Jacking Concrete Pipe

FOREWORD

Jacking or tunneling concrete pipe is an increasingly important construction method for installing concrete pipelines without interrupting commerce, or disturbing the maze of utilities services buried under the surface of our streets and roadways. The methods first used in the latter part of the nineteenth century to push concrete pipe under the Northern Pacific Railway right-of -way are still being used, but with much greater mechanical force and geotechnical and structural knowledge.

There have been many technical innovations to jacking installation practice but the general procedure remains the same; construct a reaction access shaft at the beginning of the tunnel and a reception shaft at the end of the tunnel, carefully excavate the soil at the front of the pipes and push the pipeline ahead into the excavated opening with powerful jacks. For some projects, manual excavation is still the most common construction method, but microtunneling machines and tunnel boring machines (TBM) are frequently used for mechanical excavation of soil or rock in large projects in restricted areas.

Access shafts are constructed at the start and end of the tunnel and are used to provide a location to operate the thrust jacks, to construct the structural reaction to the jacking forces, and as a means to introduce pipe and to remove soil from the tunnel. On long tunnels, intermediate shafts may be used to break the pipeline into shorter more manageable tunnel segments that can reduce the total required axial force.

Axial thrust is necessary for all of the following tunneling methods to push the pipeline through the soil and in the case of mechanical excavators, provide enough axial force on the cutter heads to break down the soil or rock at the head of the tunnel. The required axial force is greatly variable and to determine it may be more art than science. The installer must carefully estimate the axial loads transmitted through the pipeline based on factors such as pipe diameter, length of the pipeline, soil friction and the type of lubrication used, and methods of excavation.

When jacking moderate diameter pipe, the pipeline is lead with a circular steel cutting shield that defines the dimensions of the tunnel, and protects the worker as the soil in front of the pipe is excavated. The excavated soil is placed in a small rail guided cart system and transported to the access shaft. For larger diameter pipe, mechanical excavators such as skid loaders may work at the face of the excavation and transport soil to the access shaft.

Microtunneling machines are often used for installing small diameter pipe, generally in sizes that do not permit entry by the worker (usually less than 900 mm). Micro-tunneling machines are automated with a remotely controlled steerable cutter head and a method of transporting the soil to the access shaft with an auger or carried in a soil-water slurry. Operators direct the cutter head from a control panel housed on the surface in a portable control room near the access shaft.

Tunnel boring machines are used with larger sized pipe (900 mm and over) and may be full-face style with a rotating cutting head or an open-faced style equipped with an articulated mechanical excavator arm. The full-faced TBM relies greatly on the horizontal force in the pipeline to provide the necessary pressure on the teeth of the cutter to remove the soil or rock in a wide range of soil conditions. The open-faced style utilizes a mechanically operated excavating arm that may have either a bucket for removing softer soils or a rotating cutter head that can cut through rock and stiff soils. The TBM can be operating from within the machine itself or from an operating station in the pipeline.

JACKING PROCEDURE

When jacking concrete pipe, reaction and reception access shafts are first excavated with the back wall of the reaction shaft strong enough to resist the horizontal thrust of the jacks. The reaction shaft must be long enough to accommodate a full length of pipe or the length of the tunneling machine as well as the jacks. Jacks may have a stroke as long as the full length of the pipe, or have a short stroke and be combined with spacers. Occasionally, for pipelines that are jacked through an embankment, there is no effective soil structure to resist the jacking thrust so a framework of steel or concrete must be constructed to provide a reaction.

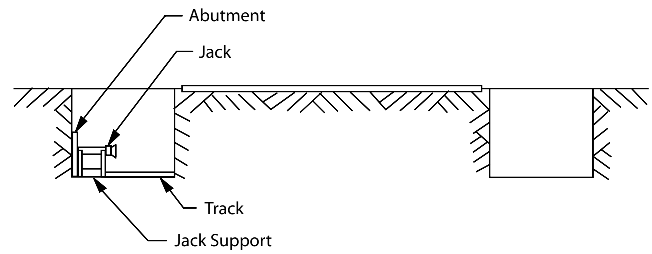
After a shield is attached to the lead pipe, together they are carefully positioned on a rail or guide system set to the specified line and grade that will intercept the reception shaft at the specified elevation. The jacks are then positioned between the reaction structure and an open steel thrust frame that distributes the jacking force uniformly across the end of the pipe. As the jacking force is applied, the mechanical tunneling machine or miners inside the pipe carefully dig the soil away from the front of the lead pipe and transport the excavated soil back to the access shaft. When the first pipe has fully advanced, the jacks are retracted, the second pipe is positioned and the process is repeated until the lead pipe enters the reception shaft.

The shield's outer diameter and extent of excavation must be carefully controlled. Over-excavation not only increases the costs of every operation in the tunneling process but also increases the earth load on the pipeline. During the advancing of the pipeline, lubricants such as bentonite, clay mixed with water, and polymers are pumped into the annular space between the soil and pipe to reduce friction and the required axial force on the pipeline. If lubricant is not used, the axial force on the pipe will be significantly higher and should be considered during design. For long pipeline lengths, intermediate jacking stations are used to minimize the length of pipe pushed at any time. After the pipeline is in its final position, a Portland cement grout should be pumped into the remaining annular space to stabilize the soil and to minimize surface subsidence above the tunnel, to prevent the flow of ground water along the outside of the tunnel, and provide complete pipe-soil interaction at the invert of the pipe. A typical installation for jacking concrete pipe is shown in Figure 1.

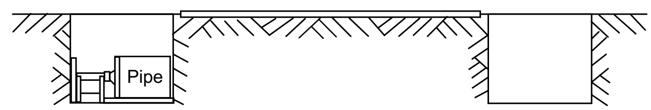
LOADS ON JACKED PIPE

A concrete pipe installed by jacking is subjected simultaneously to axial and transverse forces. For many tunneling projects, the axial strength of a pipe is the primary concern to installers because as the pipe is pushed, it may be affected by so many unpredictable variables. Axial strength of the pipe is a function of the strength of concrete, f'c, and the surface area of the contact face of the pipe being advanced through the soil. The vertical strength requirements,

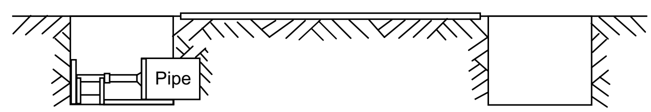
Figure 1 Steps in Jacking Concrete Pipe



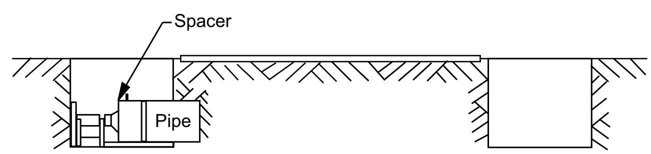
Pits are excavated on each side. The jacks will bear against the back of the left pit so a steel or wood abutment is added for reinforcement. A simple track is added to guide the concrete pipe sections. The jacks are positioned in place on supports.



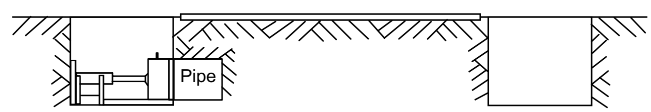
A section of concrete pipe is lowered into the pit.



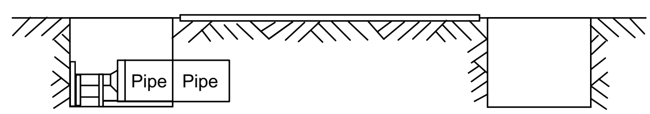
The jacks are operated, pushing the pipe section forward.



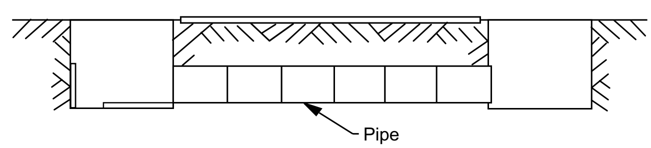
The jack rams are retracted and a "spacer" is added between the jacks and pipe.



The jacks are operated and the pipe is pushed forward again.



It may be necessary to repeat the above steps several times until the pipe is pushed forward enough to allow room for the next section of pipe. It is extremely important, therefore, that the stroke of the jacks be as long as possible to reduce the number of spacers required and thereby reduce the amount of time and cost. The ideal situation would be to have the jack stroke longer than the pipe to completely eliminate the need for spacers.



The next section of pipe is lowered into the pit and the above steps repeated. The entire process above is repeated until the operation is complete.

on the other hand, are relatively predictable and are determined with conservative and relatively insensitive design criteria. Specifying a strength Class of pipe beyond the required transverse or vertical bearing capacity has little effect on the axial bearing capacity and likely adds unnecessary costs to the project. The criteria for specifying, designing and installing precast concrete pipe are detailed in the American Society of Civil Engineer's (ASCE) publication ASCE 27-00, *Standard Practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Installations*. The Standard uses the direct design method to select the circumferential reinforcing for transverse loads and the Ultimate Strength Design method for determining the axial compressive strength of the pipe.

AXIAL LOADS

The ASCE Standard Practice details three stages of stress distribution for axial thrust; concentric or uniform distribution at the maximum compressive stress, eccentric or linear distribution with zero at one edge of the joint and maximum stress at the opposite edge of the joint, and a partial linear distribution with zero at an intermediate point on the axis of the pipe and a maximum stress at the opposite edge of the joint.

The eccentric or linear stress distribution should be used to find the maximum allowable axial force across the pipe joint. The concentric or uniform distribution is an idealized load case that would exist for only a very short pipeline. For a linear distribution across the entire joint, the allowable stress shall not exceed:

$$f = \frac{0.85\varphi f_c'}{LF_J} \quad \text{MPa} \qquad (1)$$

where:

φ = 0.9, strength reduction factor for compressive axial thrust.

f_c' = design concrete strength, (MPa)

LF_J = 1.2, load factor for jacking thrust-eccentric load.

The maximum jacking thrust force for a linear stress distribution shall not exceed:

$$P = 0.5 f' A_p \times 10^6 \quad \text{N} \qquad (2)$$

where:

A_p = contact area between joint packing and concrete surface with no joint separation, (m^2).

An appropriate cushion material, commonly plywood, should be added between the surfaces of the joints to prevent stress concentrations during jacking. If the project requires long jacking lengths with high axial forces, an external steel band can be added to the bell. The steel band confines the concrete in order to allow full development of the concrete compressive strength and prevent concrete spalling or localized crushing.

TRANSVERSE LOADS

Vertical loads on the pipe include the soil prism load above the pipe, the weight of the pipe, the weight of fluid within the pipe and any live load or surcharge loads. For most installations, the soil friction in vertical shear planes will reduce the magnitude of the soil load reaching the pipe. Depending on the type of soil surrounding the pipeline, horizontal forces due to horizontal soil pressure can develop. External ground water can cause a radial load around the periphery of the pipe but it generates primarily compressive thrust in the pipe wall and is generally ignored.

There are three common methods used to select the required vertical strength of jacking pipe:

1. Some standards use an overly conservative rule of thumb where the designer simply selects an ASTM C76, Class V, C-wall pipe instead of analyzing the loads on the pipe to determine the necessary pipe strength. This method does not adequately account for all installation variables and may provide an uneconomical pipe system. The designer of the pipe is encouraged to perform a more rigorous de sign analysis as detailed in the following methods.

2. The Marston-Spangler Indirect Method is a simple process using service or unfactored loads. First, the designer determines the loads on the pipe, and second, selects the pipe strength based on the relationship of the three-edge-bearing (TEB) load on the pipe to load in the installed condition.

3. The direct design method ASCE Direct Design method (ASCE 27-00) uses factored loads and calculates the required reinforcing of the pipe based on the reactions of the soil envelope surrounding the pipe.

The American Concrete Pipe Association (ACPA) has developed two computer programs that simplify the computation for pipe design. For Indirect Design PipePac can determine the live and dead loads on the pipe and directly select an ASTM C76 three-edge-bearing (TEB) strength class. For designers using the ASCE Direct Design method, PIPECAR may be used to calculate the moments, thrust, and shear forces in the pipe due to internal and external loads and determine the required areas of reinforcing steel.

Indirect Design

The Indirect Design method for finding earth loads on pipe installed by jacking is closely related to Marston-Spangler trench installation method. The major factors influencing the vertical load on the pipe are:

- The weight of the soil prism load directly over the bore of the tunnel
- The upward shearing or frictional forces between the soil prism load and the adjacent earth
- Cohesion of the soil

The resultant vertical earth load on a horizontal plane at the top of the tunnel is equal to the weight of the soil prism load minus the upward friction forces and cohesion of the soil along the limits over the bore hole of the tunnel. The earth load is determined by the following equation:

$$W_t = C_t w B_t^2 - 2cC_t B_t \quad \text{kn/m} \qquad (3)$$

where:
W_t = earth load, kilonewtons per meter
C_t = load coefficient for jacked pipe
w = unit weight of soil, kilonewtons per meter
B_t = maximum width of tunnel bore excavation, feet
c = cohesion of the soil above the excavation, Pa

The $C_t w B_t^2$ term in the above equation is similar to the equation for determining the backfill load on a pipe installed in a trench where the trench width is the same as the tunnel bore. The $(2cC_tB_t)$ term accounts for the cohesion of undisturbed soil. For cohesive soils, the earth load on a jacked pipe installation is always less than on a pipe installed in a trench. The cohesiveness of the soil should be verified by geotechnical

Table 1 Design Values of Coefficient of Cohesion

DESIGN VALUES OF COEFFICIENT OF COHESION

Type of Soil	Values of (Pa)
Clay	
Soft	1,900
Medium	12,000
Hard	48,000
Sand	
Loose Dry	0
Silty	4,800
Dense	14,400
Top Soil	
Saturated	4,800

testing and tested throughout the entire length of the pipeline.

Conservative values for the coefficient of cohesion are found in Table 1. Figures 2, 4, 6, and 8, at the end of this Design Data, present values for the trench load term $(C_t w B_t^2)$ in kN/m for a soil with a density of 19 kN/m^3. Figures 3, 5, 7 and 9 present values for the cohesion term, $(2cC_tB_t)$, divided by the design value for the coefficient of cohesion, c. To obtain the total earth load for any given depth of cover, width of tunnel bore hole and type of soil, the value of the cohesion term must be multiplied by the appropriate cohesion, c. The numerical product of the two is subtracted from the value of the trench load term.

The supporting strength is found in the second part of the design process. The required pipe strength in terms of D-load in the three-edge-bearing test is computed by the following equation;

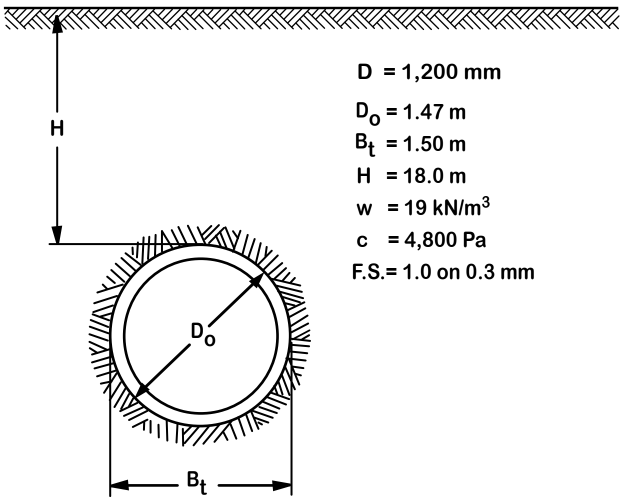
$$D-load = \frac{W_t \times F.S.}{B_f \; D} \qquad (4)$$

where :
D-Load = load required to produce either a 0.3 mm crack ($D_{0.3}$), or ultimate load ($D_{ult.}$) in a three-edge-bearing test, newtons per meter per millimeter of internal span.

W_E = earth load, pounds per linear foot
B_f = bedding factor
D = inside horizontal span, mm
F.S. = factor of safety

The bedding factor, B_f, is the ratio of the supporting strength of an installed pipe to the strength of a pipe in a three-edge-bearing test. The jacking method of installation provides a virtually uniform soil support across the lower half of the pipe. A conservative bedding factor of 3.0 may be used for design purposes because of the uniform support as well as the introduction of lubricants on the outside the pipe and grouting the annular space. If the annular space around the pipeline is not grouted, a bedding factor of 1.9 should be used.

The following example illustrates the proper use of Figures 2 through 9 and the determination of the required pipe strength.



D = 1,200 mm
D_o = 1.47 m
B_t = 1.50 m
H = 18.0 m
w = 19 kN/m^3
c = 4,800 Pa
F.S.= 1.0 on 0.3 mm

EXAMPLE
Given:

A circular 1,200 mm inside diameter pipe with a 127 mm wall thickness is to be installed by the jacking method with a fill height of 18.0 m over the top of the pipe. Geotechnical reports say the pipe will be jacked through a sand and gravel strata with a unit weight of 19 kN/m³. The sand and gravel have a tested cohesion of 4,800 Pa.

Find:

The required pipe strength in terms of the 0.3 mm crack D-load.

Solution:

On Figure 2 Sand and Gravel, Trench Term, find the intersection of a horizontal line projected from H = 18.0 m on the vertical scale and a vertical line from B_t = 1.5 m on the horizontal scale. At the intersection of the lines, interpolate the value between the two earth load curve lines. In this example, the earth load without the effects of cohesion is 134 kN/m of pipe.

On Figure 3, Sand and Gravel, Cohesion Term, find the intersection of a horizontal line projected from h=18.0 m on the vertical scale and a vertical line from B_t=1.5 m on the horizontal scale. At the intersection of the lines, interpolate the value between the two cohesion curve lines. In this example, the cohesion value for sand and gravel is .42. Multiply this value by the cohesion of 4,800 for silty sand in Table 1. Subtract the product 2,016 from 134,000 the trench load term.

D0.3 = 37 N/m/mmΦ

$$D_{0.3} = \frac{131{,}984 \times 1.0}{3.0 \times 1{,}200}$$

$$D_{0.3} = \frac{W_t \times FS}{L_t D}$$

W_t = 134,000-(.42 x 4,800)
W_t = 131,984 N per linear meter of pipe.

Answer:

Since D.3 = 37 N/m/mmΦ Class II pipe would be selected from ASTM C76M tables because a Class II pipe could withstand a three-edge-bearing-test for a 0.3 mm crack of 50 N/m/mmΦ.

ASCE Direct Design

The ASCE direct design method is more comprehensive and more complex than the Indirect Design method. Direct Design allows for unusual or difficult installation conditions using load factor designs. The method considers the combined effect of five loading cases to determine flexure, crack control, radial and diagonal tension in the transverse analysis of the pipe design. The loading cases are the pipe weight, earth load, weight of fluid, external and internal fluid pressure, and live or surcharge loads.

Direct Design requires the designer to select and calculate the loads from any of the five loading cases that affect the pipeline. The loads and bedding will depend on installation conditions such as the use of lubricants and grouting. The circumferential steel reinforcing areas may be calculated using ACPA's computer program PIPECAR. For more information on Direct Design for jacking pipe, refer to ASCE 27-00.

JOINTS

All axial forces must be transferred from pipe-to-pipe through the joints of the precast pipe. Several combinations of concrete and steel joints have been produced for mechanized construction methods such as microtunneling. Joints used for jacking pipe should have adequate bearing surfaces to transmit the required axial thrust and have the ability to resist lateral forces due to off-axis joints, curved alignment, or alignment corrections. Plywood joint cushions, at least ¾ inches thick, will redistribute the axial force and prevent damaging stress concentrations. A bell and spigot joint designed for use with gaskets work well for jacking although joints with protruding bells cannot be used. When measurable leakage rates are specified, the gaskets must have the proper volume or depth to seal the joint if the cushion material keeps the joint partially open. The inner reinforcing cage should extend into the tongue or spigot and the outer cage into the groove or bell of the pipe. The off-axis tolerance of joints for jack ing pipe should be no more than 50 percent of that allowed in ASTM C76M for pipe end misalignment and length of opposite sides.

OTHER DESIGN CONSIDERATIONS

During certain installations, the pipes will rotate slightly as the pipe is advanced in the tunnel. The reason for this phenomenon is not widely understood, but many specifications allow only full circular reinforcing cages and 360 degree stirrup placement. This requirement is for economics rather than structural integrity and generally does not affect the reinforcing design of pipes 1,200 mm or less in diameter.

Extra reinforcing beyond that required for transverse strength has, at times been specified for the bell and spigots of jacking pipe. Installers have reported that pipe manufactured with supplemental reinforcing performs more poorly than conventionally reinforced pipes. If there is inadequate space in a pipe joint, additional reinforcing may not be effective. Joint design should be robust with large bearing areas and sufficient concrete cover over the reinforcing cages.

Seldom is sufficient soil data information provided to assume a consistent benefit from cohesion along the length of the pipeline. Because of this ASCE discourages the assumption of a reduced soil load on the pipe as a result of cohesion unless adequate testing is performed.

When jacked pipe is installed in low to medium covers, there is a possibility that the soil over the pipe may be disturbed in the future for other construction projects. When removed and replaced, the soil will exert more load on the pipe than assumed for the jacked condition. Thus, future infrastructure requirements in the area of the pipeline should be considered prior to design. Some agencies require a conservative positive projecting design of the pipe in their standards to account for possible future disturbances.

Figure 2 Earth Loads On Jacked or Tunneled Installations

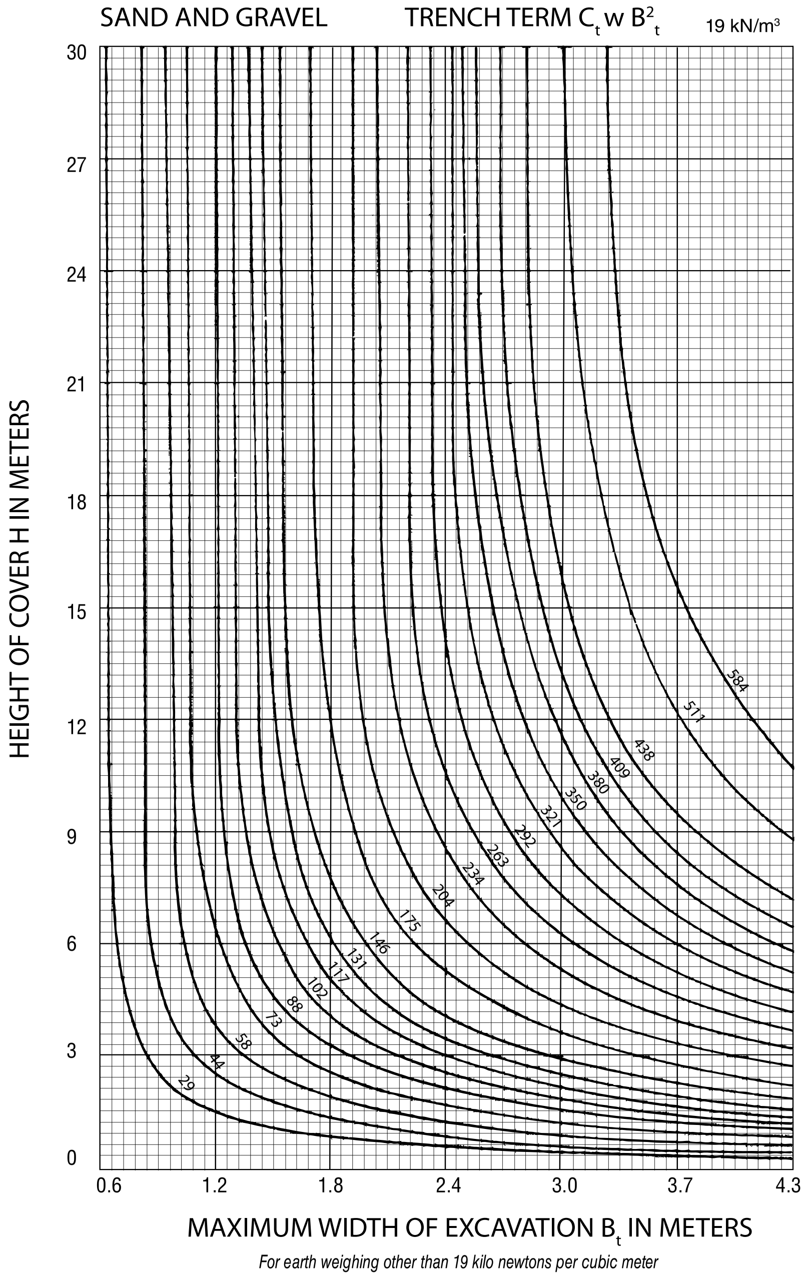


Figure 3 Earth Loads On Jacked or Tunneled Installations

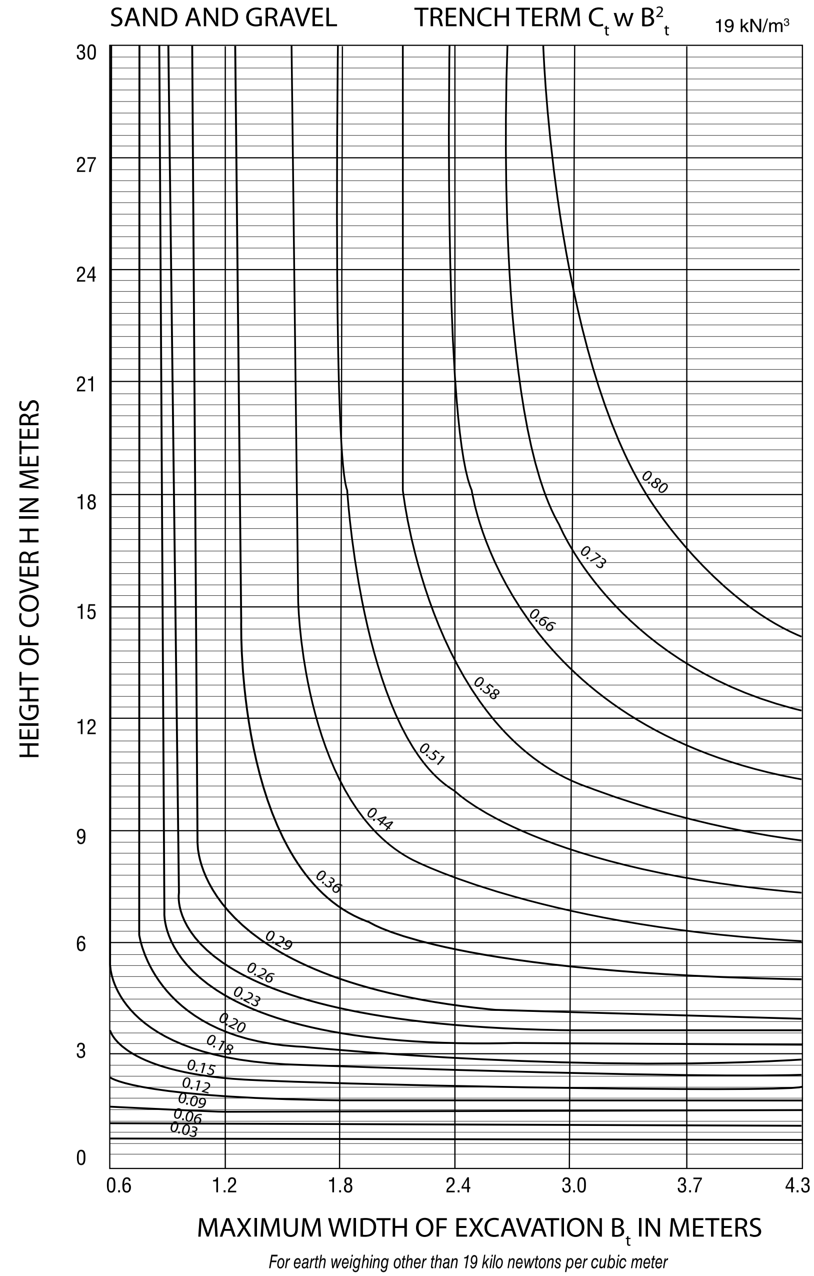


Figure 4 Earth Loads On Jacked or Tunneled Installations

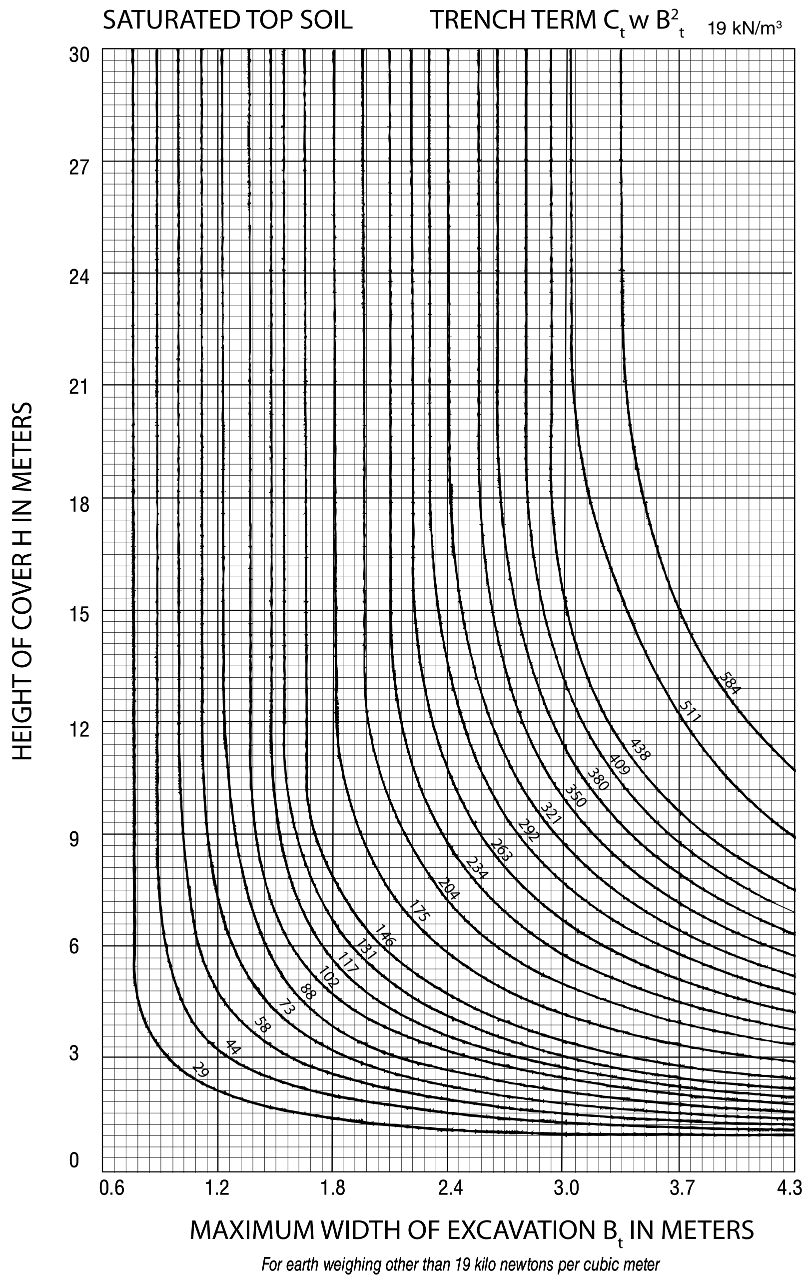


Figure 5 Earth Loads On Jacked or Tunneled Installations

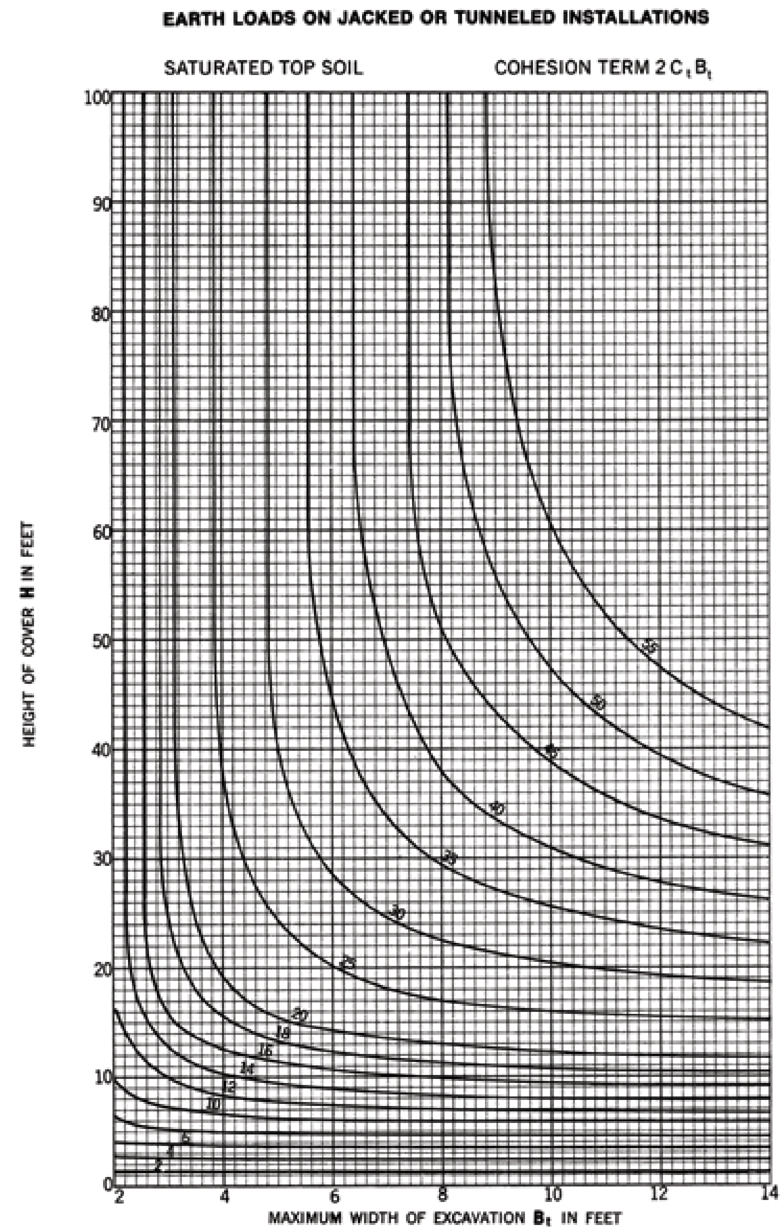


Figure 6 Earth Loads On Jacked or Tunneled Installations

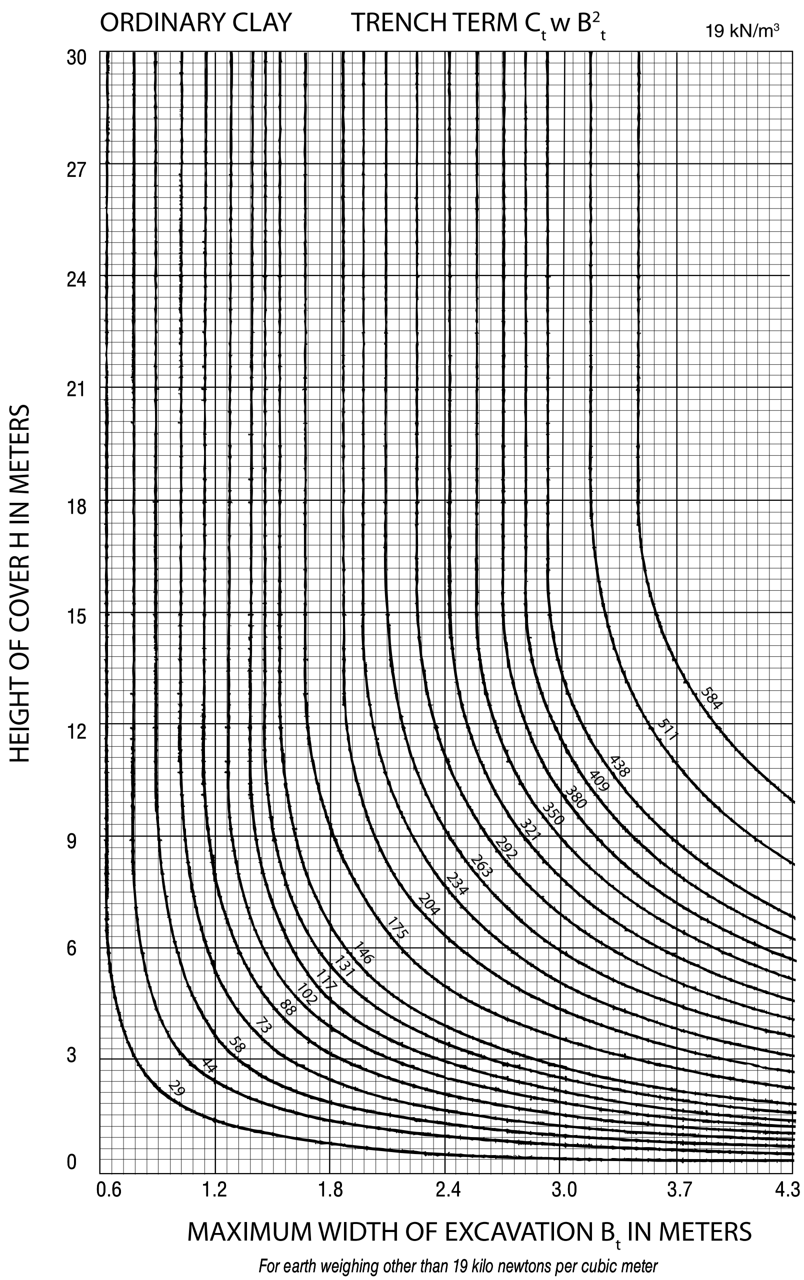


Figure 7 Earth Loads On Jacked or Tunneled Installations

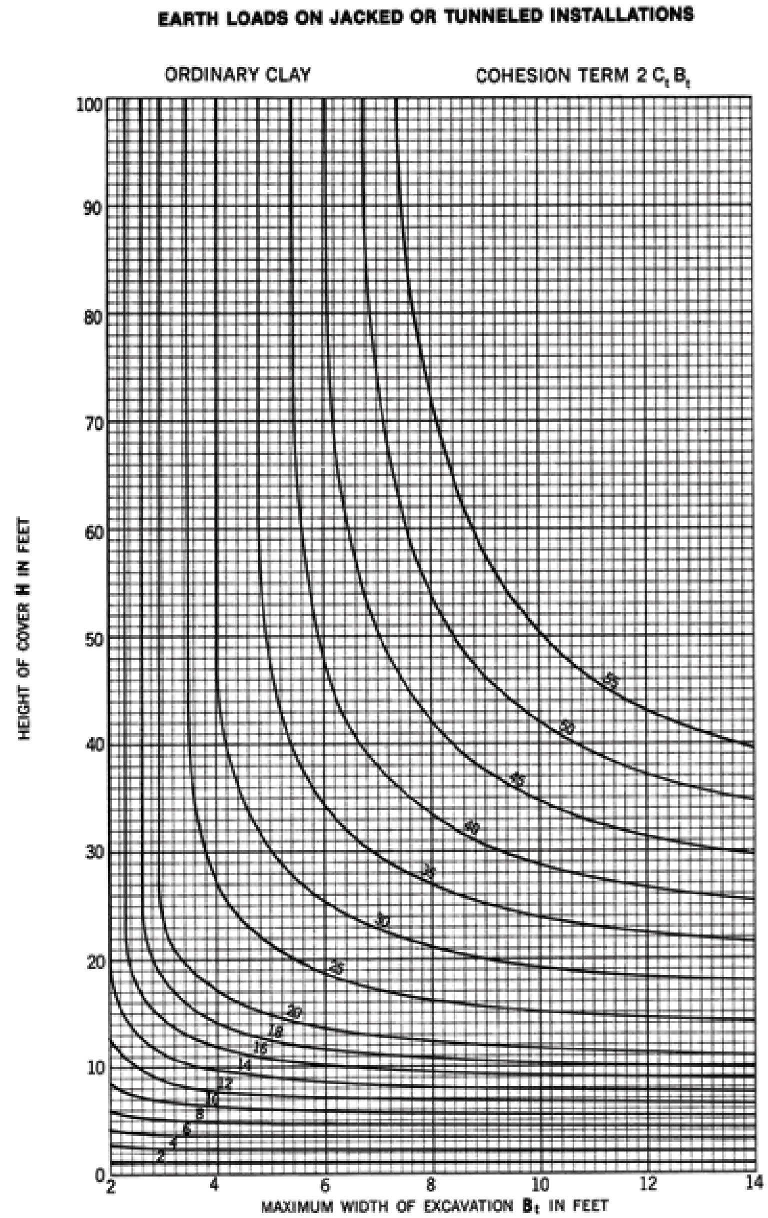


Figure 9 Earth Loads On Jacked or Tunneled Installations

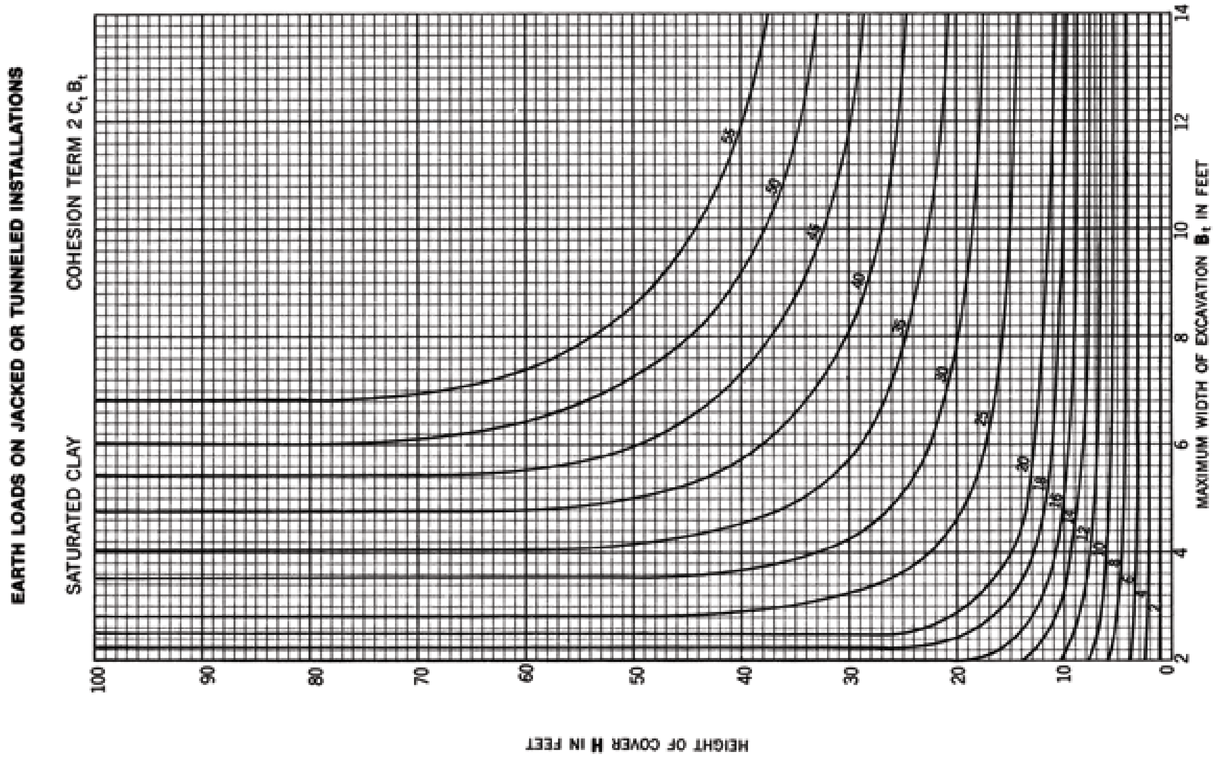
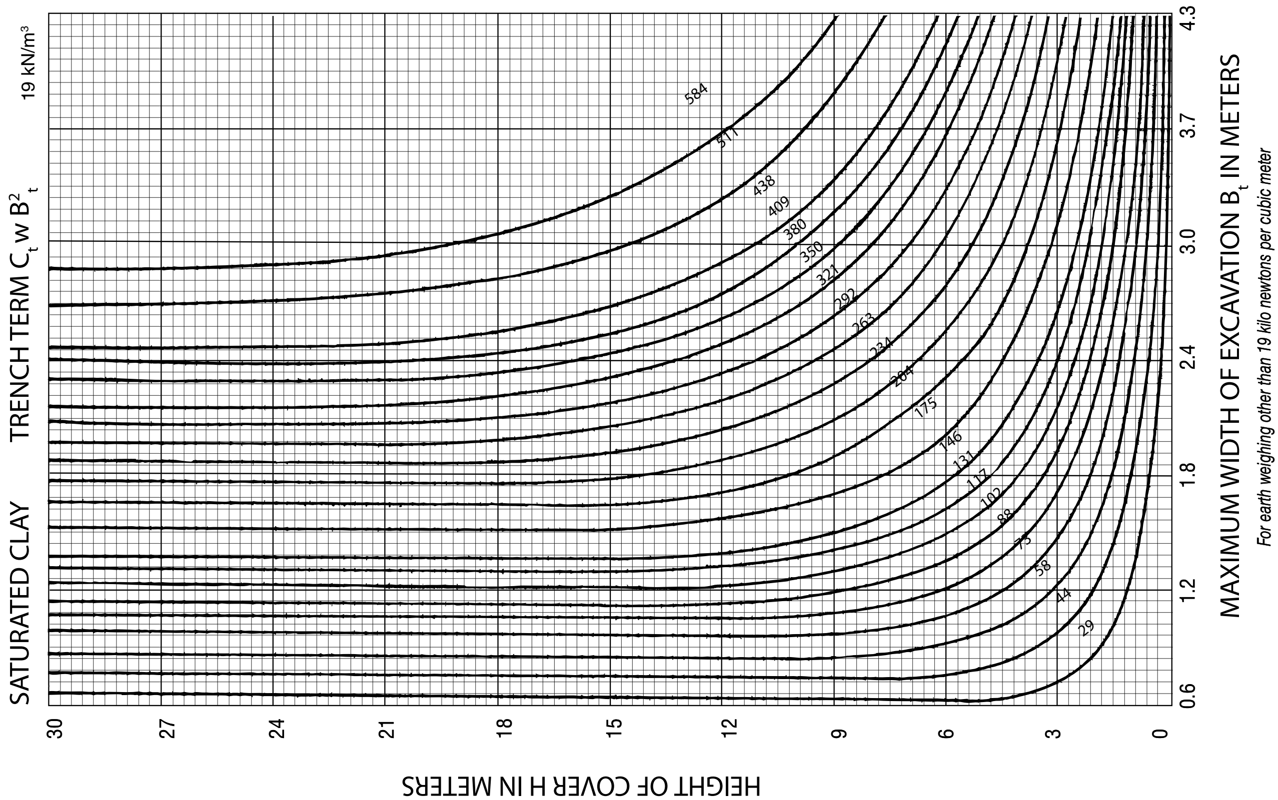


Figure 8 Earth Loads On Jacked or Tunneled Installations



For earth weighing other than 19 kilo newtons per cubic meter