Air leakage through underground ventilation stoppings and *in situ* assessment of air leakage characteristics of remote filled cement concrete plug by tracer gas technique

by A.K. Singh*, I. Ahmad*, N. Sahay*, N.K. Varma*, and V.K. Singh*

Synopsis

Between the main fan and the coalface in a mine a lot of air is lost through leakage at stoppings, doors, air-crossing etc. so that a much larger quantity of air has to be circulated by the fan in order that the stipulated quantity of air reaches the face. Stoppings are of vital importance not only for effective ventilation of underground mines but also for isolation of areas affected by fire or susceptible to spontaneous heating. Generally, isolation stoppings are made of brick in cement mortar. If the area is far from the pit or unapproachable, it is very difficult and sometimes impossible to build these stoppings. To overcome these difficulties, particularly near fire affected zones, an alternate successful attempt was made in Indian mines to make a plug underground, from surface through borehole, using cement concrete.

In this paper the salient features of the methodology adopted for construction of the plug and the experimental procedure for the measurement of air leakage by SF6 tracer gas is described. Measurements of air leakage through rows of ventilation stoppings in two mines viz. Moira (Jambad and Kajora seams) and Kuardi 11/12 (Niga seam) collieries of Eastern Coalfields Ltd. (ECL) have been incorporated. Results of experiments conducted at the Central Mining Research Institute (C.M.R.I) to determine leakage through 25 and 38 cm thick brick stoppings are also discussed. Results of all these studies are compared, which show that the efficacy and reliability of the remote filled cement concrete plug in respect of air permeability is satisfactory.

Introduction

The amount of leakage of air through a single stopping measured by the brattice window method[1] and tracer gas technique[2] has been found to be very low and its effect on a ventilation network is negligible. But the cumulative effect of a row of stoppings separating main intake and return may be quite significant. The calculation of air-flow distribution, even in a simple series parallel circuit involving leakage, is very tedious, particularly if the number of cross-cut galleries having stoppings is large. For this purpose an iteractive calculation procedure and a computer program STOPLEAK[3] were developed and used.

In underground coal mines it is vitally important to maintain a safe and productive working environment. During the normal course of underground coal mining, stoppings are provided/required at suitable locations to enable mine air to follow its prescribed course. Stoppings are also necessary to seal off abandoned areas and to isolate fire zones or areas susceptible to spontaneous combustion; the mine seals therefore are of significant importance. The seals thus should be in a position to:

- ➤ Control the gas-air exchanges between the sealed and open areas to prevent toxic and/or flammable gases from a sealed-off area entering the active workings
- ➤ Withstand normal strata load and explosion if initiated and prevent its propagation to the other side and
- ➤ Possess flame retardant properties.

However, all the above properties are not essential in each seal constructed in a mine e.g. a ventilation seal/stopping may not have the mechanical strength to withstand an explosion. Therefore, a seal must be examined, keeping in mind the purpose for which it has been designed. A number of existing and new alternative developments are available for construction of seals in mines[4–5]. In the Indian mining industry, however, until recently, seal construction using brick and cement/mud mortar was common.

With the increase in the extent of our mines, however, the conventional techniques of constructing stoppings are becoming rather difficult and uneconomical. In fact, some places in mines close to fires affected zones may not be easily approachable, thus the construction of conventional types of stoppings from underground at these locations is very difficult, full of risk, and at times impossible.

* *Central Mining Research Institute, Dhanbad, India.*

 Paper received Aug. 2003; revised paper received Dec. 2003.

In a coalmine in central India a similar problem was faced by the management. To check the advance of fire and to prevent its spreading into other areas, it was decided to isolate the fire by building a series of isolation stoppings. However, the area was not approachable. Therefore, it was decided to construct special seals, all along the affected zone, from surface through to boreholes. For this purpose a remote filling method i.e. pouring cement concrete through boreholes drilled from the surface was adopted. Before undertaking large-scale construction of these plugs around the fire area, one such plug of 2.5 m thickness at the roof level was constructed in an easily approachable area of the mine and *in situ* studies were undertaken to determine its efficacy in respect of air leakage.

Despite the proven fact that a certain degree of air leakage does exist in almost every type of stopping, there is no prescribed limit for the maximum permissible value of air leakage through various types of stoppings. Studies were conducted at the Central Mining Research Institute (CMRI) to determine the leakage of air through 25 cm and 38 cm thick brick stoppings plastered with cement and sand mortar (ratio 1:4) at various pressures[6]. These observations are shown in Table III.

From the results of the above experiments it was calculated that leakage of air at 140 Pa pressure through 25 cm and 38 cm thick brick stoppings, plastered with cement and sand mortar (Ratio 1:4) would be 0.00476 and 0.00361 m^3/s respectively. The cross-section area of the stopping was 13.41 m^2.

In the present work, the air leakage through a row of stoppings has been determined by conventional methods in two mines viz. The Moira and Kuardi collieries of Eastern Coalfields Ltd. (ECL). This paper also briefly deals with the methodology adopted by mine management for constructing cement concrete plugs from the surface. Experimental procedure, the results of the *in situ* investigation to determine the air leakage characteristics of the cement plug, and comparison of the results with the laboratory studiesare also discussed.

Method of construction of the cement concrete plug from surface

The average height and width of the gallery selected for construction of the experimental cement concrete plug were 2.98 and 4.5 m respectively. The method of constructing the cement concrete plug adopted by the mine management is briefly discussed below.

Two rows of 160 mm diameter holes were drilled from the surface at a spacing of 2.5 m (distance between the rows) across the width of the gallery. Spacing between holes in a row was 0.9 m and five such holes were drilled in a row. Three holes were also drilled in between these two rows. Figure 1 shows the cement concrete plug and position of the boreholes. The layout of holes drilled is shown in Figure 1. The depth of the holes was 30 m.

Initially dry stone chips of 40–50 mm size were packed to form barriers up to about 1 meter height in the gallery using 10 side holes. After forming the barriers with the help of stone chips, column grouting through the 3 middle holes was done by pouring cement and sand mixture in the ratio of 1:1.5 in the gallery through 50 mm diameter pipes introduced through these drilled holes. After this the pipe in the central hole was raised and stone chips were again poured through the side holes to extend the height of the barriers (the barriers were then 2 m from the floor). Again a cement–sand mixture was poured through the pipe in the central hole for column grouting up to 2 m from the floor.

In this way, the gallery was plugged to its full height in stages. Subsequently all 13 holes (10 side and 3 central holes) were plugged. In the second stage, 2 to 4 holes of 50 mm diameter were drilled in the gallery through which neat cement was injected under pressure to seal off leakage points/gaps, if any, left in the gallery around the plug, including cracks in the roof.

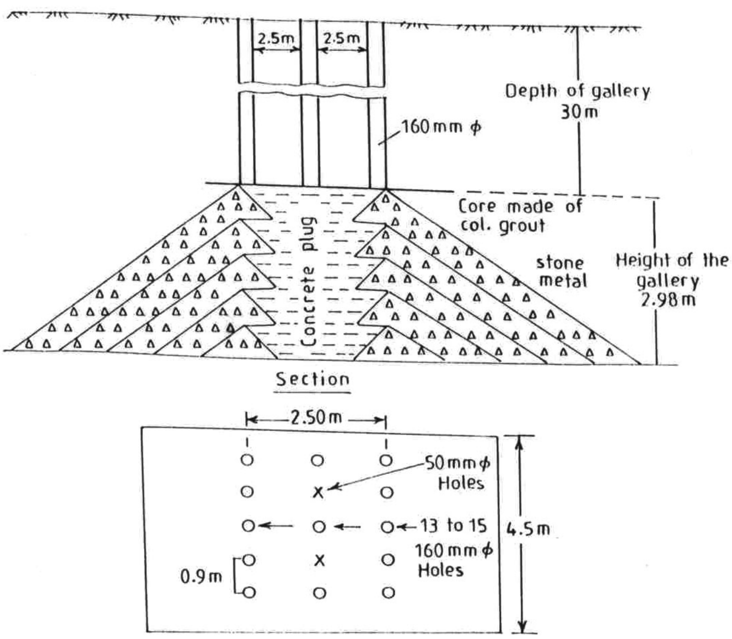

Figure 1—Sketch showing the cement concrete plug and position of boreholes

Experimental procedure for studying of air leakage characteristics of the cement plug

The air leakage test was conducted using sulphur hexafluoride (SF6) tracer gas, which is a non-toxic, colourless and odourless gas. It is chemically and thermally stable, which can be detected even in the part per billion (ppb) range. Also, it has been accepted worldwide for leakage detection and ventilation studies[7–9].

For conducting the air leakage test, a special arrangement was made for creating sufficient pressure difference across the stopping. For this purpose two chambers A and B, one each on in bye and out bye of the plug, were constructed (Figure 2).

The in-bye chamber i.e. (Chamber A) was built by constructing a brick wall stopping of 25 cm thickness about 2 m away from the cement concrete plug. The brick wall stopping was provided with an airtight door for inspection, a sampling pipe, and a 50 mm diameter The galvanised iron (GI) pipe for pushing compressed air from surface into the chamber. The GI pipe was extended up to surface through a borehole and connected to a compressor. A bypass device was connected to the GI pipe for releasing excess pressure. Before starting the experiment, the pressure of Chamber A was raised by compressed air and the brick stopping was scanned with a smoke tube to identify the air leakage source. These leakage points were then properly sealed with mortar and sealant.

On the other side of the plug another chamber (i.e. Chamber B) was made by erecting a PVC curtain stopping about 2.5 m away from the plug.

After ascertaining that leakage through the brick stopping of chamber A was negligible, one litre of SF6 gas was injected into Chamber A by a water displacement method through the sampling pipe in the brick wall stopping. An incline manometer was connected to the sampling pipe to measure the pressure of Chamber A. Atmospheric air was fed into the chamber by a compressor installed at the surface, through the 50 mm diameter GI pipe connected to Chamber A. The pressure of Chamber A was raised up to a pre-determined value (varying from 140 Pa to 400 Pa) and kept constant for some time. As soon as the pressure of the chamber reached the desired value, air flow into the chamber was regulated by the bypass valve such that pressure remained steady. Under this condition, air flowing into the chamber was equal to air leaking through the cement concrete plug as the leakage through the brick stopping was negligible.

Under this condition, air samples were collected from Chamber B every 15 minutes and then analysed by a portable SF6 detector chromatograph, model 505 (USA make). Three sets of such experiments were carried out at 140, 250 and 400 Pa pressure. The results are given in Table II.

Leakage through the concrete plug was calculated using this formula :

$$q = \frac{C_2 . V}{C_1 . t}, \text{ m}^3/\text{s}$$

Where,

q	=	the air leakage through the plug in m^3/s
C_1 and C_2	=	the SF6 concentrations part per million (ppm) in the chambers A and B, respectively
V	=	volume of the chamber B in m^3
t	=	time in sec.

The equation is derived on the assumption that the volumes of both chambers are large compared to the leakage rate through the plug.

Measurement of air leakage through rows of stoppings

Measurement of leakage of air through a single isolation stopping is extremely difficult. These measurements were conducted for rows of stoppings in the Moira colliery (two locations) and Kuardi colliery (one location). For this purpose, airway segments covering 6 to 27 stoppings in the main intake gallery were selected for measurement of air leakage. Leakage through a row of stoppings was determined by measuring airflow at the two extremities of the segment

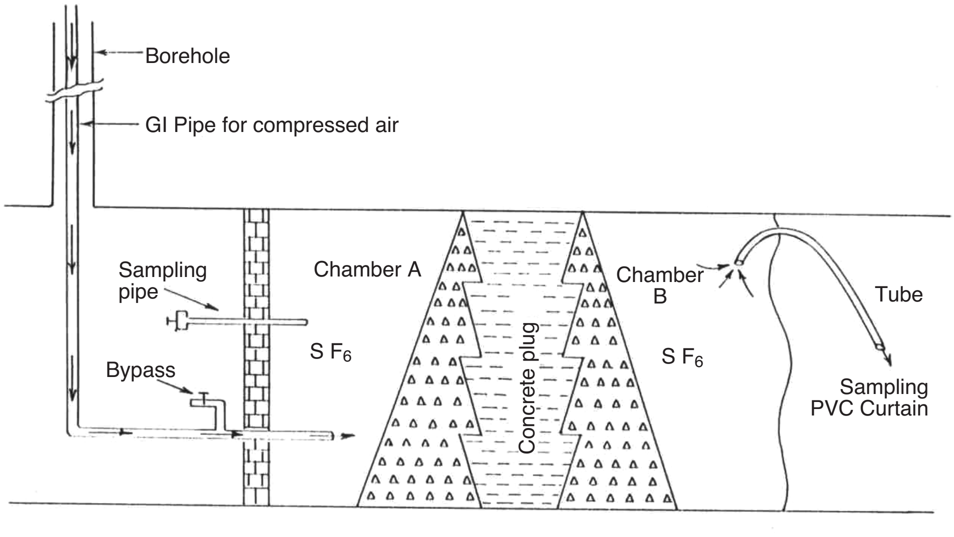

Figure 2—Arrangement of assessment of air leakage

on intake by using a calibrated vane-type anemometer. The difference between these readings gives the total leakage of air through the row of stoppings. The average leakage per stopping was obtained by dividing this value by the number of stoppings in the row. Results of field measurements are given in Table I.

The average value of resistance of an individual stopping, assuming uniform resistance, was determined indirectly by the computer program STOPLEAK. Results are summarized in Table I along with other details.

The three rows of stoppings investigated represented poor, average, and good construction. Quality of construction is apparent from the average resistance of stoppings (Table I) which varies from 150 NS^2/m^8 to 70 000 NS^2/m^8 and increases for each type by a factor of about 20. It can also be seen from the table that, even for a row of only 6 poor quality stoppings, as much as 27.5% of air can be lost to return due to leakage.

Discussion

Leakage of air through three types of stoppings, viz., ventilation stoppings in two collieries of Eastern Coalfields Ltd., brick stoppings of 25 and 38 cm thickness, and finally one remote filled cement concrete plug, were carefully studied using different techniques.

Results of the studies have been collected and tabulated in Tables I to III, which makes it convenient for comparing the performance of these stoppings. From Table I it can be seen that leakage through a ventilation stopping varies widely from 0.12 m^3/s for a wellbuilt, wellmaintained stopping, to about 0.75 m^3/s for a poorly maintained one. Comparing these values with the result of the laboratory studies is quite revealing: the air leakage rate through the stoppings in an *in situ* condition is much higher as compared to the stoppings constructed in a laboratory. It may be due to the air leakage around the periphery of the stoppings and coal pillars. From Table III it can be seen that even for 25 cm thick stoppings, a leakage rate at a pressure of 127 Pa would be about 0.0024 m^3/s as compared to 0.12 m^3/s for a wellbuilt stopping in a mine.

From Table II it can be seen that air leakage through the remote filled cement concrete plug was 0.00035 m^3/s at a pressure of 140 Pa, which is much below the leakage value obtained for wellbuilt ventilation stoppings in a mine, as well as results of laboratory studies with 25 cm and 38 cm thick brick in cement mortar stopping.

The results of laboratory studies conducted on 25 cm and 38 cm thick brick stoppings and studies conducted on cement concrete plugs in the mine are also depicted in Figure 3.

The above discussions lead to the conclusion that the remote filled cement concrete plug is quite satisfactory as far as leakage of air is concerned.

Conclusion

- Three rows of stoppings were investigated in the Moira and Kuardi collieries of ECL for assessing leakage of air through stoppings. Average leakage of air varied from 0.12 to 0.75 m^3/s of air per stopping, depending on the quality of construction and maintenance of the stoppings. In the case of poorly constructed stoppings, as much as 27.5% of out-bye air quantity leaked to return in a row of only six stoppings
- The average resistance of stoppings was determined using the computer program STOPLEAK, and it was found to vary widely from 150 NS^2/m^8 for poorly constructed stoppings to 3000 NS^2/m^8 for wellbuilt and maintained stoppings
- The conventional brick stoppings plastered with sand and cement mortar have lower air leakage when wet
- The cement concrete plug may be considered to be

Table I

Details of observations in experimental segments

Colliery/seam/location	Moira/Jambad/16D	Moira/Jambad main intake	Kuardi/Nega/main intake
Construction	Poor	Average	Good
Out bye $Q_2 m^3/s$	16.338	14.283	27.790
In bye $Q_1 m^3/s$	11.845	12.785	24.560
No. of stoppings	6	8	27
Leakage m^3/s	4.493	1.498	3.230
Total leakage %	27.50	10.49	11.62
Stopping resistance NS^2/m^8	150	3000	70000
Pressure difference at start of segment Pa	11.77	39.24	-
Average leakage m^3/s	0.749	0.187	0.120

Table II

Air leakage through remote filled cement concrete plug

Concentration of SF6 (in ppm) in Chamber A after injecting 1 litre SF6	Pressure of Chamber A (Pa)	Concentration of SF6 (in ppm) detected in Chamber B	Air leakage rate through the entire cement concrete plug (m^3/s)
73	140	1.0	0.00035
	250	8.25	0.0029
	400	16.0	0.0056

Table III

The air leakage through 25 cm and 38 cm thick brick. Stopping under various conditions

25 cm thick brick stopping plastered with cement and sand in the ratio of 1:4			38 cm thick brick stopping plastered with cement and sand in the ratio of 1:4		
Controlling of stopping	**Pressure Pa**	**Air leakage m3/s**	**Condition of stopping**	**Pressure Pa**	**Air leakage m3/s**
Wet	127.0	0.00240	Wet	127.0	0.00227
Wet	101.6	0.00190	Wet	101.6	0.00185
Wet	76.2	0.00150	Wet	76.2	0.00138
Wet	50.8	0.00090	Wet	50.8	0.00089
Wet	25.4	0.00049	Wet	25.4	0.00046
Dry	140.0	0.00476	Dry	140.0	0.00361
Dry	127.0	0.00433	Dry	127.0	0.00330
Dry	101.6	0.00348	Dry	101.6	0.00270
Dry	76.2	0.00270	Dry	76.2	0.00192
Dry	50.8	0.00181	Dry	50.8	0.00138
Dry	25.4	0.00089	Dry	25.5	0.00072

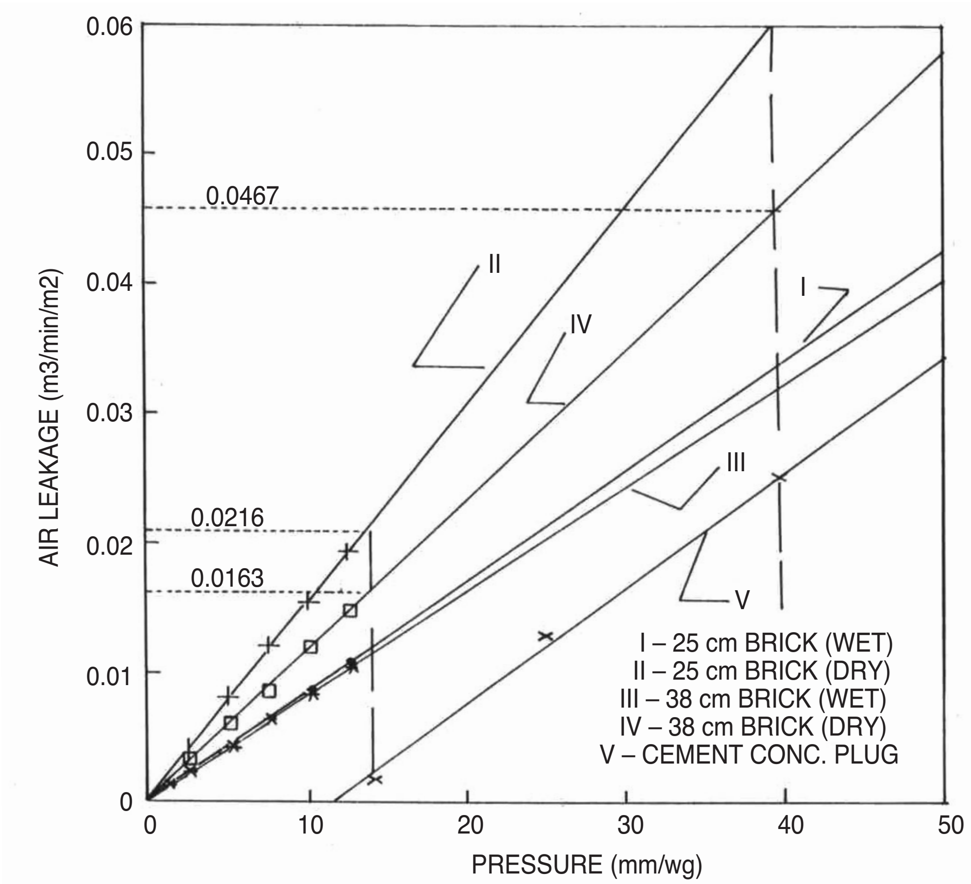

Figure 3—Air leakage through cement concrete plug and 25 and 38 cm thick brick stopping under various conditions

satisfactory from an air leakage point of view for low pressure difference i.e. up to 140 Pa. However, the leakage rate increases with an increase in pressure difference

- The leakage characteristic of the remote filled cement concrete plugs seems to be suitable for their use as an isolation stopping in underground mines subject to the condition that the pressure difference likely to be applied should be low, otherwise further treatment of the seal may be required
- The experimental setup designed for *in situ* study of air leakage characteristics of stoppings using tracer gas is effective and reliable. The stoppings may be subjected to any predetermined pressure differential with the help of this design.

Acknowledgement

The authors thank the Director, CMRI for his kind permission to publish this paper. They also thank Sri B. C. Bhowmick, Former Head, Mine Ventilation & Spl. Projects Division for his guidance in the preparation of this paper and Sri M. K.

Singh, Gr.II(I) for word processing. The authors sincerely acknowledge the help rendered by the mine management during field investigations. The views expressed in this paper are those of the authors and not necessarily of CMRI.

References

1. VINSON, R.P., THIMONS, E.D., and KISSELL, F.N. Brattice Window Method for Measuring Leakage through Mine Stoppings. *Bureau of Mines*, RI No. 8240 (1977).
2. MATTA, J.E., MAKSIMOVIC, S.D., and KISSELL, F.N. Tracer Gas Method for Measuring Leakage through Mine Stoppings. *Bureau of Mines*, RI No. 8324 (1978).
3. VERMA, N.K., SINGH, A.K., PANDEY, J.K., and GUPTA, M.L. Air Leakage through Underground Ventilation Structure with Special Reference to Isolation Stoppings. *Mines, Metals and Fuels*, 1997. pp. 103–106.
4. TIMKO, R.J. and THIMONS, E.D. New Techniques for Reducing Stopping Leakage. *Bureau of Mines*, RI No. 8949 (1983).
5. NACQUET, J. A Mine Fire Isolated from Distance. *Asian Mining*, India, 1983. pp. 706–717.
6. SINGH, R., SINGH, H.C., and CHAKROVORTY, R.N. Studies in the Leakage Properties of Underground Stoppings. *Central Mining Research Station* (CMRS), Research Paper No. 24 (1966), Reference CMRS – VII/24
7. DRIVAS, P.J., SIMMONDS, P.G., and SHAIR, F.H. Experimental Characterisation of Ventilation Systems in Buildings. *Environmental Science Technology*, vol. 6, 1972. pp. 609–614.
8. HIGGINS, J. and SHUTTLEWORTH, S.E.H. A Tracer Gas Technique for the Measurement of Airflow in Headings. *Colliery Engineering* no. 417, 35 : 1958. pp. 483–487.
9. TIMKO, R.J., LANGUS, P.L., and THIMONS, E.D. SF6 Adds a New Dimension to Mine Ventilation Analysis. *E & M Journal*, 1984. pp. 50–51. ◆

Tunnel bracing vehicle from Terratec

Thiess Hochtief JV (THJV) was awarded the contract by the NSW State Government to excavate the twin 12.5 km long tunnels that form part of Sydney's new Chatswood to Epping rail line. The contractor elected to excavate the top portion of the stations in advance, leaving the TBMs to cut 75% of the face on their way through. Because the rock pillar between the two TBM passages is only 5.2 m wide, it was felt that this pillar should be braced during the passage of the second TBM.

Tasmania-based tunnel equipment manufacturer Terratec conceived a bracing vehicle system to react the forces generated by the gripper pressure of the passing second tunnel TBM. Within the parameters set by THJV, the bracing vehicle was designed for installation in the first tunnel, clear of the main conveyor, 1 800 mm-diameter ventilation duct, pre-cast concrete floor, transport vehicles and services. The possibilities of fallout and low friction zones, steps from cutter changes, and TBM misalignment were also taken into account. The system can also traverse 400 m-radius compound curves.

The need for a clearance envelope meant it was impossible to place the grip force reaction strut at the tunnel centre line, increasing the potential for downward force if the bracing vehicle gripper pads should slip. Hence, the main portal structure was designed to support the down-force component in low friction zones, as well as the dead weight of the bracing gripper pads and hydraulic cylinders.

It was decided to use six cylinders exerting a force of up to 225 t each over a 12-m length of tunnel. The gripper cylinders have a total stroke of 600 mm, offering 300 mm extension each side from the fully retracted position. There is a 100 mm overstroke from mean tunnel diameter, while the retract of 200 mm from mean diameter assists clearance over any necessary support sets. Each gripper pad can tolerate up to ± 3 degrees of angular misalignment. A conveyor belt is employed as a tensile diaphragm to ensure the gripper pads lie perpendicular to the hydraulic cylinder axis when in the unloaded state. Each gripper assembly has the ability to float laterally within the support vehicle.

To provide a system that was sufficiently independent of other services, and to enable the bracing vehicle to operate at any fault zone location within the project, Terratec supplied a diesel-driven power pack sufficient to extend and retract the main gripper struts without overstressing or pre-tensioning the pillar. The power pack is equipped with vertical acting cylinders to hold back the bracing vehicle on the 3° gradient. The entire vehicle is supported on articulated bogies fitted with high-density polyurethane wheels to run on the prepared roadway, and side guide castor idlers designed to run on the concrete invert. Low-speed motion and indexing of the vehicle to maintain its position adjacent to the TBM is achieved using a battery-powered winch. For long traverses, a towing bridle is installed.

The system, which is designed to withstand up to 100 t force per linear metre of tunnel, registered up to 80 t/m in its first application within the tunnel. The bracing vehicle prestresses the rock using a hydraulic pressure of up to 90 bar. The limit of the design is 525 bar within the bracing vehicle gripper cylinders. At the first station, excavation forces of up to 430 bar were monitored between the bracing vehicle gripper and the passing TBM gripper.

Terratec designed and manufactured the system within a ten-week period, shipped it to site partially assembled, then completed assembly and commissioning over a further five-day period.

For more about the specification of the Terratec bracing vehicle, contact tony@terratec.com.au, and for operating experience, contact rtauriainen@thiess.com.au ◆