Art of Producing 3-D Geological Logs while Driving Highly Mechanised Tunnels

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Abstract

Geological records for tunnels form the basis for designing permanent support systems, serve as permanent records for the upkeep of tunnels, and are also used as a comprehensive tool for projection of problematic discontinuity planes like shears and fault zones ahead of the tunnel heading. 3-D Geological Logs of tunnels have served these purposes for a long time.

However, with the advent of mechanised tunnelling, the age old practice of data collection through 3-D Geological Logs is losing its sheen. Use of double shield TBMs and accelerated tunnelling techniques like NATM hinder geological data collection and have led to alternatives of Face Logs and Subsurface Geological Maps. In the process, data collection is only partial and can not compare with the 3-D logs that are the only graphical form of data presentation that provide geological and other details for the entire surface of the tunnel.

The paper reiterates the importance of 3-D Geological Logs and presents construction techniques of 3-D geological logs using data from Face Logs and other such sources. The methodology involves extraction of information on planar attitude of discontinuities and reproduction of their trace on 3-D Logs. For easy and expeditious plotting, it has been recommended to use computer programmes.

Introduction

Till recently, the 3-D Geological Logs of tunnels remained the most important geological record for river valley development projects (Deva, 1990). Besides being the basis for designing permanent support systems, these logs served as permanent records for the upkeep of tunnels. Further, these logs have also been used as a comprehensive tool for projection of problematic discontinuity planes like shears and fault zones ahead of the tunnel heading.

The changing scenario of project implementation and use of state-of-the-art mechanised technology, however, are leading to serious deviations from this age old practice of data collection. For example, use of double shield TBMs, such as at Parbati HE Project in Himachal Pradesh and at Srisailam Left Bank Canal in Andhra Pradesh, hinders geological data collection during tunnelling and, consequently, prevents preparation of 3-D geological logs. Accelerated tunnelling using NATM, such as in Delhi Metro and the Banihal Railway Tunnel, on the other hand, is an example where time for geological data collection is limited and subsurface geological maps are produced as records. However, considering that the 3-D geological log is the only graphical form of data presentation that provides geological and other details for the entire surface of the tunnel, it is irreplaceable as a record and it would be prudent to keep it for future reference.

It may be argued that the 3-D Logs can be generated from available data when the need arises. Here, it may be appreciated that it is always advisable that the data presentation process is completed by the concerned

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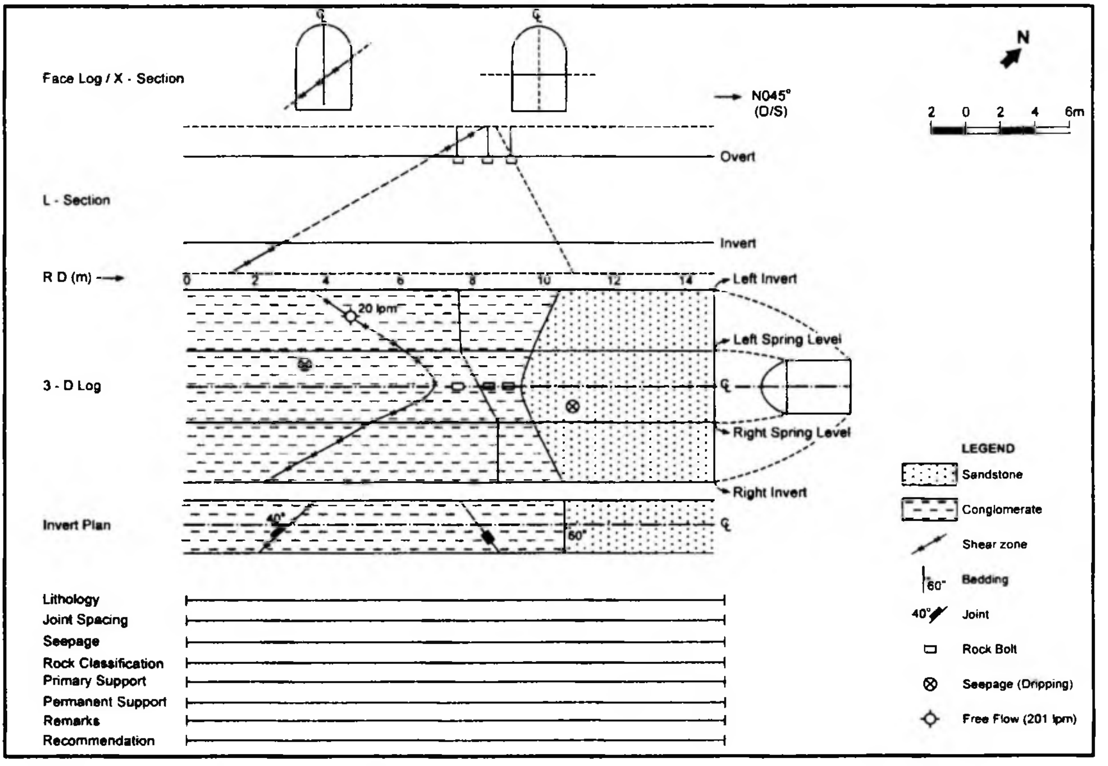

Fig. 1: Concept and Proforma of 3-D Geological Log.

Geologist himself when the works are still in progress.

While providing an overview of the 3-D Geological Log, methodologies of plotting the logs from limited geological information have been attempted in the following paragraphs. These have also been converted into easy to use computer programmes by the authors that fall outside the scope of the paper, but, are available separately.

Overview of 3-D Geological Logs

These are detailed records of the excavated tunnel, normally on large scales like 1:200 and 1:100. Larger scales are used for drifts in case greater information is needed. The logging activity is an ongoing process and follows the tunnel excavation progressively. Periodically, time needs to be given to the Geologist for the preparation of these logs.

A standard 3-D geological log provides a plot of all the engineering geological features on the excavated surface of the tunnel, invert geological plan, geological section along the tunnel axis and tunnel face logs/ x-sections (Fig.1).

An invert open log is in vogue. Crown open logs are uncommon.

When folded appropriately in the tunnel shape, the 3-D log displays the geological features in three-dimension as they appear on the tunnel surface and hence the name.

A 3-D geological log is prepared using a standard format (Anon, 1992) and, like foundation maps, consists primarily of lithological and discontinuity details.

In the simplest form of the log, the planar features are plotted by the RD of their intersections at the invert (both left and right), spring levels (both left and right) and the central line of the tunnel in the crown. In all,

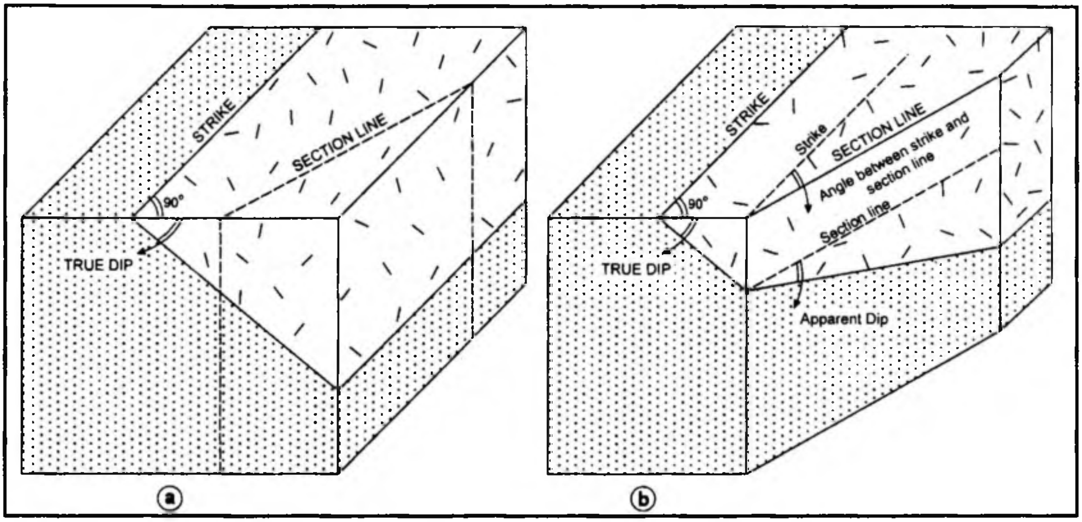

Fig. 2: The concept of Apparent Dip.

therefore, there are five intersection points that are joined to complete the trace of the planar feature on the log.

Isolated features like seepage/ free flowing locations, rock bolts, etc are easier to plot and are shown by their respective co-ordinates in terms of RD and position on the tunnel surface (walls, crown or invert).

In theory, however, the projection of the trace of the discontinuity involves mathematical computations of discontinuity dip in relation to the tunnel shape and dimension. While, in horse shoe and D-shaped tunnels, the invert or spring level RDs are the basic data input, in case of circular or other shapes, where the invert is curved, only spring level data are necessary. The reason is simple – all computations deal with geometric projection of planar features. Computing the true dip of the plane from the 3-D Log is the basic step in somewhat complex computations while reproducing these logs from partial information. It involves two steps:

1. Using the intersection RDs of the trace of the planar feature, an invert/ spring level plan is prepared that provides the strike of the plane and, consequently, the angle between the strike and tunnel direction (Fig.1).
2. Using the intersection point of the strike and tunnel axis at invert/ spring level, and that of the trace of the plane and the tunnel axis at crown, the apparent dip of the plane is computed (Fig.1). In case of D-shaped tunnels, it can also be read directly as the angle between the trace of the plane and the invert on the tunnel walls.

Computation of the True Dip of the plane can either be read from the Apparent Dip Chart (Figs. 2) in case of manual plotting, or, can be calculated (Table-1) using the following formula in case of computerised plotting.

[Tan(True Dip)=Tan(Apparent Dip) / Sin(Angle between Strike and Tunnel Direction)]

On the other hand, for known values of True Dip of a plane and any one co-ordinate of its intersection with the tunnel surface, the trace of a plane in 3-D Log can be generated through reverse calculations. Again, it would involve two steps:

1. Calculate the apparent dip of the plane along the tunnel direction using the Apparent Dip Chart/ Formula.
2. Project the trace of the plane on invert/ spring level plan and complete the trace as explained above.

Table 1 : Apparent dip chart

ANGLE OF Dip	ANGLE BETWEEN STRIKE AND SECTION LINE																																	
	80°		75°		70°		65°		60°		55°		50°		45°		40°		35°		30°		25°		20°		15°		10°		05°		01°	
10°	09	51	09	40	09	24	09	05	08	41	08	13	07	41	07	06	06	26	05	46	05	02	04	15	03	27	02	37	01	45	00	53	00	10
15°	14	47	14	31	14	08	13	39	13	34	12	28	11	36	10	04	09	46	08	44	07	38	06	28	05	14	03	33	02	40	01	20	00	16
20°	19	43	19	23	18	53	18	15	17	30	16	36	15	35	14	25	13	10	11	48	10	19	08	45	07	06	05	23	03	37	01	49	00	22
25°	24	48	24	15	23	39	22	55	22	00	20	54	19	39	18	15	16	41	14	58	13	07	11	09	09	03	06	53	04	37	02	20	00	26
30°	29	37	29	09	28	29	27	37	26	34	25	18	23	51	22	12	20	21	18	19	16	06	13	43	11	10	08	30	05	44	02	53	00	35
35°	34	36	34	04	33	21	32	24	31	13	29	50	28	12	26	20	24	14	21	53	19	18	16	29	13	28	10	16	06	56	03	13	00	42
40°	39	34	39	02	38	15	37	15	36	00	34	30	32	44	30	41	28	20	25	42	22	45	19	31	16	00	12	15	08	17	04	11	00	50
45°	44	34	44	01	43	13	42	11	40	54	39	19	37	27	35	16	32	44	29	50	26	33	32	55	18	53	14	30	09	51	04	59	01	00
50°	49	34	49	01	46	14	47	12	45	54	44	17	42	23	40	07	37	27	34	21	30	47	26	44	22	11	17	09	11	41	05	56	01	11
55°	54	35	54	04	53	19	52	18	51	03	49	29	47	35	45	17	42	33	39	20	35	32	31	07	26	02	20	17	13	55	07	06	01	26
60°	59	37	59	08	58	26	57	30	56	19	54	49	53	00	50	46	48	04	44	47	40	54	36	14	30	29	24	08	16	44	08	35	01	44
65°	64	40	64	14	63	36	62	46	61	42	60	21	58	40	56	36	54	02	50	53	46	59	42	11	36	15	29	02	20	25	10	35	02	09
70°	69	43	69	21	68	49	68	07	67	12	66	08	64	35	62	46	60	29	57	16	53	57	49	16	43	13	35	25	25	30	13	28	02	45
75°	74	47	74	30	74	05	73	32	72	48	71	53	70	43	69	14	67	22	64	58	61	49	57	37	51	55	44	01	32	57	18	01	03	44
80°	79	51	79	39	79	22	78	59	78	29	77	51	77	02	76	00	74	40	72	75	70	34	67	21	62	43	55	44	44	33	26	18	05	31
85°	84	56	84	50	84	41	84	49	84	14	83	54	83	29	82	57	82	15	81	20	80	05	78	19	75	39	71	20	63	15	44	54 11	11	17
89°	88	59	88	58	88	56	88	54	88	51	88	47	88	42	88	00	88	27	88	15	88	00	87	38	87	05	86	09	84	05	78	41	44	15

[Tan (Ap. Dip)=Tan (True Dip)*Sin (Angle between Strike & Section Line)]

Like the True Dip, computation of the Apparent Dip of the plane can either be read from the Apparent Dip Chart (Figs.3) in case of manual plotting, or, can be calculated using the following formula in case of computerised plotting.

[Tan(Apparent Dip)=Tan(True Dip)*Sin(Angle between Strike and Tunnel Direction)]

For computerised plotting, the angle between the strike and tunnel direction, and apparent dip along the tunnel direction, can be calculated using the following relationships:

1. Angle between strike and tunnel direction:

Tan (Strike-Tunnel Dir. Angle)=Tunnel Width / (Difference of Invert RDs of Plane)

2. Apparent Dip along Tunnel Direction:

Tan (Ap. Dip)=Tunnel Height / (Difference of Invert-Crown RDs of Trace along Tunnel Axis)

3-D Geological Logs in Mechanised Tunnelling

The reproduction of a 3-D geological log would involve extraction of information on planar attitude of discontinuities from face logs, subsurface maps, slit window data, etc, and plotting of special features that fall outside the reaches covered by such records.

The theory of plotting 3-D Geological Logs from data in any other form lies in reconstructing the planar feature and plotting its trace in the log form. Other features like seepage/ free flow locations, joint wedge collapses, etc are plotted at their respective locations on the tunnel surface. Following could be some of the possible scenarios.

From Face Logs

Preparation of Face Logs at convenient intervals is one of the common practices for data recording these days. This also involves recording of other important features that are found on the tunnel walls and are not covered in the Face Log. The simplest way is to use the dip data of the planar feature and its position on the Face Log. The point of intersection of the planar feature on the periphery of the Face Log is used as the Source Point for plotting the trace of the feature. The methodology used is as follows:

1. Source Point Lying on the Tunnel Wall

Using the apparent dip of the feature along the tunnel direction, plot the trace of the feature on the tunnel wall. Follow the trace plotting methodology for a normal 3-D Log.

2. Source Point Lying Above Spring Level

Using the apparent dip of the feature along the tunnel direction, project the trace of the feature down to the invert. From the intersection point of the trace and the invert, plot the strike of the feature to obtain the Source Point on the tunnel wall. Follow the trace plotting methodology for a normal 3-D Log.

3. Dip of Plane Not Known

For overhead planes, where dip measurement may not be possible, an approximate 3-D Log can be generated in case the plane corresponds to a known set of discontinuities. Here, the dip of the known set is used for all projections. However, in case the plane is a random one and does not correspond to any known discontinuity set, two Face Logs of the plane are needed. Here, the three-point solution is used for calculating the dip of the plane. Thereafter, the standard methodology is used for generating the 3-D Log.

From Slit Window Data

Tunnelling with Double Shield TBMs provides much constrained opportunity for data collection from the narrow window slits adjoining the grippers. It may not be possible to measure even the dip of the planar features. The alternative lies in picking up only continuous features like shear zones and master joints defining the rock dissection.

Record the co-ordinates of the feature in a minimum of three consecutive slit windows with the forward progress of the TBM and calculate its dip data using three-point solution. Any of the three co-ordinates can then be used as the Source Point for plotting a normal 3-D Log.

Conclusions

3-D Geological Logs of tunnels are the most important geological records for designing permanent support systems, upkeep of tunnels, and as a comprehensive tool for projection of problematic discontinuity planes like shears and fault zones ahead of the tunnel heading. Further, considering that these logs are also the only graphical form of data presentation that provide geological and other details for the entire surface of the tunnel, it would be prudent to keep them for future reference. The log construction techniques discussed in the paper would be particularly helpful in producing the 3-D logs from face and slit window data generated during highly mechanised tunnelling. It is also recdommended to make use of computer programmes on log preparation for easy and expedited plotting.

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