Planning and Geotechnical Analysis of Traverse Wall

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Abstract—
This paper presents the planning and geotechnical analysis of traverse walls in tunnel engineering projects. Tunnels present unique challenges such as geology, hydrology, construction risks, and sustainability. This work consolidates tunneling methods, route studies, and geotechnical investigations, highlighting their importance in ensuring structural safety, minimizing risks, and optimizing construction methodologies. The study also focuses on risk assessment, ground behavior, and alignment strategies for effective design and construction.
Keywords—
Geotechnical analysis, tunneling, traverse wall, groundwater, tunnel boring machine, road tunnel design.

I. INTRODUCTION

Tunneling is a significant engineering undertaking. Long and deep tunnels present a number of difficulties, including high investment costs and site conditions along alignment routes. Geology has a significant impact on this. Unexpected and unfavorable geological circumstances could affect tunnel safety, construction time, and expenses. For large-scale construction projects, engineering geologists plan related surveys and offer the fundamental geological and geotechnical advice based on specific in-depth analysis. Tunnels are a significant construction project that is part of these structures. Geology, the environment, operation, and construction are important factors that must be taken into account. The geotechnical studies that must be conducted in order to tunnel are highlighted in this course.

The physical context and key constraints that influence the planning of a tunnel alignment within Any subsurface engineering structure's backdrop is provided by the site geology. The rock's mechanical characteristics explain how the forces created by the excavation cause the geologic components to deteriorate and fail.
The amount and pressure of water that has to be managed are determined by the geohydrologic conditions.
The major tunnel elements comprise the portals, the running tunnels, and the stations.

1. Tunnelling methods:

Cut and cover tunnel :

A method of tunnel construction involving the installation of earth support systems (e.g. slurry walls) followed by the main excavation, placing of the base slab, roof slab and subsequent backfilling to the final ground level.

Sequential Excavation Method :

a method of tunnel construction that involves the use of standard construction equipment for excavation.
The tunnel is usually lined in two steps:
An initial lining of sprayed concrete provides immediate support and a subsequent secondary or permanent lining is then placed using either sprayed concrete or cast insitu concrete.
A waterproof membrane is usually installed between the primary and secondary linings.

Slurry wall :

A form of earth support system whereby a continuous trench is excavated in the ground to the required depth, using slurry to provide temporary support during excavation of the trench. Reinforcement (which may be reinforcing cages or steel H sections) is lowered into the trench and concrete is subsequently placed by tremie pipe, displacing the slurry from the trench.

2. Tunnel Boring Machine :

A method of tunnel construction that involves the procurement of a custom made piece of construction equipment. The TBM is equipped with a cutter head that is used to mine the ground. The excavation is continuously supported by installing precast concrete segments within the TBM and grouting them in place as the machine advances.

3. Road tunnels are feasible alternatives to cross a water body or traverse through physical barriers such as mountains. Road tunnels are viable means to minimize potential environmental impact such as traffic congestion, pedestrian movement, air quality, noise pollution, or visual intrusion; to protect areas of special cultural or historical value such as conservation of districts, buildings or private properties.
Planning for a road tunnel requires multi-disciplinary involvement and assessments. Certain considerations, such as lighting, ventilation, life safety, operation and maintenance, etc should be addressed specifically for tunnels.

4. Tunnelling Route Studies

In a tunnel route study, the following issues should be considered:
- Subsurface, geological, and geo-hydraulic conditions
- Constructability.
- Long-term environmental impact
- Seismicity.
- Land use restrictions
- Potential air right developments
- Life expectancy.
- Economical benefits and life cycle cost
- Operation and maintenance
- Security.
- Sustainability.

5. Geotechnical Investigations for tunnelling:

1. Geotechnical investigations are critical for proper planning of a tunnel.

2. Selection of the alignment, cross section, and construction methods is influenced by the geological and geotechnical conditions, as well as the site constraints. Good knowledge of the expected geological conditions is essential. Tunnel alignment is sometimes changed based on the results of the geotechnical to minimize construction cost or to reduce risks.

3. The type of the ground encountered along the alignment would affect the selection of the tunnel type and its method of construction.

4. Study of the impact of geological features on the tunnel alignment in the presence of

active or inactive faults. During the planning phase, avoid crossing a fault zone. If it is un avoidable then proper measures for crossing it should be implemented. Presence of faults or potentially liquefiable materials would be of concern during the planning process.

5. Geotechnical issues such as the soil or rock properties, the ground water regime, the ground cover over the tunnel should be analysed. The investigation should address not just the soil and rock properties, but also their anticipated behaviors during excavation.

6. The investigation should also address groundwater. For example, in soft ground SEM tunneling, the stability of the excavated face is greatly dependent on control of the groundwater. Dewatering, pre-draining, grouting, or freezing are often used to stabilize the excavation.

7. Analysing the ground behavior during tunneling will affect potential settlements on the surface. Measures to minimize settlements by using suitable tunneling methods or by preconditioning the ground to improve its characteristics would be required.

8. Risk assessment is an important factor in selecting a tunnel alignment. Construction risks. Sensitive existing structures. Very Hard spots (rock, for example) beneath parts of a tunnel.

6. TUNNEL TYPE STUDIES:

General Description of Various Tunnel Types:

The principal types and methods of tunnel construction that are in use are:

1. Cut-and-cover tunnels are built by excavating a trench, constructing the concrete structure in the trench, and covering it with soil. The tunnels may be constructed in place or by using precast sections
2. Bored or mined tunnels, built without excavating the ground surface. These tunnels are usually labeled according to the type of material being excavated. Sometimes a tunnel passes through the boundary between different types of material; this often results in a difficult construction known as mixed face.
3. Rock tunnels are excavated through the rock by drilled and blasting, by mechanized excavators in softer rock, or by using rock tunnel boring machines (TBM). In certain conditions, Sequential Excavation Method (SEM) is used.
4. Soft ground tunnels are excavated in soil using a shield or pressurized face TBM
5. (principally earth pressure balance or slurry types), or by mining methods, known as either the sequential excavation method (SEM).
6. Immersed tunnels, are made from very large precast concrete or concrete-filled steel elements that are fabricated in the dry, floated to the site, placed in a prepared trench below water, and connected to the previous elements, and then covered up with backfill.

7. Jacked box tunnels are prefabricated box structures jacked horizontally through the soil using methods to reduce surface friction; jacked tunnels are often used where they are very shallow but the surface must not be disturbed, for example beneath

runways or railroads embankments.

The selection of a tunnel type depends on the geometrical configurations, the ground conditions, the type of crossing, and environmental requirements.

7. Design Process

The basic process used in the design of a road tunnel is:

- Define the functional requirements, including design life and durability requirements;
- Carry out the necessary investigations and analyses of the geologic, geotechnical and geohydrological data
- Conduct environmental, cultural, and institutional studies to assess how they impact the design and construction of the tunnel;
- Perform tunnel type studies to determine the most appropriate method of tunneling.
- Establish design criteria and perform the design of the various tunnel elements.
- Appropriate initial and final ground support and lining systems are critical for the tunnel design, considering both ground conditions and the proposed method of construction.
- Perform the design in Preliminary and Final design phases. Interim reviews should be made if indicated by ongoing design issues.
- Establish tunnel alignment, profile and cross-section.
- Determine potential modes of failure, including construction events, unsatisfactory long-term performance, and failure to meet environmental requirements. Obtain any necessary data and analyze these modes of failure;
- Perform risk analysis and identify mitigation measures and implement those measures in the design.
- Prepare project documents including construction plans, specifications, schedules, estimates, and geotechnical baseline report (GBR).

8. Tunnel Cross-Section:

The tunnel cross section geometrical configuration must satisfy the required traffic lanes, shoulders or safety walks, suitable spaces for ventilation, lights, traffic control system, fire/life safety systems, etc. The cross section is also dictated by the method of tunnel construction.

The available spaces in a circular cross section can be used to house tunnel systems, such as the ventilation duct or fans, lighting, traffic control systems and signs, close circuit TV, and the like. For rectangular sections the various systems can be placed overhead, invert or adjacent to the traffic lanes if overhead space is limited.

The tunnel structural systems depend on the type of tunnel, the geometrical configuration of the cross section, and method of construction.

In addition no dripping or visible leakage from a single location shall be permitted.

Tunnel waterproofing systems are used to prevent groundwater inflow into an underground opening. They consist of a combination of various materials and elements. The design of a waterproofing system is based on the understanding of the ground and geohydrological conditions, geometry and layout of the structure and construction methods to be used.

A waterproofing system should always be an integrated system that takes into account intermediate construction stages, final conditions of structures and their ultimate usage including maintenance and operations. There are two basic types of waterproofing systems: drained (open) and undrained (closed).

Various waterproofing materials are available for these systems.
Open waterproofing systems allow groundwater inflow into a tunnel drainage system. Groundwater inflow is typically localized to distinct locations such as joints and fractures and the overall permeability is such that a groundwater draw-down in soil layers overlying the rock mass will not be affected.

HORIZONTAL AND VERTICAL ALIGNMENTS

Planning and design of road tunnel alignments must consider the geological, geotechnical and groundwater conditions at the site.

9. GEOTECHNICAL INVESTIGATIONS

To successfully plan, design and construct a road tunnel project requires various types of investigative techniques to obtain a broad spectrum of pertinent topographic, geologic, subsurface, geo-hydrological, and structure information and data.

Although most of the techniques and procedures are similar to those applied for roadway and bridge projects, the specific scope, objectives and focuses of the investigations are considerably different for tunnel and underground projects, and can vary significantly with subsurface conditions and tunneling methods.

A geotechnical investigation program for a tunnel project must use appropriate means and methods to obtain necessary characteristics and properties as basis for planning, design and construction of the tunnel and related underground facilities, to identify the potential construction risks, and to establish realistic cost estimate and schedule.

The extent of the investigation should be consistent with the project scope (i.e., location, size, and budget), the project objectives (i.e., risk tolerance, long-term performance), and the project constraints (i.e., geometry, constructability, third-party impacts, aesthetics, and environmental impact).

It is important that the involved parties have a common understanding of the geotechnical basis for design, and that they are aware of the inevitable risk of not being able to completely define existing subsurface conditions or to fully predict ground behavior during construction.

Generally, an investigation program for planning and design of a road tunnel project may include the following components:

- Existing Information Collection and Study
- Surveys and Site Reconnaissance
- Geologic Mapping
- Subsurface Investigations
- Environmental Studies

- Seismicity
- Geospatial Data Management

Typical stages of a road tunnel project from conception to completion are:
- Planning
- Feasibility Study
- Corridor and Alignment Alternative Study
- Environmental Impact Studies (EIS) and Conceptual Design
- Preliminary Design
- Final Design
- Construction

The early investigations for planning and feasibility studies can be confined to information studies and preliminary reconnaissance.

Geological mapping and minimum subsurface investigations are typically required for EIS, alternative studies and conceptual design. EIS studies may also include limited topographical and environmental investigations.

the subsurface investigation techniques typically used for planning, design and construction of road tunnels.

10. INFORMATION STUDY

The first phase of an investigation program for a road tunnel project starts with collection and review of available information to develop an overall understanding of the site conditions and constraints at little cost.

Existing data can help identify existing conditions and features that may impact the design and construction of the proposed tunnel, and can guide in planning the scope and details of the subsurface investigation program to address these issues.

Published topographical, hydrological, geological, geotechnical, environmental, zoning, and other information should be collected, organized and evaluated. In areas where seismic condition may govern or influence the project, historical seismic records are used to assess earthquake hazards.
Records of landslides caused by earthquakes, documented by the USGS and some State Transportation Departments, can be useful to avoid locating tunnel portals and shafts at these potentially unstable areas.

11. Topographical Data

Topographic maps and aerial photographs that today can be easily and economically obtained, are useful in showing terrain and geologic features (i.e., faults, drainage channels, sinkholes, etc.).

When overlapped with published geological maps they can often, by interpretation, show geologic structures.

Aerial photographs taken on different dates may reveal the site history in terms of earthwork, erosion and scouring, past construction, etc.

12. SURVEYS AND SITE RECONNAISSANCE

Site Reconnaissance and Preliminary Surveys:

The lower-resolution contour maps are sufficient only for planning purposes. However, a preliminary survey will be needed for concept development and preliminary design to expand existing topographical data and include data from field surveys and an initial site reconnaissance. Initial on-site studies should start with a careful reconnaissance over the tunnel alignment, paying particular attention to the potential portal and shaft locations.

Features identified on maps and air photos should be verified. Rock outcrops, often exposed in highway and railroad cuts, provide a source for information about rock mass fracturing and bedding and the location of rock type boundaries, faults, dikes, and other geologic features. Features identified during the site reconnaissance should be photographed, documented and if feasible located by hand-held GPS equipment.

Sources of Information Data (After FHWA, 2002a)

Source Functional Use Location Examples
Local Soil Conservation

Aerial Photographs
Identifies manmade structures
Provides geologic and hydrological information
can be used as a basis for site reconnaissance
Track site changes over time

Topographic Maps
Geologic Maps and Reports
Prior Subsurface Investigation Reports
Prior Underground and Foundation details
Construction Records

Provides information on local soil/
rock type;
strength parameters;
hydrogeological issues;
environmental concerns;
tunnel construction methods and problems

Water Well Logs:
Provide stratigraphy of the site and/or regional areas
Yield rate and permeability, Groundwater levels

Control Survey:

The reconnaissance should cover the immediate project vicinity, as well as a larger regional area so that regional geologic, hydrologic and seismic influences can be accounted for. A preliminary horizontal and vertical control survey may be required to obtain general site data for route selection and for design.

Topographic Surveys:

For tunnel projects, detailed topographic maps, plans and profiles must be developed to establish primary control for final design and construction based on a high order horizontal and vertical control field survey.

On a road tunnel system, center-line of the roadway and center-line of tunnel are normally not identical because of clearance requirements for walkways and emergency passages.

A tunnel center line developed during design should be composed of tangent, circular, and transition spiral sections that approximate the complex theoretical tunnel center line within a specified tolerance (0.25 in.).

Accurate topographic mapping is required to support surface geology mapping and the layout of exploratory borings, whether existing or performed for the project.
The principal survey techniques include:

- Conventional Survey.
- Global Positioning System (GPS).
- Electronic Distance Measuring (EDM) with Total Stations.
- Remote Sensing.
- Laser Scanning.

Global Positioning System (GPS) helps to determine the relative position of monuments in a control network.
GPS surveying is able to coordinate widely spaced control monuments for long range surveys, as well as shorter range surveys. A Total Station is also used for this purpose.

Remote Sensing can effectively identify terrain conditions, geologic formations, escarpments and surface reflection of faults, buried stream beds, site access conditions and general soil and rock formations.

Hydrographical Surveys:

Hydrographic surveys are required for subaqueous tunnels including immersed tunnel, shallow bored tunnel, jacked box tunnel, and cofferdam cut-and-cover river crossings to determine bottom topography of the water body, together with water flow direction and velocity, range in water level, and potential scour depth.

In planning the hydrographic survey, an investigation should be made to determine the existence and location of submarine pipelines, cables, natural and sunken obstructions, rip rap, etc. that may impact design or construction of the immersed tunnel or cofferdam cut-and-cover tunnel.

Additional surveys such as magnetometer, seismic sub-bottom scanning, electromagnetic survey,side scan sonar, etc., may be required to detect and locate these features. These additional surveys may be done simultaneously or sequentially with the basic hydrographic survey.

13. Geologic Mapping:

After collecting and reviewing existing geologic maps, aerial photos, references, and the results of a preliminary site reconnaissance, surface geologic mapping of available rock outcrops should be performed by an experienced engineering geologist to obtain detailed, site-specific information on rock quality and structure.

Geologic mapping collects local, detailed geologic data systematically, and is used to characterize and document the condition of rock mass or outcrop for rock mass classification, such as:

- Discontinuity type
- Discontinuity orientation
- Discontinuity infilling
- Discontinuity spacing
- Discontinuity persistence
- Weathering

In addition, the following **surface features** should also be observed and documented during the geologic mapping program:

- Slides, new or old, particularly in proposed portal and shaft areas
- Faults
- Rock weathering
- Sinkholes and karstic terrain
- Groundwater springs
- Volcanic activity
- Anhydrite, gypsum, pyrite, or swelling shales
- Stress relief cracks
- Presence of talus or boulders
- Thermal water (heat) and gas

The mapping data will also help in targeting subsurface investigation borings and in situ testing in areas of observed variability and anomalies.

14. Subsurface Investigations:

Ground conditions including geological, geotechnical, and hydrological conditions, have a major impact on the planning, design, construction and cost of a road tunnel, and often determine its feasibility and final route.

Fundamentally, subsurface investigation is the most important type of investigations to obtain ground conditions, as it is the principal means for:
• Defining the subsurface profile (i.e. stratigraphy, structure, and principal soil and rock types)
• Determining soil and rock material properties and mass characteristics;
• Identify geological anomalies, fault zones and other hazards (squeezing soils, methane gas, etc.)
• Defining hydrogeological conditions (groundwater levels, aquifers, hydrostatic pressures, etc.); and
• Identifying potential construction risks (boulders, etc.).

Subsurface investigations typically consist of borings, sampling, in situ testing, geophysical investigations, and laboratory material testing.

The principal purposes of these investigation techniques are summarized below:
• Borings are used to identify the subsurface stratigraphy, and to obtain disturbed and undisturbed samples for visual classification and laboratory testing;
• In situ tests are commonly used to obtain useful engineering and index properties by testing the material in place to avoid the disturbance inevitably caused by sampling, transportation and handling of samples retrieved from boreholes; in situ tests can also aid in defining stratigraphy;
• Geophysical tests quickly and economically obtain subsurface information (stratigraphy and general engineering characteristics) over a large area to help define stratigraphy and to identify appropriate locations for performing borings; and
• Laboratory testing provides a wide variety of engineering properties and index properties from representative soil samples and rock core retrieved from the borings.

15. Test Borings and Sampling:

Various field testing techniques can be performed in conjunction with the test borings as well. In general, borings should be extended to at least 1.5 tunnel diameters below the proposed tunnel invert. Borings at shafts should extend at least 1.5 times the depth of the shaft for design of the shoring system and shaft foundation, especially in soft soils.

16. Sampling - Overburden Soil:

Standard split spoon (disturbed) soil samples (ASTM D-1586) are typically obtained at intervals not greater than 5 feet and at changes in strata. Continuous sampling from one diameter above the tunnel crown to one diameter below the tunnel invert is advised to better define the stratification and materials within this zone if within soil or intermediate geomaterial. In addition, undisturbed tube samples should be obtained in each cohesive soil stratum encountered in the borings; where a thick stratum of cohesive soil is present, undisturbed samples should be obtained at intervals not exceeding 5m.

17. Sampling – Rock Core:

In rock, continuous rock core should be obtained below the surface of rock, with a minimum core diameter of 2.16 inch or 54.7 mm. For deeper holes, coring should be performed with the use of wire-line drilling equipment to further reduce potential degradation of the recovered core samples. The rock should be logged soon after it was extracted from the core barrel.

18. Borehole Sealing:

All borings should be properly sealed at the completion of the field exploration, if not intended to be used as monitoring wells. This is typically required for safety considerations and to prevent cross contamination of soil strata and groundwater.

19. Test Pits

Test pits are often used to investigate the shallow presence, location and depth of existing utilities, structure foundations, top of bedrock and other underground features that may interfere or be impacted by the construction of shafts, portals and cut-and-cover tunnels. The depth and size of test pits will be dictated by the depth and extent of the feature being exposed.

20. Geophysical Testing

Geophysical tests are indirect methods of exploration in which changes in certain physical characteristics such as magnetism, density, electrical resistivity, elasticity, or a combination of these are used as an aid in developing subsurface information. Geophysical methods provide an expeditious and economical means of supplementing information obtained by direct exploratory methods, such as borings, test pits and in situ testing; identifying local anomalies that might not be identified by other methods of exploration; and defining strata boundaries between widely spaced borings for more realistic prediction of subsurface profiles.

Typical uses of geophysical tests include determination of the top of bedrock, the ripability of rock, the depth to groundwater, the limits of organic deposits, the presence of voids, the location and depth of utilities, the location and depth of existing foundations, and the location and depth of other obstruction, to note just a few.

21. Groundwater Investigation

Groundwater is a major factor for all types of projects, but for tunnels groundwater is a particularly critical issue since it may not only represent a large percentage of the loading on the final tunnel lining, but also it largely determines ground behavior and stability for soft ground tunnels; the inflow into rock tunnels; the method and equipment selected for tunnel construction; and the long-term performance of the completed structure.

Groundwater investigations typically include most or all of the following elements:

- Observation of groundwater levels in boreholes
- Assessment of soil moisture changes in the boreholes
- Groundwater sampling for environmental testing
- Installation of groundwater observation wells and piezometers
- Borehole permeability tests (rising, falling and constant head tests; packer tests, etc.)
- Geophysical testing (see Section 3.5.4)
- Pumping tests

22. ENVIRONMENTAL ISSUES

Although tunnels are generally considered environmentally-friendly structures, certain short-term environmental impacts during construction are unavoidable. Long-term impacts from the tunnel itself, and from portals, vent shafts and approaches on local communities, historic sites, wetlands, and other aesthetically, environmentally, and ecologically sensitive areas must be identified and investigated thoroughly during the project planning and feasibility stages, and appropriately addressed in environmental studies and design.

23.SEISMICITY

The release of energy from earthquakes sends seismic acceleration waves traveling through the ground. The factors that can affect the response of the ground during earthquakes.

- Distance of the seismic source from the project site.
- Magnitude of the seismic accelerations.
- Earthquake duration.
- Subsurface profile.
- Dynamic characteristics and strengths of the materials affected.

Conclusion:

Geology plays a very important role in this. Any adverse and unforeseen geological conditions may influence the safety of tunnels, loss of life, construction time and costs. When a tunnel or shaft is excavated, the rock stresses are perturbed around the opening and displacements will occur. Important aspects which needs to be considered are related to the construction works, geology, environment and operation.

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