WATER SEALING OF FAULT ZONES AT PING LIN PILOT TUNNEL IN TAIWAN

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ABSTRACT

The paper deals with the great success of STG's High clay Technology in Taiwan in water sealing of 150 l/sec inflow from fault zones between Station 39K + 083 and Station 39K + 075 of Ping Lin Pilot tunnel in the beginning 1997. For sealing of high pressure water inflows the calculated quantity of bentonite-cement grout and simple drilling and grouting equipment were used. All drilling and grouting supplies was provided by Taiwanian RET-SER Agency under supervising of STG and MK specialists. The actual information on the results of production introduction of this example is presented.

The paper also presents the comments of attempts of different companies to eliminate this water inflow in Ping Lin Pilot Tunnel during 1996 using conventional cement and chemical methods.

BACKGROUND INFORMATION

The Pinl Lin 12,9 km long Tunnel is the longest tunnel in Southeast Asia and the most critical project in Taipei-Ilan Expressway, Figure 1. The excavation of Pilot Tunnel has been started in July 1991 from the eastern end, where it was commenced with a drill and blast section. After this initial section the Robbins TBM was brought in to commence the excavation. Now the tunnel is about 2 kilometers away from starting point. It comes through the rock formations on the northern tip of the Central Range of Taiwan in active seismic zone. The tectonic and hydrologic conditions along the alignment of the tunnel are very complicated.

Ping Lin Tunnel are includes East Bound Tunnel and West Bound Tunnel with diameter 11,74 meters each and Pilot Tunnel with 4,87 meters, Figure 2. Pilot tunnel was excavated by Robbins TBM, Main Tunnels was excavated by Wirth TBM.

In the February 1996 the Ping Lin Pilot Tunnel had passed the beginning of the 1800 meters of fragmental zone consists from large quantity of faults. Ass a result the geologic fault with 150 liters per second of high pressure water inflow have trapped Robbins TBM inside Station 39K+079.42 of Pilot Tunnel, Figure 3.

For one year different contractors from France Taiwan and USA tryed to suppress this water inflow from face and bypass A and bypass C of Pilot Tunnel, Figure 3. They used cement and chemical grouting, but failed to reduce it. During 1996 about 5 millions tons of water have come out of Ping Lin Pilot Tunnel that negatively influenced local Environment.

GEOLOGY AND HYDROLOGY

The Ping Lin Tunnel is located in the rocks of the Central geologic province. These rock formations are slightly metamorfosed sedimentary rocks that had been folded and faulted. The major faults along the tunnel alignment are presented Figure 2. Maximum cap rock cover is in excess of 700 meters along the Ping Lin Tunnel.

Rock formations penetrated by the tunnel in East - West direction are: the Szeleng Sandstone, the Kankow, Tsuku Sandstone, Tatungshan, Makang and the Fangchiao Formations. In the Western part of the tunnel the main lithologies comprise sandstone, shale and sandstone and shale alternations. The eastern end of the tunnel is comprised mainly of argillite and quartz sandstone. The rockmass of this formation is densely traversed by many shear waterbearing fractures and appears to be fragmented.

Argillite is assumed to be slightly metamorphosed silty mudstone. Rocks of this section had been subjected by strong tectonic action. The rockmass is intensely sheared and closely fractured. The angles of inclination of fractures are vary greatly. These fractures mostly are several tens of centimeters wide and do not exceed one meter, they frequently continue for several tens of meters, rendering the rockmass intensely fractured. Groundwater inflows in these rockmasses occur in are highly variable amounts. Coefficient of Permeability of argillite varies between 10-5 cm/sec and 10-6 cm/sec.

The Szeleng sandstone is mainly constituted of quartz sandstone with well developed joints that vary greatly in their attitudes. Shear zones mostly strike in an North East direction and intersect the tunnel alignment in an oblique small angle. These joints are wider, however, and may locally reach 5 to 10 meters wide. The above enumerated fault occurred in the section between station 39K+083 and 39K+075. In this section the material is a fault breccia with fault gouge. Hydrostatic pressure in this section is 14 bars. Groundwater inflow from this fault was 120-150 liters per second. Coefficient of permeability of fragmental sandstone varies between 10-3 cm/sec and 10-4 cm/sec. A preliminary estimation of long-term inflow based on simple assumptions has been made by the basic design consultant. The results show that the total amount of groundwater inflow into the 12,9 km long tunnel is about 180.000l/min or 3,000 l/sec. But it needs to be mentioned that the initial inflow rate near the tunnel face would be much higher than the long-term inflow. When a waterbearing zone is encountered by the excavation the inflow could increase significantly for a few days and later decrease gradually until the flow reaches a stable condition. A maximum high water inflows in fractured and fault zones were assumed to be between 1,000 l/sec and 2,000 l/sec.

INTRODUCTION

For watersealing and consolidation grouting of Ping Lin Pilot Tunnel in complicated hydrological and seismic terms the conventional cement and chemical grouting was accepted. During excavation of Pilot Tunnel there were ten collapses. To over come each collapse it was needed several months to free TBM. For water sealing and consolidation grouting the cement grout with Cement-Water ratio 1:5 to 1:1 and with adding of sodium silicate was used.

In case of 10th collapse at Station 39K+079.42 of Pilot Tunnel to eleminate the critical situation also the conventional cement and chemical methods were used for one year. But all attempts of different companies were unsuccessful.

In the beginning of 1997 Client of Ping Lin Project has accepted the MK/STG Joint Venture Bentonite-Cement Grouting Proposal for watersealing of water inflows from mentioned above zone of Pilot Tunnel.

APPLICATION OF THE STG GROUTING TECHNOLOGY

Ukrainian state agency called Spetstamponazhgeologia (STG) has developed a kaolin or illite clay-based grouting technology for groundwater flow control in vertical shafts and underground installations The STG grouting technology has been proven effective in dramatically reducing permeability in granular or porous media and in fractured rock media. It has been very successfully used in many applications dealing with soils and unconsolidated rock for creation of barriers to the movement of chemically contaminated, acidic, saline or radioactively hazardous liquid materials. Over the last 30 years STG has successfully completed over 400 large to medium to small scale grouting projects using its technology in the Ukraine, Russia and Eastern Block countries, as well as USA, India and Taiwan. Most of this projects were performed to control groundwater inflow into underground installations. STG has also applied this grouting technology to other problem areas such as waste isolation and water pollution control projects.

STG has also modified its grout injection technology to be able to construct slurry wall barriers. The key elements in the STG grouting technology revolve around grout composition, geologic, geochemical and hydrogeologic characterization and analyses of the soil and/or rock, and an integrated design procedure. Currently, the grout composition runs approximately 90 percent natural local clay, 9 percent cement or fly-ash and one percent special additives. The STG grout formulation and its application are customized for each project and the entire process is integrated, based on the nature of the problem, the objective of the application, and the detailed site specific information on geology, geochemistry and hydrogeology of the host ground.

The natural clay portion of the grout can be obtained from nearly any source which is available in the vicinity of the construction site. This has significant economic advantages as well because the transportation of the clay is not a high cost factor. Another important feature is that the STG clay-based grout remains plastic and unpermeable throughout its history.

STG has laboratory samples which were cast over 35 years ago and which still exhibit the same qualities of flexibility and durability which they initially displayed. The grout mateerial is also inert and non-toxic which will allow it to be used in environmentally sensitive applications.

Applications of the STG grouting technology include the sealing of underground trench to preclude generation of hazards drainage, to containment of chemically-contaminated soils, liquids and sludges, to stabilizing and isolating radoiactive and toxic wastes in geologic media. Same of the more common problems encountered with high-cement grouts are avoided, such as breaking down under acid or basic environments and cracking due to ground movement. The low cement content of STG's normal grouting formulation creates a barrier which is less susceptible to cracking, enables the grout to remain plastic, and allows the use of special additives for corrosive or radioactive situations. Additionally, the STG high clay grout would be chemically resistant to the contaminants, virtually impermeable to contaminant outflow and long-lasting even under corrosion conditions.

INTEGRATION

MK/STG Proposal planned to eliminate 120-150 l/sec water inflow in Pilot Tunnel from geological fault in three Stages, Figure 3.

First Stage - elimination of 50-60 l/sec water inflow from By-Pass C through holes No. 1 and No. 2 with length 35 and 30 meters and diameter 76 mm.

Second Stage - elimination of 20-30 l/sec water inflow around cutter-head of TBM Robbins through hole No. 3 with length 18 meters.

Third Stage - elimination of 50-60 l/sec water inflow from By-Pass A trough two holes with length 20 and 25 meters.

The practical results of implementation of 1st and 2nd stages are summarized in Table 1.

Details of 1st and 2nd Stages of Bentonite-Cement Grouting
(injection from Pilot Tunnel at Station 39K+114 and 39K+095)

Table 1

Stage Number	Number of Grout holes	Grout Hole length (metres)	Angle (degrees)	Azimuth (degrees)	Stand-pipe Length (metres)	Grout Volume (cubic metres)	Final Injection Pressure (Bars)
1st	1	35	+10	-75	4.5	121	40-50
	2	30	+20	-55	4.5	246	50-60
2nd	3	18	+5	-25	9.0	225	60-70
Total Volume						592	

After injection of calculated volume of bentonite-cement grout in holes from 1 through 3 water inflows from By-Pass C and above of TBM cutter head decreased to zero and from By-Pass A reduced to 40 liters per second. The realization of 3rd stage of watersealing was stopped by Taiwanian side. It was done to provide water depression of the site of excavation of future West Bound Tunnel. All drilling and grouting work at this zone of Pilot Tunnel were performed by RET-SER Engineering Agency in accordance with STG calculations and under MK/STG management.

CONCLUSION

It is necessary to admit that while developing the Ping Lin Tunnel design, plans and specifications not all the geological and seismic terms were taking into account. As a result the application of conventional cement and chemical grouting did not provide the planning rate of excavation of Ping Lin Tunnel and their Shaft No. 3.

From the other side successful experience of application STG High clay grout Technology for treatment of fault zone of 10th collapse in Ping Lin Pilot Tunnel proved that for reliable watersealing of fractured, fragmental and fault zones it is more effective for Ping Lin Tunnel Project to use high clay-cement or high bentonite-cement grouts.

In zone of bentonite-cement watersealing RET-SER Engineering Agency excavated eastern detour tunnel behind the site where have trapped TBM. After avoiding difficult fragmental section, the detoured tunnei will be merged back to the original Pilot Tunnel. Water inflow in bentonite-cement grouted zone during excavation of detour tunnel was only one liter per second. All fractures with aperture from 0.2 mm to 5-10 cm with bentonite-cement grout was sealed.

Reference

1. Summary report geology & TBM operation Ping Pilot Tunnel.
2. Experts' Suggestion on Ping Lin Tunnel. February 24, 1995, China Times News.

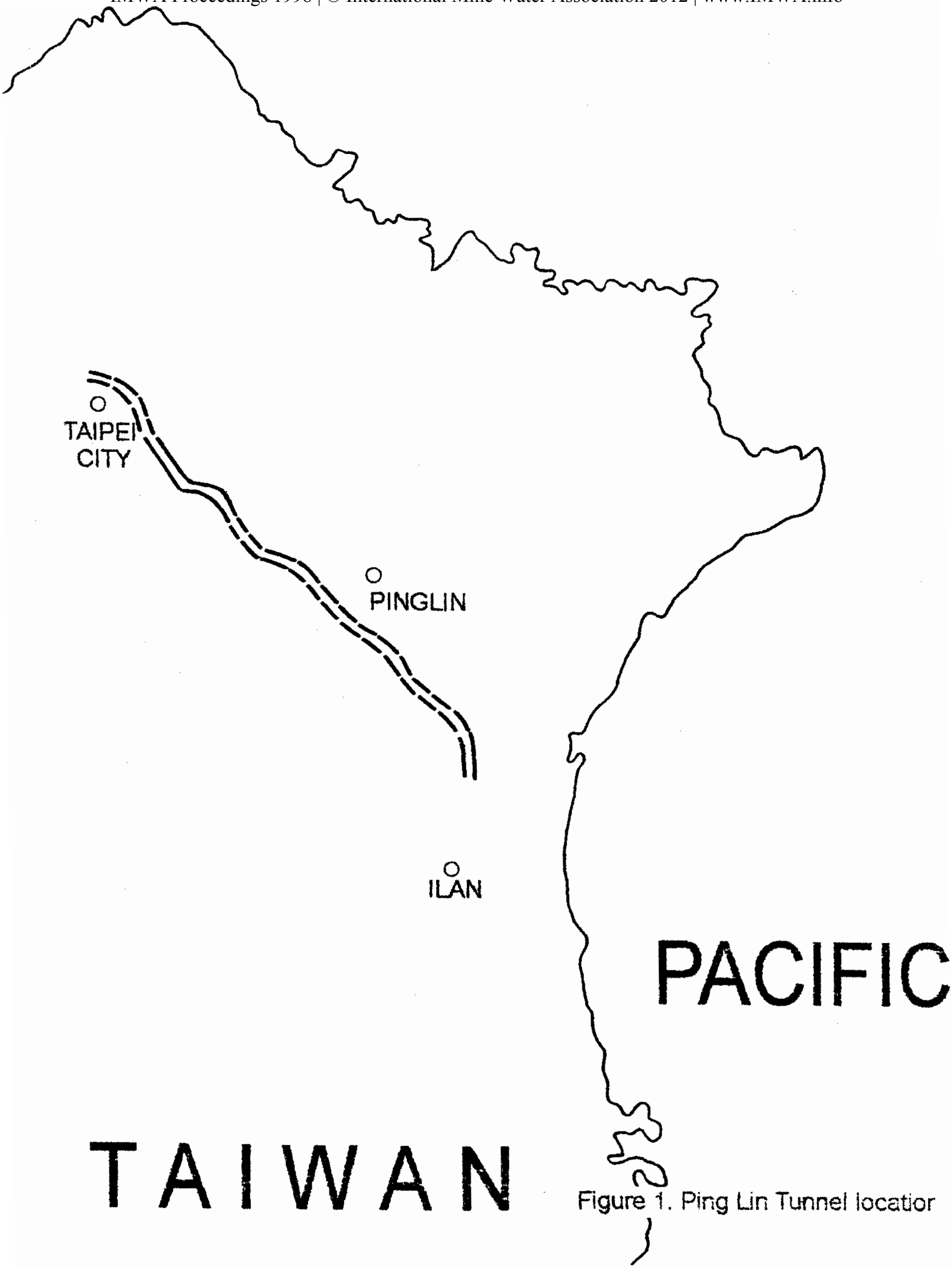

Figure 1. Ping Lin Tunnel locatior

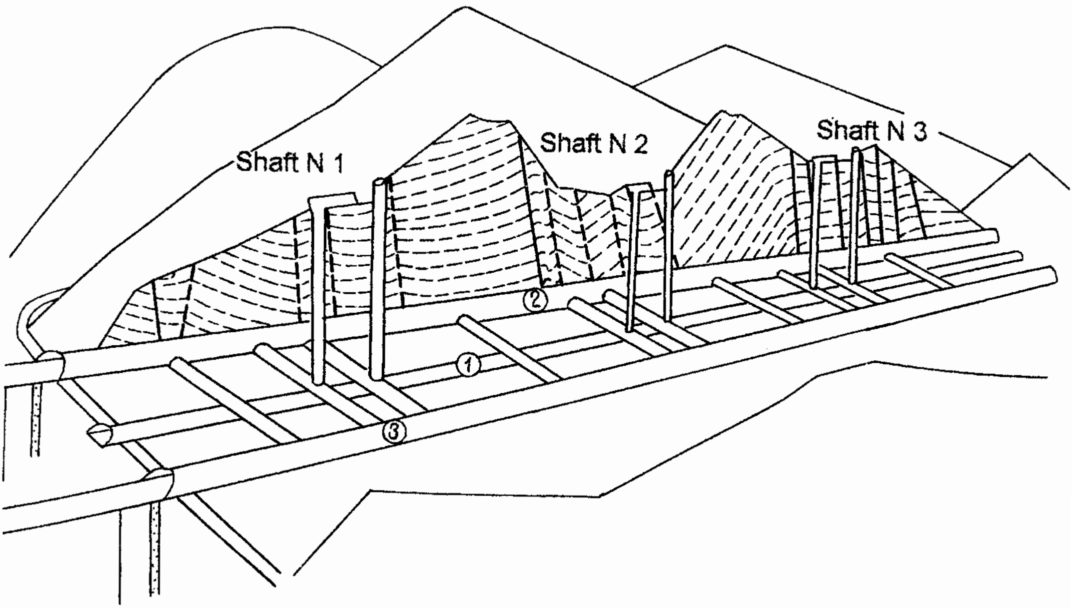

Figure 2. Excavation System and Geological cross-section of Ping Lin Tunnel
1 - Pilot Tunnel
2 - West Bound Tunnel
3 - East Bound Tunel

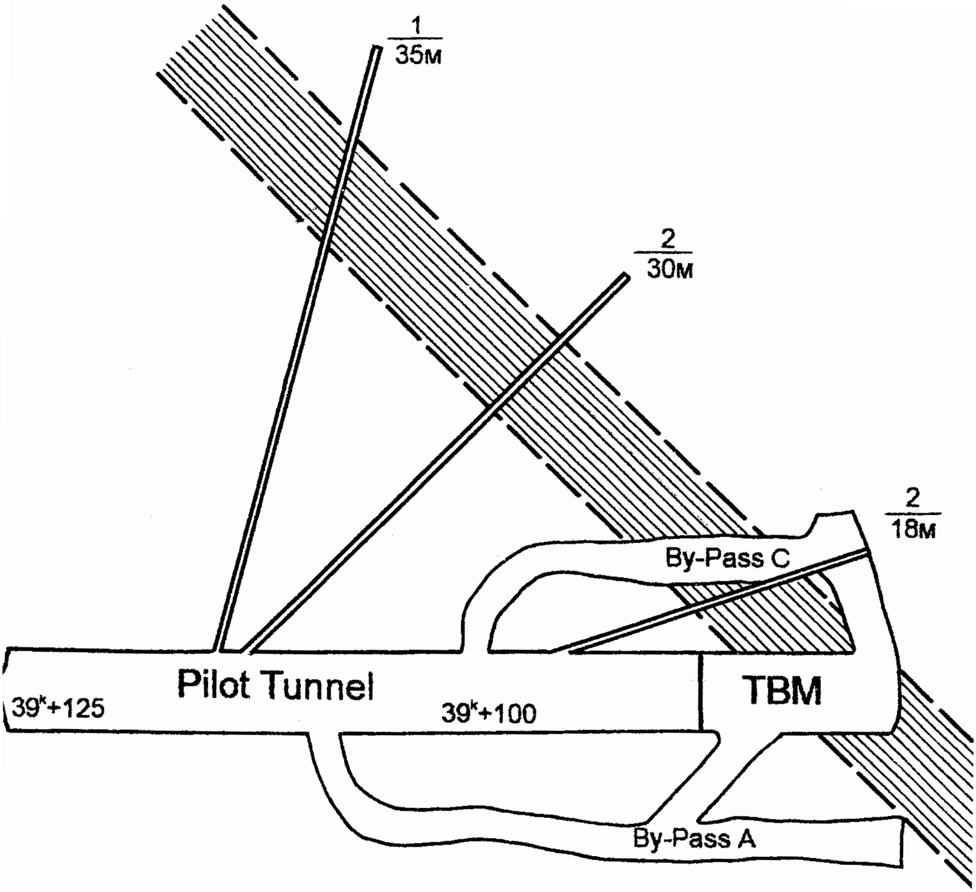

Figure 3. Arrangament of grout holes at Pilot tunnel