CHAPTER 6: STRUCTURAL DESIGN OF RIGID CONDUITS, UNDERGROUND

Figure 6-1: Rigid conduits provide a structural component needed to support service loads.

This chapter deals with the structural design as outlined by the analysis of trench loads developed in Chapter 4: Structural Analysis of Rigid Conduits Underground. Structural support is achieved by selecting and providing proper trench and bedding conditions. This chapter describes the methods by which the trench loads must be supported.

Structural Stability

It is of fundamental importance to recognize the variable supporting strengths of pipe in the trench, including a design factor of safety, under various bedding and field construction conditions.

Several factors influencing the structural stability of the proposed installation must first be considered. These factors include:

1. Design Load Versus Actual Load
2. Trench Width
3. Moving of Trench Box or Removal of Sheeting
4. Sloping Trench Walls

When these factors have been taken into consideration, the supporting strength of Vitrified Clay Pipe (VCP) can be calculated.

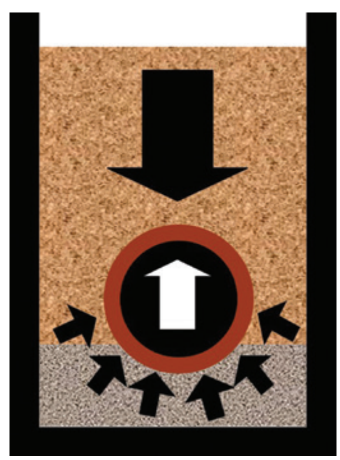


Figure 6-2: Structural support is achieved by selecting and providing proper trench and bedding conditions.

Design Load Versus Actual Load

The design load is the actual load adjusted by a factor of safety. The factor of safety is determined by dividing the field supporting strength of the pipe by the total trench load.

It should be clear that all loads considered in Chapter 4, have been the actual loads imposed upon a conduit in a given installation. In structural design all actual loads must be translated into design loads so that the factor of safety is incorporated in the final design.

An engineer determines the factor of safety based on his knowledge of local soil conditions, construction practices, plans for future development of the area and any unusual variations of land use.

The Effect of Trench Width

The trench width at the top of the pipe is one of the most important factors. It is involved not only in design, but throughout construction.

As shown in the Marston Equation (page 4-4), the load on the pipe increases in relation to the square of the trench width. Therefore, even a relatively small increase in width results in a large increase in load.

For example, an 8-inch pipe installed in a sandy soil weighing 100 lbs/ ft^3 at a cover depth of 14 ft., with a trench width of 24 in. will have a load imposed of 1,170 lbs/ LF. If the trench width is increased only 25% (6 in.) to 30 in., the load imposed will increase to 1,700 lbs/ LF, or more than 45% (Load Table on page 5-3).

The design trench width at the top of the pipe equals the sum of the outside diameter of the pipe, the minimum working space on each side of the pipe and the thickness of sheeting if removed or of the trench box wall on each side of the trench.

Controls used during the course of construction to preserve the design trench width are vital to the structural performance and useful life of the pipe.

The Effect of Moving the Trench Box or Removing the Sheeting

When a trench box is moved or sheeting is removed from a trench after bedding has been placed, a space may be created at the sides of the trench. Sufficient bedding material shall be placed so that the bedding meets the requirements of the specified class of bedding following removal of any trench sheeting or box.

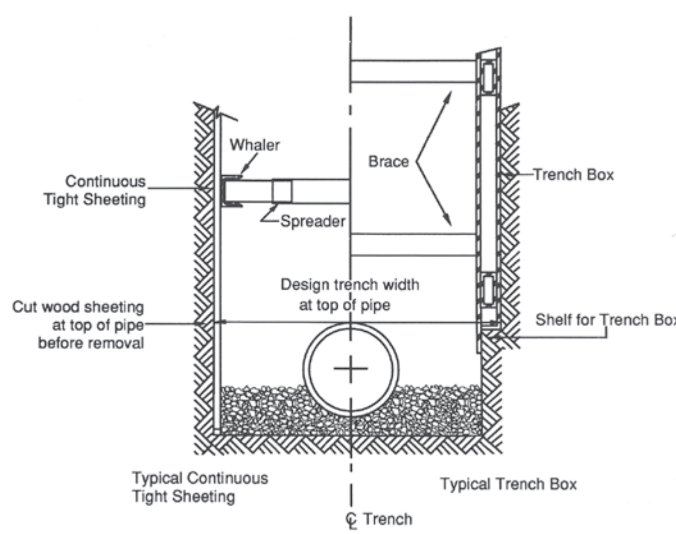


Figure 6-3: Typical sheeting or trench box

Good engineering practice recommends that timber sheeting be cut off at the top of the pipe. The upper portion may be removed without harming the support conditions. Thin steel sheeting may be carefully withdrawn.

The Effect of Sloping Trench Walls

Since the load on the pipe increases with the square of the width of the trench at the top of the pipe, it follows that trenches should be as narrow as practical.

All available evidence shows that the width or shape of the trench above the level of the top of the pipe does not increase the load on the pipe. The trench walls above that level may be sloped or benched outward without adding to the load on the pipe.

Supporting Strength of Vitrified Clay Pipe

The factors influencing the supporting strength of Vitrified Clay Pipe (VCP) are:

1. Bearing Strength of VCP
2. Foundation
3. Bedding Materials
4. Haunch Support
5. Load Factors

Bearing Strength of Vitrified Clay Pipe

Tests to determine the bearing strength of vitrified clay pipe are consistent throughout the country. Testing standards and protocols are established by the American Society for Testing and Materials (ASTM), as set forth in ASTM C301, *Standard Methods of Testing Vitrified Clay Pipe.*

Figure 6-4: *In a three-edge bearing test, a 12" pipe is subjected to minimum load of 2,600 pounds per linear foot.*

VCP is tested and certified at the place of manufacture, by the manufacturer to determine the bearing strength in terms of pounds per linear foot. Testing may be observed by the engineer in charge of construction or by the engineer's designated representative. VCP may also be certified by qualified testing laboratories approved by the engineer.

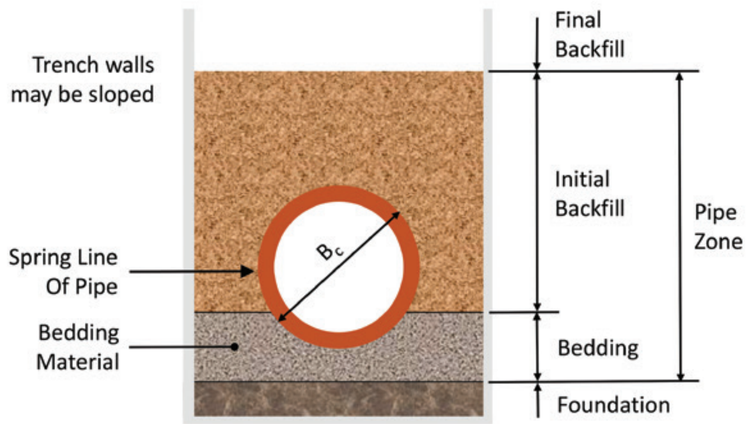


Figure 6-5: *Trench Cross Section*

Foundation

Trench load design for all pipe is based upon a firm and unyielding foundation. It is essential that the foundation remain stable during backfilling, compaction and under all subsequent trench operations.

The foundation is critical to the performance of the entire pipe installation. The foundation must be firm and unyielding as it needs to support the bedding, pipe and backfill as shown in Figure 6-5.

In cases where the trench bottom is soft and unsuitable to support the pipe, bedding and backfill; removal of material is necessary. Replacement can be accomplished with crushed rock or a woven geotextile fabric or both, to stabilize the foundation. Consult a Geotechnical engineer to ensure the foundation can support the entire trench load.

Bedding Materials

The National Clay Pipe Institute has conducted extensive laboratory and field research on bedding materials, load factors and trench load development. Subsequent field experience has confirmed that pipe movement is the leading cause of structural problems. Consequently, the objective of a quality installation must be to develop a stable pipe bedding system, which will minimize pipe movement in the long term. It is known that not all bedding materials provide the same longitudinal and circumferential pipe support.

An ideal bedding material can be defined as one that (a) provides uniform support over the greatest pipe area, (b) does not develop point load, (c) does not migrate under various trench conditions, (d) is easily placed with little or no compaction and (e) is widely available.

Uniform Soil Groups for Pipe Installation

The soil groups used in each bedding class are defined in Table 6-1.

Uniform Soil Groups for Pipe Installation[1]		
Soil Class	**Definition**	**Symbols**
Class I[2]	**Crushed Rock** 100% passing 1-1/2 in. sieve, </= 15% passing #4 sieve, </= 25% passing 3/8 in. sieve, </= 12% passing #200 sieve	
Class II[3]	**Clean, Coarse Grained Soils** Or any soil beginning with one of these symbols (can contain up to 12% fines) Uniform fine sands (SP) with more than 50% passing a #100 sieve should be treated as Class III material	GW, GP, SW, SP
Class III	**Coarse Grained Soils With Fines** Or any soil beginning with one of these symbols	GM, GC, SM, SC
	Sandy or Gravelly Fine Grained Soils Or any soil beginning with one of these symbols, with >/= 30% retained on #200 sieve	ML, CL
Class IV	**Fine-Grained Soils** Or any soil beginning with one of these symbols, with < 30% retained on a #200 sieve	ML, CL
Class V[4]	**Fine-Grained Soils, Organic Soils** High compressibility silts and clays, organic soil	MH, CH, OL, OH, Pt

1 Soil Classification descriptions and symbols are in accordance with ASTM D2487 and ASTM D2488
2 For Class I, all particle faces shall be fractured.
3 Materials such as broken coral, shells, slag, and recycled concrete (with less than 12% passing a #200 sieve) should be treated as Class II soils.
4 Class V soil is not suitable for use as a bedding or initial backfill material.

Table 6-1: *Uniform Soil Groups for Pipe Installation (from ASTM C12)*

Soil Gradations

The gradation for Class I and Class II soil for Class C bedding (Figure 6-14, page 6-11) shall have a maximum particle size of 1 in.

The gradation for Class I and Class II bedding material for Class B (Figure 6-15, page 6-12), Crushed Stone Encasement (Figure 6-16, page 6-12), and CLSM installation (Figure 6-18, page 6-13) shall be as follows:

- 100% passing a 1 in. sieve
- 40-60% passing a 3/4 in. sieve
- 0-25% passing a 3/8 in. sieve

Class II soils shall have a minimum of one fractured face. For Class B (Figure 6-15), Crushed Stone Encasement (Figure 6-16), and CLSM installations (Figure 6-18) where high and/ or changing water tables are present; Class II material shall have a minimum percentage by particle count of one fractured face-100%, two fractured faces-85%, and three fractured faces-65% in accordance with ASTM D5821 *Test Method for Determining the Percentage of Fractured particles in Coarse Aggregate.*

Due to the particles being 100% fractured, Class I material is considered to be more stable and provide better support than Class II materials that have some rounded edges.

All bedding material shall be shovel-sliced so the material fills the haunch area to support the pipe to the limits shown in the trench diagrams starting on page 6-10.

Allowable Bedding Material & Initial Backfill per Bedding Class					
Bedding Class	Allowable Bedding Material			Allowable Initial Backfill	
	Soil Class (Table 6-1)	Gradation	Size	Soil Class (Table 6-1)	Particle Size
Class D	N/A	N/A	N/A	I, II, III or IV	1"
Class C	I or II		1"	I, II, III or IV	1½"
Class B	I or II	- 100% passing a 1" sieve - 40 – 60% passing a ¾" sieve - 0 – 25% passing a ⅜" sieve	1"	I, II, III or IV	1½"
Crushed Stone Encasement	I or II		1"	I, II, III or IV	1½"
CLSM	I or II		1"	I, II, III or IV	1½"
Concrete Cradle	N/A	N/A	N/A	I, II, III or IV	1½"

Table 6-2: *Allowable Bedding Material and Initial Backfill per Bedding Class (from ASTM C12)*

Native Bedding

Many native materials taken from the trench will provide suitable support for clay pipe and may be the most cost efficient method of installation. Care must be exercised to remove rock particles larger than those indicated on Table 6-2, which could cause point loading. Native materials may be used when the required load factor design can be achieved.

Haunch Support

Proper haunch support is necessary for the achievement of the load factor and thus, the structural integrity of the pipe. Lack of proper haunch support can cause a pipeline failure.

Haunch support depends on three factors:

- Proper compaction of the bedding materials in the pipe haunches
- Mobilization of the bedding within the limits of the haunch area
- Bell or coupling holes/ pipe barrel uniform support

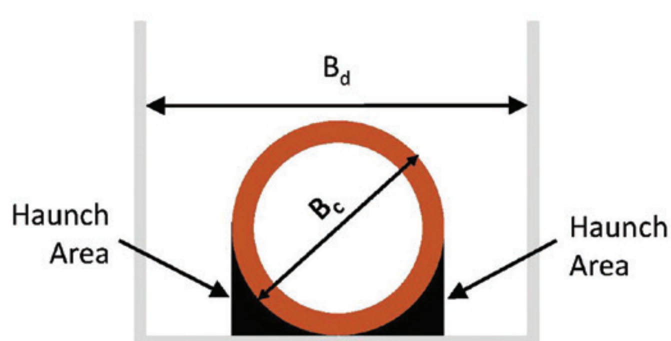


Figure 6-6: *Pipe Haunch Areas*

Compaction of Haunch Soil

Compaction of the soil in the haunch area significantly increases the support for the pipe. Gravels and crushed rock dumped into a trench beside the pipe result in the minimum densities of the soil, which is about 80-85% of their maximum density. Compacting the soil to about 95% (ASTM D4253 *Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table*) can increase the stiffness (modulus) of the soil 300 to 600% (Howard 2013).

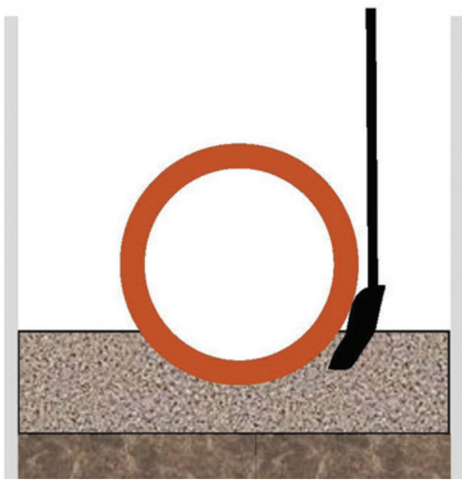


Figure 6-7: *Initial haunching should be performed before the bedding is no higher than the quarter point of the pipe diameter.*

Figure 6-8: *Shovel-slicing the bedding material into the haunches of the pipe is essential if the total load factor is to be realized.*

To obtain the installed supporting strength in accordance with the class of bedding used, the pipe barrel must be uniformly supported by direct contact with firm bedding.

Firm bedding means the pipe barrel must rest on undisturbed native or imported material. The native material in the trench bottom must be capable of excavation to a uniform undisturbed flat bottom in the case of Class D (see page 6-10). If the trench is over-excavated, the trench bottom should be brought back to grade with the required bedding material.

Shovel-slicing the bedding material in the haunch areas is critical. It takes little time, maintains grade, eliminates voids beneath the pipe and in the haunch areas, consolidates the bedding, and adds little or nothing to the cost of the installation. To be the most effective, shovel slicing should be done before the bedding is no higher than the quarter point of the pipe. Shovel-slicing the bedding material into the haunches of the pipe is essential if the total load factor is to be realized.

Bell or Coupling Holes

Bell or coupling holes must be carefully excavated so that the bells or couplings support no part of the load. The pipe barrel is designed to support the trench

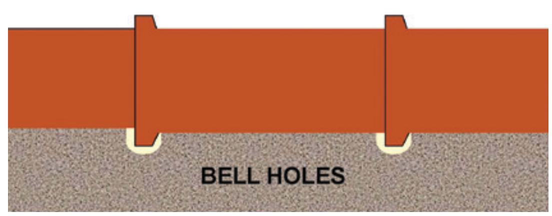


Figure 6-9: *Provide uniform and continuous support of pipe barrel between bell or coupling holes for all classes of bedding.*

load. Compaction of material around and under the bell and couplings during bedding and backfilling should be avoided because it may create a concentrated load resulting in a decreased field supporting strength. The field supporting strength of the pipe is substantially reduced when the pipe is improperly bedded. The engineer should ensure that the class of bedding specified is actually provided during construction. The need for implementation of proper installation procedures is clearly demonstrated by significant losses in the field supporting strength of the pipe as a result of improper bedding.

Increased Haunch Support by Soil Mobilization

Haunch support for pipe can be effectively actuated by providing an uncompacted bedding for the pipe. The weight of the pipe, fluid in the pipe, and the backfill soil over the pipe help push the pipe into the uncompacted material creating a small cradle. Since uncompacted bedding under the pipe has a low stiffness, minor pipe settlement will mobilize the haunch soil support. Compacted haunch material is not as effective if the pipe is resting on hard compacted bedding. The soil simply acts as a filler. However, if the pipe is raised during compaction of the haunch soil, then the haunch support can be mobilized similar to uncompacted bedding.

Discussion of Haunch Voids

Uniformly graded gravel will typically leave a void in the haunches of a pipe when it is loosely placed or dumped beside a pipe and will result in a decreased load factor no matter the bedding class. The gravel has an angle of repose, which is the angle of the slope of the material when dumped into a pile. Gravel with fractured faces will have a steeper angle than gravel with rounded edges. Figure 6-10 shows crushed rock with an angle of repose of 39 degrees dumped beside a 36 in. pipe with a 44 in. outside diameter.

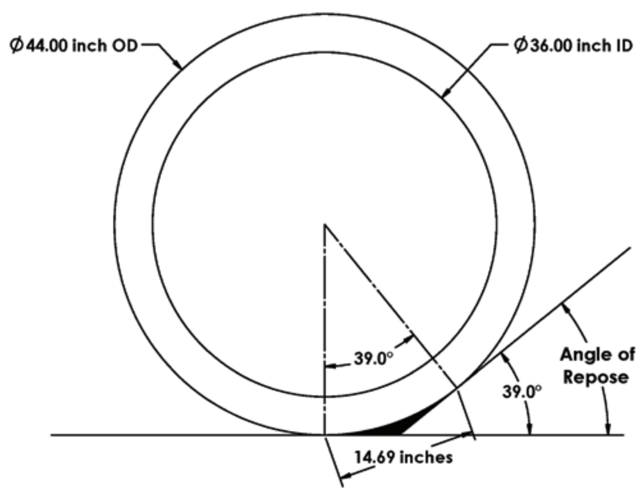


Figure 6-10: Illustration of the void space left in the haunches of a 44-in. OD pipe when the bedding material angle of repose is 39 degrees and dumped.

Figure 6-11 is a photo from a research project, which illustrates the reality of the haunch void. The photo was taken after the crushed rock had been dumped in beside a 36 in. pipe. Daylight can be seen on the other end of the pipe indicating a void running along the full length of the pipe in this lower haunch area. A video taken at the time of this photo clearly demonstrates the mechanism of the formation of a void in this area. This video is available for viewing on the NCPI YouTube channel.

Figure 6-11: In testing, daylight was visible on the other end of a length of pipe.

Good haunch support:

- Significantly increases the load carrying capacity of buried pipe
- Requires compacting the soil in the haunch area using a shovel, spade, or other suitable tool
- Can be attained by using CLSM (flowable fill) with the proper flowability
- Is not attained by dumping gravels and crushed rock beside the pipe
- Can be aided by pipe settling into uncompacted bedding to mobilize the strength of the haunch soil

Load Factors

The load a pipe can support varies according to the class of bedding.

Trench details shown on the following pages as well as in ASTM C12 depict the recommended classes of bedding. Load factors have been determined for each bedding class. The load factor is the ratio of the supporting strength of the pipe in the trench to its three-edge bearing test strength. It does not include a design factor of safety. The three-edge bearing strength has been established as a base and is considered equivalent to a load factor of 1.0.

Using Load Factors to Determine Field Supporting Strength

Field Supporting Strength (FSS) = Minimum Three-Edge Bearing Strength x Load Factor. See Table 6-3 (page 6-18) for a FSS of VCP pipe sizes from 6-in. to 48-in. in various bedding classes.

The load factor is used to compute the field supporting strength of vitrified clay pipe with any designated bedding class. The specified minimum three edge bearing strength of vitrified clay pipe is multiplied by the appropriate load factor to obtain the field supporting strength of the pipe. Therefore, it is possible to provide the necessary field supporting strength to exceed the calculated trench loads. Field supporting strengths of extra strength clay pipe (ASTM C 700) are shown on Table 6-3 on page 6-18. Also see the section on the discussion of haunch voids and the importance of haunching for the achievement of the bedding class load factor on pages 6-6 to 6-9.

Figure 6-12: Load factor development at the NCPI Research laboratory

Example 6-1: Calculating Field Supporting Strength

Per ASTM C700, a 36-in Extra Strength (ES) VCP has a minimum bearing strength of 6,000 lbs/ LF. If it is installed with a Class C Bedding (1.5 load factor), what is the FSS?

FSS = Minimum Pipe Bearing Strength x Load Factor

FSS = 6,000 X 1.5

FSS = 9,000 lbs/ LF

<u>Bedding Classes</u>

All bedding classes outlined here are in accordance with ASTM C12. For more information, refer to the original standard.

Class D Bedding, Load Factor = 1.1

The pipe shall be placed on a foundation with bell holes provided. The bottom of the entire pipe barrel shall have a continuous and uniform bearing support.

The initial backfill shall be either Class I, II, III, or IV soil having a maximum particle size of 1 inch. Refer to the Uniform Soil Groups Table (Table 6-1) on page 6-5 for specific information about soil classes..

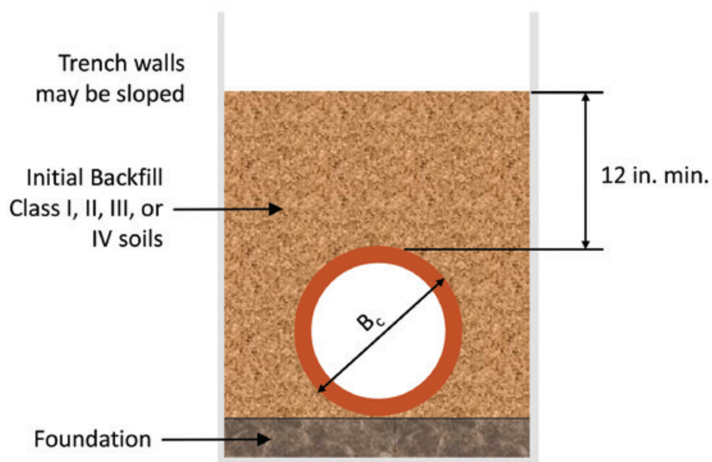


Figure 6-13: *Class D Bedding – Load Factor = 1.1*

Class C Bedding, Load Factor = 1.5

The pipe shall be bedded in Class I or Class II soil having a maximum particle size of 1 in. Refer to Bedding Materials starting on page 6-4 for requirements.

Sand is suitable as a bedding material in a total sand environment but may be unsuitable where high and rapidly changing water tables are present in the pipe zone. It may also be undesirable in a trench cut by blasting or in trenches through clay type soil. Regardless of the trench condition or bedding class, the maximum load factor for sand bedding is 1.5.

The bedding shall have a minimum thickness beneath the pipe of 4 in. or one-sixth of the outside diameter of the pipe (B_c), whichever is greater, and shall extend up the haunches of the pipe one-sixth of the outside diameter of the pipe. The bedding material shall be carefully placed and sliced into the haunches of the pipe with a shovel or other suitable tool.

The initial backfill shall be of selected material either Class I, II, III, or IV having a maximum particle size of 1½ in.

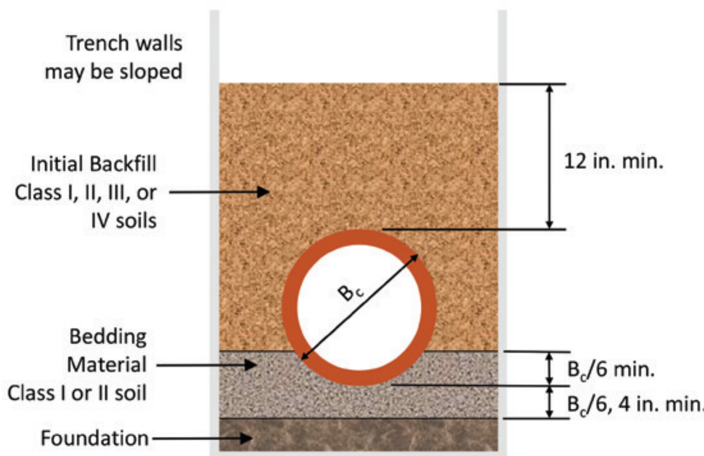


Figure 6-14: *Class C Bedding – Load Factor = 1.5*

Class B Bedding, Load Factor = 1.9

The pipe shall be bedded in Class I or Class II soil. Refer to Bedding Materials starting on page 6-4 for gradation and fractured face requirements.

The bedding shall have a minimum thickness beneath the pipe of 4 in. or one-sixth of the outside diameter of the pipe (B_c), whichever is greater, and shall extend up the haunches of the pipe to the springline. The portion of the bedding directly beneath the pipe and above the foundation **should not be compacted**. The bedding material shall be carefully placed and sliced into the haunches of the pipe with a shovel or other suitable tool. Initial shovel slicing should be performed before the bedding is no higher than the quarter point of the pipe diameter. Shovel-slicing the bedding material into the haunches of the pipe is required to achieve the 1.9 load factor.

The bedding material shall extend to the specified trench width and upward to the top of the pipe barrel following removal of any trench sheeting or boxes. The initial backfill shall be either Class I, II, III or Class IV having a maximum particle size of 1½ in.

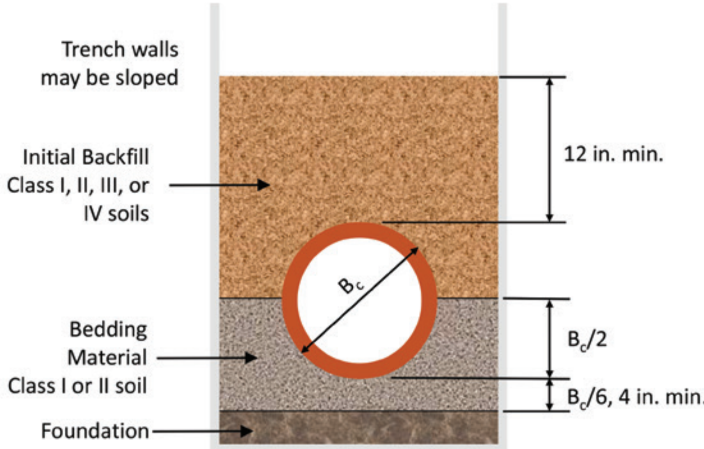


Figure 6-15: *Class B Bedding – Load Factor = 1.9*

Crushed Stone Encasement, Load Factor = 2.2

The pipe shall be bedded in Class I or Class II soil. Refer to Bedding Materials starting on page 6-4 for gradation and fractured face requirements.

The bedding shall have a minimum thickness beneath the pipe of 4 in. or one-sixth of the outside diameter of the pipe (B_c), whichever is greater, and shall extend upward to a horizontal plane at the top of the pipe barrel. The portion of the bedding directly beneath the pipe and above the foundation **should not be compacted**. The bedding material shall be carefully placed and sliced into the haunches of the pipe with a shovel or other suitable tool. Initial shovel slicing should be performed before the bedding is no higher than the quarter point of the pipe diameter. Shovel-slicing the bedding material into the haunches of the pipe is required to achieve the 2.2 load factor.

The encasement material shall extend laterally to the specified trench width and upward to a horizontal plane at the top of the pipe barrel following removal of any trench sheeting or boxes.

The initial backfill shall be either Class I, II, III or IV having a maximum particle size of 1½ in.

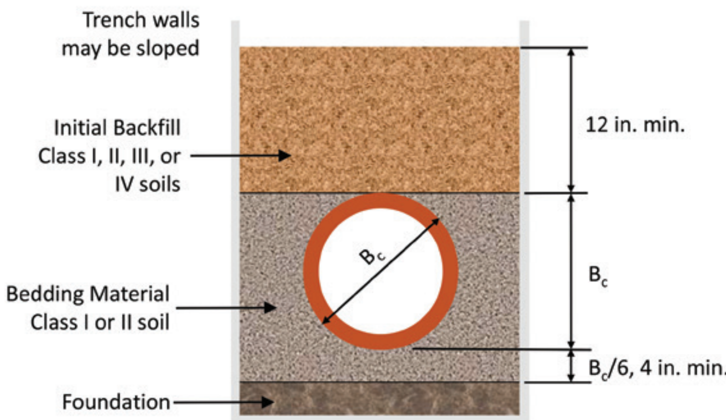


Figure 6-16: *Crushed Stone Encasement Bedding – Load Factor = 2.2*

Controlled Low Strength Material (CLSM) Bedding, Load Factor = 2.8
The pipe shall be bedded on Class I or Class II soil. Refer to Bedding Materials starting on page 6-4 for gradation and fractured face requirements.

The bedding shall have a minimum thickness beneath the pipe of 4 inches or one-sixth of the outside pipe diameter (B_c), whichever is greater.

For pipe diameters 8 to 21 inches, CLSM shall extend a minimum of 9 inches on each side of the pipe barrel. For pipe diameters 24 inches and larger, CLSM shall extend a minimum of 12 inches on each side of the pipe barrel.

Testing for flow consistency should be conducted in accordance with ASTM D6103 *Standard Test Method for Flow Consistency of Controlled Low Strength Material (CLSM).* When placed, CLSM shall have a measured spread of 7 – 9 inches. A typical result is shown in Figure 6-17.

The 28-day compressive strength shall be 100 to 300 psi as determined by Test Method ASTM D4832 *Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylninders.*

Figure 6-17: *Measuring the spread diameter to determine flowability prior to placement.*

CLSM shall be directed to the top of the pipe to flow down equally on both sides to prevent misalignment. Place CLSM to the top of the pipe barrel.

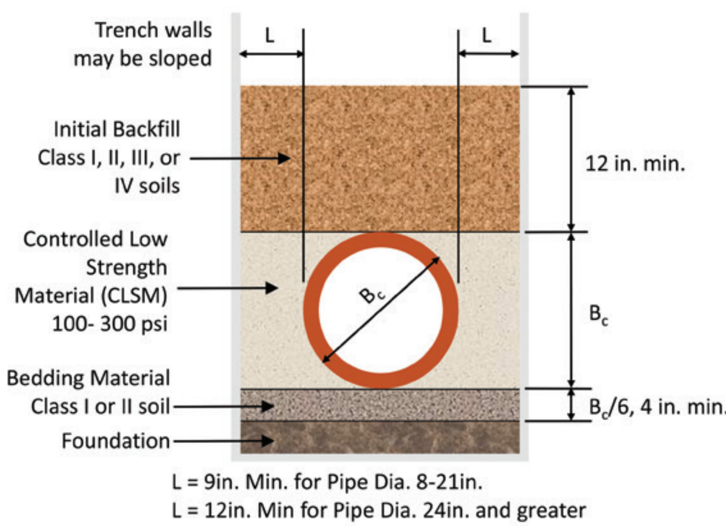


Figure 6-18: *Controlled Low Strength Material (CLSM) Bedding – Load Factor = 2.8*

Initial backfill shall only commence after a 500 psi minimum penetrometer reading is achieved as determined by Test Method C403/C403M *Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance*. The penetrometer shall have a maximum load capability of 700 psi and have a 1 square inch by 1 inch long cylinder foot attached to a ¼-inch diameter pin as shown in Figure 6-19. The initial backfill shall be either Class I, II, III, or IV having a maximum particle size of 1½ inches. The fill can be completed in a single pour to the top of the pipe or it can be done in two or more lifts if desired. No field installations using CLSM have resulted in flotation of clay pipe. However, buoyancy calculations done using the Archimedes' Principle (that a body wholly or partly immersed in a fluid is buoyed up with a force equal to the weight of the fluid displaced by the body) indicate that the pipe should have floated. Further research to date supports the theory that clay pipe does not float because CLSM acts as a Bingham fluid. A Bingham fluid, also known as a Bingham plastic, is a viscoplastic material that resists movement at low values of shear stress in the fluid. Buoyancy forces generate shear stress in the CLSM. If the stress applied by the buoyant force does not exceed the shear yield stress of the CLSM, the pipe will not float.

Figure 6-19: *A pocket penetrometer can be used to determine CLSM strength prior to backfill*

Optimal Mix for CLSM

NCPI conducted tests to define the optimal mix for CLSM used in gravity sewer applications with vitrified clay pipe. Varying percentages of 3/8-in. coarse aggregate, accelerator and entrained air were tested. The primary goal was to determine a mix design that would yield the fastest cure time over a maximum of six hours based on penetration resistance readings using a penetrometer.

Cement: 188 pounds (type I/II or II/V)

Fine aggregate: 75% - 80% (by weight)

Coarse aggregate: 25% - 20% (by weight)

Water: Water necessary to obtain Flowability (7"- 9" spread diameter)

Accelerator: 4% (as a percent of cement)

Air entrainment: 15% - 20%

Flowability: 8-in., +/- 1 in. spread diameter (3-in. diameter by 6-in. long cylinder, per ASTM D6103)

Further evaluation may be necessary where native soils are expansive.

For more information on CLSM as a bedding material, see the Technical Papers listed below (available on our website):

- *Guidelines for Controlled Low Strength Material (CLSM) Mix Design, Placement and Testing for use as a Bedding Material for VCP*
- *Consideration for Flotation When Controlled Low Strength Material (CLSM) is Used as a Bedding Material for VCP*
- *Optimal CLSM Mix Design*
- *Consideration for the Use of Fly Ash when Controlled Low Strength Material (CLSM) is Used as a Bedding Material for VCP*

Concrete Cradle Bedding, Load Factor = 3.4

The pipe shall be bedded in a cradle of reinforced concrete having a thickness under the barrel of at least 6 inches or one-fourth of the outside diameter of the pipe (B_c), whichever is greater, and extending up the haunches to a height of at least one-half the outside diameter of the pipe. The cradle width shall be at least equal to the outside diameter of the pipe plus 4 inches on each side or 1.25 times the outside diameter of the pipe, whichever is greater. If the trench width is greater than either of these dimensions, concrete may be placed to full trench width.

The initial backfill shall be either Class I, II, III, or IV having a maximum particle size of 1½ in.

The load factor for concrete cradle bedding is 3.4 for reinforced concrete with p = 0.4%, where p is the percentage of the area of transverse steel to the area of concrete at the bottom of the pipe barrel as shown in Section A-A of Figure 6-20.

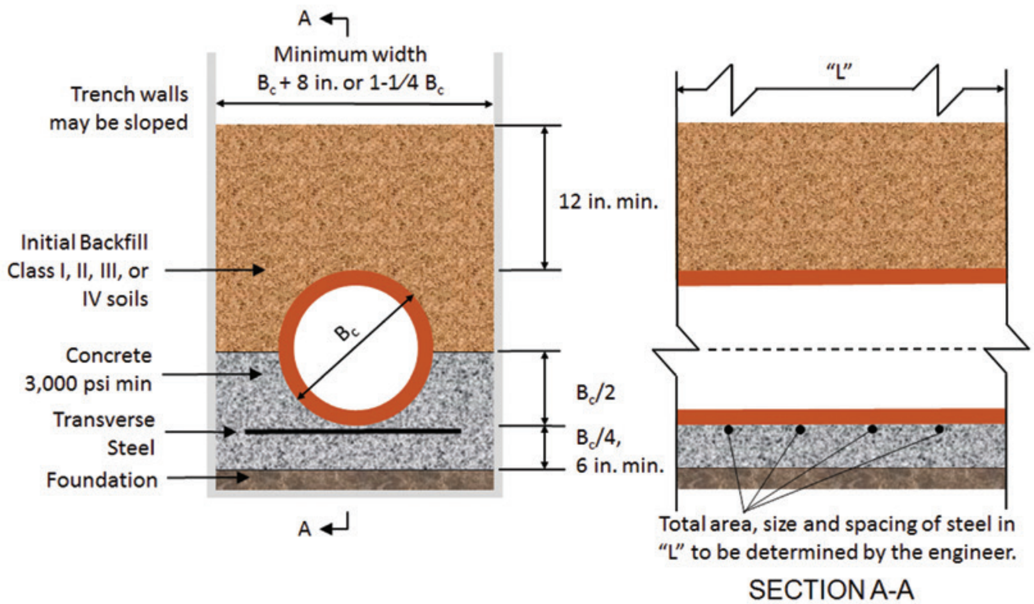


Figure 6-20: *Concrete Cradle Bedding – Load Factor = 3.4*

Full Concrete Encasement

There are specific sites where concrete encasement may be desirable. Concrete encasement shall completely surround the pipe and shall have a minimum thickness, at any point, of one-fourth of the outside diameter of the pipe or 4 inches whichever is greater.

The encasement shall be designed by the engineer to suit the specific use.

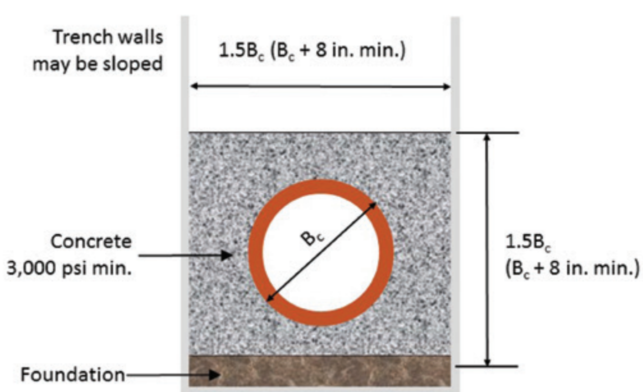


Figure 6-21: *Concrete Encasement*

Principles of Concrete Design

The use of concrete cradle or full encasement class bedding permits the pipe to support substantially higher backfill loads. A vibrator or stinger must be used when concrete is placed to ensure consolidation of the material in the pipe haunches.

Consideration must be given to the following items associated with the use of concrete bedding systems.

Figure 6-22: *Special conditions may require the use of concrete encasement.*

1. **Delay Backfilling the Trench**
   The trench must not be backfilled before the concrete has gained sufficient strength to support the backfill load. A minimum of two days is recommended. Although it may be impractical to delay backfilling longer than this, it is obvious that the strength of the pipe-concrete system is still in a structurally critical stage.

2. **Delay Consolidation of the Trench Backfill**
   When the trench backfill is allowed to consolidate through natural means, the maximum load on the pipe will be delayed. However, paving requirements and other considerations such as traffic flow may preclude the possibility of extended delay. In those instances the engineer and or contractor must evaluate the possible risks involved.

3. **Accelerate the Early Strength of the Concrete**
   Early strength increase is normally accomplished by increasing the cement content, adding accelerators or by the use of Type III high early strength Portland cement. The addition of fly ash or other pozzolanic material may retard early strength development and should not be used.

4. **Construction Joints**
   When using concrete as a component of a pipe bedding system, consideration should be given to the use of construction joints to maintain pipeline flexibility. For concrete cradle and full encasement installations, a construction joint is needed. These joints shall be aligned with the face of the socket (end of the pipe bell). Expanded polystyrene (EPS) foam blocks and sheets, mastic, plywood or various other means have been utilized to direct the fracture of the concrete beam (see Figure 6-23).

   Considerable success has also been achieved through the use of shaped EPS foam to support the pipe during the concrete pour.

Figure 6-23: *EPS foam used to support a pipe during a concrete pour*

5. **Use of Steel Reinforcing**
   A common method of increasing the strength of the concrete is through the use of steel reinforcement. The strength increase is generally in proportion to the cross-sectional area of steel to the concrete above or below the pipe. The steel should be placed in the transverse direction to the pipe.

   In concrete cradle construction, p is the percentage of the area of transverse steel to the area of concrete at the bottom of the pipe barrel as shown on Figure 6-20 on page 6-15.

   Welded steel wire fabric is recommended for use in bedding design because of its uniformity and relative ease of installation.

6. **Transition Joints**
   Where construction of the line changes from concrete bedding to another bedding class, steel casing or other rigid structure, it is necessary to provide flexibility at the transition to allow for potential differential settlement. Changes of bedding and other transitions should always terminate at the face of the bell.

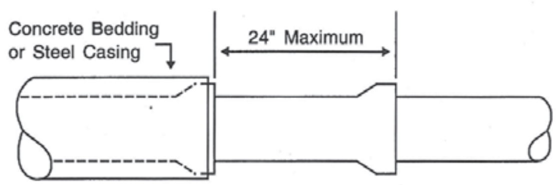


Figure 6-24: *Field Transition Joints*

Design Safety Factor

The design safety factor is a discretionary decision for the Professional Engineer during design based on the number and magnitude of unknown variables. The greater effect these unknown variables may have, the greater the need for a large safety factor. Hence, the safety factor is intended to insure a successful project, without adding unnecessary costs.

During trench design for Vitrified Clay Pipe, a safety factor having a value between 1.0 and 1.5 is typically specified. This may be accomplished by using the appropriate bedding class.

FIELD SUPPORTING STRENGTH OF EXTRA STRENGTH VITRIFIED CLAY PIPE

(Pounds Per Linear Foot of Pipe)
Field Supporting Strength = 3 Edge Bearing Strength x Load Factor

	THREE-EDGE BEARING STRENGTH Minimum* per ASTM C700	CLASS D	CLASS C	CLASS B	CRUSHED STONE ENCASEMENT	CONTROLLED LOW STRENGTH MATERIAL	CONCRETE CRADLE p = 0.4%**	FULL CONCRETE ENCASEMENT
								
NOMINAL SIZE	**LBS/ LINEAR FT.**	**LOAD FACTOR 1.1**	**LOAD FACTOR 1.5**	**LOAD FACTOR 1.9**	**LOAD FACTOR 2.2**	**LOAD FACTOR 2.8**	**LOAD FACTOR 3.4**	**Design by a Structural Engineer**
6"	2000	2200	3000	3800	4400	5600	6800	
8"	2200	2420	3300	4180	4840	6160	7480	
10"	2400	2640	3600	4560	5280	6720	8160	
12"	2600	2860	3900	4940	5720	7280	8840	
15"	2900	3190	4350	5510	6380	8120	9860	
18"	3300	3630	4950	6270	7260	9240	11220	
21"	3850	4235	5775	7315	8470	10780	13090	
24"	4400	4840	6600	8360	9680	12320	14960	
27"	4700	5170	7050	8930	10340	13160	15980	
30"	5000	5500	7500	9500	11000	14000	17000	
33"	5500	6050	8250	10450	12100	15400	18700	
36"	6000	6600	9000	11400	13200	16800	20400	
39"	6600	7260	9900	12540	14520	18480	22440	
42"	7000	7700	10500	13300	15400	19600	23800	
48"	8000	8800	12000	15200	17600	22400	27200	

* Check with local manufacturers for bearing strengths available in a particular area
** Refer to page 6-15 for definition of p

Table 6-3: *Bearing Strength, Load Factors and Field Supporting Strength for 6-in to 48-in VCP*

Example 6-2: Bedding Design Using the Trench Load Tables and the NCPI Toolbox

A 24-inch clay pipe line is to be installed in an area of CH (Fat clay) which has a weight of 107 pounds per cubic foot and a Kμ' = 0.110 (see Soil Classification Chart on page 4-7). The depth of cover over the top of the pipe is 18 feet and the trench width at the top of the pipe is 48 inches. Determine a structurally sound and economic bedding design.

The trench load can be determined by using the Trench Load Tables as shown below:

Pipe size:	24 in.
Depth of cover:	18 ft.
Backfill – CH:	(*Kμ'* = 0.110) @ 107 lbs/ft^3
Trench width:	48 in.
From Trench Load Table pg 5-9:	4,570 x 107/100
Total Trench Load:	4,890 lbs/ LF

The trench load and factor of safety per bedding class can also be determined using the NCPI Toolbox, Trench Load program available on the NCPI website. ASTM C700, Greenbook Extra Strength or Greenbook High Strength standards can be selected. The results page for the same project is shown below:

Pipe Size:	24 in.
Pipe Standard:	ASTM C700 ES (4400 lbs/LF)
Soil Weight:	107 lbs/ ft^3
***Kμ'* Used:**	0.11
Trench Width:	48 in.
Trench Depth:	18 ft. over top of pipe
Max Load:	4,890 lbs/ LF

	Load Factor	Safety Factor	Safety Factor @ Transition
Class D	1.1	0.99	0.66
Class C	1.5	1.35	0.90
Class B	1.9	1.71	1.14
CR Stone	2.2	1.98	1.33
Concrete Cradle	3.4	3.06	2.05
CLSM	2.8	2.52	1.69

When using the trench load tables to determine the load on the pipe, the next step is to calculate the field supporting strength and safety factor per bedding class.

Example 6-2 (Continued): Bedding Design Using the Trench Load Tables and the NCPI Toolbox

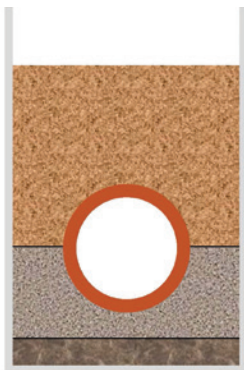
ASTM 3-edge bearing strength, 24-inch Extra Strength pipe = 4,400 lbs/ LF

Class D Bedding

Load Factor for Class "D" bedding = 1.1

Field Supporting Strength = (4,400 x 1.1) = 4,840

Safety factor (4,840/4,890) = **0.99**



Class B Bedding

Load Factor for Class "B" bedding = 1.9

Field supporting strength = (4,400 x 1.9) = 8,360

Safety factor (8,360/4,890) = **1.71**

Class C Bedding

Load Factor for Class "C" bedding = 1.5

Field supporting strength = (4,400 x 1.5) = 6,600

Safety factor (6,600/4,890) = **1.35**

Evaluation:

1. Class D bedding should not be selected because it does not provide an adequate factor of safety.
2. Class B bedding provides a sufficient safety factor but is not cost effective.
3. Class C bedding should be selected because it meets the criteria for safety factor and cost effectiveness.