Tunnelling: Coming through the ages

Tunnels have played a vital role in the evolution and sustenance of man-kind through the ages. History has seen the evolution of tunnelling starting with cave formation, for water management, under ground transportation, mineral extraction and for warfare purposes. The oldest reference of a tunnel was in Persia where tunnels were built to connect wells called "Qanats", that used to provide a reliable supply of water during hot, arid and semi-arid climates. The deepest known qanat is in the Iranian city of Gonabad, which after 2,700 years, still provides water for drinking and agriculture to nearly 40,000 people.

Initially hand dug with crude tools like chisels, hammers, spades and shovels, the civil engineering tunnelling technology has seen progress in leaps and bounds. The ever increasing needs of the modern human race have driven the tunnelling technology to its pinnacle. This is being realized through rapid advancements in terms of geological and hydro-geological engineering, tunnel design, capacity, construction methods and speed and maintenance during operations. Safety during construction and operations is getting integrated in all aspects through conscious and educated decisions.

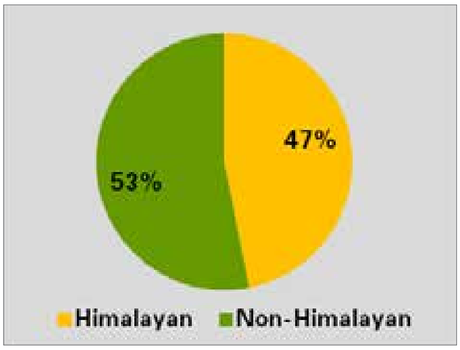
Historical Evolution

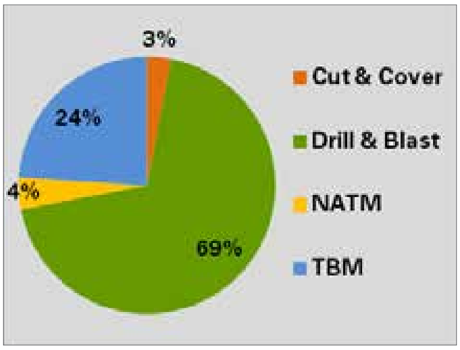
In regard to civil engineering applications of tunnels, the ever increasing need for earlier revenue generation and meeting of the coveted objectives has led to manifold changes in all the aspects of tunnelling, while some fundamental aspects still remain unchanged. For example, the cut-and-cover method (that involves digging a deep trench, constructing a roof at an appropriate height and covering the trench) has its first reported use in 2000 BC in Babylon and is still employed in modern-day construction.

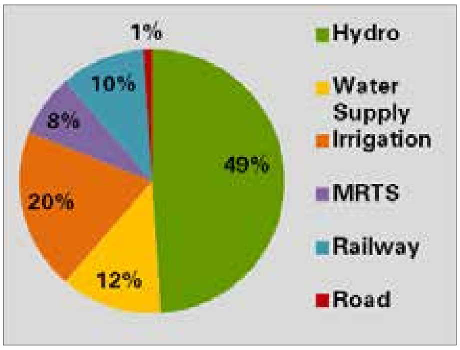
Geology is the most important factor that determines the nature, form and cost of any tunnel. Owing to the uncertain geology, tunnelling presents a risky undertaking primarily because of the geological complexity encountered and also because of the lack of commensurate knowledge, skill and experience.

Although the basic principles of geotechnical and geological engineering have remained the same, the application of interdisciplinary sciences, evolution of analytical tools and refinement in instrumentation, and computational methods over the past 25 - 30 years have improved our ability to better understand the in-situ conditions and hence tunnel designs.

The explosives technology has undergone significant advancements. What started with the use of gun powder as an explosive in the first mechanized tunnel construction (the drill and blast method) in France in 1681, transited to the use of Nitroglycerine as dynamite. During the past 50 years, ammonium







Statistics of tunnels built by HCC under various types of terrains, tunnel methodologies and tunnelling applications

nitrate has played a dramatically increasing role as an explosive. As a safer and sustainable alternative, water gel explosives have evolved over the past 25 years as commercial explosives.

Envisaging the construction of twin tunnels under the Thames River between 1820 and 1865 , British engineers Marc Brunel and James Greathead developed models of a tunnelling shield.

To sustain construction speed and safer operations, ground stabilization techniques evolved over time. This started with the technique of freezing the soil by circulating a coolant through the pipes and was introduced in 1900 in the United States of America. Injection grouting into soils and weaker rocks was introduced in the 1970s as a mechanism for waterproofing and ground improvement. Concrete, initially used in the dry form (Guniting) in 1907 developed into its wet form (Shotcreting) in 1950. These were utilized both as preliminary and final lining options for tunnels.

In 1931, the first drilling jumbos were devised to dig tunnels that would divert the Colorado River around the construction site for Hoover Dam. These jumbos consisted of 24 - 30 pneumatic drills mounted on a frame welded to the bed of a truck. Modern jumbos allow a single operator to control several drills mounted on hydraulically controlled arms.

In 1954, while building diversion tunnels for the construction of a dam in South Dakota, James Robbins invented the tunnel boring machine (TBM), a cylindrical device with digging or cutting heads mounted on a rotating front face that grinds away rock and soil as the machine creeps forward. Modern TBMs are customized for each project by matching the types and arrangement of the cutting heads to the site geology; also, the diameter of the TBM must be equal to the diameter of the designed tunnel (including its lining).

Advancing tunnelling in India

The tunnelling history in India is non-different from the tunnelling history of HCC. HCC's long-standing expertise in tunnelling dates back to the inception of the company in 1926. Undertaking its first contract in 1926, HCC constructed the Bhoreghat Tunnel on the Mumbai-Pune Railway line in 1928.

Evolving since then and never looking back, HCC, to its credit, has served the nation and its neighbouring countries by building over 290 km of tunnels for most civil engineering applications across challenging and uncertain geologies, extreme climatic conditions and with some of the best state-of-the-art technologies and state-of-the-art practices.

With its unflinching determination, HCC has matured its understanding of tunnelling, starting with classical methods, the elementary drill and blast method, the cut and cover method, the New Austrian Tunnelling Method (NATM), shields and tunnel boring machines and special methods. With a proud contribution of one fourth of the nation's hydro power construction, HCC's 290 km of tunnelling experience can be divided as follows – 3% with the cut and cover method, 69% with the drill and blast method, 24% with the Tunnel Boring Machine (TBM) and around 4% with the NATM method. The tunnel construction experience includes major civil engineering applications viz. hydropower generation, water supply, irrigation and transportation infrastructure such as roads, railways and Metros.

Bhorghat Tunnel on Mumbai-Pune rail link built by HCC in 1928

Kolkata Metro built by HCC using the cut and cover method

First TBM tunnel built in Himalayan region for Kishanganga Hydel Power Project

Longest transportation tunnel in India, the Pir Panjal Railway tunnel built by HCC

Dealing with variegated geology

Constructing tunnels through various geological formations in India and its neighbouring countries, HCC has a great deal of experience in dealing with proportionate and occasionally disproportionate magnitudes of uncertainties and risks. This includes tunnelling in soils, that are relatively younger and assorted geological formations in the Himalayan region, recent and Pleistocene area, Deccan Trap, Gondwana, Vindhwan , Alluviam areas and Pre-Cambrian geologies. The risk constituted construction in almost all the seismic zones of India.

Encounters with the Himalayan Mountains

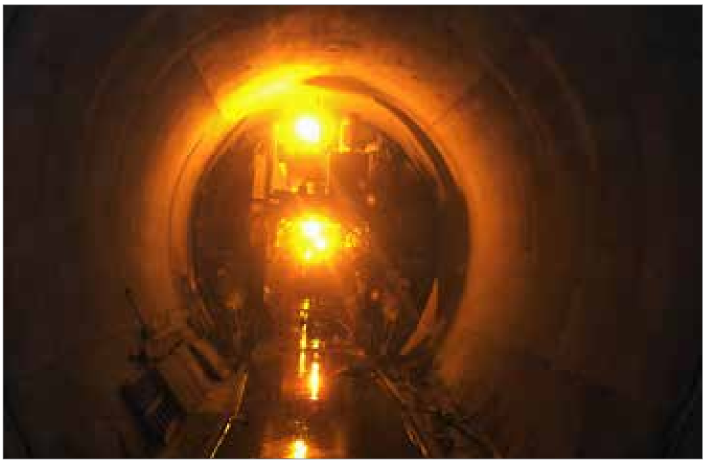
Tunnelling through fragile, weak and jointed rock masses of the Himalayas is often challenging for planners, designers, engineers, geologists and, most importantly, construction contractors. This is primarily due to high overburden, thickly vegetated and inaccessible terrain, varied rock formations, presence of small and big shear zones/thrusts and associated hydrological challenges. Tunnelling in such regions invites multiple, often unforeseen problems such as face collapse, chimney formation, water-inrush, hot water springs, gas explosion, squeezing and so on. Dealing with such issues necessitates responsive and "on the toes" engineering and construction, often requiring sleepless vigil and presence of mind. To alleviate and surmount such challenges, HCC in its bloodline has built sound construction practices that include detailed geological explorations, state-of-the-art designs, adaptable tunnelling practices, in-depth knowledge of monitoring and feedback systems and mechanisms with an inbuilt culture for safety.

First successful TBM in Himalayan region - a World Record: Undertaking one of the longest constructed tunnels in India (23.65 km length and 6 m dia) with a maximum overburden of 1,470 m, HCC utilized a double shield TBM for its Kishanganga hydropower project. Completing 14.75 km of tunnel, HCC created a world record of being the 1st successful TBM operations in the Himalayan region in a record time of 24 months, with an average monthly progress of 406 m. While dealing with adverse geologies, HCC also created a national record of the highest monthly progress in tunnelling of 816 m in the month of October 2013. The remaining length of 8.89 km of the tunnel was constructed using the drill and blast method.

Building nation's longest transportation tunnel: Entrusted with the responsibility of building the longest railway tunnel, Pir Panjal (J&K), HCC utilized the NATM method for dealing with rugged terrains of the Pir Panjal region, connecting Bichleri Valley on the south side and the Kashmir Valley on the north side. In this challenging and marvellous project in the history of Indian Cilvil Engineering, many geological surprises and challenges were faced in the relatively younger Himalayan geology. This state-of-the-art tunnel of 11.125 km is 100% waterproof and equipped with the latest fire fighting systems. As an accolade for completing this project HCC was awarded two more projects along the same alignment.

Worst geology encountered so far: Dealing with the sub-Himalayan areas in Bhutan and

Majority of the water supply tunnels in Mumbai is built by HCC



HRT at Dagachhu Hydel Power Project, Bhutan - worst geology encountered so far

Delhi Metro Tunnel built on Airport line

Delhi Metro CC30 tunnel nearing completion

some of the treacherous median to heavy zones of soil, HCC has undertaken projects in Bhutan. During the construction of Dagachhu Hydro Power Project in Bhutan, HCC engineers experienced one of the most challenging geology. The ground strata was not adequate to hold the structure as there were several water courses beneath the surface and the land was marshy. Inclinometers, geotechnical equipment used to measure the underground movements/ deformations and extensive monitoring, were used. The results revealed that the land had significant underground movements.

To deal with this situation, the alignment of the head race channel was changed and soil stabilization was utilized to improve the foundations with the use of additional shotcrete and special anchoring. At the Head Race Tunnel various support systems such as rock bolts, wire mesh with shotcrete, steel ribs, lattice girders and winches were used in varying quantities. Frequent encounters of this type made this project ever challenging and added great value to HCC's experience.

Serving urban transport

Tunnelling in urban grounds is complex and challenging, often due to construction in soft soils, existing urban infrastructure, high rise buildings, existing public utilities and, most importantly, safety for human life. While meeting such challenges of developing the nation, HCC has built India's first Metro rail project at Kolkata, wherein 5.33 km of stretch was built using the cut and cover method and a length of 1.14 km using the shield tunnelling method.

HCC has been involved in the construction of five underground sections, which are a part of the strategic plan of Delhi Metro Rail Corporation (DMRC). 4.47 km of stretch was built using the cut and cover method and a length of 10.30 km using the shield tunnelling method. The key to developing such designs is an understanding of tunnelling-induced ground loss mechanisms and the associated displacements, and the risks they pose to adjacent buildings, structures and utilities. The route alignment for this Metro line passed below various heritage structures and buildings of national importance.

In HCC's endeavour to serve the nation faster and keep its time commitment, HCC has deployed five TBMs at Delhi Metro of which four TBMs are operational at CC34 package, involving 4.4 km long twin tunnels on Janakpuri West–Kalindi Kunj Corridor, and one is operational at CC30 package, involving 2.2 km twin tunnels between Shalimar Baug and Subhash Place stations.

Meeting dimensional challenges

Largest diameter Tunnel Boring Machine deployed by HCC: For constructing a 19.2 km long tunnel for Pula Subbaiah Veligonda irrigation channel in Andhra Pradesh, HCC deployed a 10m diameter Double Shield Tunnel Boring Machine of Robbins make. The continuous lining behind the machine consists of 300 mm thick concrete segments in 6+1 arrangement, making the finished tunnel diameter 9.2 m. The tunnel path was located in sedimentary rock with a number of faults and folds with some ground water. A

Delhi Metro CC 34 twin tunnel currently under construction

A rare double breakthrough achieved at Delhi Metro CC 34 project

Largest diameter (10 M) Tunnel Boring Machine deployed at Veligonda Tunnel

Deepest shaft in India (300 m) built for Nathpha Jhakri Hydel Power Project

probe drill mounted on the machine allowed for verification of the geology 30 m ahead of the TBM. A strict programme of probe drilling combined with adequate ground stabilization allowed the TBM to advance through difficult sections of rock.

Smallest and largest diameter tunnels: The smallest diameter tunnel constructed by HCC was for Brihanmumbai Municipal Corporation. It was a 2.74 km long sewage tunnel with a finished diameter of 2.5 m, constructed using a shield TBM and lined with precast concrete segments. Tunnelling challenges included massive and weathered basalt as well as the groundwater level along the tunnel alignment. A Herrenknecht Hard Rock TBM of 3.065 m diameter with integral automatic grout injection system was used for the construction of this tunnel. For the first time in India, a shielded hard rock TBM and the gasketed linings were used in this project.

On the other hand, the largest diameter tunnel constructed by HCC was for the Nathpa Jhakri Hydroelectric Power Project. The 1530 MW project boasts of the largest and longest Head Race Tunnel (HRT), the largest desilting chambers, the deepest and the largest surge shaft, and the largest underground power complex. Of the total length of the 27.4 km HRT, HCC was involved in the construction of the 11.33 km long concrete lined HRT of 10.15 m finished diameter. Excavation of the HRT was carried out by the drill and blast method. The company also constructed the deepest surge shaft in India for this project, which was 301 m in depth and 21.6 m in diameter.

World record in long distance concrete pumping for tunnel lining

HCC created a World Record in horizontal long distance concrete pumping while constructing the Head Race Tunnel for the Sainj Hydroelectric Power Project in Himachal Pradesh. The concrete was successfully pumped for a distance of 2,432 m. The main reason behind opting for the long distance concrete pumping methodology was the relatively smaller diameter of the tunnel. At 3.85 m finished diameter, the two way simultaneous movement of transit mixers was not possible, effectively ruling out the conventional method of concreting. The project team successfully tackled the challenges with precise planning, commensurate testing, training, responsive engineering and, most importantly, seamless coordination among the team members to achieve this major feat.

The way ahead

With India's strategic infrastructure development plans on their way to implementation, there is great scope for tunnelling in India, especially for developing urban infrastructure, underground rail and road networks, transportation in mountainous regions and so on. Refinements in designing capabilities and the ability to utilize instrumentation data will enhance our ability to foresee uncertainties and risk. In order to better access risk and uncertainties, detailed geological explorations will have to take deeper roots. A greater level of mechanisation of tunnels will reduce construction time and help early revenue generation.

Ghatkopar sewage tunnel - Smallest diameter tunnel built by HCC

Nathpa Jhakri HRT - Largest Diameter tunnel built by HCC