The Padur Cavern: a strategic reserve for the nation

The cavern for strategic storage of crude oil at Padur in Karnataka being built by HCC

India, along with 17% of the world's population, contains less than 1% of the known oil and gas reserves. It imports about 70% of its oil and gas requirement and this dependence may increase to 90% by 2020. The supply of fossil fuels to India is dependent on various geopolitical forces. If the supply is disrupted due to theft by pirates, geopolitical blocks/ alignments, shipping accidents, cartel formation by companies, price shocks, wars, political unrest, threat by terrorist attacks etc., the whole economy is forced to a grinding halt with losses to the tune of billions of rupees. Furthermore, in case of such an occurance, it will take more than six months for the economy to normalise.

Therefore, strategic storage of fuels was envisaged by the Government of India to tide over sudden disruption in fuel supply. Strategic storage will also help in price stabilisation as fuel can be strategically stocked during low demand and used during high demand. Storage of fuels in underground unlined rock caverns is currently being implemented in India.

It is a mature and well-proven technique that was originally developed in Sweden in order to achieve advanced protection against possible weaponised attacks. The storage principle has been implemented in several countries, including Sweden, Finland, Norway, Japan and South Korea.

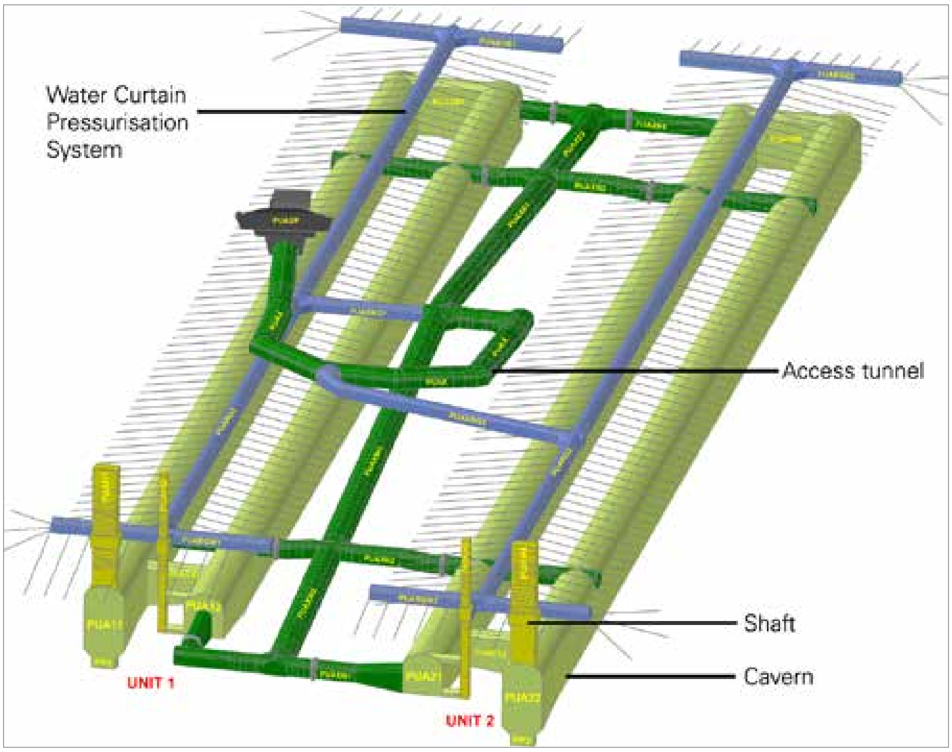
Ensuring our energy security

In pursuance of the decision of the Ministry of Petroleum and Natural Gas, a Special Purpose Vehicle (SPV) called the Indian Strategic Petroleum Reserves Ltd (ISPRL) was incorporated as a wholly owned subsidiary of Oil Industry Development Board. ISPRL has ownership and control of the crude oil inventories and is coordinating the release and replenishment of the crude oil stock with an empowered committee constituted by the government.

At present, three projects are in progress under ISPRL totalling the crude oil reserve of 5 MMT at Vizag (1.33 MMT), Mangalore (1.5 MMT) and Padur near Mangalore (2.5 MMT). The first underground oil cavern at Vizag, Andhra Pradesh, was awarded to HCC in January 2008, which is almost complete, and the second one at Padur was awarded to HCC in December 2009. ISPRL has appointed Engineers India Limited (EIL) as the project management consultant for this Project.

Project details

The construction of an underground storage requires large underground excavation within a short period. It requires a tight construction schedule with detailed planning, deployment of necessary equipment,



Conceptual Design of Underground Caverns

qualified manpower and strict adherence to all quality and safety procedures. The entire scope of the work envisages feasibility, analysing and planning for various construction stages, geological, geo-hydrological and geotechnical models for engineering and design, construction methodology and geotechnical and geo-hydrological monitoring during the construction and post-construction phases of the Project.

At Padur Cavern, HCC was awarded works equivalent to 50% of the total storage capacity of 2.5 MMT. Accordingly, the storage cavern work by HCC at Padur comprises two parallel caverns, with a pair of U shaped legs of 656m and 700m length. The total length of caverns is 2,772 running metres. The cavern width is 20m with a maximum height of 31.4m. The access tunnels measures 1,570m and the water Curtain tunnels comprises of total length of 1940m.

The cavern has two main shafts (Pump Shafts) of 12m X 6m dimensions and inlet shafts of 4m X 4m dimensions measuring a total length of 321m. The work also involves construction of eight tunnel barriers, four shaft plugs, cavern flooring works, piping fabrication and erection works and the New Austrian Tunnelling Method (NATM) for supporting excavated tunnels.

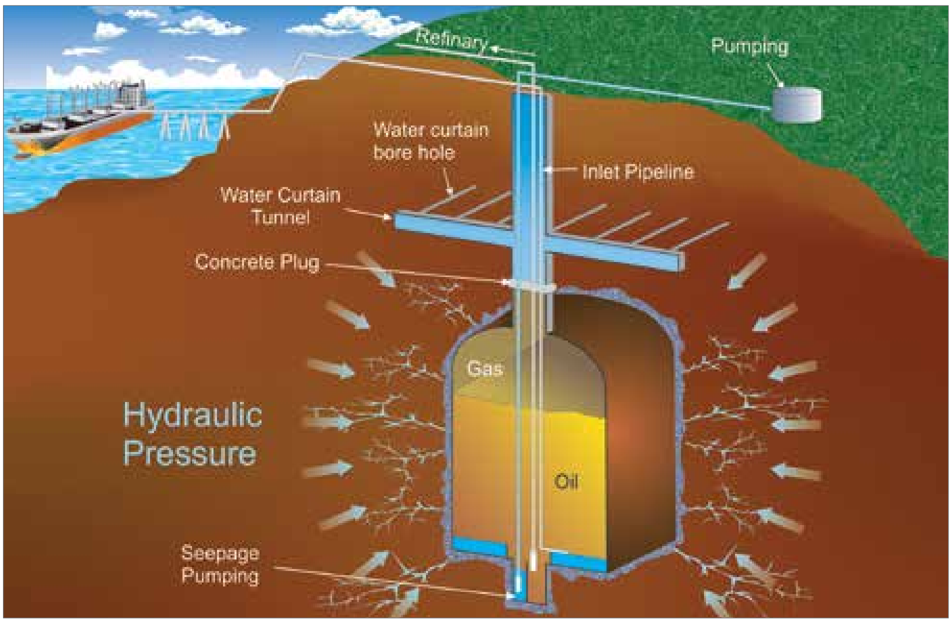
Working principle of oil storage

The underground oil-storage caverns are not lined with concrete as in the case of hydro/road/metro/rail tunnels. The basic principle of storage in unlined rock caverns is hydraulic confinement. Rock caverns are planned at a depth such that there is sufficient hydrostatic pressure to counter the vapour pressure of the stored hydrocarbon. Storage in unlined caverns is based on the fundamental principle that the stored cavern is located well below the surrounding groundwater level and the stored oil is lighter than water and not soluble in it. When the cavern is excavated below the surrounding groundwater level, due to natural fissures in the rock, water continuously percolates into the cavern, thus preventing oil from leaking out in form of vapour/gas.

The crown elevation of caverns in the Padur Project is –60 m. In order to check and secure water flow from the rock mass towards the cavern, a water curtain system is provided, which consists of galleries located above the crown of the cavern. Boreholes are drilled from the water curtain tunnel to intersect all the joints of rock mass. Saturated rock mass and groundwater flowing into caverns ensure proper sealing of the stored product. Water leaking in through the rock-mass joints into the cavern is drained to a pump pit and pumped out at regular intervals. Particular attention is given to ensure that the rock mass remains saturated with water even while excavation is being carried out. The cavern should not be excavated before pressurisation of water 50 metres ahead of excavation. The principle behind the requirement is to ensure that cavities and fissures inside rock-mass do not dry up.

Construction process

The excavation was carried out using conventional drilling and blasting methods with drilling jumbos for drilling, 6.5 cum loaders and 30MT Volvo/Scania dumpers were used for mucking. Excavation is done in stages with heading and three benches each of 8 metre high. The sequence of excavation follows a pattern shown in the figure 1.



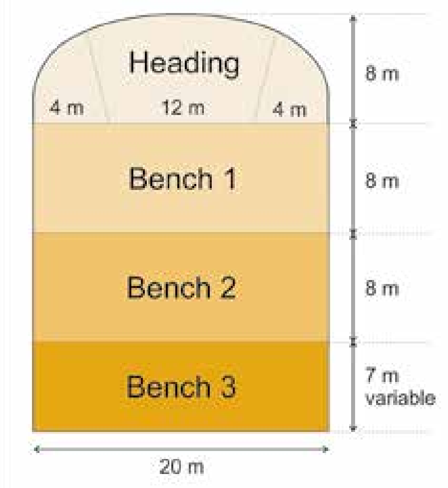


Fig 1: Cross-section of the excavation sequence across the cavern

In order to complete the excavations in a shorter time period, HCC mobilised a fleet of state-of-the-art equipment and achieved more than 1 lakh cubic metres underground excavation per month consistently for four months.

Access tunnels are made to allow for the use of heavy equipment for excavation of rock caverns and execution of underground civil works installation. The access tunnels are 12m in width and 8m in height. Cross-access tunnels are 8m X 8m.

Water curtain tunnels of 6.5m X 6.5m are made for allowing drilling of water curtain boreholes. The excavation was done using drilling jumbos and mucking with 3.0cum loaders and 10MT reversable dumpers.

Excavation of shafts was taken up once the open excavation was completed in all respects. Excavation of shafts was carried out by the full sinking method from the top. Jackhammers were used for carrying out drilling required for the excavation.

Drilling and blasting works: 5.5-metre long drilling jumbos were used for achieving optimum pull and improved productivity in drilling. Bulk explosives in combination of non-electric detonators are being used as blasting explosives. By using bulk charging units, 50% time was saved in charging of explosives and hence resulted in increased productivity.

Rock bolting: Rock bolts used for support are 25 mm diameter with length varying from 3m to 8m. Centralisers are installed over rock bolts to ensure grout cover all around the rock bolt. The water-to-cement ratio requirement was 0.28 to 0.32. Mai pumps are used to achieve the water-to-cement ratio. S-N Method of grouting is followed for rock bolt grouting works.

Shotcreting is being done with Normet spraymec machines. Steel fibres are mixed in shotcrete for better tensile strengths.

Water curtain pressurisation system: 254 water curtain boreholes of 95 mm diameter were drilled up to individual lengths of 55-75 metres from inside the water curtain tunnel. Accuracy of drilling was extremely important and deviation permitted was just 5%. Acute monitoring of drilling was ensured using Ez-trac camera. The total length of the water curtain borehole was 12,145m. The job was satisfactorily completed ahead of schedule.

These water curtain boreholes were then pressurised with water by a temporary main supply line from outside the tunnel, with each individual hole having separate connections and flow and pressure metres installed.

The pressure and flow are monitored daily in order to know the water inventory, both in terms of water intake by the rock mass and seepage pumped out of the cavern. The pressure in any case should not be below 4 bars and none of the monitoring wells should go below the - 20m elevation.

Monitoring wells were drilled at 13 locations and piezometers were installed to monitor surrounding groundwater levels. Daily water levels are being checked in these monitoring levels to understand water table behaviour and ascertain that the water table at any locations around caverns does not fall below - 20m. Prior to testing the tightness of the caverns, the temporary water supply system to the water curtain boreholes will be disconnected and water will be filled up to the driveway level (El.- 18.5m). After completion and acceptance of the caverns tightness testing the water curtain tunnel (including part of the access tunnel) will be filled up to 0.0 MSL to ensure hydraulic confinement by saturation of the rock mass.

Checks and balances

Geotechnical monitoring is done regularly to check the deformation in the cavern during excavation. Displacement of the rock mass is monitored with a borehole extensometer, optical targets and tape extensometers. Trigger values have been specified for allowed deflections based on rock strata. In case deformations are beyond these trigger values, then corrective actions such as additional rock bolting and shotcreting are taken immediately before proceeding with further excavation.

Geological mapping and data analysis: Q value system is used for excavation mapping and data is fed into the KRONOS software, specially designed for geological modelling. Every fortnight, a predictive 3D geological model is prepared using data and analysis of previous mappings. The 3D Q value map is also plotted to have a better understanding of geological features. Core drilling is carried out at El. - 18.2 m in order to know geological features ahead of cavern excavation. After the excavation of faces, optical targets are installed


Access Tunnel

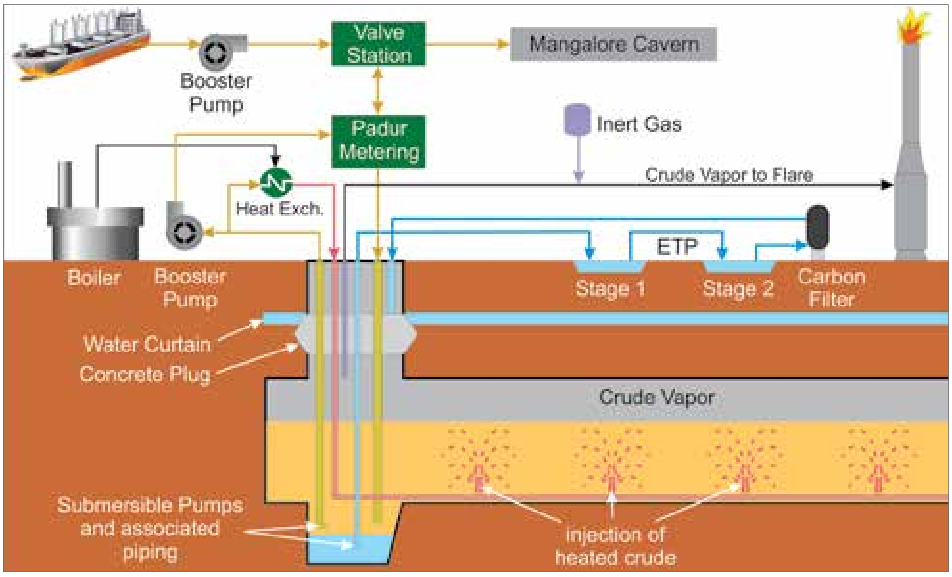

Water Curtain Tunnel


Piping Work in Progress

Pipelines being installed in the shaft

and monitored by the survey team on a daily basis to know deflections in the rock mass, if any. The data is also fed to KRONOS, which gives off an automatic alarm if deflections are above set critical limits. The NATM method is followed for rock support system.

Hydro-geological monitoring: The purpose of hydro-geological monitoring was to ensure that there is no impact on the hydraulic safety of the caverns during construction and operation phase. Hydro-geological monitoring of the rock caverns consists of monitoring of water levels in piezometers and monitoring wells, monitoring the flow rate of water injected and pressure in individual water curtain boreholes, monitoring rainfall and a chemical analysis of water samples fed to the water curtain system.



Operations of an underground cavern for crude oil storage

Piping works

Loading and unloading of the crude oil from the cavern is done through pipelines anchored in shafts. Besides loading and unloading pipelines, the shaft also anchors pipelines for the submersible crude oil pump, the seepage water pump casing, hot oil recirculation pipes, perforated casings for level transmitters and temperature transmitters, pipes for steam injection, vent line and casing for water curtain monitoring and filling of make-up water.

The loading pipeline is extended up to the bottom of the inlet shaft and then horizontally up to 20m at the cavern floor level, so that crude oil flows from the inlet shaft to the pump pit thus minimising the risk of sediments or sludges settling down on the cavern floor. The withdrawal of the crude oil from the storage unit is done by five submersible pumps installed inside the casings anchored in the concrete plug.

The seepage water is removed from caverns by submersible pumps installed inside casings anchored in the concrete plug. For the inventory of product quantity in the caverns and for safety reasons, an accurate level control system is needed for both product and water, so as to avoid overfilling/overpressure/product pumping by the seepage water pumps.

The continuous level measurement instruments are installed inside the casing at the concrete plug level and extend up to the pump pit floor. In order to have a free flow of crude oil/vapour and equalisation of vapour pressure inside the casing and the cavern, perforations/holes at regular intervals have to be provided in the casing pipes.

The temperature sensor pipeline is installed with cables connected to temperature sensors distributed at various levels and locations in the storage galleries. In order to have a free flow of crude oil/vapour and equalisation of vapour pressure inside the casing and the cavern, perforations/holes at regular intervals have to be provided in the casing pipes.

The purpose of the vent line casing is to allow vapour in and out from the cavern and for its pressure control. It is also used to inject inert gas to avoid excessive decrease in the cavern pressure during withdrawal. Contrary to the other casings, this casing only extends down to the cavern roof.

To remove sludge, the heating arrangement for the bottom portion of the crude is considered by circulating crude through a crude/steam heat exchanger. Two common sets of exchangers are provided for the caverns. The total crude is re-circulated and heated up to 60°C (max) during a period of approximately one month for each cavern. A horizontal pipeline is located along the bottom of each unit with jet nozzles for the injection of heated crude into the crude liquid. By injecting heated oil at the bottom of the cavern, an effective mixing is achieved in the whole storage. Crude oil is also circulated by one or two of the crude oil pumps. The re-circulation pipes along the cavern bottom are encased in concrete for protection. The pipeline diameter and nozzle size ensures equal flow throughout the total pipe length and optimises throw length and flow.

Conservation of water by recycling

Water consumption at the Padur Cavern Project is mainly for drilling, concrete/shotcrete mixing/curing and for supply to water curtain boreholes. The total requirement of water is about 5 lakhs litres/day, which is sourced locally.

As part of the UN Global Compact's 'CEO Water Mandate', the project team installed a wastewater treatment plant of 1 MLD capacity with an investment of Rs 55 lakh. The reuse of water has not only led to substantial savings on the cost of water, but also drastically reduced

1MLD capacity wastewater treatment plant setup at Padur cavern site

the stress on local aquifers ensuring that the water needs of the local community are not affected due to extraction of groundwater. The investment cost for the plant was recovered within just four months.

During FY 2012-13, 78% of the water requirement at the site was catered through reuse of treated wastewater. The site demonstrated water-use efficiency of 1,467%, which is the highest amongst HCC sites.

Summary of fresh water conservation – April 2012 to March 2013:	
Activity	**Total (KL)**
Tunnel activities	1,30,324
Dust suppression activity	4,755
Casting and curing	88,000
Total fresh water saving	**2,23,079**

Safety in tunnelling

Safety is extremely important and the company officials worked towards sensitising labour and creating greater awareness of safety standards with gentle persuasion, consistent motivation and toolbox meetings. Various training programmes on blasting safety, traffic safety, mock drills and first-aid training, and AIDS awareness training were conducted at the site.

The Project has achieved six million safe man hours without any loss-time incident and received an award from the top management at HCC-HO for excellence in safety performance for the year 2012-13. The site also received various safety awards from the client ISPRL and the engineering consultant EIL.

Equipment used

Equipment	Quantity
Drilling jumbos	8
Robo arm shotcreting machines of Normet make	2
6.5 Cum capacity loaders	2
4.5 Cum capacity loaders	3
30 Ton dumpers	28
18 Cum batching plant	2
250 MT crane	1
EOT crane	2
Bulk charging units	3
Tele handlers	3
Automatic access gate	3
Mai pumps for rock bolt grouting	7
Unigrout pump for rock mass grouting works	2
Vertical drilling machine of Sandvik make (DX 700)	1
Percussion and core drilling machines	3
Reversible 10 MT dumpers	6

Major quantities

UG rock excavation	17.0 Lac Cum
Rock bolts	3.40 Lac Rmt
Fibre reinf. shotcrete	20000 Cum
Water curtain boreholes	12150 Rm / 254 No
Rock mass grouting	1300 MT
Piping fabrication works	14000 inch dia.
Piping erection works	135000 inch m.
Concrete	30000 Cum
Reinforcement	2200 MT

DID YOU KNOW ?

Economics of underground storage

Underground storage of hydrocarbons in large quantities is technologically proven, more secure, safe and economical, generates less evaporation losses and is more environment friendly than above-ground storage.

Unlined rock caverns require low maintenance and safety is in-built as product storage is underground, which is fully isolated. Hazards on account of sabotage by terrorist activity, war, bombing (nuclear bombs), storms, earthquakes, floods, typhoons, tsunamis, external fires, etc., are minimised. The life of the underground storage is longer than above-ground storage.

Generally, underground storage installations are below sea level, hence faster unloading of tankers/ships takes place. The control system and fire-fighting system are much simpler and cheaper to construct and operate.

The construction cost of underground rock cavern storage is cheaper than that of surface tanks. As the size of the caverns increases, the cost of the cavern decreases, ie, the cost decreases with storage volume.

The most significant savings in operating costs are: (i) reduced land rent/cost, (ii) reduced amortisation of construction costs, (iii) considerable savings in insurance costs (reduction of 60–70% when compared to above-ground facilities), (iv) reduced maintenance cost and (v) reduced safety requirement and cost.