Tunneling in Difficult Ground

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PDH: 2

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CONVERSION FACTORS

Approximate Conversions to SI Units			Approximate Conversions from SI Units		
When you know	Multiply by	To find	When you know	Multiply by	To find
(a) Length					
inch	25.4	millimeter	millimeter	0.039	inch
foot	0.305	meter	meter	3.28	foot
yard	0.914	meter	meter	1.09	yard
mile	1.61	kilometer	kilometer	0.621	mile
(b) Area					
square inches	645.2	square millimeters	square millimeters	0.0016	square inches
square feet	0.093	square meters	square meters	10.764	square feet
acres	0.405	hectares	hectares	2.47	acres
square miles	2.59	square kilometers	square kilometers	0.386	square miles
(c) Volume					
fluid ounces	29.57	milliliters	milliliters	0.034	fluid ounces
gallons	3.785	liters	liters	0.264	gallons
cubic feet	0.028	cubic meters	cubic meters	35.32	cubic feet
cubic yards	0.765	cubic meters	cubic meters	1.308	cubic yards
(d) Mass					
ounces	28.35	grams	grams	0.035	ounces
pounds	0.454	kilograms	kilograms	2.205	pounds
short tons (2000 lb)	0.907	megagrams (tonne)	megagrams (tonne)	1.102	short tons (2000 lb)
(e) Force					
pound	4.448	Newton	Newton	0.2248	pound
(f) Pressure, Stress, Modulus of Elasticity					
pounds per square foot	47.88	Pascals	Pascals	0.021	pounds per square foot
pounds per square inch	6.895	kiloPascals	kiloPascals	0.145	pounds per square inch
(g) Density					
pounds per cubic foot	16.019	kilograms per cubic meter	kilograms per cubic meter	0.0624	pounds per cubic feet
(h) Temperature					
Fahrenheit temperature(°F)	5/9(°F- 32)	Celsius temperature(°C)	Celsius temperature(°C)	9/5(°C)+ 32	Fahrenheit temperature(°F)

Notes: 1) The primary metric (SI) units used in civil engineering are meter (m), kilogram (kg), second(s), newton (N) and pascal (Pa=N/m^2).
2) In a "soft" conversion, an English measurement is mathematically converted to its exact metric equivalent.
3) In a "hard" conversion, a new rounded metric number is created that is convenient to work with and remember.

CHAPTER 8
TUNNELING IN DIFFICULT GROUND

8.1 INTRODUCTION

Engineers like to work with materials having defined characteristics that do not change from one location or application to another. Unfortunately, geology seldom if ever cooperates with this natural desire but instead tends to present new and challenging conditions throughout the length of a tunnel. Some of these conditions approach the "ideal" closely enough that they can be approached as presented for rock and soft ground. However, in many cases special approaches or arrangements must be made to safely and efficiently drive and stabilize the tunnel as it passes through this "Difficult Ground".

The factors that make tunneling difficult are generally related to instability, which inhibits timely placement or maintenance of adequate support at or behind the working face; heavy loading from the ground which creates problems of design as well as installation and maintenance of a suitable support system; natural and man-made obstacles or constraints; and physical conditions which make the work place untenable unless they can be modified.

8.1.1 Instability

Instability can arise from: lack of stand-up time, as in non-cohesive sands and gravels (especially below the water table) and weak cohesive soils with high water content or in blocky and seamy rock; adverse orientation of joint and fracture planes; or the effects of water. The major problems with mixed face tunneling can also be ascribed to the potential for instability and this class of tunneling will be discussed under this heading.

8.1.2 Heavy Loading

When a tunnel is driven at depth in relatively weak rock, a range of effects may be encountered, from squeezing through popping to explosive failure of the rock mass. Heavy loading may also result from the effects of tunneling in swelling clays or chemically active materials such as anhydrite. Adverse orientation of weak zones such as joints and shears can also result in heavy loading, but this is usually dealt with as a problem of instability rather than loading. Combinations of parallel and intersecting tunnels are a special case in which loadings have to be evaluated carefully.

8.1.3 Obstacles and Constraints

Natural obstacles such as boulder beds in association with running silt and caverns in limestone are just two examples of natural obstacles that demand special consideration when tunneling is contemplated. In urban areas, abandoned foundations and piles present manmade obstructions to straightforward tunneling while support systems for existing buildings and for future developments present constraints which may limit the tunnel builder's options. In urban settings, interference conflicts, public convenience or the constraints imposed by the need or desire for connection to existing facilities will sometimes result in the need to construct shallow tunnels, which have a range of problems from working in confined spaces, avoiding subsidence and uneven ground loading and support.

8.1.4 Physical Conditions

In areas affected by relatively recent tectonic activity or by ongoing geothermal activity, both high temperatures and noxious, explosive or deadly gases may be encountered. Noxious gases are also commonly present in rock of organic origin; and elevated temperatures are commonly associated with tunneling at depth. In an urban setting, contaminated ground may be encountered and will be especially troublesome when found in association with other difficult conditions.

Where appropriate, some information is provided as to the reasons why the condition under discussion creates problems for construction. Some examples of each of the conditions referred to above are discussed briefly to yield insight into the problems and to define the range of solutions available.

8.2 INSTABILITY

8.2.1 Non-Cohesive Sand and Gravel

Cohesion in sands is more than a matter of grain size distribution. For instance, beach-derived sands normally contain salt (unless it has been leached out), which aids in making sand somewhat cohesive regardless of grain size. The moisture content then becomes a determining factor.

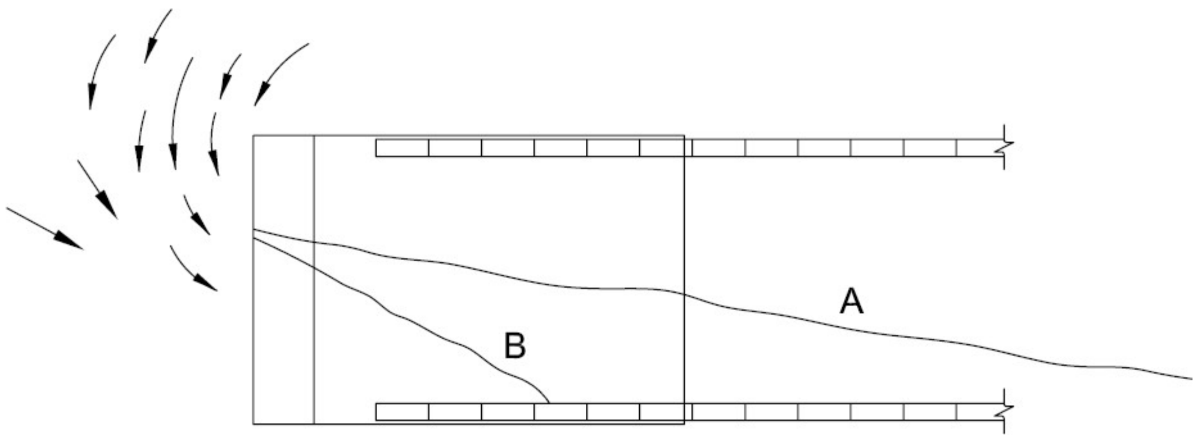
The age and geologic history of the deposit is also important since compacted dune sands with “frosted” grain surfaces may develop a purely mechanical bond; and leaching and redeposit of minerals from overlying strata may also provide weak to strong chemical bonding.

As discussed in Chapter 7, a very low water content amounting to less than complete saturation will provide temporary apparent cohesion as a fresh surface is exposed in tunnel excavation because of capillary forces or “negative pore pressure.” This disappears as the sand dries and raveling begins. Nevertheless, some unlooked-for stand-up time may be available. In this case, it is important not to overrate the stability of the soil. As it dries out, the cohesion will disappear and it cannot be restored by rewetting the ground.

If groundwater is actually flowing through the working face, any amount may be sufficient to permit the start of a run which can develop into total collapse as shown in
Figure 8-1.

There is no such thing as a predictably safe rate of flow in clean sands. Uncontrolled water flows affect more than the face of the excavation. If the initial support system of the tunnel is pervious, water flowing behind the working face will carry fines into the tunnel and may create substantial cavities--sometimes large enough to imperil the integrity of the structural supports. This phenomenon occurred in Los Angeles where a ruptured water main caused sufficient flow through a tunnel support system to cause a failure and resulting large sink hole in the street.

While factors such as compaction or chemical bonding may permit some flow without immediate loss of stability, this is not a reliable predictor. Soil deposits are hardly ever of a truly uniform nature. It has been observed in soft ground tunnels in recent deposits that all that is necessary to trigger collapse may be the presence of sufficient water to result in a film on the working face; i.e., there is no negative pore pressure to assist in stabilizing the working face. Of course, there is never a safety factor arising from surface tension (capillary action) in coarse sand or gravel.



Key:
A: Flowing Sand
B: Sand at Normal Angle of Repose

Figure 8-1 Flowing Sand in Tunnel

The cleaner the sand, the more liable it is to run or flow when exposed in an unsupported vertical face during tunnel construction. Single sized fine-grained sands (UCS classification SP) are the most troublesome, closely followed by SP-SM sands containing less than about 7% of silt and clay binder. Saturated sands in these classes have been observed to flow freely through sheet piles and to settle into fans having an angle of repose of less than 5°. Unconfined SP sands will run freely, as in an hourglass, whether wet or dry, having some stability only when damp but less than saturated (no piezometric head). The large proportion of the sand particles of the same size allow the sand to move almost as freely over one another as would glass marbles.

Silt, intermediate in grain size between sand and clay, may behave as either a cohesive or non-cohesive material. In some areas it is common to find thin seams of saturated fine sandy silt trapped between clay beds in glacial deposits. In general, unless the seams are thicker than about 9-12 inches, when the silt layer is exposed in the wall of an excavation, the soil slumps out at intervals leaving a series of small shallow caves like entrances to burrows. The water appears to drain fast enough from the increased surface area exposed so that the remainder of the exposed material stabilizes.

The usual problem encountered with running sand is settlement and cratering at the surface with damage to structures or utilities in the area. If the ground is permeable, consolidation grouting of the entire sensitive area can be undertaken to stabilize the soil before tunneling. If dewatering is successful in depressing the water table below the tunnel invert, it may be found that the sand is just as unstable dry as wet. The alternative of using compressed air is attractive, provided the working pressure is very carefully controlled; but even so, the ground may be too dried out for stability.

If the face is a full face of sand and similarly weak materials, a slurry machine or an earth pressure balance machine, will be required. In general, rotary head tunneling machines for soft ground tunnels require very similar physical properties over the entire working face and the entire job. If these conditions do not prevail, then weaker ground, and running sands in particular, must be prevented from entering the shield more rapidly than is proper for the rate of advance. Slurry shields have the best opportunity of controlling variable conditions where running sands are present; but they will prove difficult to keep on line and grade in mixed face conditions if one of the beds presents is even a strong clay. If the sand and clay beds are more or less evenly distributed (e.g., a varved clay), then this problem may not arise. Of the digger type shields, neither extensible poling plates nor orange peel breasting have proved to be generally successful, hence these machines are now rarely used.

A problem with all shield construction is the necessary difference in diameter between the shield and the lining. If the soil has no stand-up capability by the time it is exposed in the upper part of the tunnel before expansion of a primary lining or introduction of pea gravel or more commonly, grout into the annular space for non-expanded linings, then there will be loss of ground. If the unfilled annular space averages one inch in a 20 ft tunnel, the lost ground from this single cause is approximately 1.7% shown in Table 7.2 as "poor" practice. Even if only local ravelling takes place, it may choke off the flow of grout before the void can be filled with a continuous supporting fill material. This loss of ground results in a contribution to settlement.

8.2.2 Soft Clay

For the purposes of this discussion, soft clay includes any plastic material that will close around a tunnel excavation if free to do so. This will be the case if the overburden pressure at spring line exceeds the shear strength of the clay by a factor of about three or more. However, if the clay is sensitive and loses strength when remolded, the remolded strength will govern some of the clay behavior during tunnel construction. The phenomenon of sensitivity is mediated by several factors that cannot be fully discussed here but, in general, sensitivity may be suspected in clays with a high moisture content. Particularly at risk are marine clays from which the salt has been leached. The loss of strength may lie within a wide range, the ratio of undisturbed to remolded strength sensitivity being from 2 to 1,000. Moderate sensitivity of 2 to 4 is quite common. During remolding, the void ratio in the clay is reduced and free water is released. When this free water has access to a drainage path such as a sand bed or the tunnel itself, there will be a volume change in the soil mass which will result in surface settlement.

As discussed in Chapter 7, Equation 7-1 is used to calculate a Stability Number to estimate ground behavior in tunneling. Table 7-2 summarizes the behavior of cohesive soils during excavation. As shown in Table 7-2, if the cohesive soil is to be stabilized so that closure around the tunnel lining is minimized and stable control of line and grade are maintained, the critical number must be reduced below about 5; this will enable reasonable control of alignment and grade. Equation 7-1 can be writem to the following equation:

$$P_a = P_z - (N_{crit} \times S_u) \qquad \text{8-1}$$

where Ncrit is the critical number, Pz is the overburden pressure at tunnel spring line, Pa is the working pressure in a compressed air tunnel or the equivalent average pressure provided by the initial support system, and Su is the undrained shear strength of the soil in compatible units. As an example, if N is to be maintained at a value of 5, the overburden pressure is 40 psi and the unconfined shear strength of the soil