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# *Geological Overbreak: A Viewpoint of Storage Cavern Excavation*

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## ABSTRACT

Geological overbreak is an inseparable part of underground construction by rock excavation, more so in case of drill and blast method. In view of structural stability and cost factor associated with the geological overbreak, the role of engineering geologist includes: prediction, prevention & control, demarcation and documentation (PPDD).

In the present paper an attempt has been made towards deciphering of geological overbreak resulting during the excavation of large underground cavern. The project, being constructed for storage of crude oil, is located within granite gneiss of Archaean age. The rockmass is good with occasional shear seams and mafic dolerite dykes traversing the country rock. The emplacements of dykes are associated with hydrothermal alteration of country rock. Geological overbreak were observed to be mainly associated with crown instability due to low cover in near surface excavation of portal area, block failure associated with weak geological features like intrusion of mafic dolerite dykes & shear zones, slaking and softening of mafic dykes and hydrothermally altered zone. These encountered details have been recorded during regular face mapping.

The rock classes as per Q-system were compared to geological overbreak to find correlation between them. The major geological factors influencing overbreak have been observed to be persistence or continuity of features and joint conditions. The joint conditions are governed by both roughness and alteration factor.

Structural projections of features were made with the help of 3D modelling to predict areas susceptible to overbreak during subsequent stages of excavation. The same was shared with blasting expert so that areas necessitating modification in blast pattern could be identified in advance. Pre-excavation measures like fore polling, pilot excavation and control blasting were adopted to minimize overbreak. Post-excavation measures of site specific rock supports like directional spot bolting and sealing fibercrete or fibre reinforced shotcrete were recommended to prevent secondary overbreak

At times, the constructional overbreak becomes almost inseparable from geological overbreak and there can be inadvertent inclusion of constructional overbreak as geological overbreak and vice versa. The site observations are used to identify certain constructional factors influencing overbreak. Survey discrepancies, change in tunnel alignment, repeat/undercut blasting are some such identified factors.

In the project, the above PPDD methodology has been adopted to control geological overbreak satisfactorily. The observations are documented to provide an insight of geological overbreak in the present project and to aid engineering geologists in understanding and minimizing geological

overbreaks in future projects.

***Keywords**:* Drill & blast; Cavern excavation; Geological overbreak; Construction overbreak; Secondary overbreak

## 1. INTRODUCTION

The design profile of tunnels consists of 3 lines (Fig. 1):

- T-line or Theoretical line is the desired profile.
- U-line or Undercut line demarcates the minimum allowable limit of excavation within which there should be no unexcavated material. It is within the T-line.
- O-line or Overbreak line demarcates maximum allowable limit of excavation beyond which, ideally, there should be no excavation. It is outside T-line.
- A-line: The actual line of excavation lies within or outside the T-line.

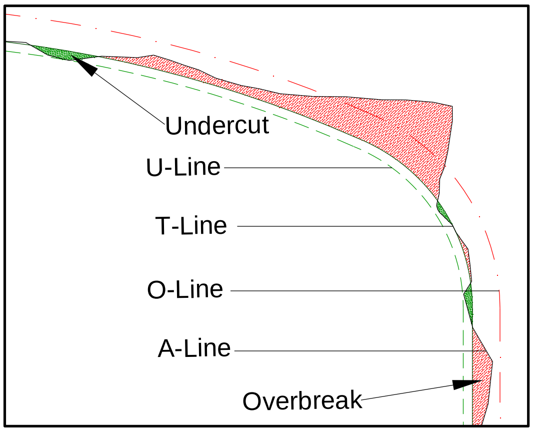


Fig. 1 - Excavation lines

Overbreak in underground tunnels is the extent of excavation beyond desired profile (T-line). The major overbreak results when the excavation goes beyond the overbreak O-line.

Overbreaks do result in tunnel either by improper drilling and/or blasting. This has been termed in the paper as 'construction overbreak'. But overbreak may also result even after control of drilling and blasting due to formation of unstable blocks/wedges along weak geological features like filled joint, shear, dyke etc. This is known as 'geological overbreak'.

Occasionally a notion of time may be involved between blast and overbreak influenced by geological factor. This may result at time of rockbolt drilling or even after blast at subsequent face. This is known as "secondary overbreak" (Schmitz, 2003).

## 2. STABILITY AND COST FACTOR

Geological overbreak or potential overbreak zones may pose serious threat to stability of large caverns owing to tendency of rock fall along the overbreak surface. The unwarranted situations are to be prevented through rock support of the zones under proper geological supervisions.

Unlike lined tunnels, where overbreak lead to additional cost of concrete for backfilling upto lining, the cost factor associated with overbreak in unlined cavern is mainly related to efforts for additional muck removal and additional support required for stability of the zone. Generally, in all underground projects, non-geological overbreak is at the risk of contractor and geological overbreak is at the risk of owner. At times, the constructional overbreak becomes almost inseparable from geological overbreak and there can be inadvertent inclusion of constructional overbreak as geological overbreak and vice versa. That is where engineering geologists role in demarcation of overbreak is important.

## 3. PROJECT OVERVIEW

The project under discussion is mined rock cavern for underground storage of crude oil. The major project components are (Fig. 2):

- Four numbers of parallel caverns (900m long x 30m high x 20m wide)
- Vertical circular Shafts (8m diameter)
- Access tunnel (8m high x 12m wide)
- Water curtain galleries (6.5m x 6.5 m)

The water curtain galleries are placed 20m above cavern top. The project area is located within gneiss of Archaean age in west coast of India. The country rock belongs to family of granite-gneiss with four major discontinuity sets. Out of four, 3 sets are steeply dipping (75° to 88°) and 1 set is sub-horizontal. Parent rock is intruded by mafic dolerite dykes. The dyke bands vary in thickness from few cm to 30m. Hydrothermal alterations of country rock have taken place with emplacements of different dyke bodies. Occasional shear seams intercede the rock mass. The thicknesses of crushed infillings are less than 10 cm but total affected widths including sympathetic joints are 1-2m.

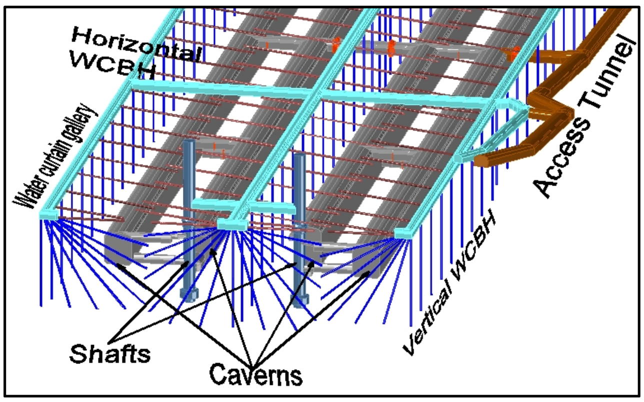


Fig. 2 - Layout of project

## 4. MODE OF FAILURE AT GEOLOGICAL OVERBREAKS

Several ground behaviours have been defined by Thapa et al. (2007) in terms of failure modes and manifestations, modified from Austrian Society of Geomechanics. The broad areas/ categories of geological overbreak observed in the project can be fitted into following modes of failures:

### 4.1 Crown instability due to low cover at near surface excavation

This type of failure was recorded during excavation of portal area for access tunnel. The overall cover in this zone ranges from 11 to 16 m (Fig. 3a) with combination of distressed joints and flowing ground water conditions. It manifested rock fall and ravelling resulting in geological overbreak above crown (Fig. 3b).

### 4.2 Block failures

This type was manifested by discontinuity-controlled-gravity-induced failure of rock blocks. Such type of failures was observed along features like dyke bands (few cm to 1.5m) and shear seams. Block failures at crown were observed along low to gentle dipping discontinuities (Fig. 4a) and that on wall were observed mainly along steep dipping discontinuities (Fig. 4b).

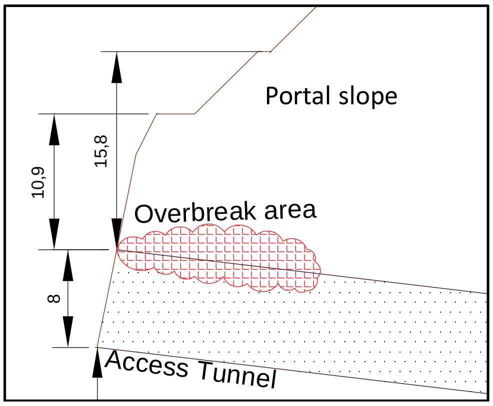


Fig. 3a - Section access tunnel

Fig. 3b - Overbreak in portal area

Fig. 4a - Overbreak on crown along gently dipping dyke band

Fig. 4b - Overbreak on wall along steeply dipping shear seam

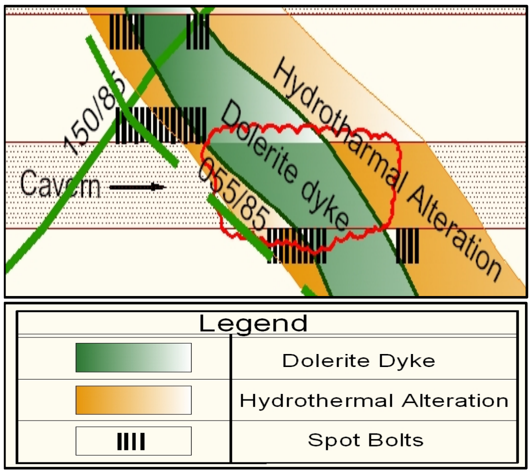


Fig. 5a - Geological map of dyke

Fig. 5b - Dyke and hydrothermal alteration

### 4.3 Slaking along major dyke (25-30m thick) and softening along hydrothermally altered zones

A sub-vertical dolerite dyke cut across all the four caverns (Fig. 5a). The hydrothermally altered zones along the dyke contact varied from few meters to 30m. The dyke body is traversed by 5 sets of discontinuities. The dyke was susceptible to progressive, discontinuity controlled failure of small blocks or ravelling as well as deterioration of rock upon exposure by excavation (slaking). The hydrothermally altered zones associated with dyke led to softening or reduction of rock strength on exposure by excavation (Fig. 5b).

## 5. FACTORS AFFECTING GEOLOGICAL OVERBREAK

The major geological factors affecting overbreak were:

- Persistence: Overbreak was found associated with discontinuities having persistence > 10m.
- Joint condition: The roughness of joints in the overbreak areas were either smooth undulatory (Barton's joint roughness number, Jr = 2) or rough planar (Jr = 1.5). This is true in case of dyke bands as well as in shears. Also, the joints are either filled with disintegrated rock in shear seam areas or in hydrothermally altered dyke area. Barton's joint alteration number, Ja was considered as 2 in both cases.
- Rock class: When all instances of geological overbreaks in cavern were analyzed, it was observed that 46 % of geological overbreaks were observed in Type 3 rock (Barton's Q = 4 to 10) and 42 % were observed in Type 4 rock (Barton's Q = 1 to 4). The remaining 12 % were observed in Type 2 rock (Barton's Q = 10 to 40) (Fig. 6a).

The overbreaks in Type 4 were mainly associated with major dyke and hydrothermal alterations at its contact. The geological overbreaks in Type 3 rocks were mainly related with major geological features like shear seam and thin dyke bands whereas those in type 2 were mainly restricted to local wedges (Fig. 6b).

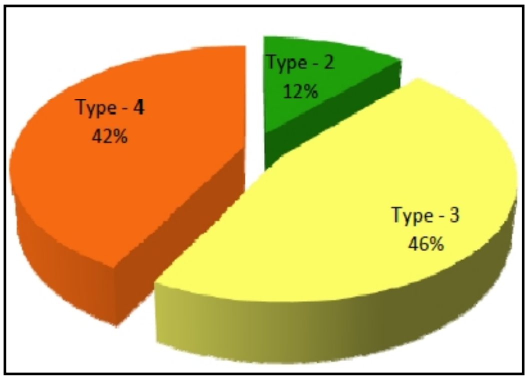


Fig. 6a - Distribution of overbreak

Fig. 6b - Wedge failure on wall

## 6. PREDICTION

Geological overbreak were attempted to be predicted at same level as well as subsequent lower level bench mainly by structural projection of geological features.

- Same level of excavation: geological features intersecting cavern alignment at low angle (< 30°) intersect one wall much before the other wall. Whenever such geological feature susceptible to overbreak was encountered on one side, it was strike wise projected on plan to anticipate the zone of intersection and possible geological overbreak on the other side at same level (Fig. 7a). This helped in identification of zones requiring additional control during blasting.

- Lower levels of excavation: Using the above principle, features were projected in 3D geological model to foresee the area of influence both laterally as well as vertically at the subsequent levels of excavation (Fig. 7b).

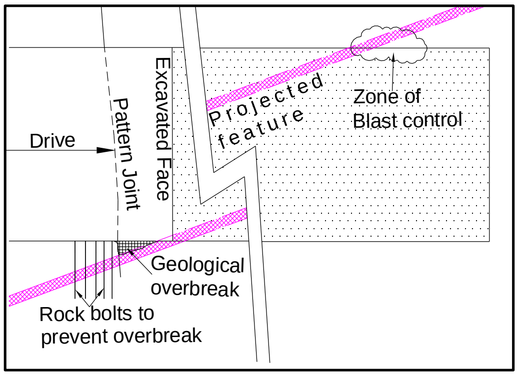


Fig. 7a - Prediction of geological overbreak

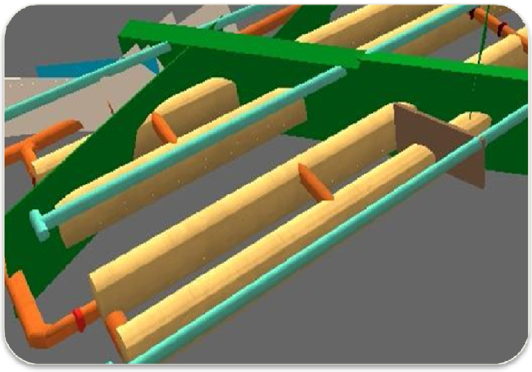

Fig. 7b - 3D predictive model

The blasting team was provided with such information to be well equipped for blast control in such areas.

## 7. PREVENTION AND CONTROL MEASURES

Different measures were adapted to control geological overbreak, in particular, by preventing secondary overbreak.

In portal area, overbreak was minimized by pre-excavation treatment of rockmass through fore poling and pilot excavation. The post-excavation rock support installed were fibercrete, rockbolts welded mesh and steel ribs (Fig. 8a). In case of block failure, possible detachable blocks were timely supported through increasing number of bolts through spot bolting (Fig. 8b) and directional bolts. In major dyke and hydrothermally altered zones, slaking and softening was prevented by immediate sealing fibercrete after blasting, thereby reducing exposure of excavated rock.

The site specific measures are summarized in following Table 1:

Table 1 - Treatments to control geological overbreak

| Area/Features | Mode of Failure | Preventive Measures/ Special Support |
|---|---|---|
| 1. Portal of access tunnels | Crown instability due to low cover | Forepolling, welded wire mesh, steel ribs |
| 2. Shear seam, dyke bands, wedge | Block failure | Spot bolts, directional bolts |
| 3. Major dyke / hydrothermally altered zone | Slaking / Softening | Immediate sealing fibercrete/shotcrete |

## 8. DEMARCATION FROM NON-GEOLOGICAL OR CONSTRUCTIONAL OVERBREAK

Based on observations in the project, certain factors have been identified to initiate / influence overbreak:

Fig. 8a - Steel rib installation

Fig. 8b - Spot bolting to prevent block failure

- Blasting to remove undercuts left after initial blast: overbreak often observed as a result of undercut blast. So undercuts should be mapped and undercuts blasts should be carefully designed and properly recorded.
- Area at junction of two levels of excavation: The area at junction of two subsequent bench levels is prone to overbreak due to influence of repeated blasts of two different levels (Fig 9a).
- Inaccurate survey and drilling: Improper profile marking may lead to higher lookout angle or drilling entire blast holes outside profile (Fig. 9b). In many cases this is manifested by half-caste marks along overbreak profile. Any geological features present at the periphery of tunnel will be amplified by such improper drilling.

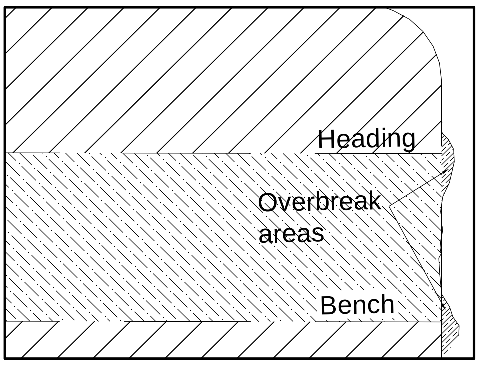


Fig. 9a -Overbreak in repeat blasting zone

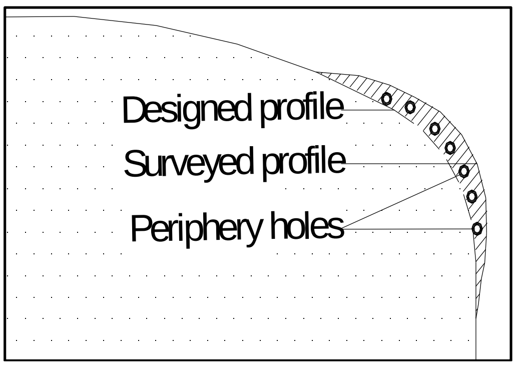


Fig. 9b - Overbreak due to inaccurate survey

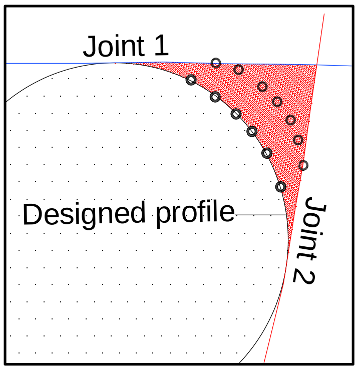


Fig. 9c - Overbreak in shaft

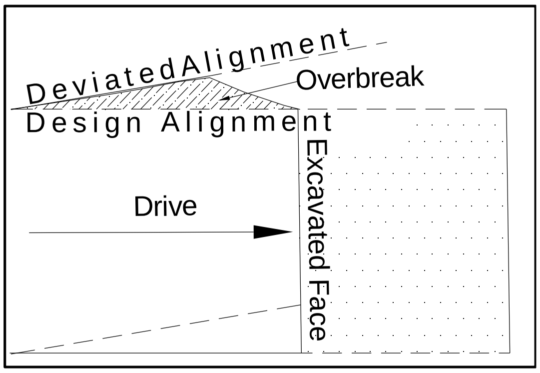


Fig. 9d - Overbreak due to directional deviation

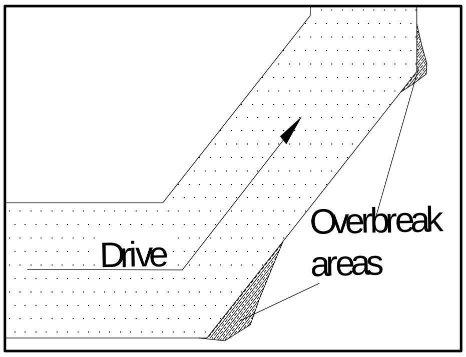


Fig. 9e - Overbreak due to alignment

- Also, any directional error in tunnel may need rectification through corrective blast, thus, leading to overbreak of distorted shape (Fig. 9d). For example in case of vertical circular shafts bounded by two sets of persistent sub-vertical joints (joint 1 and joint 2 in Fig. 9c) , the tendency of overbreak was more when the contour or periphery holes were drilled away from the designed profile.
- Delay in support: this may lead to secondary overbreak through "ravelling" (Thapa et al., 2007) or progressive discontinuity controlled failure.
- Change in tunnel alignment: wherever the direction of drive has to be changed to follow design alignment, it is done through differential pull at the turning points. Larger pulls are designed at outer bends compared with that of inner bends. This lead to tendency of overbreak on outer bends of tunnels (Fig. 9e).

In all above areas, engineering geologist has to ensure the cause before approving these as geological overbreak.

## 8. DOCUMENTATION AND QUANTIFICATION

*Profile survey*: The foremost thing required for identification of geological overbreak is marking the specified profile (as per T-line) on the excavated face by surveyor (Fig. 10a). This acts as the reference for depicting undercuts/overbreaks.

*Record during face mapping*: In the project, identified geological overbreaks were recorded at the time of face mapping (Fig. 10b). The geological factors responsible for overbreak were also noted in the face map. This helped to record the primary geological overbreak and get rid of claims at a later date, out of overbreak resulted due to delay in support etc.

*Quantification* : The exact volume of overbreak material was actually measured through surveyed profile reports (Fig. 10 c).

Fig. 10a - Profile marked on face before drilling

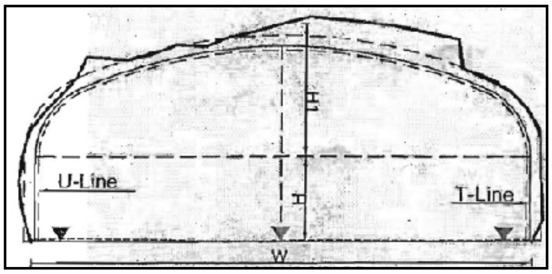


Fig. 10b - Geological overbreak marked on face map

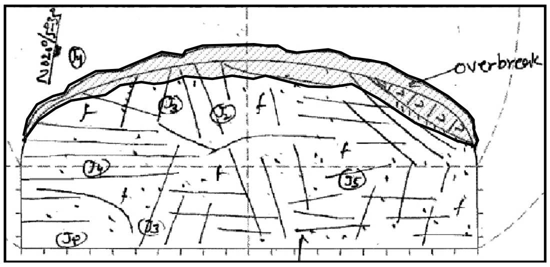


Fig. 10c - Surveyed profile for quantification

## 9. CONCLUSION

Prediction of possible areas of geological overbreaks through geological modelling and timely site specific treatment are very important and found very useful in controlling of geological overbreak during excavating large underground caverns. In the project the above PPDD methodology has been adopted to control geological overbreaks satisfactorily. The observations are documented to provide an insight of geological overbreaks in the present project and to aid engineering geologists in understanding and minimizing geological overbreaks in the future projects.

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