the other units.

A set of NE trending regional faults is superposed to an older set which trends NW (Borgia et al., 1994). North trending faults form the youngest set and are related to the sakung: normal faults riming the ridges are accompanied by compressional structures at mountain foots (Forcella, 1984). In addition to these major structural trends, the landslide area is cut by faults that are antithetic to the sakung and that isolate secondary blocks.

Structural surveys carried out in the lanslide area (ISMES-Reg. Lombardia 1988) produced the following data:

	STRIKE	DIP	JRC	JCS
K1	50-70	45	7	110
K2	350	35-50	7.5	150
K3	100-150	35-50	8.5	110
K4	150-170	70-90	10	120
K5	350-20	65-90	10	120
K6	40-100	70-90	11	110

The Val die Pola Landslide

Account of the event

Between July 17th and 20th, the Valtellina basin received an average rainfall precipitation of 200 mm with maximum values of over 300 mm.. Temperatures were also high with freezing point between 3600 m and 4200 m for several days.

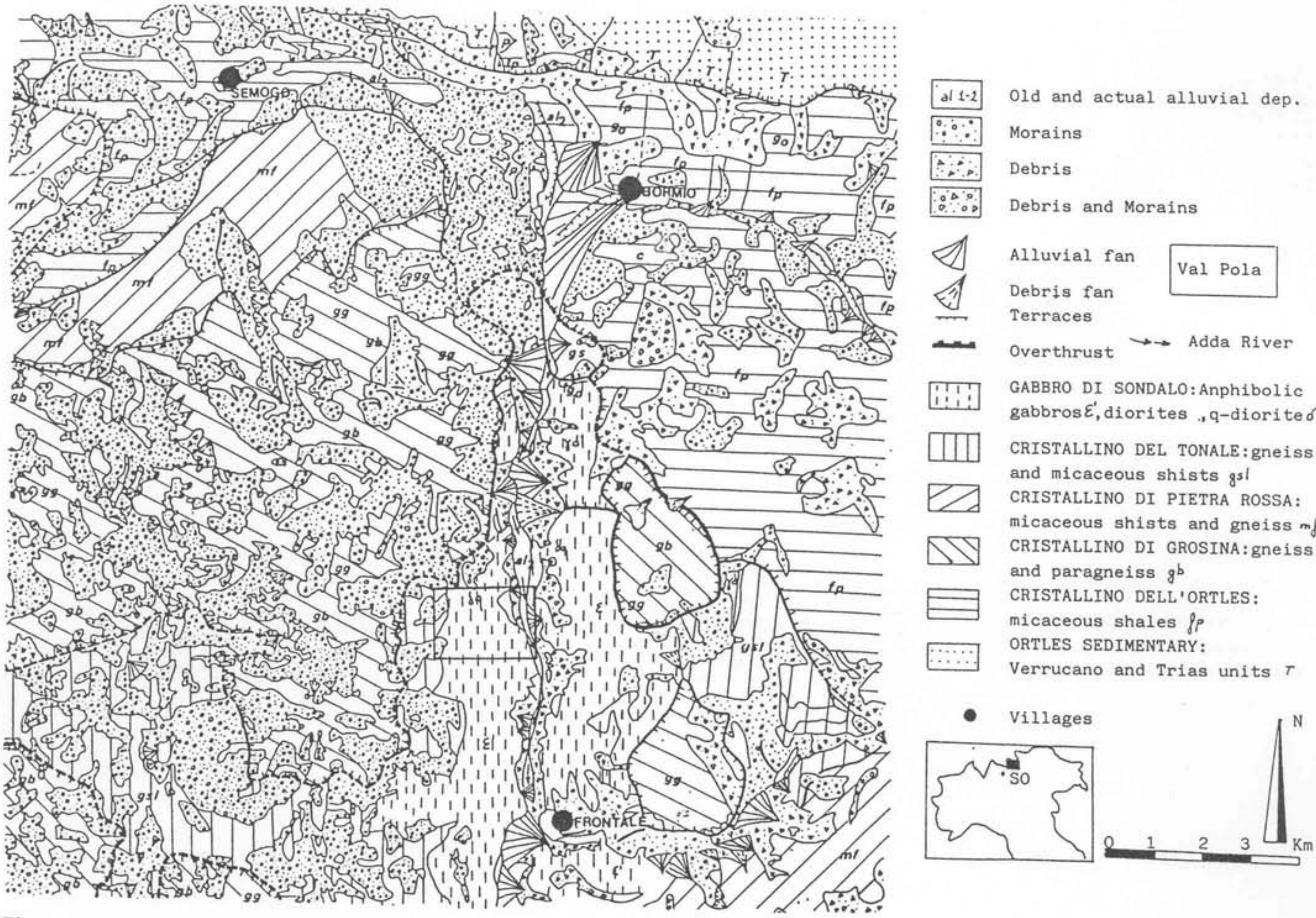

Figure 1 Geological map of Upper Valtellina.

Meteorological stations next to the slide area reported the following data: Arnoga 213 mm., Bormio 150 mm., Le Prese 131 mm., Cancano 125 mm (AEM data).

The first results of the heavy rainfall were the deep erosion of the Pola River and formation of a debris fan on the main valley bottom. The fan covered 60,000 sq. m. and dammed the Adda river. On July 28th a lake was formed behind the debris dam and reached a size of 266.000 sq. m..

Seven days later, while erosion of the Pola River increased, a 600 m. fracture was found near the paleoslide crown at 2,300 m.. In the following days the fracture reached a length of 1 km.. During the same period the frequency of local rockfalls increased.

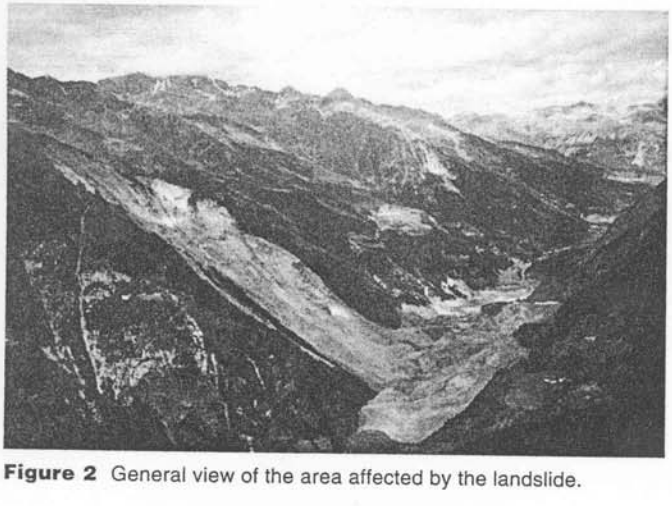

Figure 2 General view of the area affected by the landslide.

On July 28th early in the morning, 35 million cu. m. of rock collapsed, sliding along the two main joints (K1, K2). The huge rock mass moved north and hit the spur located beside the Pola River and then slid east generating a rock avalanche.

Below the change of gradient, located at 1,700 m., only superficial deposits were involved in the phenomena. The rock avalanche went up the opposite slope reaching an altitude of 1,350 m..

A wave of water and mud running up hill (North), was caused by the landslide impact on the lake formed by the Pola debrisflow. The villages of S. Antonio Morignone, Poz, Tirindre and part of Aquilone were swept away by the mud wave.

The whole area affected by the landslide (Fig. 2) was 5 sq. km., the debris being 2.5 km.. Iong and 90 m. thick (max).

Conditioning and triggering factors

Aerial photos taken before the landslide (1954-55, 1975, 1980-82, GAI, Regione Lombardia) showed a clear paleoslide niche. This structure was characterized by two major uninterrumpted joints (K1, K2) with wide extension, persistence and unfavourable dipping.

Heavy rainfall caused an increase of hydrostatic pressure in these deep fractures and decreased friction along joint surfaces.

Deep erosion of the Pola River decreased the contrasting thrust at the foot seriously affecting the equilibrium of the slope.

The first emergency interention

The experts on the „Valtellina Commission“, set up immediately by the Ministry of Civil Protection, were given the task of preventing further damage to persons and property and also that of dealing with the following three problems:
1. the conditions of stability of the landslide niche: knowledge of this was indispensable for accessing the landslide accumulation and the small lake that was forming above it and for rapidly carrying out the works needed to deal with the emergency;
2. the conditions of stabilitv of the landslide accumulation: although the dimensions (2,300 m. long and an average of 70 m. high and 200 m. wide) were such that it did not appear serious, it was subject to hydrostatic pressure that was increasing. Obviously the stability of the accumulation was tied to the granulometry and permeability of the detritus material and in the long term to its integrity when saturated and its resistance to erosion in the case of overflow;
3. drainage of the water, that was forming a lake above the landslide accumulation and which would soon have reached a volume of 18 million cu. m. of water.

The first problem was solved by creating a monitoring network based on topographical, strain, microseismic and optical measurement. This was designed and set up before 20th August 1987 (ISMES) solving the problem of access to the bottom of the valley.

The second problem was tackled in the first instance by simulating, on a mobile bed model, the overflow of the lake onto the landslide accumulation under variable conditions of granulometry and flow rate. The scale was 1:250 and it was created by CRIS ENEL in the record time of 10 days (Fig. 3).

The third problem was solved in the short term by setting up three pumping stations with a total flow rate of 13.5 m³/sec to draw off the water (CONDOTTE, AEM, SNAMPROGETTI) to deal with slight precipitations during August. An operation called „controlled overflow“ (using the results from the model created by CRIS-ENEL) to deal with heavy precipitation. It was also useful for testing the retaining power of the landslide accumulation.

General outline of the final project

Long term stabilisation of the landslide accumulation was accomplished with works to stabilise the lower face at an altitude of between 1,070 and 1,000 metres. This consisted of a system of arch shaped reinforcements with their foundations in ground improved by jetgrouting. The work was completed by April 1988 (CORVAR consortium consisting of the contractors: LODIGIANI, COGEFAR, CARIBONI and PIZZAROTTI) and also involved drainage of the accumulation with a new overflow channel.

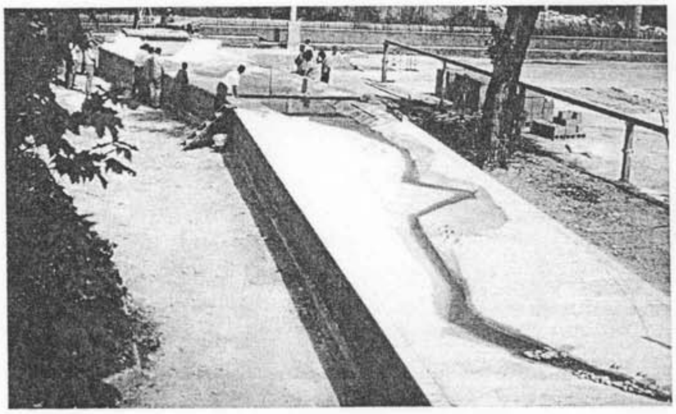

Figure 3 Simulating model for the „controlled overflow“ onto the landslide accumulation.

Permanent works for emptying of the lake formed by the landslide accumulation consisted of constructing two bypass tunnels (Fig 4) (one polycentric approximately 6.00 m. in diameter, the other circular with a diameter of 4.20 metres) with a total flow rate of 400 m³/sec to drain away

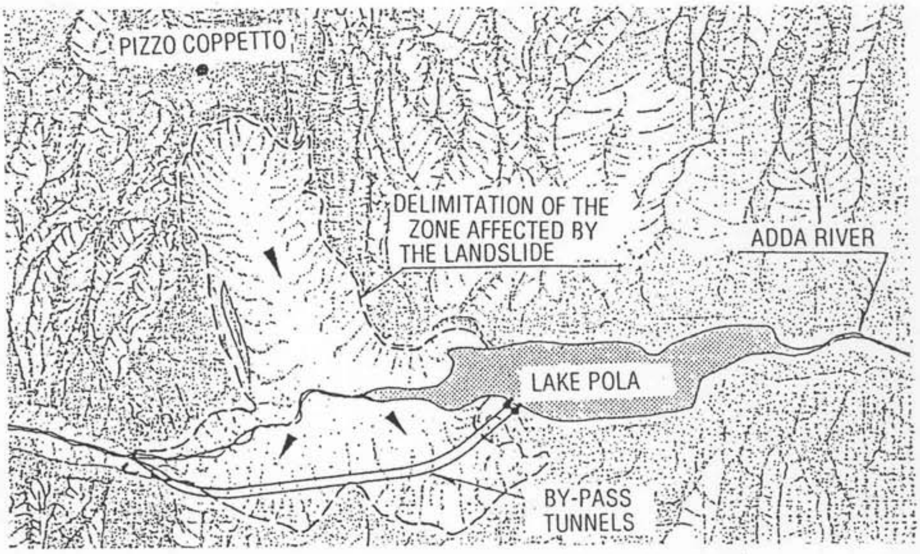

Figure 4 Chorography showing the planimetrical layout of the by-pass tunnels.

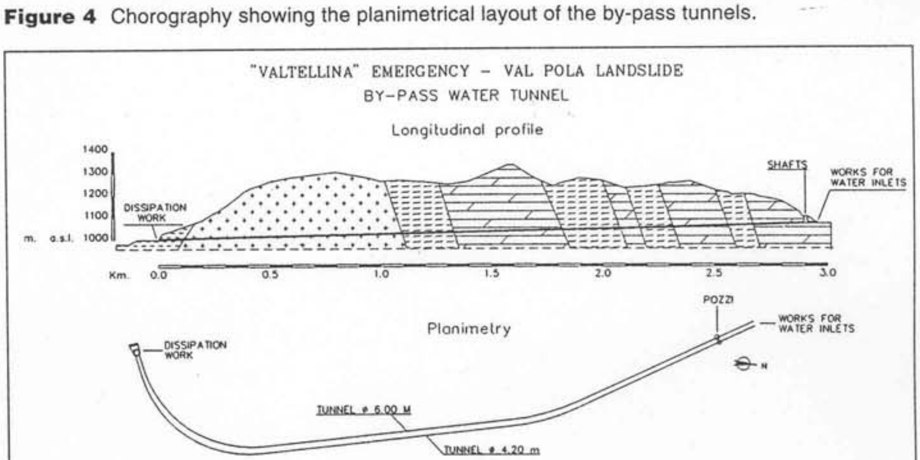

Figure 5 Geometrical and geological characteristics of the by-pass tunnels.

water from the bottom of the basin and guarantee control of flooding of the River Adda.

Construction of the tunnels, together with connected inlet and outlet works, was carried out in record time between November 1987 and April 1988 (a group of contractors: ITALSTRADE, TORRI, MAGRI and POSCIO). It guaranteed the safety from flooding, in relation to the Val Pola emergency, of the 25,000 people residing below the landslide. This was before the thaw and rains of Spring. Considering the importance of the tunnels to the overall project for making the area permanently safe, it was felt that a detailed description should be given. For brevity, the two tunnels will be referred to as 0 6.00 for the first and 0 4.20 for the second.

Both tunnels run side by side to the left of the river going down stream with the distance between centre lines varying between 20 and 30 metres. The length of ∅ 6.00 is approximately 2,854 m. and that of ∅ 4.20 is 2,898 m.

The geometry of the tunnels is shown in figures 4 and 5: the gradient is constant (i = 0.0252 for ∅ 6.00 and i = 0.0238 for ∅ 4.20) and the overburden varies between 200 and 300 m.

The works for the water inlet portals, for draining the water from the artificial lake that formed after the landslide, consisted of concrete structures fitted with a wide mesh grid the bottom of which is at an altitude of 1,078.00 m. for ∅ 6.00 and 1,075.00 m. for ∅ 4.20 (Fig. 6 and 7). This was completed by a 25 m. section of tunnel operating under pressure and running into a circular shaft with a diameter of about 15 m.

The top of the shaft for ∅ 4.20 is at an altitude of 11,107 m. while that for ∅ 6.00 is lower at an altitude of 1,094.50 m with a shaped profile so as to function as a spillway should the inlet tunnel become partially or totally blocked. At the bottom end of the underground tunnels there is a single section of artificial tunnel which diverges on the horizontal plane. It leads the water into a cylindrical shaft with an internal diameter of 25.00 m.. This functions as a dissipator before the water is allowed into the final outlet channel that returns the water into the River Adda (Fig. 8).

All the works were designed to ensure maximum hydraulic efficiency. In the shafts at the top end, the underground tunnels are preceded by shaped channels to ensure open channel flow in the tunnels. The dissipator shaft at the bottom end has openings in the bottom to catch any

Figure 6 View of up-hill works for water inlets.

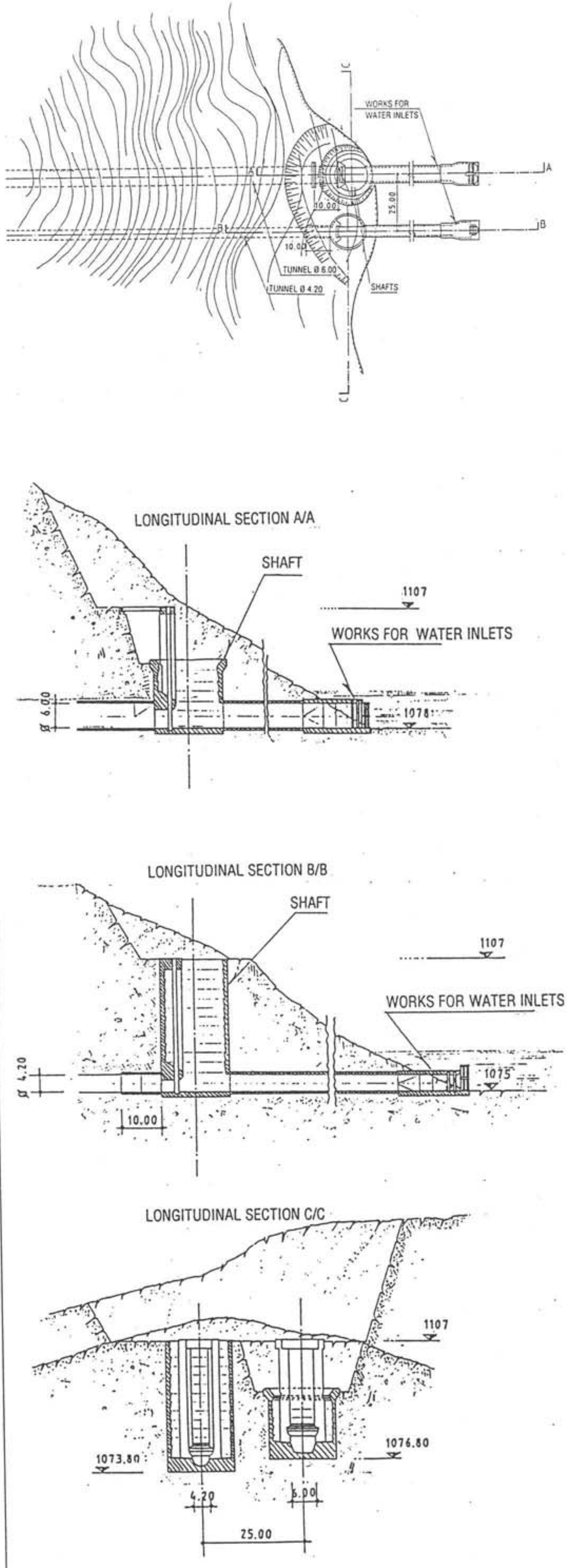

Figure 7 Horizontal and vertical sections of up-hill works for water inlets.

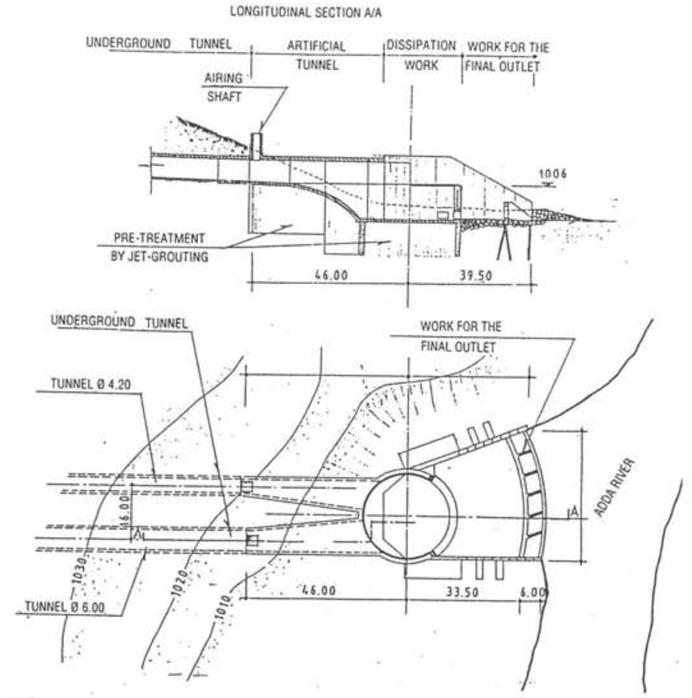

Figure 8 Horizontal and vertical sections of down-dale works.

material transported by the water and to ensure that the flow rate of the water is suitably slowed before it is returned to the River Adda.

Experimental testing of the entire project was carried out before work commenced using a hydraulic model. Given the phenomena to be investigated it was decided to construct a model based on Froude numbers to a scale of 1:40 using various materials according to the structure concerned: steel, plastics and wood.

A flow rate of 50 l/sec was employed to feed the model corresponding to a real maximum flow rate of 500 m³/sec. The functioning of each individual component (the dissipator, the inlets and shafts, tunnels, outlet channels) was tested for different flow rates. This meant that the whole system could be calibrated and adjustments made to ensure optimum efficiency.

Construction and operational aspects

The project for the diversion of the waters of the River Adda in the proximity of the Val Pola landslide involved (moving downstream) the following works:
works for water inlets and access shafts;
underground water tunnels;
artificial connecting tunnel;
dissipation works;
works for the final outlet.

The emergency nature of the works to be carried out meant that personnel were continuously employed on three shifts, seven days a week.

Work began in October 1987 with the construction of the access shafts upstream consisting of underpinning with reinforced concrete rings approximately 2 m. in height (Fig. 9).

At the same time work began at the bottom end on preparing the adits for the two by-pass tunnels and the foundations for the artificial connecting tunnel, the dissipator and the final outlet channel (Fig. 10).

Figure 5 shows a longitudinal profile of the route of the tunnels with the main lithotypes encountered.

Figure 9 General view of the up-hill access shafts.

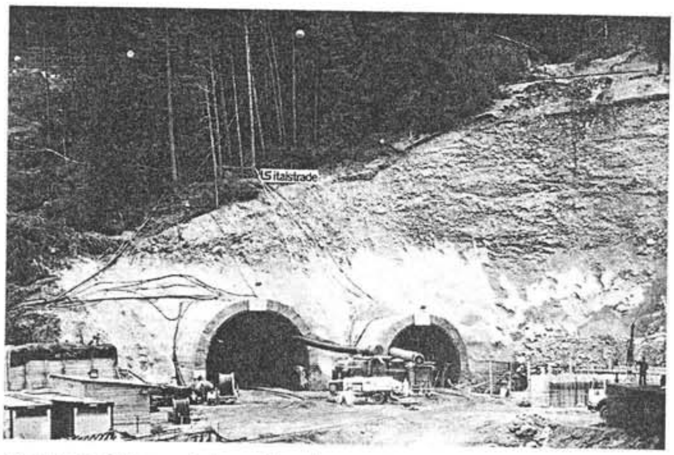

Figure 10 General view of the down-dale adits of the by-pass tunnels.

With the adits at the bottom end, resort to mechanical means of advance was needed to get through the first section (170 m. approx.) of detritus over the bedrock. An arch of improved ground had to be created in advance over the crown.

Confinement ahead of the face was effected using horizontal jet grouting to create columns of improved ground, 10 m in length reinforced with steel tubes.

Once the detritus deposits had been tunnelled, the consortium responsible for the works considered the need to have at least one of the two tunnels operational before the Spring thaws (so as to be able to control possible river floods). Given the good geomechanical characteristics of the rock mass of the route, it was decided to continue tunnel advance using two full face continuous TBMs: a 4 m. diameter WIRTH TBS IIE and a 3.00 m. diameter WIRTH TB IE, both equipped with instruments for monitoring functioning and advance parameters essential for calculating the strength of the rock mass according to the „RS Method" (Lunardi 1986).

The circular ∅ 4.20 tunnel was excavated full face with the first TBM while a pilot tunnel for the ∅ 6.00 was driven along the centre line. This was subsequently widened using explosives. At the same time, to speed completion times, once the shafts were finished at the top end, excavation began downstream towards the TBMs coming up (Fig. 11). In this case traditional advance methods were used employing rounds of explosive with „pulls" of approximately 4 m.. With this method, 370 m. of ∅ 4.20 and 185 m. of ∅ 6.00 were driven.

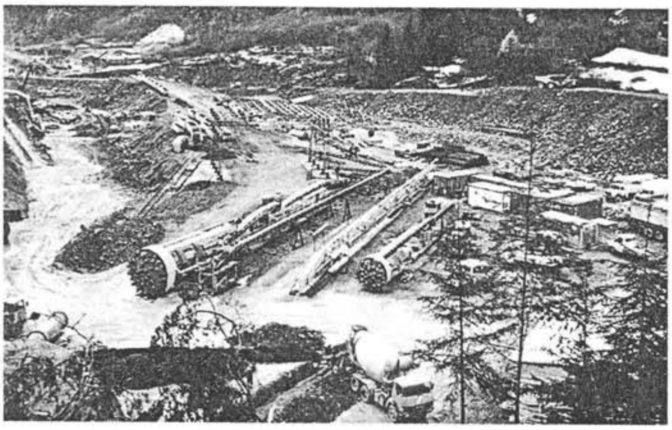

Figure 11 The two TBMs during assembling.

Figure 12 Tunnel profile obtained using blast advancing.

Figure 13 Tunnel profile obtained using TBM advancing.

Figures 12 and 13 show the difference between the profiles obtained using traditional advance methods and those obtained using TBMs. The lesser degree of disturbance caused to the rock mass by the TBMs translates into much less overbreak, while blasting intensifies existing fracture systems in the rock mass favouring the formation of substantial overbreaks.

Before the tunnels were put into service linings were applied to those sections where particular fracture systems and the chemical and physical characteristics of the matrix, the rock mass and the material used for filling fractures made it advisable. this was to protect the surface of the excavation and ensure that the structures functioned properly with water flowing.

In those sections where confinement had been needed during excavation with the TBMs, the armouring already in place was added to with full length anchor bolts (number = 8, length = 2.50, spacing = 1.50 m.) cemented with non-shrink mortar. Finally an 8 cm layer of shotcrete reinforced with electrically welded steel mesh was applied to the „wetted perimeter". On the other sections only full length roof bolts (number = 6, length = 2.50, spacing = 2.00) and a 5 cm layer of shotcrete reinforced with electrically welded steel mesh was applied.

The first type of final confinement was implemented on a total of approximately 195 m of tunnel and the second on 180 m.

Conclusions

The intense precipitation that occurred during the month (more than 200 mm on average in the River Adda catchment area) gave rise to the immense landslide (more than 35 million cu. m. of rock) that hit the Valtellina on the moming of 28th July 1987.

The rain caused both an increase in the hydrostatic pressure along the discontinuity surfaces of a large palaeolandslip and deep erosion of the bed of the Pola River. The result was a considerable decrease in the contrasting force at the foot of the slope seriously disturbing its equilibrium.

Firstly, a series of emergency operations were carried out including the operation of „controlled overflow" of the lake that was forming dangerously above the landslide accumulation. A plan for a permanent solution to the problem was then implemented in record time. This included the construction and commissioning of two by-pass water tunnels (more than 5.5 kilometres of excavation), with a flow rate of approximately 400 m³/sec., to drain the basin before the Spring thaws and ensure that the flooding of the River Adda could be controlled. The result was a final solution to the problem of the safety of the people residing below the Val Pola landslide.

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