26. Tunnel Design Criteria.

a. General.

1) This section presents soft ground tunnel design criteria only. The criteria for rock tunnels are to be determined on a project specific basis, subject to WSSC approval.

2) The primary objectives of tunnel design must satisfy the following requirements: stability of tunnel openings, protection of adjacent or overlying structures and ability of the tunnel to perform over the intended life.

3) The criteria presented in this section are generally applicable to soft ground tunnel design. If conditions are encountered which are not covered in this section, the relevant design criteria are to be established in conjunction with WSSC.

4) The term "tunnel" as used in this section, micro tunneling and bore, open cut casing installation and jack casing installations.

b. Tunnel Use.

1) Whenever possible and agreed by the affected land owner, the primary choice of WSSC for constructing water and/or sewer pipelines is the cut and cover method. When the conditions stated in “Conditions and Requirements for Tunnels”, under Part Three, Section 25 (Tunnels) requires the water and/or sewer pipeline to be in a tunnel, design the tunnel following the criteria in this section.

2) Also, verify with the affected landowner and/or appropriate jurisdictional authority as to whether or not a tunnel crossing is required.

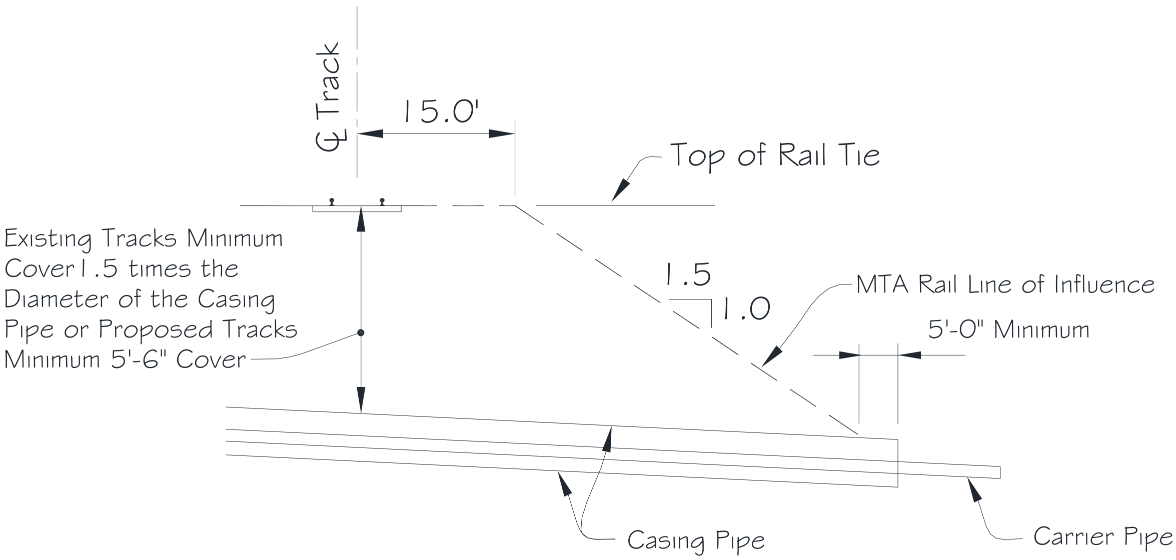
c. Tunnel Casing Length.

1) Maryland Transit Administration (MTA) Rail Lines.

a) Tunnels crossing a MTA Rail Lines, the angle of the crossing is to be based on the economics of the practical alternatives. The crossing is to be located as near perpendicular to the rail line alignment as practical.

b) Minimum length of a tunnel crossing a MTA rail lines is to be as follows:

(1) At a location were top of the tunnel crosses MTA Rail Line of Influence plus a minimum five (5) feet, see Sketch “VV”.



SKETCH "VV"

Profile of Tunnel Crossing MTA Light Rail

2) Other Railroad or roadway. For tunnels crossing a railroad or roadway, the angle of the crossing is to be based on the economics of the practical alternatives. The crossing is to be located as near perpendicular to the railroad or roadway alignment as practical and the minimum length of tunnel casing is to be the width of the railroad right of way.

3) State highways. Minimum casing length of a tunnel crossing a state highway is to be as follows:

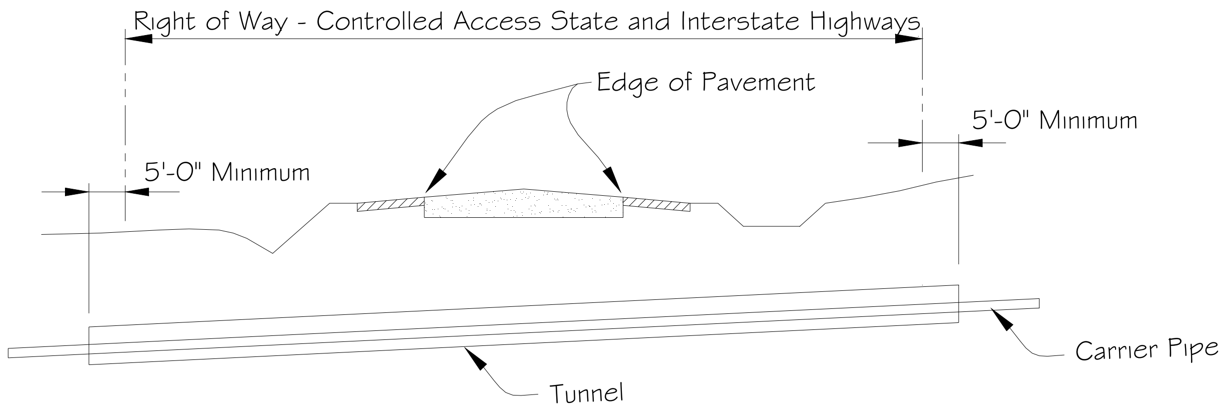
a) The width of the right of way plus five (5) feet for controlled access state highways and interstate highways, see Sketch "FF".

b) On other state highways:

(1) The width of the highway (from shoulder to shoulder or paved ditch to paved ditch) plus a horizontal distance measured out from the edges of both shoulders or paved ditches and equal to the elevation difference between the bottom of the pipe and the roadway surface (for shoulder to shoulder case) or the ground surface beside the ditch (for ditch to ditch case) plus five (5) feet.

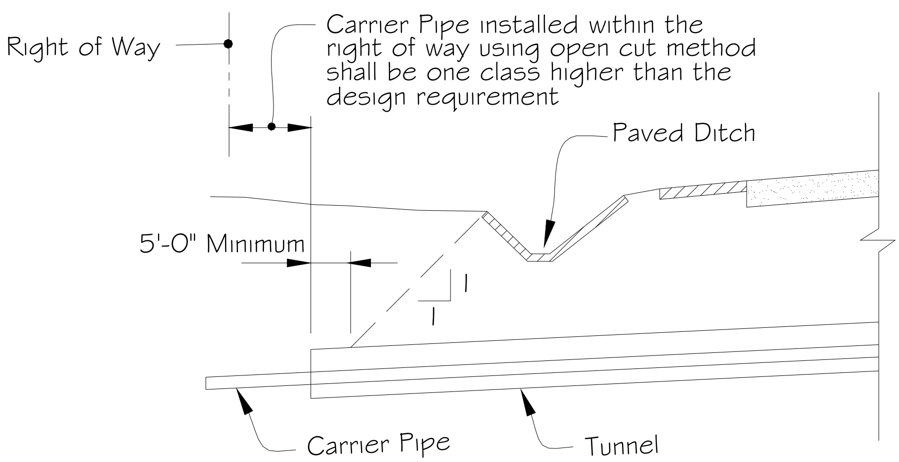
(2) If the width of the highway (from shoulder to shoulder or from paved ditch to paved ditch) is much narrower than the width of right of way, the contractor may be given the option of mixed construction using tunneling and open cut excavation within the right of way for carrier pipe installation. For the remaining part of the right of way, open cut method design the carrier pipe with one (1) class higher than the design requirement, see Sketch "GG".

c) All tunnels. Extend the length of the tunnel casing beyond the limits of planned future expansion of the surface structure. This distance will be the width of the estimated pressure influence zone outside the planned structure area. As an approximation, the pressure influence zone may be bounded by a forty five (45°) degree line extended outward from the edges of the loading area.



SKETCH "FF"

Profile of Tunnel Crossing MSHA Controlled Access and Interstate Highway



SKETCH "GG"

Profile of Tunnel Crossing MSHA Highway other than Controlled Access and Interstate Highway

d. Tunnel Casing Diameter.

1) Tunnel diameter requirements using pipe sleeves, liner plates and casing pipes will vary based on the carrier pipe diameter and the carrier pipe type and contents as follows:

a) Tunnel sizes for gravity sewers to be in accordance to Standard Detail M/17.0.

b) Tunnel sizes for water pipelines and pressure sewers to be in accordance to Standard Detail M/17.6. In certain ground conditions or in special cases, it may be necessary to use a liner plate or other larger diameter tunnel for a water pipeline or a pressure sewer. See Standard Detail M/17.1 for the tunnel diameters.

c) Tunnel diameters for carrier pipe diameters not included in the Standard Details are to be based on ease of installation and maintenance as well as economic considerations, for review and approval by WSSC.

e. Minimum Soil Cover.

1) The minimum soil cover above the tunnel is to be the greater of four and one half (4-1/2) feet, one and one half (1.5) times the outside diameter of the tunnel or the depth requested by the jurisdictional authority.

f. Soft Ground Tunneling Methods.

1) Bore and jack. A method of installing a casing by means of cutting, hand mining or boring an opening in the soil while simultaneously forcing the pipe through the opening with hydraulic jacks. Design the tunnel using steel pipe or reinforced concrete pipe for the casing; see Specifications for casing pipe requirements. The method is limited to a maximum diameter casing pipe of 60" and the maximum tunnel length is limited to two hundred (200) feet.

2) Excavation with liner plate support. Use only for tunnels 48-inch or larger diameter, see the Specifications for the requirements for liner plate, gravel packing, grout and concrete.

3) Microtunneling. A method of installing a casing pipe by jacking the casing pipe behind a remotely controlled, steerable, guided Microtunnel Boring Machine (MTBM) which fully supports the excavated face with either slurry or earth pressure balance at all times. Design the tunnel using steel pipe for the casing; see specifications for casing pipe requirements. Alternate casing materials require approval by the Commission.

g. Clearances with Surrounding Existing Installations.

1) Vertical clearance. Maintain a minimum of two (2) foot clearance between tunnel and other utility lines. The actual location and elevation of the existing utilities over or under the tunnel alignment are to be determined prior to design.

2) Horizontal clearance. For tunnels 72-inch and smaller diameter, maintain (15) feet horizontal clearance between the outside of surrounding surface or subsurface structures/utilities and the outside diameter of the tunnel and tunnels greater than 72-inch diameter, determine the horizontal clearance subject to WSSC approval, typically the horizontal clearance will be greater than (15) feet.

3) Ends of tunnel. The ends of a tunnel are not to be located in steep slopes, streams or drainage ditches. Steep slope is defined as being 3:1 and higher than ten (10) feet from the toe to the top of slope. Extend the ends of a tunnel at least fifteen (15) feet beyond the toe of a steep slope.

h. Tunnel Soil Investigation Submittals and Tunnel Geotechnical Report.

1) A tunnel soil investigation is required for all proposed tunnels. A well-planned and detailed tunnel soil investigation is of great importance to the successful design and construction of a tunnel. The investigation is to be planned by a registered professional geotechnical engineer experienced in tunnel design and meet the minimum requirements of Appendix "F", Soil Investigation for Soft Ground Tunnel Projects. Conduct all fieldwork under the continuous inspection of a person experienced in subsurface explorations. Conform to Appendix "F" for all submittals for the tunnel soil investigation.

2) Preliminary tunnel submittal to contain a natural scale profile of the proposed tunnel (1" = 10'- 0" horizontal and vertical) and tunnel soil investigation submittals are specified in Appendix "F".

3) Tunnel geotechnical report.

a) In general, when a proposed tunnel is greater than 72-inch diameter or a tunnel project appears to be complex such as tunneling in soft clay or loose sand and silt under the water table, a tunnel geotechnical report may be requested to supplement the tunnel soil investigation submittals.

b) The necessity of a tunnel geotechnical report for a particular project will be decided by WSSC after the initial review of the preliminary submittal.

c) If a tunnel geotechnical report is requested by WSSC, bind the report in a suitable cover, signed and sealed by a registered professional geotechnical engineer, including the following minimum information. All pages are to be marked draft until the report is acceptable to WSSC.

(1) All submittals required under Appendix "F" for the tunnel soil investigation.

(2) Description of the site, field program and laboratory testing program.

(3) Area geology and subsoil conditions.

(4) Recommended design groundwater level.

(5) Present estimated subsurface profiles and groundwater levels along the tunnel alignment.

(6) Discuss any special dewatering problems as well as unfavorable soil conditions for tunneling. Propose possible methods of handling these tunnel construction problems including the limitations and advantages of each.

(7) Estimation of design pressure due to dead and live loads for the tunnel liner plates.

(8) Estimation of surface settlements for the ground above and adjacent to the tunnel when it is requested by WSSC.

(9) Evaluation of the face stability for tunneling. This should be discussed in tunneling terms in accordance with Behavior of Ground at Heading, in this section.

(10) Recommend the soil parameters as discussed in this section, including but not limited to parameters such as unit weight, friction angle, cohesion or undrained shear strength and effective grain diameter for use in the tunnel access shaft and jacking pit designs.

i. Soil Parameters.

1) Cohesionless soil. Due to the difficulty of obtaining relatively undisturbed samples, the in-situ properties of cohesionless soils are seldom determined in the laboratory. For complex projects where the effort is warranted, commonly accepted field testing methods shall be used. For most projects, the soil parameters may be determined on the basis of local experience or empirical correlation with SPT blow counts and effective grain diameter (D_{10}). Some typical empirical correlations are included in Table "25".

2) Cohesive soil. Soil parameters such as unit weight, coefficient of permeability and shear strength of cohesive soils may be determined by laboratory testing on undisturbed samples. For a complex project, emphasis on the method of determination shall also be placed on field testing.

j. Behavior of Ground at Heading.

1) Definitions.

a) Firm ground. Heading can be advanced without initial support.

b) Raveling ground. Chunks or flakes of material begin to drop out of the arch or walls sometime after the ground has been exposed. "Fast raveling" begins within a few minutes, otherwise the ground is "slow raveling".

c) Running ground. Granular materials without cohesion are unstable at a slope greater than their angle of repose. When exposed at steeper slopes they run like granulated sugar or dune sand until the slope flattens to the angle of repose.

d) Cohesive running ground. Material with sufficient cohesion to stand for a brief period of raveling before it breaks down and runs.

e) Flowing ground. A mixture of soil and water flows into the tunnel like a viscous fluid. The material can enter the tunnel from the invert as well as from the face, crown, and walls, and can flow for great distances, completely filling the tunnel in some cases.

2) Ground behavior and face stability in various soil conditions.

a) Plastic clay. For plastic clays at depths not less than approximately two tunnel diameters, the stability of the tunnel face may be evaluated by the following ratio: (Ratio should not exceed six (6) in order to maintain face stability.)

$$(P_z - P_a) \div S_u$$

Where:

P_z = total vertical pressure at depth z of center of tunnel, (psf)

P_a = air pressure above atmospheric, (psf)

S_u = undrained shear strength of clay, (psf)

b) Silty sands.

(1) Soils with a unified classification of SP-SM, SW-SM or SM are included in this group. Coarse silt of ML classification may also have similar behavior. The permeability of these soils is commonly moderate to low, in the range of 10^{-3} to 10^{-5} cm/sec.

(2) Above water table.

(a) The ground behavior may be estimated from the ratio of overburden pressure to unconfined compressive strength if the materials have sufficient cohesion or cementation to permit sampling and testing to define the unconfined compressive strength.

(b) Firm ground. When the overburden pressure at tunnel depth is in the range of about 1/10 to 1/6 the unconfined strength or less, the ground is likely to be firm.

(c) Slow raveling. Likely to occur when this ratio is in the range of 1/5 to 1/4.

(d) Fast raveling. When the overburden pressure is in the range of 1/3 to 1/2 the unconfined strength, the behavior is likely to be fast raveling or worse.

(e) Estimate of ground behavior based on D_{10} size. When the soil has too little cohesive strength or cementation to be cored and strength tested, an estimate of ground behavior may be based on effective grain diameter (D_{10}) as shown in Figure "D". The figure is drawn for the case of dense soils (N>30) above the water table assuming relatively uniform gradation (C_u less than 6), and grain shape and packing typical of materials which have experienced moderate transport and working by water. Loose sand (N<10) or sand with very rounded particles would likely exhibit a behavior one to two classes poorer. Soils with very angular particles, significant cementation or relict bonding, or an unusual history such as previous deep burial and compaction, may exhibit behavior one or two classes better.

(3) Below water table.

(a) The ground behavior depends upon the external water head, the nature of the fine contents, relative density, soil stratification, rate of excavation advance and other factors.

(b) When compressed air is used to control excavation stability, the tunneling system should have the capability of balancing the full external water head at the level of the excavation invert. This is necessary for times when the excavation is stopped. When tunneling with compressed air in clean sands, it is necessary to balance the external water pressure at the level of the lower portion of the tunnel face to prevent excessive water seepage into the invert. If the pressure is balanced at invert level, then at the crown the air pressure is greater than the water pressure, resulting in air losses and drying of sand in the crown. A balance point commonly around the lower 1/4 point of the face is usually selected as a compromise.

(c) The estimated bands shown in Figure "E", are intended to represent reasonable lower limits of required air pressure for stability of a tunnel face advancing at a steady rate in the range of thirty two (32) feet per day or more, assuming good construction practice and good ground control.

c) Clean sand and gravel.

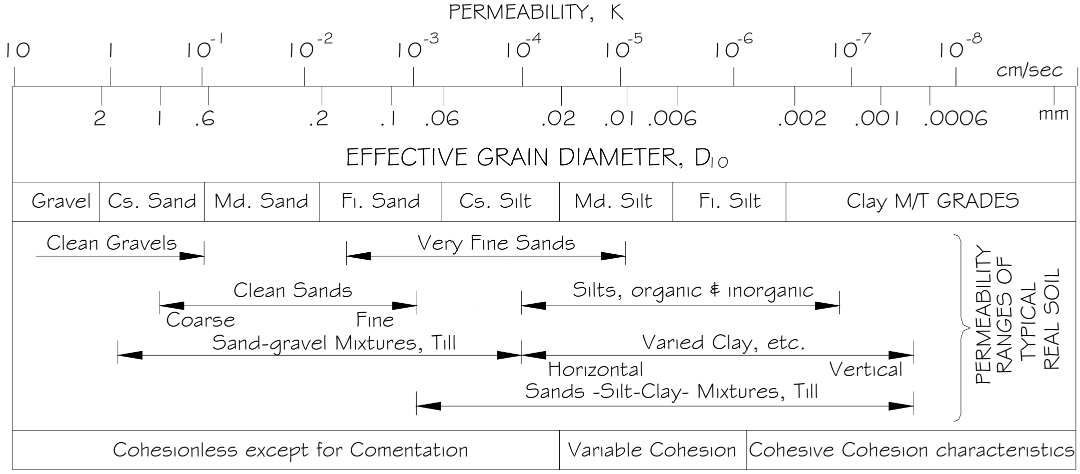
1) Above the water table. These soils must be assumed to act as running ground unless the soil investigation shows a significant cementation or a very dense and angular interlocked grain structure in the deposit. For the later case, a raveling ground may be assumed.

2) Below the water table. These soils must be assumed to act as flowing ground. Some form of ground water control such as dewatering or the use of compressed air must be considered. The internal air pressure must approximately balance the external water head.

Compactness	Very loose	Loose	Medium	Dense	Very dense
Relative density Dd	0 – 15%	15% – 35%	35% – 65%	65% – 85%	85% – 100%
Stardard penetration resistance, N= no. of blows per ft	0 – 4	4 – 10	10 – 30	30 – 50	50 –
Ø (degrees) *	– 28	28 – 30	30 – 36	36 – 41	41 –
- Unit weight, pcf					
moist	<100	95-125	110-130	110-140	>130
submerged	<60	55-65	60-70	65-85	>75

* increase 5 degrees for soils containing less than 5% fine sand or silt.

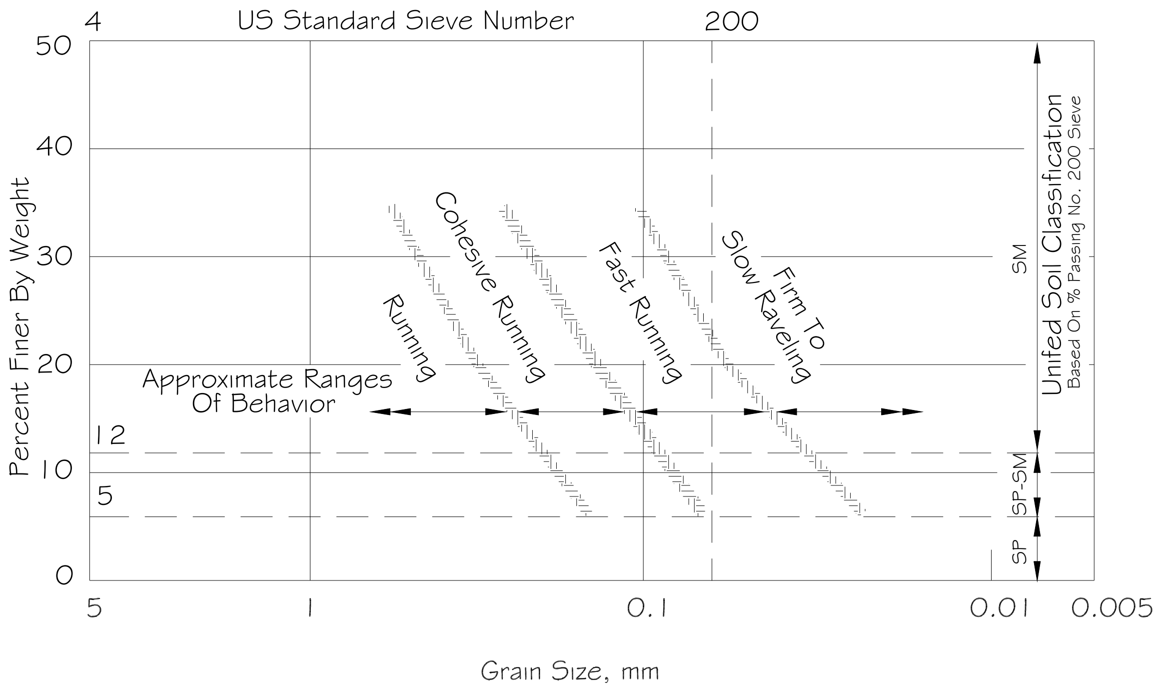
COHESIONLESS SOIL PROPERTIES AND N VALUES (TENG. 1962)



COEFFICIENT OF PERMEABILITY AND D_{10} SIZE
(BICKEL & KUESEL, 1982)

TABLE "25"

Empirical Correlation of Soils



Sand			Silt or Clay
Coarse	Medimum	Fine	

Anticicipated Ground Behavior Based on D_{10} Size
Dense Soil N>30, Above Water Table
(HEUR AND VIRGENS, 1987)

FIGURE "D"

Anticicipated Ground Behavior Based on D_{10} Size.

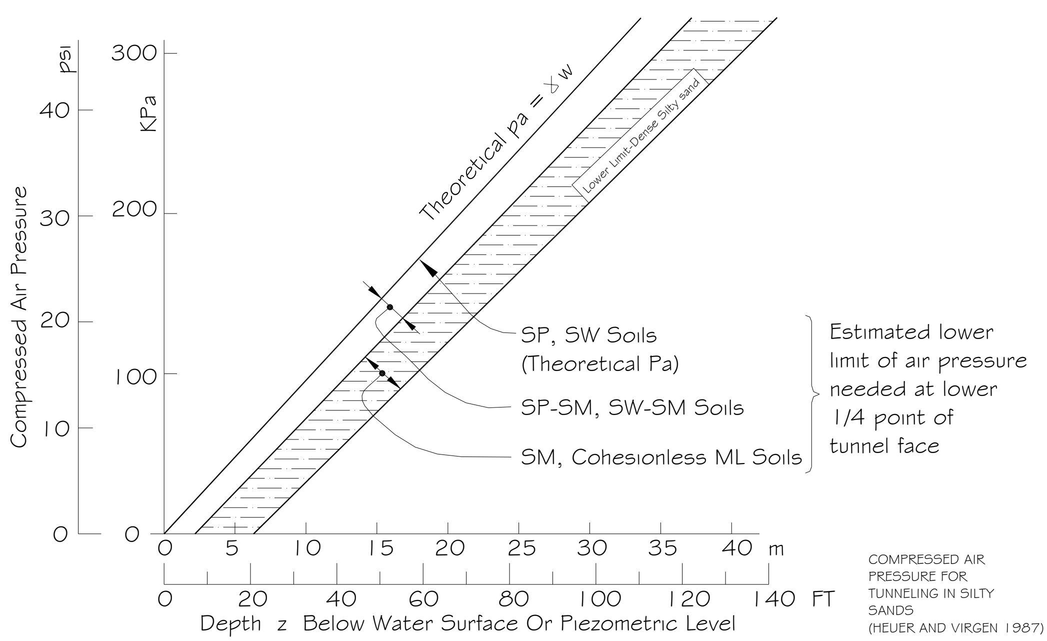


FIGURE "E"

Compressed Air Pressure for Tunneling in Silty Sands

k. Surface Settlement Estimation.

1) Perform surface settlement estimation if it is requested by WSSC after the initial review of the preliminary tunnel submittal, which includes the submitted plan and the soil investigation results. In general, surface settlement analysis may be requested if the soil borings indicate that the tunneling operation will be mainly in soft clay or loose sand and silt under the water table. Settlement analysis may also be requested for tunnel diameters greater than 72-inch in any soil condition or for a proposed tunnel alignment where sensitive structures will be closer than fifteen (15) feet in horizontal direction from the center of the tunnel. Either one of the following methods may be used for the analysis.

a) Semi-empirical method. The surface settlement trough over a single tunnel may be represented with an error function. The pertinent properties of the error function and its relationship to the dimensions of the tunnel are shown in Figures "F" and "G". Using these figures, the width of the settlement trough is expressed as a multiple of i. The maximum settlement, δ_{max}, above the center of the tunnel may then be estimated from the i value and the volume of the trough as follows:

$$\delta_{max} = V \div 2.5\, i$$

The volume of the trough, V, in clay may be expressed as:

$$V = 3\,(S_u \div E)\ \mathrm{EXP}\,(OF - 1) \qquad (\text{For } OF > 1)$$

Where:

$OF = (P_z - P_a) \div S_u$

P_a = air pressure above atmospheric on the tunnel face (psf)

P_z = overburden pressure (psf)

S_u = undrained shear strength (psf)

E = deformation modulus (psf)

(Note: Usual range of $(S_u \div E)$ is between 0.002 and 0.005)

The volume of lost ground in sand over a single tunnel is usually estimated from past experience with similar methods of tunnel construction.

b) Theoretical analysis. A finite element method which simulates tunneling operation and load deformation characteristics of the soils may be used to estimate the soil deformation and surface settlements. The selection of deformation modulus for the soil in the analysis shall be based on local experience, actual field measurements or the estimation from SPT values in accordance with NAVFAC, Soil Mechanics Design Manual, 7.01.

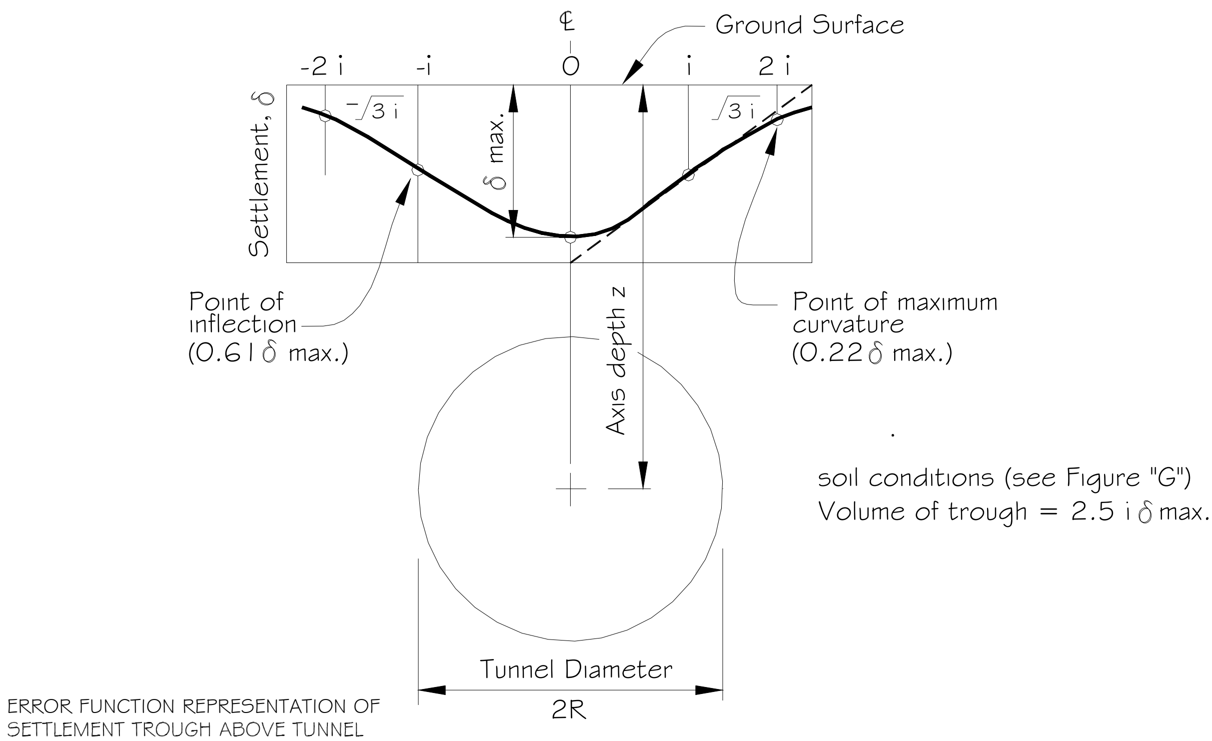


FIGURE "F"

Error Function Representation of Settlement Trough Above Tunnel

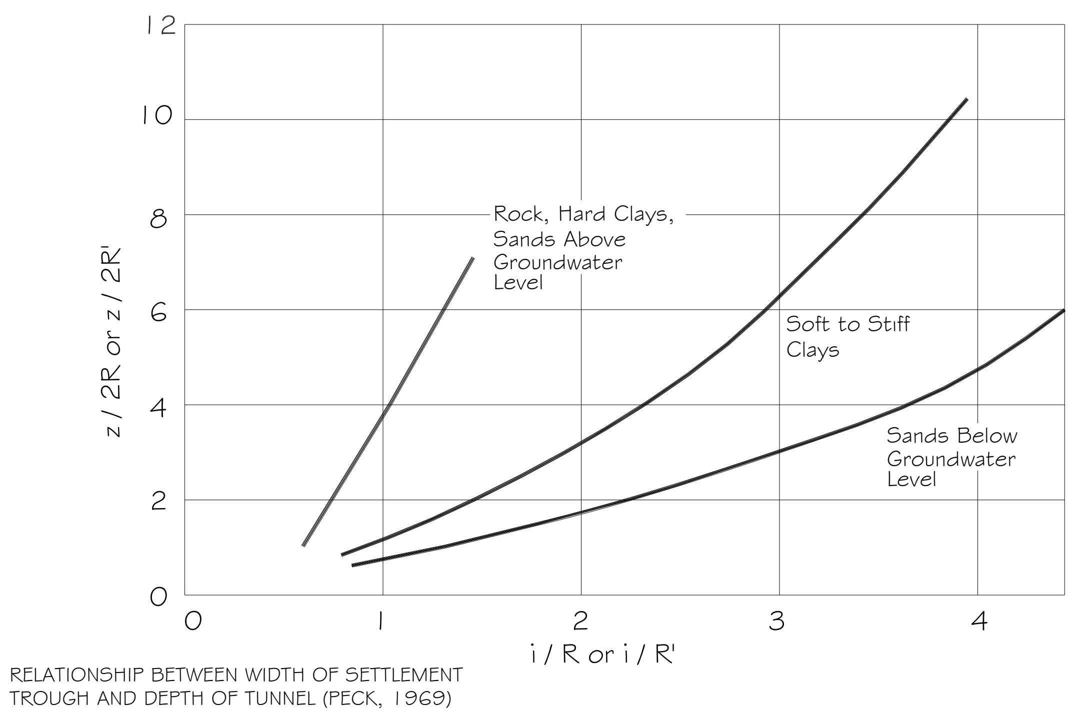


FIGURE "G"

Relationship Between Width of Settlement Trough and Depth of Tunnel

l. Tunnel Design.

1) Design external pressures.

a) External pressures acting on a circular tunnel which may be constructed with either liner plates or a casing pipe may be computed approximately with the following procedures.

(1) If grouting is used to fill the voids between the tunnel liner and the soil and grouting pressure is greater than the computed external pressures, use grouting pressure for design of the tunnel.

(2) In general the external pressure due to earth load, ground water, and live load can be computed by the following formula:

$$P = P_d + P_w + P_l$$

Where:

P = external pressure on the tunnel liner (psf)
P_d = vertical pressure at the level of the top of the tunnel liner due to the soil load (psf)
P_w = water pressure in excess of that considered in the saturated soil load (psf)
P_l = vertical pressure at the level of the top of the tunnel liner due to live loads (psf)

(a) Earth load.

$$P_d = C_d \; W \; D$$

Where:

C_d = coefficient of pressure for tunnel liner, (H is height of cover in feet in Figure "H").
W = total unit weight of soil (pcf) (Saturated unit weight for soil below water table.)
D = horizontal diameter of tunnel (ft)

The charts for earth loads on jacked or tunneled installations published in the Concrete Pipe Design Manual by American Concrete Pipe Association (ACPA) can also be used for this purpose. However, the loading obtained from the charts shall be divided by "D" above and furthermore the cohesion term from the charts shall be neglected in the design.

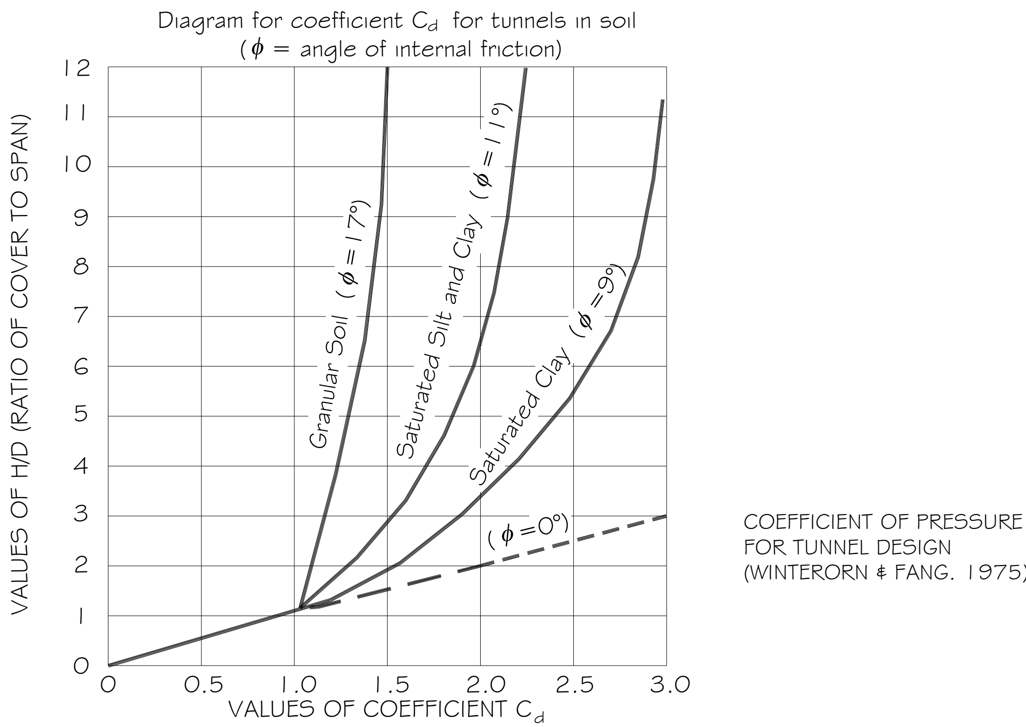


FIGURE "H"

Coefficient of Pressure for Tunnel Design

(b) Live load. The value of P_l for both highway and railway loadings can be taken from Table "26", which includes both static and dynamic loading.

TABLE "26"

Value of P_l

Height of Cover (feet)	Highway H20 (psf)	Height of Cover (feet)	Railway E-80 (psf)
1	1800	2	3800
2	800	5	2400
3	600	8	1600
4	400	10	1100
5	250	12	800
6	200	15	600
7	175	20	300
8	100	30	100

The affect of live load less than 100 psf may be disregarded.

(c) Ground water pressure.

$$P_w = \Gamma_w \ [h_w - (C_d \ D)]$$

Where:

Γ_w = unit weight of water (pcf)

h_w = height of water surface above the top of the tunnel liner (ft)

This excess water pressure will be included only if h_w is greater than (C_dD). When h_w is less than (C_d D), the water pressure is included in the evaluation of P_d when the saturated unit weight of soil is used.

2) Design of tunnel liner plate.

a) Consider the following criteria in the design of tunnel liner plates:

(1) Joint strength. Liner plates must be sufficient to withstand the thrust developed from the pressure determined in Tunnel Design, Design External Pressures, in this Section. The thrust may be calculated as follows:

$$T = PD \div 2$$

Where:

T = thrust (lb/ft)
P = pressure (lb/ft^2)
D = diameter (ft)

The ultimate joint strength of the plate should be at least three times (safety factor of 3) the thrust value. Values of the ultimate joint strength of steel liner plates can be obtained from the manufacturer's literature.

(2) Minimum stiffness for installation. The liner plate ring shall have enough rigidity to resist the unbalanced loadings of normal construction such as grouting pressure, local slough-ins and miscellaneous concentrated loads. The values given here for minimum stiffness are only recommended minimums. Actual job conditions may require higher values of effective stiffness. Minimum eight (8) gauge liner plate shall be used for tunnels not grouted shut.

$$\text{Minimum Stiffness} = (E\ I) \div D^2 = 111 \text{ minimum}$$

Where:

D = diameter in inches
E = modulus of elasticity of steel (29 x 10^6 psi)
I = centroidal movement of inertia of the liner plate section (in^4/in); value of the centroidal movement of inertia can be obtained from the manufacturer's literature

(3) Buckling strength. Design for buckling is accomplished by limiting the ring compression thrust, T, to the buckling stress multiplied by the effective cross section area of the liner plates divided by the factor safety:

$$T = (f_c\ A) \div FS$$

Where:

T = thrust per lineal foot
A = effective cross section area of liner plate (in^2/ft), (from manufacturer's literature; equal to 2 actual area)
FS = factor of safety is 2 for buckling
f_c = buckling stress (psi)

Buckling stress is determined from the following formula, and shall not exceed the specified yield strength (f_y = 28,000 psi) of liner plates.
For diameters less than:

$(r \div k)\,[(24\,E) \div f_u)]^{1/2}$

$$f_c = f_u - [f_u^2 \div (48\,E)]\;[(k\,D) \div r]^2 \quad \text{(psi)}$$

For diameters greater than:

$(r \div k)\,[(24\,E) \div f_u)]^{1/2}$

$$f_c = (12\,E) \div [(k\,D) \div r]^2 \quad \text{(psi)}$$

Where:

- f_u = minimum specified tensile strength of steel, psi
- k = soil stiffness factor, which will be 0.22 for soils where friction angle >15E and 0.44 where friction angle <15E
- D = pipe diameter (in)
- r = effective radius of gyration of section (in) (from manufacturer's literature; equal to 0.75 of actual radius of gyration).
- E = modulus of elasticity of steel (29×10^6 psi)

(4) Deflection. Over size the structure to provide for a normal deflection where the tunnel clearances are important. Good construction methods shall result in deflections of not more than three (3%) percent of the normal diameter.

3) Design of steel casing pipe.

a) Consider the following criteria in the design of steel casing pipe. However, under no circumstances shall the wall thickness and the yield strength of the casing pipe be less than 3/8" and 35,000 psi respectively.

(1) Deflection.

$$\triangle x = D_l\left((K\;W_L\;r^3) \div [(E\;I) + (0.061\;E'\;r^3)]\right)$$

Where:

- $\triangle x$ = horizontal deflection of pipe (in)
- D_l = deflection lag factor (use 1.5)
- K = bedding constant (0.1)
- W_L = load per unit length of pipe (lb/linear in of pipe); this can be calculated using P, see Tunnel Design, Design External Pressures, in this Section and is equal to PD/12
- r = radius of pipe (in)
- E = modulus of elasticity of steel (29×10^6 psi)
- I = transverse moment of inertia per unit length of pipe wall (in^3) (equal to $t^3/12$ where t is the wall thickness of the pipe)
- E' = modulus of soil reaction (lb/in^2)

The deflection $\triangle x$ shall be less than three (3%) percent of the pipe diameter.

(2) Buckling pressure. The allowable buckling pressure may be determined as follows:

$$q_a = (1 \div FS)\left(32\;R_w\;B'\;E'\;[(E\;I) \div D^3]\right)^{1/2}$$

Where:
q_a = allowable buckling pressure (psi)
FS = design factor
= 2.5 for $(h/D) \geq 2$
= 3.0 for $(h/D) < 2$
h = height of ground surface above top of pipe (in)
D = diameter of pipe (in)
R_w = water buoyancy factor
= $1 - 0.33 \times (h_w \div h),\ 0 \leq h_w \leq h$
h_w = height of water surface above top of pipe (in)
B' = empirical coefficient of elastic support (dimensionless)
= $1 \div (1 + 4e^{(-0.065H)})$
H = height of fill above pipe (ft)
e = 2.7183 (constant)
E, I & E' are as defined previously, herein

The external pressure P computed in Design External Pressures in this section shall be equal to or less than $144 \times q_a$.

(3) Jacking force. Design the pipe to withstand the axial stress induced by the jacking operation. The required jacking force may be estimated from the total area of exterior surface of the pipe and the unit friction between the soil and the pipe. The unit friction may be evaluated from the external pressure determined from Tunnel Design, Design External Pressure, in this section, and the pipe weight or it may be estimated from past experience.

4) Design of RCP casing.

a) Consider the following criteria in the design of the RCP casing: The casing pipe to meet the requirements of ASTM C 76 minimum class IV and for casing pipes crossing under a railroad, meet the requirements of ASTM C 76 Class V with type C wall.

(1) Selection of pipe strength. The required pipe strength for the external pressure may be determined as follows:

$$D_{0.01} = (P \div L_f)\, FS$$

Where:
$D_{0.01}$ = 0.01 inch crack D-load (psf)
P = external pressure P computed in Tunnel Design, Design External Pressure, in this section (psf)
L_f = load factor (use 1.9)
FS = factor of safety (use 1.0 for 0.01 inch crack)

(2) Jacking force. Design the pipe to withstand the axial stress induced by the jacking operation. The same approach as described in Tunnel Design, Design of Steel Casing Pipe, in this section, can be used for estimation of the jacking force.

5) Design of carrier pipe inside the tunnel for the total soil prism load. For railroad crossings, it is further required that the highest class of pipe, DIP Class 56 be used.

m. Access Shaft and Jacking Pit.

1) As indicated in the Specifications, the design and construction of the access shaft and jacking pit are the responsibility of the contractor. The following information is presented only for reference.

a) Access shaft.

(1) Locate the access shafts at the low end of the tunnel and a receiving pit at the another end for a short tunnel. The surface area around the shaft needs to be large enough to contain all necessary services and working space such as space for trucks removing muck, space for storage of tunnel lining materials, etc.

(2) Earth pressures.

(a) In earth pressure calculations, use the total unit weight of soil for the shafts above the water table. For shafts below the water table use the submerged unit weight of soil and add the hydrostatic pressure due to groundwater.

(b) Surcharge load accounting for the sloping ground surface, adjacent fill, equipment or structures is to be considered in the analysis. In the case where no detailed information is available, assume a minimum of three hundred sixty (360) psf of uniform surface loading beside the shaft.

[1] Shaft in sand. For a vertical cylindrical shaft, the earth pressure surrounding the shaft may be determined in accordance with the method on pp. 7.1-201 of NAVFAC, 1986, Soil Mechanics Design Manual, 7.01.

For a rectangular or square shape braced excavation the earth pressure on the walls may be calculated following the procedures on pp. 7.2-100 of NAVFAC, 1986, Foundation and Earth Structures Design Manual.

[2] Shaft in clay. For a cylindrical shaft in soft clay, the earth pressure surrounding the shaft may be evaluated in accordance with the method on pp. 234 of Proctor, R. V. and White, T. L., 1977, Earth Tunneling with Steel Supports, Commercial Shearing, Inc., Youngstown.

The procedure presented on page 7.2-100 NAVFAC, 1986, Foundation and Earth Structures Design Manual, may be used to evaluate the earth pressure for a rectangular or square shape braced excavation.

2) Jacking pit. Provide a jacking pit at the lower end of the tunnel when using the bore and jack method. The earth pressure on the jacking pit walls due to the excavation may be calculated similar to the access shaft. Design a reaction backstop suitable to resist the jacking force required to install the casing pipe.

n. Dewatering.

1) There are several efficient methods of dewatering that may be considered, such as pumping from well points or pumping from deep wells. Required pump capacity may be sized from the estimated coefficient of permeability of the soils. Without previous in-situ test data, the soil permeability may be preliminarily estimated from effective grain diameter (D_{10}). Pump size shall

then be adjusted as required during construction.

2) Well points and deep well pumping are only workable if the percentage of soil particles smaller than 0.05 mm (millimeter) is not more than ten (10) to fifteen (15%) percent. Dewatering by pumping from deep well points can cause varying amounts of settlement. Carefully consider the settlement of ground due to loss of water before using these methods.

3) Compressed air methodology may sometimes be used as an alternative to dewatering when ground water draw down is expected to cause excessive settlement.

o. Casing Seal, Permanent/Temporary Bulkhead or Tunnel Access Manhole.

1) Casing end seals are used at each end of a small diameter water and pressure sewer casing which uses casing spacers as shown in Standard Details M/17.6 and M/17.7.

2) Provide permanent bulkheads on both ends of large diameter water and pressure sewer tunnels installed according to Standard Detail M/17.1 when the tunnel invert is less than or equal to twenty (20) feet. Provide the design for a permanent brick or concrete bulkhead on the plans.

3) Provide tunnel access manholes at both ends of large diameter water and pressure sewer tunnels installed according to Standard Detail M/17.1 when the tunnel invert is greater than twenty (20) feet. Provide tunnel access manholes according to Standard Detail M/17.5.

4) For gravity sewer tunnels installed according to Standard Detail M/17.0 that are to be grouted shut, the specifications requires the contractor to provide temporary bulkheads to facilitate grouting the annular space between the carrier pipe and the casing.

p. Carrier Pipe Tie-Downs.

1) When the annular space between a carrier pipe and casing pipe or tunnel is not grouted shut, such as the case for water pipelines and pressure sewers, provide permanent tie-down assemblies. All types of tie-downs are included in the Standard Details and depend on the material type and size of the tunnel or casing pipe as follow:

a) Refer to Standard Detail M/17.2 for hold down assembly for bore and jack steel casing pipes, Standard Detail M/17.3 for hold down assembly for steel liner plate and Standard Detail M/17.4 for hold down assembly for RCP casing pipes.

b) Refer to Standard Details M/17.6 and M/17.7 for casing spacers for supporting carrier pipes in small diameter casings installed according to Standard Detail M/17.6.

c) For sewer tunnels where the annular space between carrier pipe and the casing or tunnel is to be filled with concrete or grout, temporary supports to prevent pipe flotation are provided in accordance with Standard Detail M/17.0.

q. Ground Movement Monitoring.

1) Specify the locations of critical structures, surface or subsurface installations to be monitored other than those generally specified for roadway and railroad crossings in the Specifications. Take a minimum of three movement measurements on any critical structures during tunnel construction as follows:

a) Tunnel face is ten (10) feet before passing the structure.

b) Tunnel face is passing the structure.

c) Tunnel face is ten (10) feet beyond the structure.

2) Unless a more stringent criteria is required for a specific structure, the maximum allowable settlements or heaves are included in the Specifications.

3) Surface settlement markers and subsurface settlement indicators should be installed prior to the tunnel construction. Surface settlement markers can take the form of paint on a concrete surface, pk nail on the paved areas and a wood hub in unpaved areas. Details of subsurface settlement indicators are shown on Standard Detail M/7.0.

r. Codes.

1) Codes, standards, regulations, and recommended practices.

a) The American Society for Testing and Material Standards (ASTM).

b) Regulations of the Maryland Department of Transportation, State Highway Administration (MSHA).

c) Applicable regulations of affected Railroad Authorities.

d) Standard Details.

e) Occupational Safety and Health Administration (OSHA) 29 CFR 1926.

f) American National Standards Institute (ANSI) A10.16-1995 (R2001), Safety Requirements for Construction of Tunnel Shafts and Caissons.

g) American Concrete Institute (ACI) and American Institute of Steel Construction (AISC) Manuals.

h) The BOCA Basic Building Code with Montgomery County and Prince George's County Amendments.

i) Regulations of the State of Maryland.

j) Applicable Regulations of the Federal Government.

k) American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications.

l) American Railway Engineering Association (AREA) Design Manual.

m) NACE International Recommended Practices.

s. References.

a) Proctor, R. V. and White, T. L., 1977, Earth Tunneling with Steel Supports, Commercial Shearing, Inc., Youngstown.

b) Peck, R. B. et.al., November 1969, Some Design Considerations in the Selection of Underground Support Systems, Department of Civil Engineering, University of Illinois, Urbana.

c) Peck, R. B., 1969, Deep Excavations and Tunneling in Soft Ground, State of the Art Volume, 7th International Conference on Soil Mechanics and Foundation Engineering, Mexico City, pages 225 to 290.

d) Commercial Pantex Sika, Inc., Soft Ground Tunneling Catalog.

e) Warren Consolidated Industries, Inc., Tunnel Liner Plates Catalog.

f) Golder Associates and James F. Maclaren Ltd., 1976, Tunneling Technology: An Appraisal of the State of the Art for Application to Transit Systems.

g) Bickel, J. O. and Kuesel, T. R., 1982, Tunnel Engineering Handbook, Van Nostrand Reinhold Co.

h) NAVFAC, 1986, Soil Mechanics Design Manual 7.01.

i) NAVFAC, 1986, Foundation and Earth Structures Design Manual 7.02.

j) NAVFAC, 1982, Soil Dynamics, Deep Stabilization and Special Geotechnical Construction Design Manual 7.3.

k) Heuer, R.E. and Virgens, D.L., 1987, Anticipated Behavior of Silty Sands in Tunneling, Proceedings Volume 1, Rapid Excavation and Tunneling Conference, New Orleans, Louisiana, June 14-18, pages 221-237.

l) Winterkorn, H.F. and Fang, H.Y., 1975, Foundation Engineering Handbook, Van Nostrand Reinhold Company.

m) TENG, W.C. 1962, Foundation Design, Prentice Hall, Inc., Englewood Cliffs, N.Y.

n) Spangler, M.G. & Handy, R.L., 1982, Soil Engineering, Harper & Row Publishers, N.Y.