Treatment of geological hotspots in large underground storage caverns

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Abstract

Large underground unlined rock caverns is one of the economical alternatives for buffer storage of crude oil to ensure energy security of import dependent countries. An established technology successfully adopted in many countries, the principle of storage essentially employs ground water pressure for containing the product within an unlined rock cavern.

Based on a site investigation campaign involving geological, geo-physical, geo-technical and hydro-geological investigations, it is established that rock formations in conjunction with ground water conditions are competent for construction of rock caverns and suitable to store the hydrocarbons. In this connection, engineering geology forms an important aspect not only during the initial feasibility stage of the project, but also in subsequent execution phase, where in unlined rock caverns are built by conventional drill and blast technique.

Underground excavations by very nature require an active and dynamic design intervention during the construction progress. In this context during the excavation works predictive geological model is developed based on initial investigation results, which is further updated on a continuous basis as the excavation progresses through the stages of heading and benches. As part of this model, critical segments of the caverns are identified as geological hotspots. This approach, devised through geometric analysis of geological discontinuities, helps to ensure preparedness to address the rock-mechanical aspects of the identified segments, thus results in a reduced risk exposure.

The present paper outlines, the process of identification and the adopted approach to treat the geological hotspots during the underground excavation works for large underground storage caverns currently being executed in India.

1. Introduction:

Storage of crude oil in large mined rock caverns is one of the economical alternatives to secure energy security of import dependent countries. The principle of storage essentially employs hydrodynamic containment of product within an unlined rock cavern where the tightness of storage is ensured by directing ground water gradients towards the storage caverns (figure 1). In the process ground water table is maintained by uninterrupted artificial charging through water curtains so as to rejuvenate the ground water regime (Rath, R. et. al. 2008).

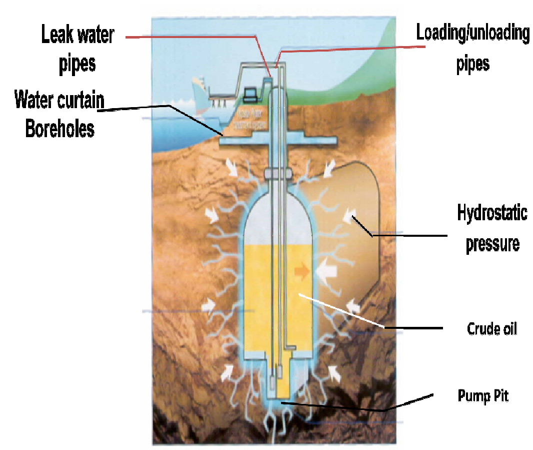


Figure 1 Schematic principle for unlined storage cavern

The water curtains are constructed by drilling and charging horizontal as well as vertical boreholes from small dimension water curtain tunnels encasing the storage caverns. In the present project inverts of water curtain galleries are designed to be 20m above the crown of the caverns.

Large caverns (900m x 30m x 20m) are constructed by conventional drill and blast technique wherein sequential excavation takes place through top heading and different benches.

2. The active and interpretative geological model:

The underground storage facilities are located within Archaean gneissic terrain of south India. The facility consists of four parallel caverns making up two units with two caverns each for storing two different products. During the routine site investigations of a storage cavern involving geological, geo-physical, geo-technical and hydro-geological investigations it was established that rock formations in conjunction with ground water conditions are competent for construction of rock caverns and suitable to store the hydrocarbons.

However, in one of the drill holes, a dolerite body was found to be intruding the parent rock formation in the form of a dyke with zones of hydrothermal alterations along the contact. This was included in the geological model (figure 2) as an intrusion within cavern alignment.

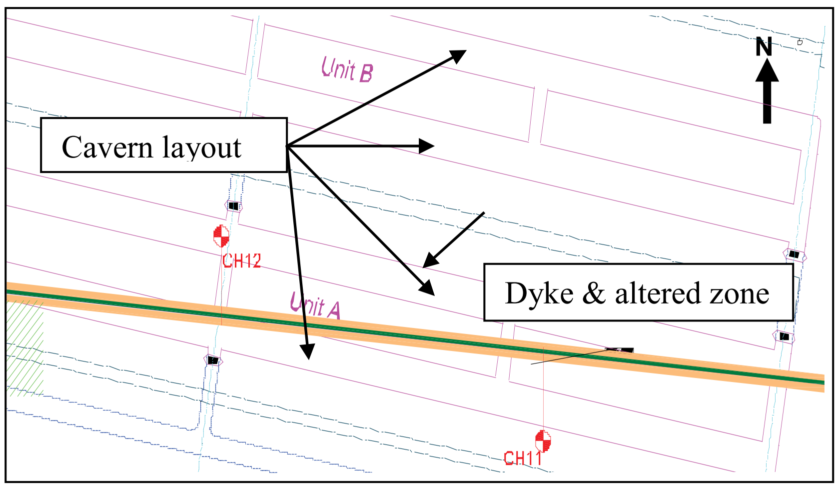


Figure 2 Geological model at investigation stage

The orientation of the dyke with respect to cavern alignment remained to be confirmed during additional site investigations in the pre-construction stage.

On the basis of judgement of friable cores (Photo 1), very poor (Q<1) rock was foreseen to be negotiated during excavation of cavern in the dyke section.

Photo 1 Core of investigation hole

During additional site investigations in pre-construction stage, definitive inclined bore holes were drilled to ascertain the orientation of the inferred dyke and the geological model. The geological logging of the core holes revealed that the hydrothermally altered dyke is oriented N-S with a westerly dip transecting the caverns across the alignment (figure 3). In this context, critical segments of cavern with likeliness of negotiating such features were marked as "Geological Hotspots".

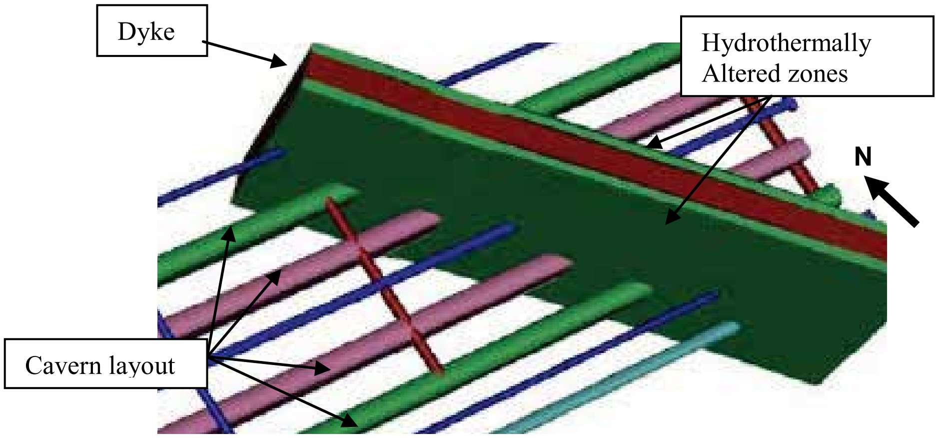


Figure 3 Geological model after additional investigation

During excavation of water curtain gallery which was likely to negotiate the dyke body; thin dyke bands were reported which was sub parallel to the alignment of galleries as well as the caverns. In order to confirm the disposition of the dyke as well as to assess the geological conditions associated with dyke in tunnel grade, a horizontal investigation hole of 69 m was cored along tunnel alignment. It confirmed the oblique model with the thin dykes being offshoots of the major dyke. The investigation hole revealed condition better than design stage with sharp contact on west and altered wider contact on east. The thickness of dyke along cavern was inferred to be 32m. No water seepage condition was observed along the contacts.

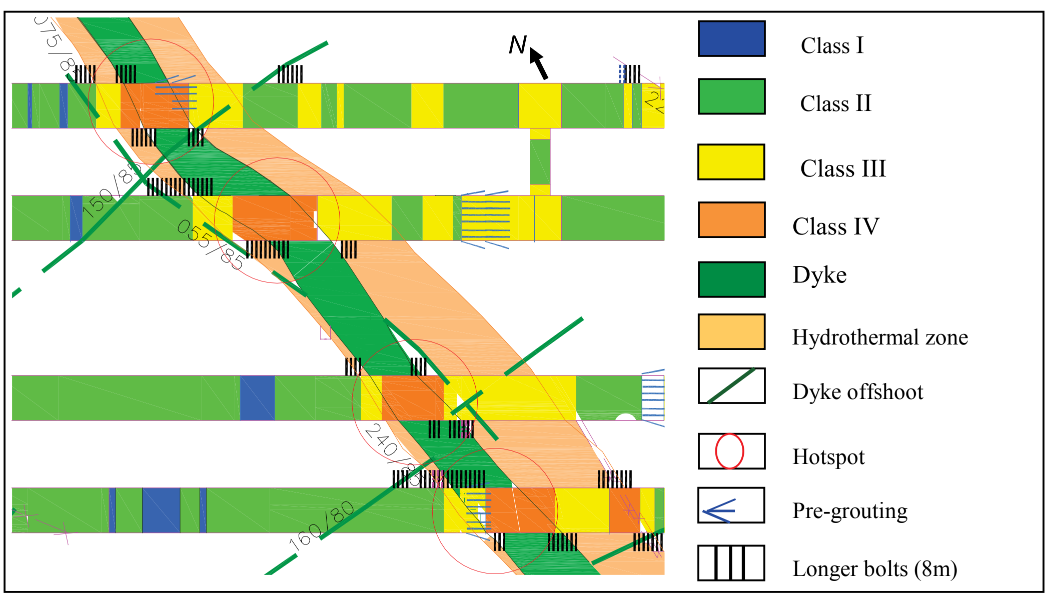


Figure 4 Excavation map of caverns

This investigation hole data and ongoing excavation mapping of the water curtain gallery helped to conceive a reasonably accurate geological model. However, presence of dyke offshoots and more severity of altered zones were additional information gathered during excavation of the cavern heading resulted in having a definitive model (figure 4).

3. Nature of the geological feature

The dyke is reported as mesocratic, and fine grained. The sub vertical (80° to 88°) tabular body extends over a length of more than 300m making an angle of 50°with the cavern alignment. Certain dip reversals are also observed with the dyke body dipping towards south west in southern part and towards north east near northern part. The thickness of dyke ranges from 24 to 31m. The contact is smooth undulating with alterations in form of weathered materials. The body is closely jointed with at least 5 sets of joints resulting in brittle behaviour of dyke (Photos 2 and 3).

Photo 2 Dyke in top heading

Photo 3 Dyke in Bench 1 excavation

At places the dyke is traversed by calcite veinlets as secondary infillings. Some dragging effects are observed in major joint set (J1) along the contacts of dyke. The Q values of dyke are in range of 2.1 to 3.9. Q values of dyke are in range of 1.85 to 3.9.
The western contact (Photo 4) is relatively sharp with width of hydrothermal alteration zone varying from 3-4m only. In northern part it is about 12m wide. The eastern contact (Photo 5) is widely affected by hydrothermal alteration, the width varying from 30 to 45m.

Photo 4 Western contact of dyke

Photo 5 Eastern contact of dyke

4. Active design in treatment of hotspot areas

At the basic design stage, provisions were kept for pilot excavation and side slashing for heading and benches. And in difficult rock conditions (Q<0.1) spilling, reduction of section and steel rib installation was scheduled (Tilak, R. et. al. 2006):.

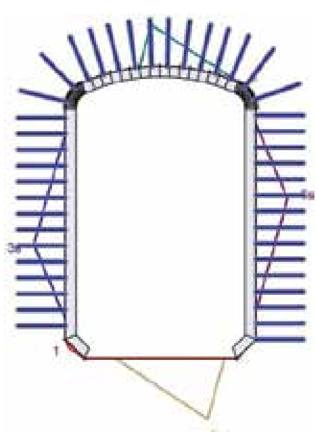
On the basis of rock mass characterization from geological logging of investigation hole as well as rock-mass classifications from water curtain galleries the model of dyke evolved to be persistent across all the caverns with altered zone on east and some water along eastern contact. As per the evolved model, following excavation plan was adopted:

- ✓ Pre-grouting before contact zone of the host rock and the dyke,
- ✓ Controlled blasting pattern (pilot blast, if required) with contour holes alternately charged along with dummy holes
- ✓ Sealing with fibrecrete immediately after the blast,
- ✓ Type 4 rock support with rockbolts at 1.3 m spacing and 200mm fibercrete.

During excavation, full face controlled blasting was used throughout the dyke. Selective pre-grouting was performed once the hydrogeological condition is affirmed.
In view the dimensions of caverns (heights of about 30m) and sequential stages of excavation it is difficult to revert back to earlier excavated benches. In the unavoidable scenarios, if reverting is compulsion, the project encounters cost and time overruns. Hence, it is absolute necessity to recheck and confirm the completeness of rock mass treatment before initiating the next lower bench. Therefore, clearances for lower benches were given only after revisiting and assurance of the following:

- ➢ Rock support adequacy for major wedges, in particular, in the hotspot areas
- ➢ Adequacy of treatment of water bearing joints
- ➢ Continuity of geotechnical monitoring system.

In order to analyse the potential wedges formed along the contact, wedge analyses (figure 5) were undertaken using Unwedge software with input for the model as C = 0.20 Mpa and $\phi = 33^0$ with a considered Factor of Safety >1.5.



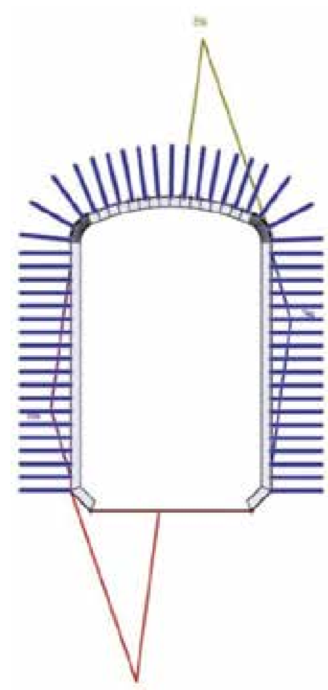


Figure 5 Wedge analyses in the identified hotspot areas

Scaling of wedges was done as trace lengths and persistence observed during mapping. The combination analyzer was used to find out wedges with least factor of safety. The wedges were found to be stable with installed support system.

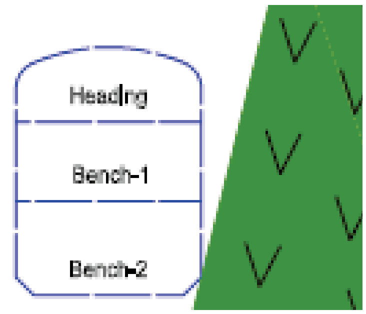


Figure 6 Geometrical analysis

However, to ensure the stability of walls, geometrical analyses were done for entire cavern sections considering the contacts of dyke to be the major detachment surface. Sections of full cavern were cut at the locations where dyke touches the invert (figure 6). Considering dip of 80°, the maximum distance of detachment surface was found to be 5.3m. To counteract any such wedges longer bolts (8m) were installed at the areas around inflexion points of dyke body, identified as geological hotspots.

In the hotspot area, optical targets were installed along the complete cavern section for convergence monitoring in order to validate the installed support providing stability of the excavated structure (figure 7).

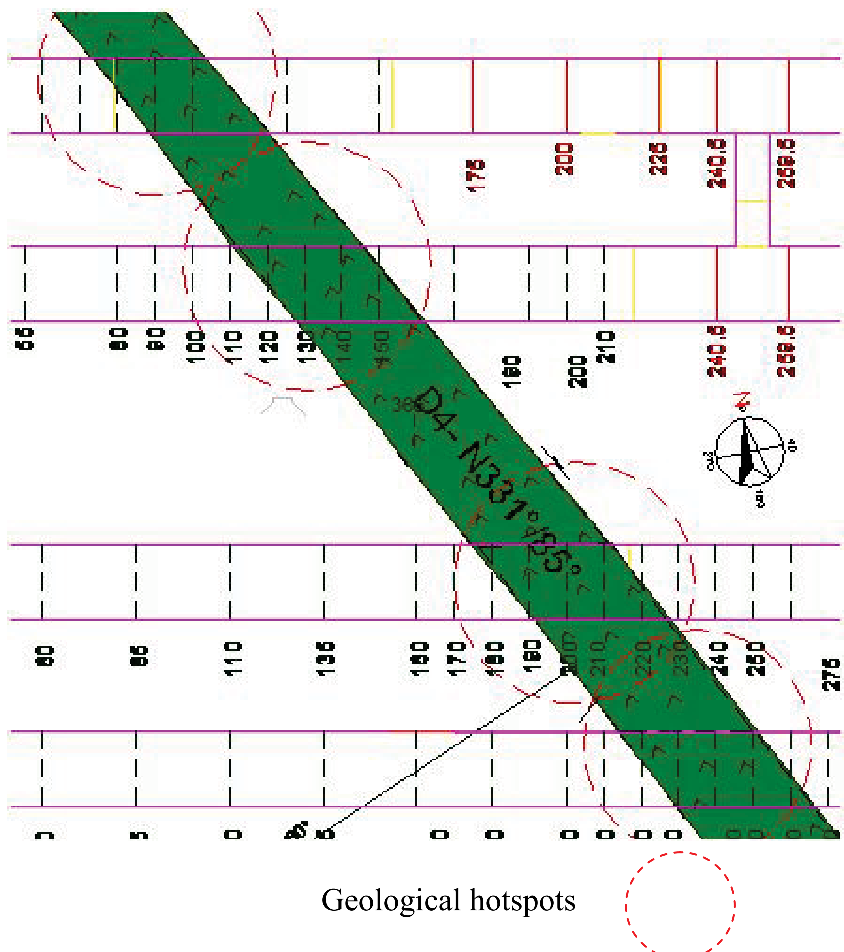


Figure 7 Optical target sections in hotspot areas.

Total ten targets are installed along the periphery of cavern in each section (figure 8).

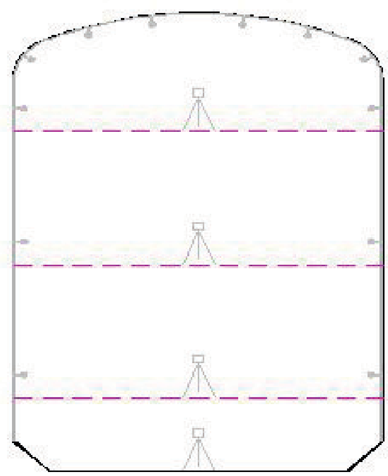


Figure 8 Optical targets in a setion

The displacements were found to be within safe limit of monitoring w.r.t to design displacements, taking in consideration the type of rock (figure 9).

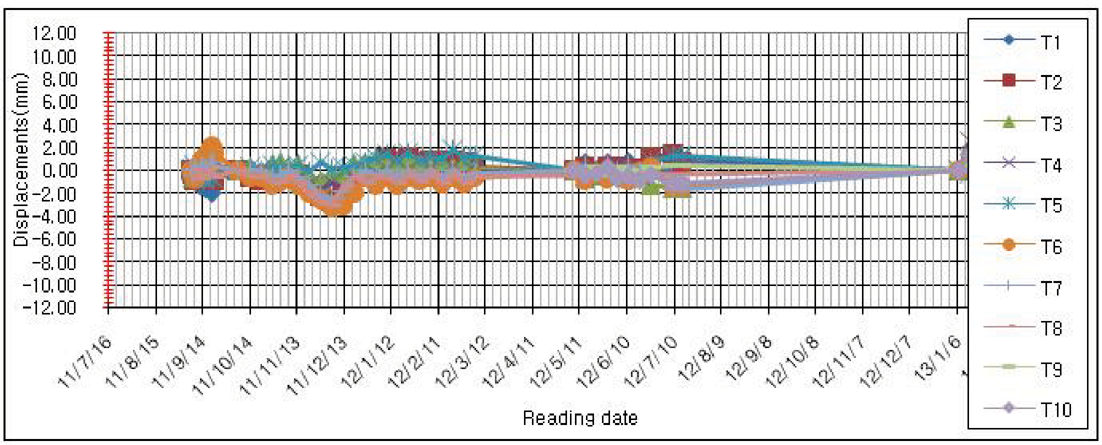


Figure 9 Displacement graph in hotspot area

5. Conclusion

Treatment of geological hotspots in large unlined rock storage caverns essentially comprise of identification of adverse features and hotspots in the geological model during investigation stages, ascertaining the model in pre-construction stage and constantly incorporate the inputs during different stages of construction.

The constant evolution and updating of geological model aids to participate in the dynamic modelling and active design so as to optimize the rock support system as per actual encountered site conditions. The process considered both analytical as well as geometrical analysis.

This is coupled with continuous convergence monitoring to check and validate the installed support. The entire approach builds and adds to confidence in completing the underground rock caverns on a safe note.

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References

1. Rath, R., Nanda, A., Malkani, S., Grover, R. K., (2008) : Under Ground Rock Caverns for Storage of Hydrocarbons, Tunnels & Underground Structures, Civil Engineering & Construction review, November 2008.
2. Tilak, R. and Nanda, A. (2006): "Design Aspects of Underground Rock Caverns for Storage of Hydrocarbons", Proc. Indian Geotechnical Conference, Chennai.