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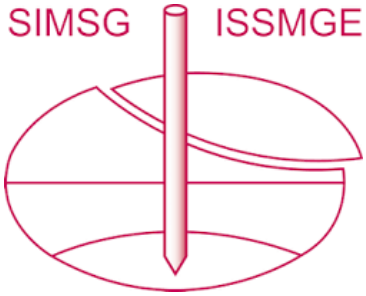

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Tunnelling through soft grounds in India

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SYNOPSIS: Tunnels in India have largely been used for water resources development projects. Rail and Road tunnels are also constructed, particularly in the Himalayan region or in Deccan plateau. Some of these tunnels pass through highly stressed environment in weaker formations leading to squeezing ground conditions. The paper describes the methods of geological investigations and geotechnical characterization, the design philosophy, the construction techniques, supporting systems, instrumentation to monitor performance and the codes of practice/manuals etc. used in the country.

PURPOSE

Tunnels are constructed in India mainly for the water resources development projects, railways, roadways or sewerage. Tunnels for water resources projects are large in diameter (from 5 to 15 metres), long (a few kilometres to 30 kilometres) and traverse through ground with high stresses. Road and rail tunnels are mainly in the mountains up in the north or in the deccan plateau. Tunnels for transsit in urban areas or sewerage system are very few.

Railway tunnels

A number of tunnels carrying the rail track were constructed before Independence (1947), particularly in Simla (Himachal Pradesh), Darjeeling (West Bengal) and Ootacmund (Nilgiris) areas. Two major projects of the Indian Railways presently under construction are -

i) Jammu Udhampur Rail Link Project
ii) Konkan Rail Project

Both these projects include several tunnels of small to medium length.

Road tunnels

A number of tunnels have been constructed in the Himalayan region and in the Nilgiris for the transit of road traffic. The most important of these is the Jawahar Tunnel or the Banihal tunnel in Jammu and Kashmir. A major tunnelling project presently under construction is at Manali at an elevation of above 300m. The tunnel length is about 10 km. and it is located in an area which is mostly snow bound.

City Metros

Even though India has some big cities with extremely large population who commute from one place to the other, tunnels have not been used for urban transit. The only city where it has been recently started is Calcutta. There is a proposal for Delhi under active consideration.

Tunnels for water resources development projects

A number of hydro-electric projects have tunnels, particularly in the Himalayan region. These tunnels pass through weak formations subjected to high stresses, leading to squeezing ground conditions. Even though the tunnels may be located in rocky strata, because of the weakness of the strata and high stresses, it behaves like a tunnel in soft ground.

GEOLOGICAL INVESTIGATIONS

A detailed geological investigation programme is undertaken before the tunnel alignment is finalised. In most of the cases, this input is provided by the engineering geologists of the Geological Survey of India (GSI). Their headquarter is in Calcutta and they have eight regional offices from where they cover different parts of the country. GSI has been in existence for a long time with excellent traditions and is a treasure house of information on Indian geology. Some of the States like Gujarat and Corporations like National Hydro-electric Power Corporation have their own engineering geological departments.

The Himalayas form the North-Western boundary of the Indo-Australian plate. This is a continent to continent collision boundary, the delineation of which runs along the axis of the Himalayas. The trailing margin forms the mountains along the boundary of the Eastern States of India and Burma. In the West, a trailing edge turns southwards to form the Hindu Kush mountain of Afghanistan. The highest concentration of seismic energy release occurs at these syntaxial bends.

This continental collision margin has produced some of the highest mountain ranges and deepest valleys on any of the continental plate boundaries. The mountains also act as a rain divide, the rainfall decreasing as one moves to the West from a maximum in excess of 3000 mm (in the foothills of Nepal, Darjeeling and Bhutan), some 80% of which is confined to the four monsoon months and is sometimes of cyclonic

intensity. This has led to extensive weathering and erosion of these ranges.

Such is the general make up of the area which is formed by an active continent-to-continent crustal collision. As a result of the fracturing and failure, the once horizontally bedded rocks forming the crust prior to collision are observed to be distorted and fractured. Major thrust faults contain glide planes along which continued movement has taken place, permitting rocks of different ages to slide past one other over considerable distances, thus accommodating the continued collision. Such thrust faults are known at several locations, striking along a series of ever rising mountain peak ranges, and are associated with many faults and shear zones. The Main Boundary Fault extends beyond the foothills in an almost unbroken sequence from the north-eastern States of Meghalaya and Mizoram to Kashmir.

The rock types vary across the Himalayas. Starting with the youngest deposits along the foothills, which are sandstones, mudstones and conglomerates of the Siwaliks, one passes to the Archean crystallin rocks of the inner Himalayas.

EVALUATION OF GEOTECHNICAL PARAMETERS

Geotechnical parameters are evaluated and the ground characterised by the Research Laboratories associated with State Irrigation Departments or under the federal set up like Central Soil and Materials Research Station, New Delhi. Testing includes -

Laboratory tests:

Rocks
* Physical properties like specific gravity, density, porosity, water absorption etc.
* Engineering properties like uniaxial compressive strength, modulus of elasticity, poissons ration triaxial shear strength.
* Slake durability index.
* Ultrasonic pulse velocity.
* Angle of friction of fractures (from laboratory direct shear tests).

Soils
* Identification tests like particle size distribution, Atterberg limits, unit weight, water content, permeability etc.
* Mechanical properties like friction angle, cohesion and compressibility.

Field Tests:

* Core recovery.
* Deformation modulus using Goodman jack or Menard Pressuremeter.
* In-situ stresses - ratio of lateral ground pressure to major principal stress.
* Water conditions - piezometric levels in boreholes, water chemistry, water temperatures and expected inflows.
* Seismic velocity.
* Mechanical properties like shear strength by vane test, N values by penetration test.

DESIGN PHILOSOPHY

Following approaches are generally used for the design of tunnels in soft grounds.

Analytical approach

A continuum or discontinuum model is used. The ground is modelled as homogeneous or heterogeneous, isotropic or anisotropic, as a two dimensional, i.e., allowing some stress release before the lining is acting or a three dimensional stiff medium. The lining is modelled as a beam element with bending stiffness or as a continuum. Plasticity, viscosity, fracture of the rock, non-linear stress strain and deformation behaviour etc. are covered by making special assumptions for material laws.

Numerical methods of computation like the finite element method and the boundary element method are used. Thus, homogeneous media and stress-strain fields are evaluated best. In general, discontinua such as fissures and faults, failure modes, which are initiated by local rupture, shear failure or full collapse, cannot be covered by a continuum methods. These methods are, therefore, though used for computations, but rarely used in actual designs.

Empirical approach

The structural elements and the excavation procedure, especially for the preliminary support of the tunnel is selected mainly based on experience and empirical considerations that rely more on direct observations than on numerical calculations. Rock mass classification approach is used.

Terzaghi's (1946) rock load classification has been used extensively for the calculation of rock loads and the design of steel supports. Bartons Rock Mass Quality Index and Bineawski's RMR system has also been tried, particularly for tunnels supported with rock bolts and shotcreting.

Interactive approach

In this approach, the design of the tunnel takes into account the interaction between the ground and the lining. In order to do so, the lining must be placed in closest possible bond with the ground. To preserve its natural strength, the ground is kept as undisturbed as possible. The deformations resulting from tunnelling process reduce the primary ground pressure and create stresses in the lining corresponding to that frictional part of the primary stresses in the ground which act on sustaining lining. The stresses depend upon the relative stiffness of the lining and the ground, as well as on the shape of the tunnel cross section.

In soft ground, immediate support is provided by a relatively stiff lining. For tunnels at shallow depth, as for underground railways in cities, a two dimensional cross section for a plane strain analysis is considered, neglecting the three dimensional stress release at the face

of the tunnel during excavation. For shallow tunnels, the full overburden is taken as load. The ground reaction is simplified by radial and tangential springs.

For moderately stiff ground, the soil stiffness is employed bny assuming a two dimensional continuum model and a complete bond between lining and ground. Stress release due to pre-deformations of the ground are neglected. Inward displacements result in a reduction on the pressure on the lining.

Convergence confinement models

For tunnels with pronounced stress release due to inward deformations, for example deep tunnels in soft rocks, convergence confinement model is used. This method is based on the interaction of radial inward displacement and the support reaction to these deformations by resisting ring forces and the corresponding outward pressure.

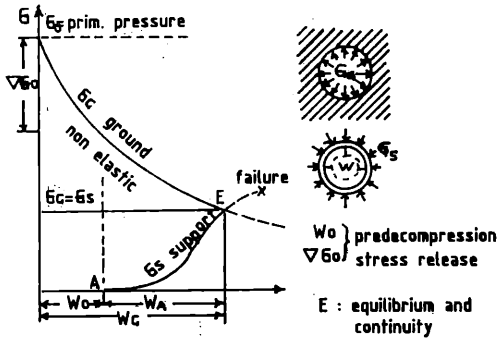

Fig. 1. Characteristic curves for the ground and the support for convergence confinement method (Fenner-Pacher Curves).

The primary stresses σ_o in the ground are released with progressive inward displacement. The acting pressure may even increase when joints are opening with larger displacements. In self supporting ground, the ground characteristic meets the w-axis; because the primary stresses are released completely, a supporting lining is not necessary. Pre-deformation w_o occurs before the supporting members are installed. The stiffness of the lining determines where both the characteristic lines intersect. At this point, equilibrium as well as compatibility conditions are satisfied. Ground characteristic line can be determined either by in-situ monitoring or by using the procedure indicated by Brown et.al.(1983). Support characteristic lines are determined more easily using the standard procedures (Hoek and Brown 1980).

In its usual analytical form the convergence - confinement method assumes constant ground pressures along a circular tunnel lining. Consequently, it yields only ring forces and no bending moment at all. However, it may be extended to cover ground pressures that vary along the tunnel lining using Gesta's method (1986).

CONSTRUCTION METHODS

Most of the tunnels are constructed by drilling and blasting. When the diameter of the tunnel is comparatively small, say up to 5 metres, full face excavation is done. When the diameter goes beyond 5 metres, heading and benching method is used. In difficult ground conditions, multiple drift method is used. Forepoling or grouting is resorted to wherever running ground conditions are met with.

Tunnel boring machines have rarely been used. A modern full face tunnel boring machine is presently being used on Dul-Hasti Project in J&K where a French Company has undertaken the construction. In softer strata, roadheaders are more favoured. An Alpine Miner was used on Loktak Project in Manipur, where the water conductor system included a 6.6 km. long tunnel. The tunnel was passing through coal measures and was met with methane gas leading to a large explosion killing several persons. The tunnelling media which was predominantly clayey also showed squeezing behaviour and upheaval of the bed at several places.

Mucking is done by rail cars for which a rail-track is laid.

PRIMARY TUNNEL LINING

Heavy steel girders are used for supporting the rock. Pre-cast concrete panels are placed between the girders and the space between the rock and the panels is filled up with lean concrete placed with a pneumatic placer.

Rock-bolting and shotcreting has also been used on some projects. Wedge type or expansion shell type rock bolts are more common, though Williamson's type of bolts with a hole in the centre for grouting have also been used.

MONITORING PERFORMANCE

Most of the monitoring work is carried out during the construction period. Instrumentation programme generally includes closure measurements, use of borehole multiple-point extensometers, piezometer, loadcells etc. The purpose is to determine the adequacy of the support provided and to find out when the ground has stabilised. Since most of the projects are faced with squeezing ground conditions, closures are very relevant. Fig.2 shows a typical diagram for Giri Bata project.

Probing ahead is undertaken to overcome the problems of geological uncertainties and sudden ingress of water. A horizontal borehole with a diamond core drilling machine is done for this purpose.

CODES OF PRACTICE

The Bureau of Indian Standards undertakes the job of preparing and printing codes of practice for construction of tunnels. Some of the relevant codes are as follows.

IS:5878 - Code of practice for construction of tunnels.

Part I - Precision survey and setting out.
Part II - Underground excavations in rock.
Section 1 - Drilling and blasting.
Section 2 - Ventilation, lighting, mucking and dewatering.
Section 3 - Tunnelling method for steeply inclined tunnels, shafts and underground powerhouses.
Part III - Underground excavations in soft strata
Part IV - Tunnel supports.
Part V - Concrete lining.
Part VI - Steel lining.
Part VII - Grouting.

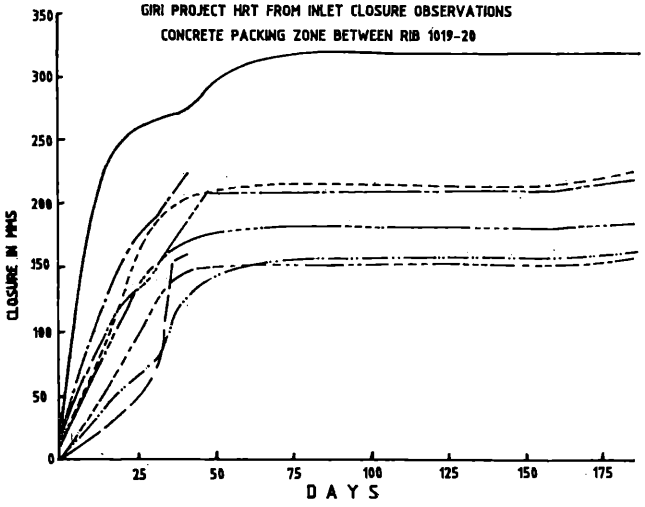

Fig.2. Typical Time-Closure Curves for tunnels of Giri Bata Project.

MANUALS

A manual on Planning and Design of Hydraulic Tunnels has been prepared by the Central Water Commission.

PROBLEMS OF TUNNELLING IN WATER RESOURCES DEVELOPMENT PROJECTS

Most of the water resources development projects in the Himalayan region have a very large element of underground excavation. These are in the form of tunnels, underground powerhouses and sedimentation chambers. Experience has shown that these works are invariably on the critical path. Wherever rock covers are very high, the investigation of geological strata at tunnel grade becomes very difficult. Due to enormous faulting and folding which these ranges have undergone, there are several surprises met with during excavations.

Squeezing ground conditions

Due to high stresses and material of weaker strength, tunnelling frequently leads to squeezing ground conditions. Examples of Giri Bata Project, Maneri Bhali and Yamuna project are worth mentioning. At Giri Bata Project, the philosophy of the designers was to allow the steel supports to deform and buckle. The excavated diameter was increased to allow for the enormous closure of the tunnel. Closures as much as 1.4 metres were recorded in a tunnel of about 5 metre excavated diameter (finished 3.7 m). Uncontrolled deformation of the tunnel led to a lot of loosening of strata around the excavated diameter. When the buckled steel sections were cut for proving the concrete lining, at some places, the ground became unstable once again. This resulted in non-uniform diameter of the head race tunnel leading to a continuous loss of energy.

At Yamuna Project, attempt was made to stop the deformations. In the process, the heaviest steel girders available in the market with extra flanges welded to increase the moment of inertia were used and even those buckled.

At Yamuna Project Stage II, to overcome the difficult reach of about 1 km length, it was decided not to continue with the large diameter tunnel (7.5 m finished) in the remaining portion and to join the two ends with three smaller diameter tunnels.

Water bearing strata

Water charged quartzitic formations in a syncline were met with at Maneri Bhali Project due to which the work was held up for a long time. Owing to squeezing ground conditions and buckling of steel supports, the tunnel diameter is also non-uniform.

Hydraulic fracturing

At Kopili HE Project, the tunnel between the surge shaft and the penstock was about 600 metres in length. Out of this, about 60m was provided with steel liner and its preceding 70m length was provided with reinforced concrete liner. The remaining length of the tunnel up to the surge shaft was lined with plain concrete. When the intake gate was opened for the pressure-testing of the tunnel, the RCC portion of the tunnel cracked open and water gushed out of the sloping hill mass.

The failure of Kopili tunnel showed that it was not enough to estimate the vertical stresses on the basis of rock cover and the density of material.

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