Underground Rock Caverns For Storage Of Hydrocarbons

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Oil consuming economies, in particular Indian economy is likely to become increasingly vulnerable to oil / gas supply disruptions in the coming decades for the growing reliance on specific regions for energy supply vis-à-vis the political instability associated with such regions. Therefore, the political economic damages from oil supply interruptions could be limited through emergency preparedness and response measures, both long term and short term.

The emergency response measures that could be implemented to alleviate the gap in the oil supply and demand include demand restraint, fuel switching, surge production and emergency oil stocks. The emergency oil stocks can be used reliably, at the government. discretion, during an emergency to make up for the short fall caused by interrupted oil supply.

Conceptualisation of Strategic Petroleum Reserve for India dates backs to 1998, and Engineers India Ltd. has been a key technology provider and consultant to Ministry of Petroleum & Natural Gas, Govt. of India. Currently, three sites have been identified for storage of crude oil, viz. Vishakhapatnam, Mangalore and Padur (Udupi). The present campaign of Govt. of India is aimed at creating storage facilities of 5.00Million Tonnes of imported crude oil which is equivalent to 15 days refining throughput. In all the three selected sites the storage facility involves creation of underground unlined rock caverns with hydro-geological containment philosophy.

The present article deliberates on the broad outlines and technical requirements for creation of such underground storage facilities.

Hydrocarbon Storage

Owing to the present geo-political scenario of the world, energy security of a nation has become very important. In order to ensure energy security, federally owned oil stocks are stored in huge underground storage caverns. Strategic locations are selected with an option of providing the most flexible means of oil and gas transport network.

Advantages of underground storages are essentially based on aspects such as space saving, economical, environmental friendly and strategically safe. Selection of a storage concept for underground storage of hydrocarbons are made according to the following parameters:

- Storage requirements
- Subsurface rock mass quality
- Purpose of storage ; civil or military
- Storage product loading and unloading
- Safety and environment conditions
- Geological setting of the site

In general, four different types of storage concepts are in use:

Type 1: Unlined underground rock caverns with hydraulic containment of storage products (Scandinavian Storage Concept)

Type 2: Unlined underground salt caverns in impermeable rock formations that is in salt beds and salt domes

Type 3: Pore space storage in depleted oil and gas reservoirs/ deep aquifers

Type 4: Lined rock caverns (In pilot stage)

Storage In Underground Unlined Rock Caverns

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 campaign involving geological, geo-physical, geo-technical and geo hydrological investigations, it is established that rock formations in conjunction with ground water conditions are competent for construction of caverns and suitable to store the hydrocarbons (Fig 1).

Storage In Salt Caverns

Salt caverns are created out of salt formations by a process called "Solution Mining". Essentially, the process involves drilling a well into a salt formation, then injecting massive amounts of fresh water. The dissolved salts are pumped out as brine and disposed. Besides being the most economical way to store petroleum products for long periods of time, the use of deep salt caverns is also one of the most environmentally safe option. Rock salt provides an excellent impervious environment for oil, fuel and gas storage- it is insoluble in hydrocarbons and does not show any chemical reactivity with oil and liquid fuels.

Storage In Depleted Oil & Gas Reservoirs And Deep Aquifers

This type of storage involves usage of depleted reservoirs for storage of hydrocarbons by pumping the products in the reservoirs. Formerly a product bearing reservoir formation overlain by an impermeable rock formation satisfies the confinement requirements, it would be either a stratigraphic trap or a structural trap or both. The permeability and porosity conditions of the product bearing strata also conform to the storage requirements. Owing to its wide availability, this type of storage forms one of the most predominant storage options for natural gas.

In case of deep aquifers the water bearing pore spaces are confined underneath an impermeable cap rock formation. The products are pumped into the pore spaces and contained within the formation.

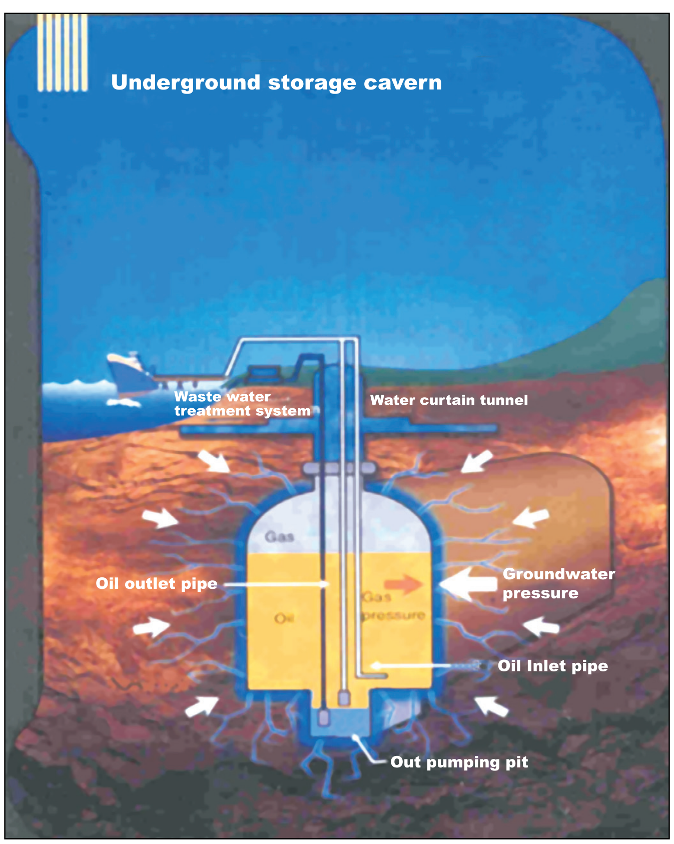

Fig. 1: 3 Dimensional Model Of A Typical Unlined Underground Cavern

Storage In Lined Rock Caverns

This storage concept has an advantage that it is suitable for any storage product whatsoever without restriction. Further, it offers the advantage that the storage product is stored in a neutral atmosphere as it is not in contact with rock formation and ground water and its quality is therefore not disturbed. This technology provides advantages in terms of environmental aspects and improved safety and a wide variety of product storage options but is very expensive. The lining provided for these storages are of steel alloy and reinforced cement concrete. Normally lined storage facilities are used for storing a product which does not get liquefied by pressure alone such as natural gas. These storages could also be cryogenic, to fit in higher volumes of petroleum gas in liquid form.

Underground Unlined Rock Caverns

Storage of hydrocarbon in unlined rock caverns is the most economical solution for storage of large volumes. The basic principle of storage in unlined rock caverns is the hydraulic confinement. Thus the rock caverns are planned at a depth such that there is sufficient hydrostatic pressure to counter the vapour pressure or liquid pressure of the stored product on the walls of the cavern.

These caverns are created where permanent ground water table is high. In order to further secure the water flow from the rock mass towards the cavern, a water curtain system is provided consisting of galleries located above the crown of the cavern. A saturated rock mass and ground water flowing into caverns, ensures proper sealing of the stored product from leakage. For ensuring stability of the caverns, a support system of shotcreting and rock bolting is commonly used.

Site Characterisation

A Pre-feasibility study for selection of site is carried out including collection and reviewing of all available geological, geotechnical and hydro-geological data of shortlisted sites in addition to proximity to available infrastructure for transportation, nature of habitat and population density, adequate and suitable areas for dumping of the excavated muck and associated environmental concerns.

Thereafter a detailed feasibility study of the selected site is carried out once the site has been selected based on pre-feasibility studies. The detailed feasibility studies encompass extensive field investigations campaign, followed by analysis of on-site information both laboratory and numerical modelling so as to establish suitability of the site. Based on the collected information and results there of, design of the proposed facilities shall be undertaken. In general, the investigations include geological assessment, core drilling in rock to a depth of about 150m, geo-physical and hydro-geological investigations etc. so as to establish the geological setting of the site, the rock mass characteristics, the geo mechanical properties, in situ rock stresses, permeability of different rock strata and hydro-geological characteristics of the proposed area.

The planned investigation campaign is necessary not only to perform the detailed design of the facilities but also to minimize the possibility of encountering any geological surprises during the excavation.

Design Aspects

For underground rock cavern storage facilities, the following pre-requisite information are necessary:

- Geo-mechanical parameters of the rock mass
- Geological setting of the site
- Hydro-geological setting of the site
- Type of the product to be stored
- Geographical constraints of the area
- Environmental consideration and restrictions within the area
- Resources available at the location or the region
- Emergency procedures required to be developed

The facility is designed to handle the product stored and to control the entire process for receipt and evacuation of the product from the cavern while ensuring secure inventory of the product.

The layout, cross-section and elevation of the caverns are designed considering the product to be stored and operational requirements as well as the geotechnical conditions and geological setting at site. The overall layout and the cross-section of the cavern is selected so as to achieve a favourable stress condition vis-à-vis the in-situ stress regime of the site which also take into account any major geological structures (Fig 2).

Estimation of the rock mass properties and rock support are initially performed using the empirical rock mass classification schemes proposed by Bieniawski (RMR), Barton (Q-system) and / or Hoek-Brown (GSI). The rock caverns are then numerically analysed for stresses and wedge stability.

Depending on the site conditions, while the size and shape of the caverns could vary, the crown level of the caverns is designed adequately below the ground water level so as to

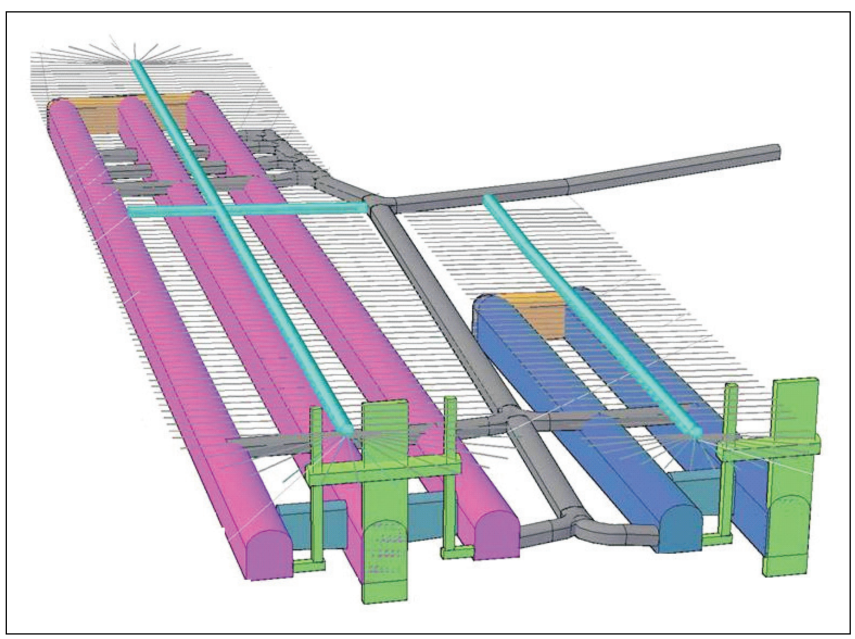

Fig. 2: A Typical Cavern Layout Along With Superimposed Water Curtain System.

ensure the hydro static pressure requirement for containment of the product. Hydrodynamic containment is further reinforced by provision of a water curtain system above the cavern. This is then further confirmed through numerical modelling.

For the storage purpose, in general 'U' shaped caverns are planned, having leg lengths proportional to volume of the type of crude to be stored and number of caverns depending on the suitability of the site. The caverns are oriented in a direction so as to come across minimum geological problems such as joints, shear zones and principal planes of horizontal stresses in the rock while excavating the caverns. The caverns, in general have a D shaped cross section. For ensuring stability of the caverns, a support system of shotcreting and rock bolting is envisaged.

While the cavern geometry is dependent on the geological setting of the selected area, in general the typical dimension of a cavern cross section is about 26m to 31m in height and 16m to 20m in width. However, the length of the cavern is designed to accommodate the requisite volume of storage and the extent of suitable rock quality at required depth is available. In general approach, the caverns are laid out in parallel with minimum separation of 30m.

Water infiltration gallery and water curtains, above the crown level of the cavern are provided to ensure a constant water pressure towards the caverns. Boreholes are drilled from the water curtain tunnel to intersect all the joints of rock mass.

The submersible pumps in the caverns are designed to deliver the crude oil either to the nearest refineries or back loading in the tankers for despatch to other refineries, through new pipelines to be connected to the existing pipelines.

Construction Methodology

In general excavation of an underground storage cavern is undertaken either through an access shaft or through an access tunnel (inclined drift) or a combination of both. While various factors contribute in deciding the methodology, availability of land around cavern site and the depth of the cavern are two most important considerations.

In either case, the access tunnel / shaft is designed to handle/ accommodate the following:

- Access of men and material into the cavern during construction;
- Entry of all equipment required for the underground works
- Removal of muck, simultaneously with the movement of men and material

Underground excavation is carried out by conventional drilling and blasting cycle, in stages with the top heading being taken up first followed by excavation of the benches. The top heading is excavated with horizontal drilling for smooth contour of the crown, followed by the benches, which are either excavated by horizontal drilling or vertical drilling depending on the construction methodology with respect to the progress of the execution.

The stages of excavation broadly involve construction of entry portal for access; excavation of access tunnel and / or shaft; excavation of water curtain tunnels; excavation of the storage caverns in stages; providing rock support as the excavation progresses; followed by concrete plugs to seal the cavern. Concurrently, water curtain boreholes are drilled from the water curtain tunnel and filled with water after being sealed.

A typical cycle of excavation includes the stages such as surveying and setting out; drilling probe-holes; marking the excavation face; drilling of blast-holes; charging of blast-holes; blasting; defuming; scaling; demucking; geological mapping; estimation of rock support; installation of shotcrete and spotbolts; ventillation; excavation face.

Per cycle excavation progress achieved depends on various factors viz. the design requirements, blasting patterns and the nature of rock mass with a typical pullout or progress of 3.5 to 4.0 m vis a vis a blast cycle of about 10 to 12 hrs.

During the entire excavation process, particular attention is given to ensure that the rock mass remains saturated with water even while excavation works are in progress.

In view of the cavern size and excavation sequence, muck removal from the cavern face forms an integral part of the construction planning. Therefore, while a suitable site of adequate holding capacity is selected for muck disposal; the lead distance between the construction site to the disposal site is also very important.

On completion of the excavation, the caverns are isolated and sealed by installation of concrete plugs. While this ensures confinement of the stored product, the shafts provide the necessary inlet and outlet pumping facilities.

Conclusions

Advantages in support of under ground storage in unlined rock caverns compared to conventional surface storage can be listed as under:

(a) Minimal requirement of surface land;

(b) Nearly zero risk of fire hazards;

(c) Almost complete protection against bombing and sabotages;

(d) Zero risk of ground water contamination through oil seepage.

Unlined storage caverns are normally excavated as large horizontal tunnels. Since confinement of the stored product is achieved through the existing hydrostatic pressure, in principle, caverns can be designed to a shape confirming the structural stability and stress regime of the site, provided they are constructed well below the ground water level. However, the cavern roof is located at such a depth below the water table that the ground water pressure is higher than the gas pressure in the cavern. And, dimensions of the cavern such as height, width and layout are decided based on the requisite storage volume, rock quality, excavation methodology to be adopted, and technical requirements.

Acknowledgements: The authors wish to thank management of Engineers India Ltd. New Delhi for according permission to publish the article.

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