1.0 DESCRIPTION OF THE PROJECT

The Airport Metro Express Line (AMEL) comprises of about 22.7 km long high-speed metro connection from New Delhi Railway Station to Indira Gandhi International Airport and further extended to Dwarka sub city. The line comprises of both underground and elevated tracks and the Construction methods include tunnelling by TBM, NATM, Cut & Cover and elevated corridor by launching of precast girders. This line has a designed speed of 135 kmph and provides connectivity of city centre at New Delhi to Indira Gandhi International Airport. This line is being built on Public Private Partnership (PPP) model wherein the civil structures shall be done by the Government being represented by Delhi Metro Rail Corporation and the system installations as well as Rolling stock shall be supplied, installed and operated by a private partner i.e. Concessionaire. The concessionaire for this line is a joint venture comprising of Reliance Infra-CAF. The concessionaire shall be operating the line for 30 years and the revenue shall be shared by the Government and the concessionaire.

2.0 SALIENT FEATURES OF THE LINE:

- Length 22.7 kms, 7 km elevated, 15.7 kms underground
- Designed speed of 135 kmph and operating Speed of 120 km/hr (~18 min from New Delhi to Airport)
- 6 coach train, mainly seated with half coach reserved for baggage.
- Designed frequency 2 mins
- 6 stations, namely New Delhi, Shivaji Stadium, Dhaula Kuan, Delhi Aero city, IGI Airport, Dwarka sector 21
- City Air Terminals at 3 locations viz New Delhi, Shivaji Stadium, Dhaula Kuan
- Check in facility for Air Travelers, baggage carrying facility
- Multi Level Parking at New Delhi station
- Integration with existing Metro, Indian Railways at New Delhi station

The works of Construction of 2 underground stations viz. New Delhi and Shivaji Stadium and also tunnels between these 2 stations as well as approach tunnels on either side was awarded to a consortium of Alpine-Samsung – HCC in sept 2007 with a target to complete major works by Sept 2009 so that the concessionaire can take up system works and the entire line can be opened for commercial operations by Sept 2010, prior to scheduled commonwealth games in Oct. 2010.

3.0 CONSTRAINTS DURING INVESTIGATIONS:

A detailed and systematic Geological, Hydro geological and Geotechnical Investigation was taken up along the axis of the tunnel from the New Delhi Station to the Talkatora Garden Area to delineate areas of difficulties likely to be faced during tunnelling. However the major stretch could not be investigated since the tunnel was to pass under major heritage structures such as the...
Auliya Mosque and buildings of the Connaught Place, Minto Bridge – an important gateway to the New Delhi Railway Station, roads with heavy traffic inflows such as the Connaught Place outer and inner circles, and most importantly the underground Rajiv Chowk Metro Station which presently has tracks at two different levels.

The Bore Hole Drilling could not be taken up in the Connaught Place area because of the presence of the Rajiv Chowk Metro Station and various heritage building structures. This inaccessibility made the tunnelling under the Connaught Place more challenging.

All options for geophysical exploration including the Cross Borehole Methods, Electrical Resistivity Tests and Ground Penetrating Radar Tomography were taken into consideration prior to the start of the Tunnelling in the Connaught Place stretch. The cross borehole method was abandoned because of limited availability of space. The Ground Penetrating radar tomography was carried out on an experimental basis but this could not provide us the desired results since the Radar was not powerful enough to penetrate to the required depth of 44 m below the ground surface. The depth of the tunnel below the Rajiv Chowk station was the maximum depth to be attained in the Airport Metro Express Line. The Electrical Resistivity tests were also not found suitable due to the vacuum created by the built-up station area below the ground surface.

To summarize, the detailed geotechnical investigations could not be carried out at these locations due to available constraints.

4.0 MAJOR CHALLENGES FACED DURING TUNNEL BORING:

The major challenges faced during Tunnelling were as follows:

1. The tunnel passed under some important heritage structures and structures of national importance along the alignment which include the, Minto Bridge, Auliya Mosque, Connaught Place heritage buildings, Rajiv Chowk Metro Station, Idarsiya Masjid. The heritage buildings in Connaught Place were in a very dilapidated condition and thus all precautions were taken for an effective back fill grouting in all respects.

2. The tunnel along its stretch from the New Delhi Station to the Shivaji Stadium Station was entirely below the ground water table. The major hurdle was to pass the deepest point under the Rajiv Chowk Metro Station (appr. 44 m deep), where the water pressure was at its maximum and the geology was totally unexplored.

3. Heterogeneous soil conditions were prevailing all through the stretch especially under the Connaught Place which further added to stoppages at various point of time. The mixed soil conditions hampered the progress as boulders stuck to the cutter head at times and there were hard Quartzites which made the progress go slow.

4. The greatest task was however to minimize the settlements at Rajiv Chowk Metro station which had two levels of tracks and was fully operational. It was further more challenging to monitor the station wherein the standard Instruments, the likes of Inclinometers, settlement markers, etc. could not be placed due to the lack of accessibility. Instruments such as the Electrolytic Beam Sensors, Tilt Sensors, Precise Levelling Points and Bi-Reflex targets were placed along the platforms and the tracks of the North-South Corridor.

5.0 TUNNELING BELOW RAJIV CHOWK METRO STATION (DEEPEST STRETCH)

The twin bored tunnels pass through some of the deepest zones in New Delhi (between proposed New Delhi Station and Shivaji Stadium Station) where tunneling work has been undertaken. The construction of the twin bored tunnels through this deepest zone encountered a series of severe difficulties and risks mainly due to delicate urban context within the working area which required particular attention to be paid to both the design and construction aspects.

DESIGN PHASE

The main considerations during design phase were:

- Passing of TBM excavation below infrastructures of historical and national importance that was sensitive to settlements.
- Passing of the tunnels below a cover of around 44 meter (at deepest point), where groundwater head was at its zenith and that too in unexplored geology.
CONSTRUCTION PHASE
Similarly the main considerations during the construction phase were:
- Particular attention to public safety during construction along the main roads of the city.
- Settlement controlled operation of TBM between New Delhi and Shivaji Stadium station in order to control the settlement in heritage structures along this stretch.
- The unexplored geology of the stretch under Connaught place was also a major constraint in tunneling.

TIME FACTOR
Beyond the above mentioned design and construction constraints time was also a significant constraint, as it was necessary to complete the metro line before the commonwealth games to be held in October 2010.
All these constraints collectively made tunneling in these deepest stretches of the city to be a formidable challenge to the designers and builders.
The Fig.1 shows the section of tunnel passing below the existing metro station near CH.1200 which is the deepest zone along the stretch.

Fig.1 AMEL Twin bored tunnel below existing metro station

Tunneling Operations
The geology was unpredictable and to minimize the risk, the machine were ordered to cover the risk of this changing geology. 2 mixed shield TBMs (S 495, S496) were ordered of Herrenknecht make that would work in both soil and rocky strata and also under such high water pressure.
Some specifications of the machine are as under
Length of the segments       1.400 mm
No. of segments            5 + 1
TUNNELLING SYSTEM max. Working pressure   4 bar
Number of center cutter (2 Ring cutters)  4 pcs.
Number of cutter(1 Ring cutter)   32 Tool
Number of the cutting knives    72 pcs.
CUTTING WHEEL DRIVE Installed electric power (4x 400 kW)  1.600 kW
Electrical power for other systems  800 kW
Total installed Power         2400 kW

The finished dia of the tunnel was 5.8 m and each ring comprised of 5 segments and one key segment, each 1.4 m long. The segments were precast with M50 grade concrete in casting yard located in Mundka (30 km away from the site). The transportation of the segments would only be allowed in the night time and added a challenge to the tunneling works.

The launching chamber at New Delhi was made ready by oct 2008 and the tunneling started in 1st week of Nov., 2008 for S 495 and in Jan 2009 for S 496. The progress in soil was an average of 15 rings a day and in rock, an average of 4 rings a day over a month cycle. The entire tunneling operation of 1150 rings for each tunnel were completed in April 2009 and July 2009 respectively. While crossing Rajiv Chowk station, the tunneling was done very cautiously and regular monitoring at track level of existing metro station was done using Electrical resistivity sensors. Also sufficient precautions were taken while crossing the heritage structures of Connaught place area. Proper primary and secondary grouting was ensured behind tunneling on daily basis.

The tunneling was carried out under an unexplored geology and the TBM encountered totally varied geology changing all along the stretch which required Continuous monitoring of the geology as TBM progressed. The tunneling along this stretch was entirely below the water table. Fig. 2 shows the geological profile actually encountered along the stretch from New Delhi Station to Shivaji Stadium Station which shows that the geology was changing continuously along the stretch making TBM operations challenging.
To encounter the water ingress in between this stretch of maximum overburden and below ground water table, the earth pressure was maintained from 2.5 to 4 bars in accordance to the design calculations. The particular stretch underneath the Rajiv Chowk metro station where the groundwater head was maximum the machine progressed cautiously and at slower pace keeping in view the importance of the running metro station above it.

CONSTRUCTION OF CROSS PASSAGE-2 AT DEPTH OF 44 M FROM GL

A part of overall scope of the tunneling includes construction of 3 number cross passages in the bored tunnel stretch and all these three were below ground water table. Among these cross passages, the one at CH. 1242 was having the maximum overburden of around 44 meters and lies within an alluvial zone. The Cross passage was also to be provided with a sump around 4 meters in depth to be constructed below the invert level. The salient features and typical section of this cross passage (Fig.3) are provided below.

**SALIENT FEATURES OF CROSS PASSAGE-2**

- **Chainage:** 1242.00
- **Length:** 10 meters (Approx)
- **Finished Diameter:** 3.8 meters
- **Ground Water Head:** 15 m (Above crown Approx)
- **Soil Classification:** Clayey Silt
DEWATERING AROUND CROSS PASSAGE

The vacuum dewatering technique was deployed to lower the ground water table in the vicinity of cross passage in order to facilitate the excavation of cross passage. Vacuum dewatering method proved to be most effective method of dewatering when excavation is to be done below ground water levels. This system of dewatering is very effective in a wide range of soils ranging from fine silty sands to coarse gravels.

Lowering of water table through conventional method of bore well system was not feasible because of presence of station and other structures above the cross passage and also magnitude of resources that would have been required for such operations. Therefore vacuum dewatering was the preferred technique.

This method has been deployed for the first time in underground tunneling works in Delhi.

Dewatering holes of different lengths were drilled all around the cross passage confirming to the Fig.4 and Fig.5 shown below.
In principle the vacuum dewatering system consists of the following:

A small diameter pipe known as (riser pipe) is fitted with a fine filter that prevents fines entering into the system and being removed from the ground in the pumped water. This riser pipe is connected to a flexible pipe via a control valve to the header pipe which in turn connects to the suction connection of a specialist vacuum dewatering pump. The discharge side of the vacuum pump is connected via the discharge pipe to a settlement tank which further collects any fines and then on through the discharge pipe to the discharge point. Once the pump is switched on it creates vacuum and pulls water out of the ground thus lowering the ground water level and pumps the water to the designated discharge point. The Well points are jetted into the ground using high pressure water pump (jetting pump) delivering water down a steel tube (jetting tube). The filter and riser pipe are installed along with a granular filter pack to aid drainage and then connected to the system.

The pumps that are required for vacuum dewatering duties are critical to the efficiency of the system and must have excellent air handling and air separation capabilities as such they are regarded as specialized units. 18 No. of holes were made around each cross passage for dewatering and special pumps were deployed for pumping water. The total discharge from all these dewatering holes was approx. 12000 litre per hour.
6.0 MONITORING SYSTEM
During the construction phase an effective monitoring system was deployed at Rajiv Chowk metro station. The monitoring system facilitated a continuous comparison between the on site situation and the design predictions. Furthermore, predefined actions and countermeasures were associated with the monitored parameters to manage potential, critical situations for guaranteeing the safety of people and the existing metro station. As per the design the following parameters were monitored and recorded:

- Stresses, strains and displacement in the existing metro station
- Strains at the surface and at depth
- Environmental data (such as ground water table)
- Displacement in structures of existing metro station

The continuous monitoring of Rajiv Chowk metro station located above the running tunnels was performed by the installation of 3D monitoring Bi-reflex targets, pavement markers, tilt markers, building markers, Electrolytic beam sensors and crack markers where old cracks were visible. Entire work has now been completed within stipulated time of 2 years since award of contract without any incident of settlement below important structures. Also, the tunneling and cross passage works was planned and executed through an experienced team (national and international experts) of designers and engineers from contractor as well as client side. Strict Safety and Quality assurance was also ensured from planning stage to execution stage through national and international experts from both sides.

7.0 CONCLUSIONS
With the above constraints and necessary precautions taken during execution and efficient planning at site, tunneling under adverse geological conditions, greater depths and also below important structures was carried out within following strict boundary conditions:

1. No cracks in the structure were observed.
2. The settlements recorded were under the prescribed limits.
3. The works were completed as per the schedule.
4. No untoward incident occurred at these critical locations.

The project has faced a few challenges for mechanized tunneling in urban areas in Indian context. The project has come out as a huge success due to thoughtful planning and dedicated execution of the construction.