Geotechnical Training Manual No. 7

Pipe Bedding and Backfill

United States Department of the Interior
Bureau of Reclamation
Technical Service Center
Geotechnical Services
Denver, Colorado
1996

GEOTECHNICAL TRAINING MANUALS

Control of Earth Construction

No. 1 - "Moisture-Density Relationship of Soils"
No. 2 - "Earth Work Construction Control"
No. 3 - "Rapid Method of Earthwork Construction Control"

Unified Soil Classification System

No. 4 - "Laboratory Classification of Soils"
No. 5 - "Visual Soil Classification"
No. 6 - "Guides for Visual Soil Classification"

Pipeline Construction

No. 7 - "Pipe Bedding and Backfill"

These self-learning manuals are designed to teach the basic concepts of soil mechanics for earthwork construction personnel. The material progresses from simple to more difficult topics. This allows the reader to begin anywhere in the manuals depending on the individual's background.

OTHER REFERENCES

Earth Manual, Second Edition, Reprinted 1990

Earth Manual, Part 2, Third Edition, 1990

The National Technical Information Service sells the seven geotechnical training manuals and the *Earth Manual* at:

National Technical Information Service
5285 Port Royal Road
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SECOND EDITION

Pipe Bedding and Backfill

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by

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Bureau of Reclamation

Denver, Colorado

SI METRIC

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island Territories under U.S administration.

The Bureau of Reclamation test procedures referred to in this manual (e.g., USBR 5123), can be found in Part 2 of the Third Edition of the *Earth Manual* (1990)

CONTENTS

PREFACE

This manual presents the requirements of the Bureau of Reclamation (Reclamation) for constructing bedding, embedment, and backfill for buried pipe. Many of these requirements are new as of 1991. All Reclamation personnel involved in installing buried pipelines should become familiar with these requirements and the reasons they are important.

Proper installation of buried pipe is being emphasized because of:

1. The present trend to use pipelines rather than canals. - Pipelines provide more farmland use, reduce evaporation and maintenance, and are safer for the public, livestock, and wildlife.

2. The use of larger pipe. - Each pipe unit becomes more expensive and specific installation requirements are necessary to prevent failures.

3. The availability of new pipe types and materials. - Some of these may require special installation requirements.

4. Problems with installations. - Recent experience in pipe installation has shown that updated requirements are necessary.

Reclamation has recently completed a comprehensive review and revision of the specifications paragraphs and drawings for pipe installation. The discussions in this manual on bedding, embedment, and backfill requirements reflect these revisions and pertain only to specifications issued after the summer of 1991. However, many of the concepts presented are also applicable for prior specifications.

Occasionally, there are pipelines that have special design and construction considerations which require site-specific specifications. These special cases are not covered in this manual because each situation may be unique. These special installations may include, but are not limited to, cast-in-place pipe, pipe with diameters larger than 3000 mm (120 inches), and pipe on very steep slopes.

On and off, Reclamation uses a modern form of the metric system called SI (International System of Units). The SI units are used in this manual, followed by the inch-pound system of units in parentheses.

Reclamation test procedures are indicated by "USBR 5123" (for example) and these procedures can be found in the Third Edition of the *Earth Manual*, Part 2, 1990.

INTRODUCTION

Proper pipeline installation involves much more than just covering up the pipe. A BURIED PIPE IS A STRUCTURE THAT INCORPORATES BOTH THE PROPERTIES OF THE PIPE AND THE PROPERTIES OF THE SOIL SURROUNDING THE PIPE. The structural design of a pipeline is based on certain soil conditions, and construction control is important to ensure these conditions are met.

There are two basic types of pipe, rigid and flexible. Rigid pipe must be supported on the bottom portion of the pipe. Flexible pipe must be supported on both the bottom and on the sides of the pipe.

Proper soil support of the pipe is critical to the performance of both types of pipe, and proper inspection of pipe installation is essential in obtaining the required support.

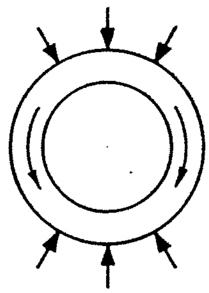
Inspection for proper soil support involves checking the:

1. Adequacy of soil in trench walls and foundation
2. Type of soil used for bedding, embedment, and backfill
3. Distribution of soil around pipe
4. Density of soil around pipe
5. Deflection of flexible pipe

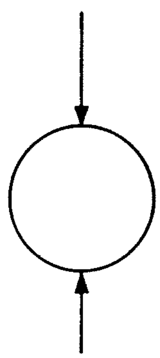
In the Bureau of Reclamation, installation requirements are different for each of the following cases:

1. Rigid pipe
2. Flexible pipe
3. 250-mm (10-in) diameter pipe and smaller

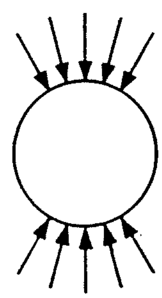
BACKFILL LOAD



FOUNDATION SUPPORT



LINE LOAD



DISTRIBUTED LOAD

RIGID PIPE

CHAPTER 1

DEFINITIONS AND TERMINOLOGY

Rigid Pipe

Rigid pipe is designed to transmit the backfill load on the pipe through the pipe walls to the foundation beneath the pipe. The pipe walls must be strong enough to carry this load.

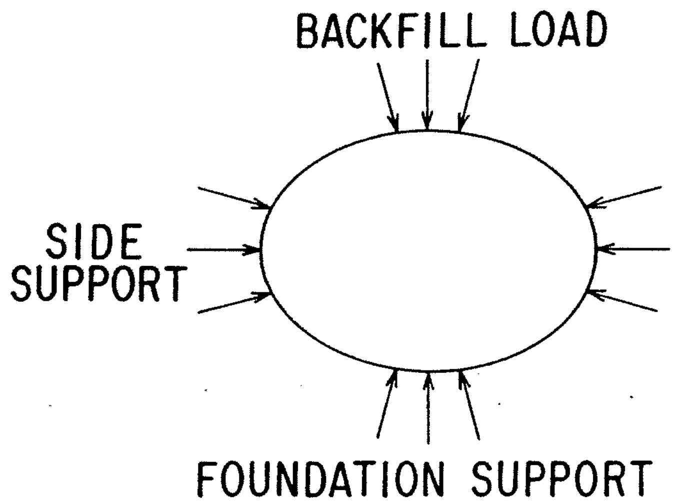
A line load at the top and bottom of a pipe is the worst possible loading case. If the load can be distributed over a large area at the top and at the bottom of the pipe, the pipe walls will not have to be designed as strong as for a line load. The backfill load is normally well distributed over the top of the pipe. However, proper pipe support must be constructed on the bottom of the pipe to distribute the load.

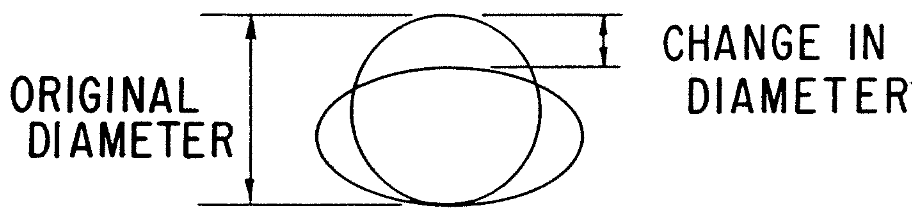
Proper soil support under the bottom of the pipe is also necessary to maintain grade (elevation) of the pipe. Continuous, uniform support under the pipe prevents unequal settlement of the pipeline.

If a rigid pipe is overloaded, or if the load is not distributed around the pipe, a rigid pipe will fail by cracking.

Types of Rigid Pipe

- Reinforced concrete pipe
- Ductile iron pipe 500 mm (20 in) in diameter and smaller
- Reinforced concrete cylinder pipe





FLEXIBLE PIPE

Flexible Pipe

Flexible pipe is designed to transmit the load on the pipe to the soil at the sides of the pipe. As the load on the pipe increases, the vertical diameter of the pipe decreases and the horizontal diameter increases. The increase in horizontal diameter is resisted by the soil at the sides of the pipe. The soil must be strong enough so the pipe does not deflect significantly. The allowable amount of deflection varies according to the type of pipe, and ranges from 2 to 7.5 percent.

Deflection is expressed as a percentage and is calculated from the following equation:

$$\text{Percent deflection} = \frac{\text{change in diameter}}{\text{original diameter}} \times 100$$

A 1-inch deflection in a 36-inch-diameter pipe would be almost 3 percent

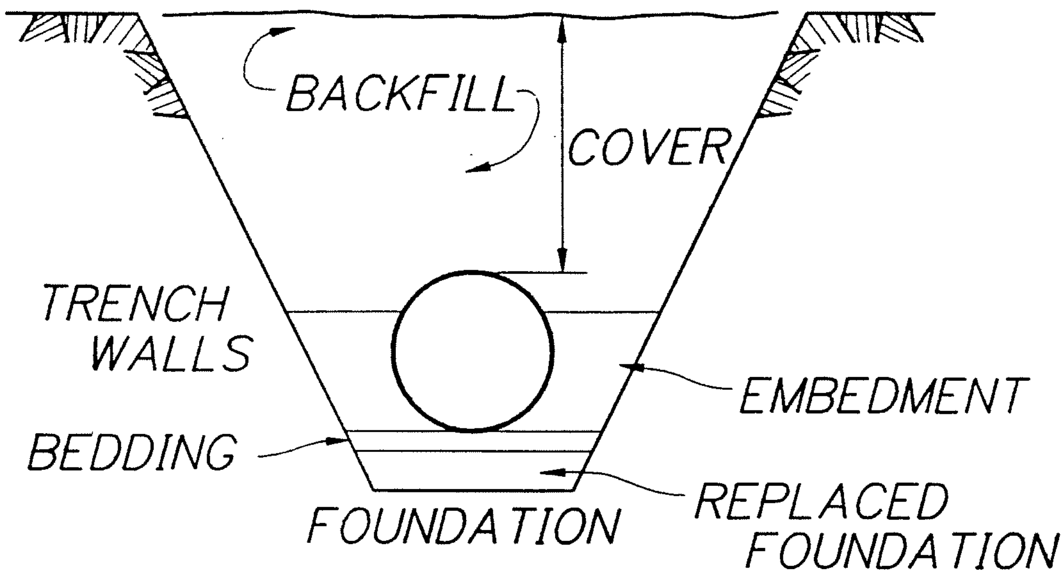
$$\text{Percent deflection} = \frac{1\ \text{in}}{36\ \text{in}} \times 100 = 2.8\ \text{percent}$$

Adequate soil support on the sides of the pipe is essential for proper performance of the pipe. Overdeflection of the pipe can cause the pipe to collapse or cause cracking in protective coatings and linings of metal pipe that would result in corrosion failures.

Proper soil support on the bottom of the pipe is also necessary to maintain the grade of the pipe and to provide uniform support.

Types of Flexible Pipe

- Steel pipe
- Pretensioned concrete cylinder pipe
- Ductile iron pipe 600 mm (24 in) and larger
- CMP (corrugated metal pipe), steel or aluminum
- Fiberglass pipe
- Polyvinyl chloride (PVC) pipe
- Polyethylene (PE) pipe



TRENCH TERMINOLOGY

Foundation

The foundation is the inplace material beneath the pipe. If the foundation is unsuitable, it must be removed and replaced with a suitable material.

Bedding

The bedding is the material placed in the bottom of the trench on which the pipe is laid.

Embedment

The embedment is the soil placed to support the load on the pipe. For rigid pipe, embedment helps distribute the load over the foundation. For flexible pipe, embedment resists the deflection of the pipe due to load.

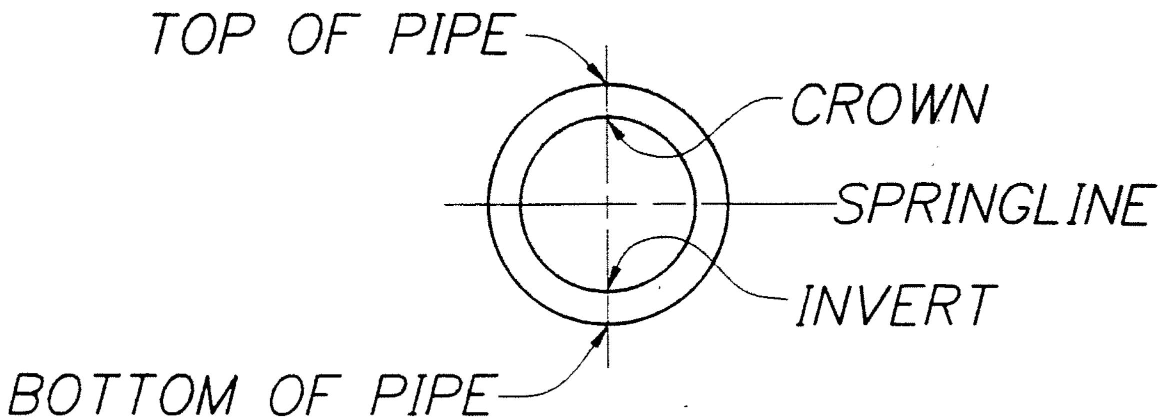
Backfill

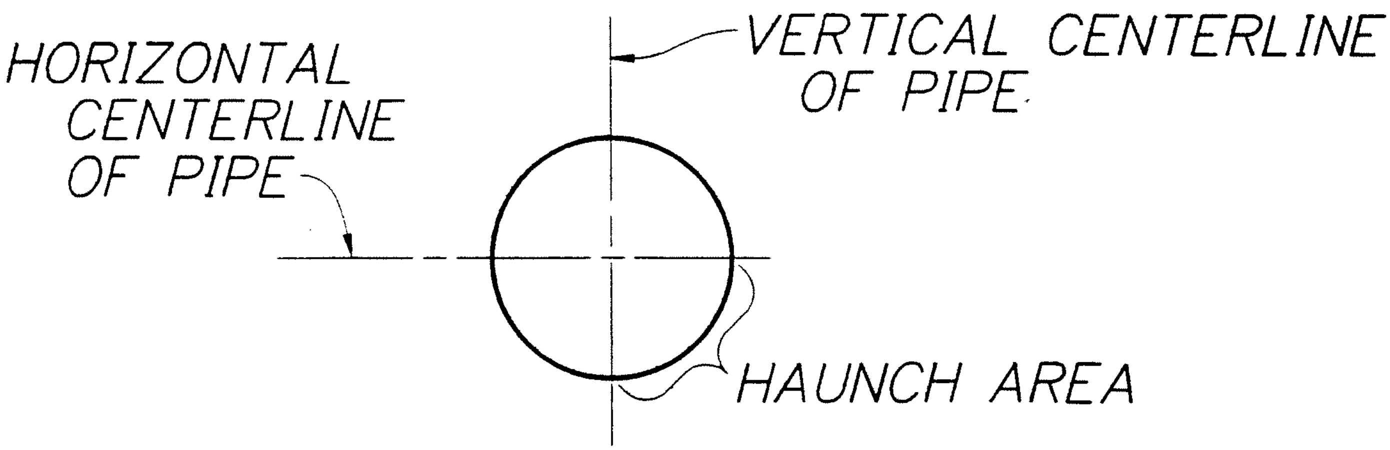
The backfill is the material used to refill the trench after the pipe and the embedment have been placed.

Cover

The cover is the depth of backfill over the top of the pipe.

> Even though some specifications, manuals, and handbooks use "unit weight," the term "density" will be used in this manual since it is a measured value and the most familiar term. For further discussion, see Appendix C.





PIPE TERMINOLOGY

Pipe Terminology

The crown is the inside top of the pipe. The invert is the inside bottom of the pipe. The spring line is the horizontal line at the midpoint of the vertical axis of the pipe. The haunches of the pipe are the outside areas between the spring line and the bottom of the pipe.

Compaction Methods*

Dumped - Soil is dumped into place with no compactive effort.

Sluicing - Soil is washed into place with a high velocity stream of water.

Ponding or flooding - Water is added after soil is placed and until free water stands on the surface.

Jetting - A hose or other device, using a high velocity stream of water, is worked down through depth of soil placed.

Puddling - Soil is deposited into pool of water and stirred or rodded.

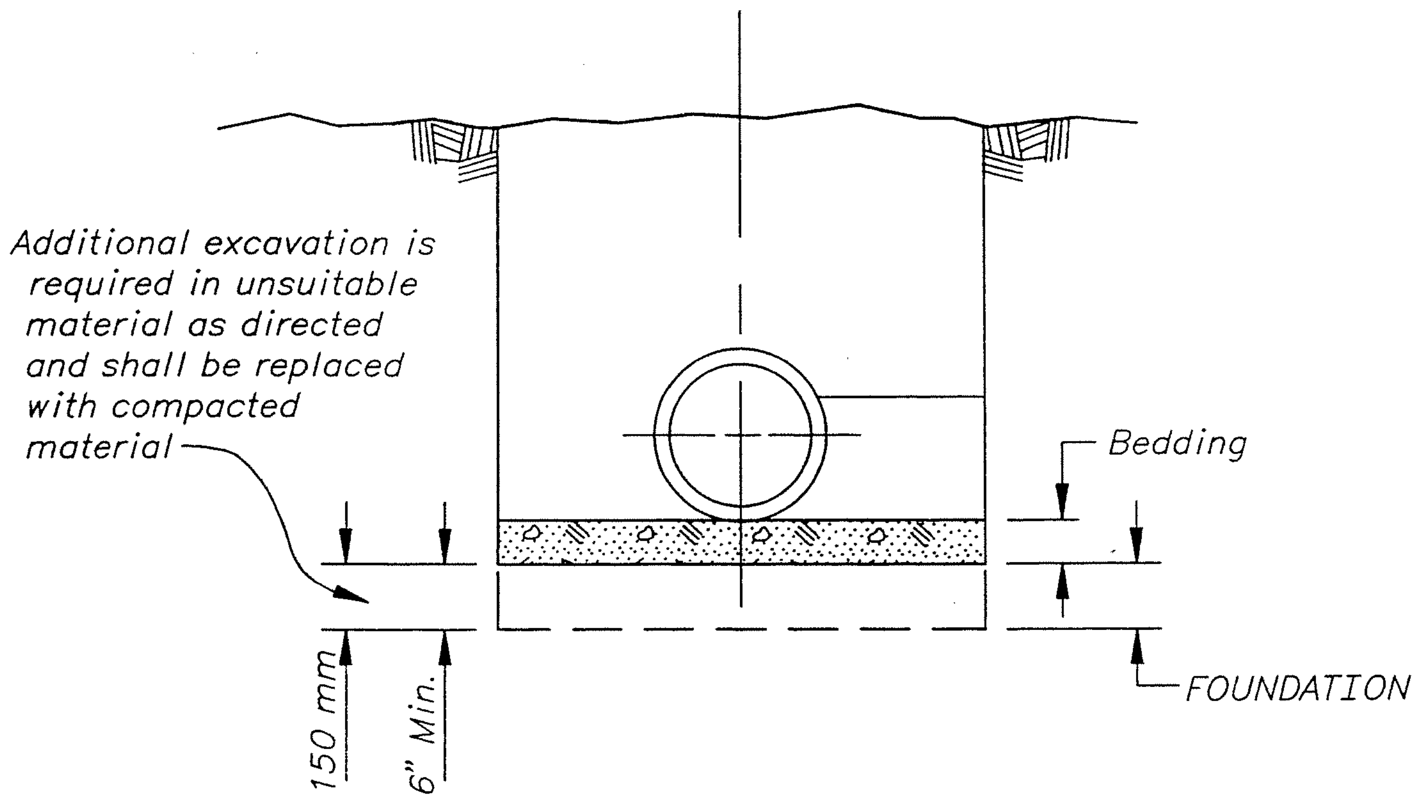
Saturation and internal vibration - Water is added to loose soil and internal vibrators (such as a concrete vibrator) are worked down through depth of soil placed.

Surface vibration - A vibrating plate or vibrating smooth drum roller is used on the surface of soil placed.

Tamping - The impact of a power or hand tamper on surface of soil placed.

Rolling - Use of sheepsfoot roller or smooth drum roller.

* These are common methods of compacting soils, but not necessarily those approved by the Bureau of Reclamation.



ADDITIONAL EXCAVATION OF FOUNDATION

CHAPTER 2

TYPE AND DISTRIBUTION OF SOIL

The soil placed around a buried pipe must be:

1. The right type of soil
2. In firm, complete contact with the pipe

Foundation

The foundation is the inplace material beneath the pipe. If the foundation is unsuitable, it must be removed to a minimum depth of 150 mm (6 in) and replaced with appropriate material. In some instances, removal of 1 to 1.5 m (3 to 5 ft) or more of material may be necessary.

Unsuitable foundations would include:

1. Potentially expansive material

    Shale
    Mudstone
    Siltstone
    Claystone
    Dry, dense, fat clay (CH)*

> See Earth Manual on how to identify and test potentially expansive soils

2. Soft, unstable soils

    Very wet soils that flow into excavation
    Low-density soils
    Peat or other organic material (OL, OH)*

Mudstone, shale, etc., are materials that may have expansive characteristics when wetted. Uplift pressures created from expansion of these materials have been known to cause broken backs in pipe.

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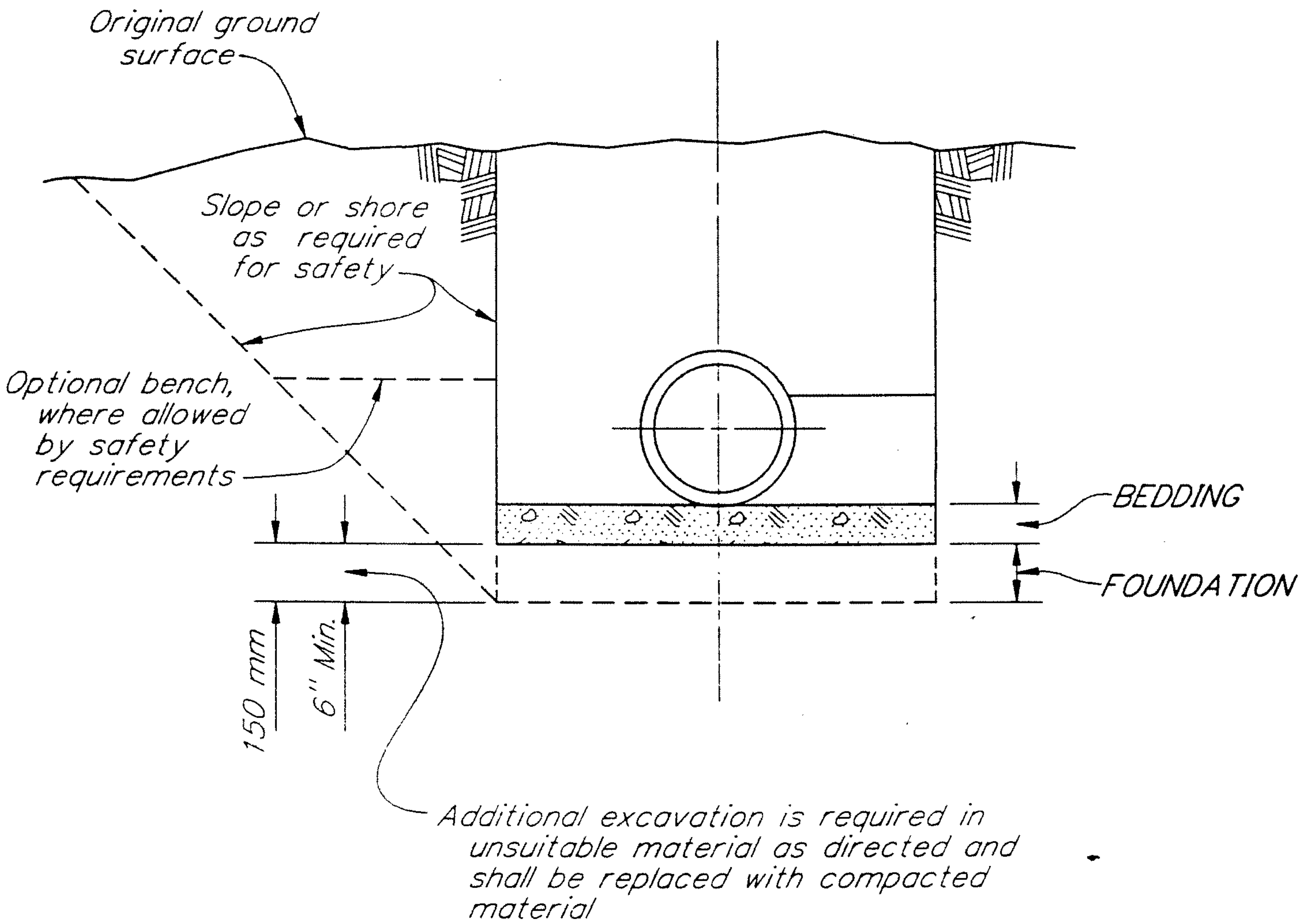
* Group classification symbol of the soil using the Unified Soil Classification System. (ASTM D 2487, USBR 5000) See Appendix A for list of soil testing procedures.



TRENCH WALL SLOPE
FOR ADDITIONAL EXCAVATION
OF FOUNDATION

A soft, unstable foundation may result in unequal settlement of the pipe causing broken backs or broken bellies. Low-density soils may collapse upon wetting. Very wet, unstable soils must be removed and a stable foundation created that will maintain grade and provide uniform support for the pipe. Peat or other organic soils are highly compressible, and significant settling of the pipe may occur if these soils are left in the foundation.

When the side walls of the trench are sloped, the toe of the slope (with or without a bench) MUST begin at the lowest point of the additional excavation, not at the bottom of the bedding (see illustration).

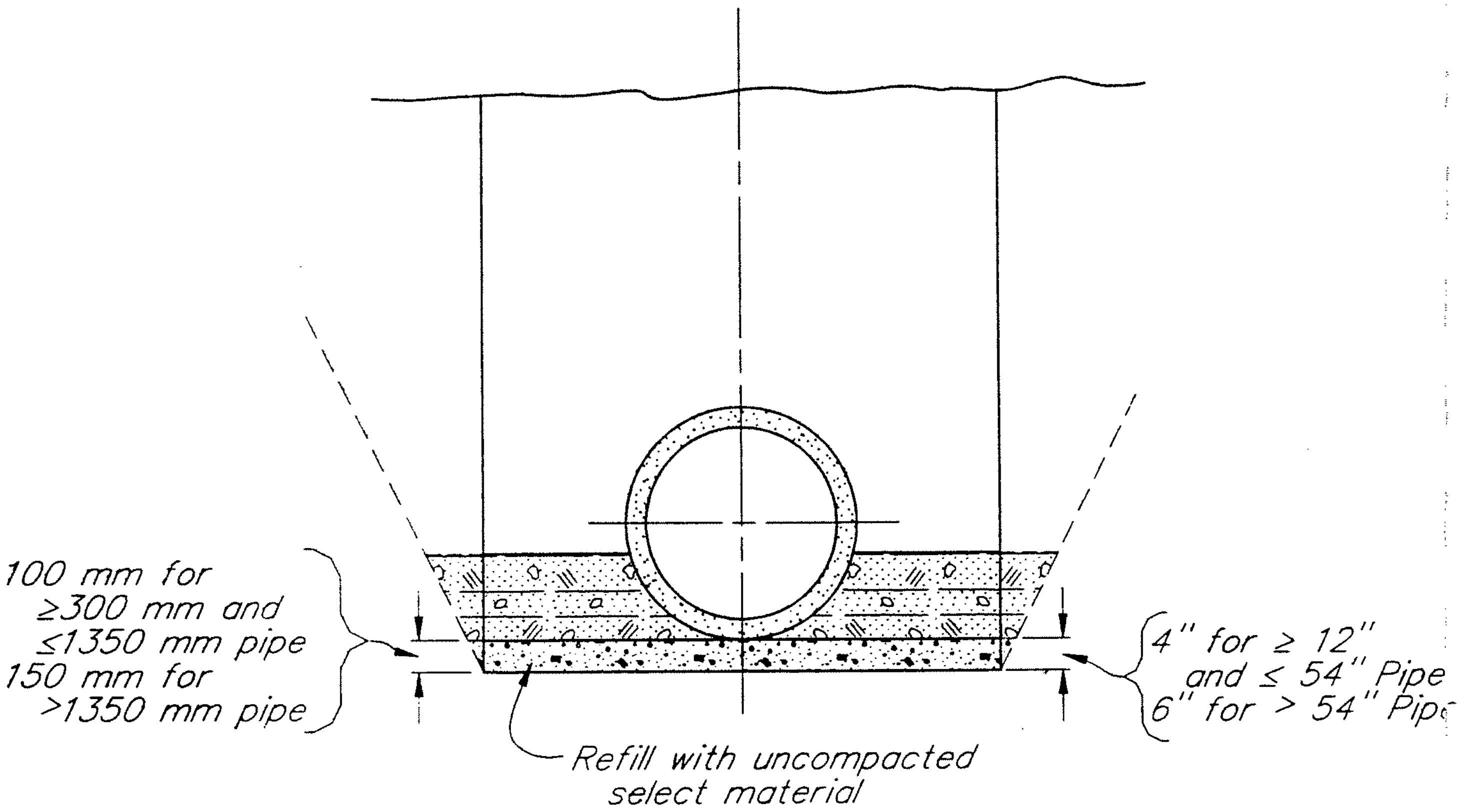
Foundation materials disturbed during construction must be removed. The disturbed material may be compacted back in place or imported material may be used to replace the disturbed material and then compacted.

Replaced Foundation

The right type of soil must be used to replace the removed foundation material. Fat clay soils (CH) are generally avoided because moisture changes can cause a significant volume increase or decrease. Elastic silts (MH), peat, or other organic material must not be used because they are highly compressible. Frozen soils must not be used.

Material that would permit migration of fines from the native material should not be used for the replaced foundation. For example, crushed rock or a gravel material containing significant voids placed next to fine-grained native material should not be used. The fine-grained material could migrate into the voids of the coarser material and result in the rock particles floating in a matrix of fine-grained material. This could possibly cause loss of support for the pipe which could further result in unequal settlement.

Any method of compacting the replaced foundation may be used; however, the density requirements for compacted backfill must be met. The replaced foundation must be compacted for the full width of the trench.



PIPE BEDDING

Bedding

The bedding for both rigid and flexible pipe is an uncompacted layer of select material. This layer of uncompacted select material is placed over the foundation or the replaced foundation. The thickness of this layer depends on the pipe diameter:*

For pipe with a diameter of 300 to 1350 mm (12 to 54 in), the thickness of the bedding is 100 mm (4 in).

For pipe diameters larger than 1350 mm (54 in), the thickness of the bedding is 150 mm (6 in).**

Pipe is laid directly on the bedding.

Fine grading of the surface of the bedding shall be such that the final grade of the pipe shall not exceed the specified departure from grade. Because the bedding material is uncompacted, there will be some slight settlement of the pipe when the pipe is laid on the bedding. The amount of settlement will vary depending on the type of soil, the type of pipe, and the diameter of the pipe. The initial (placement) thickness of the bedding layer will have to be established by trial and error at the beginning of a job or after any change that would affect the settlement.

If the bedding becomes compacted by excessive foot traffic, equipment travel, or rain, before the pipe has been placed, it must be loosened by removal and replacement or by scarifying.

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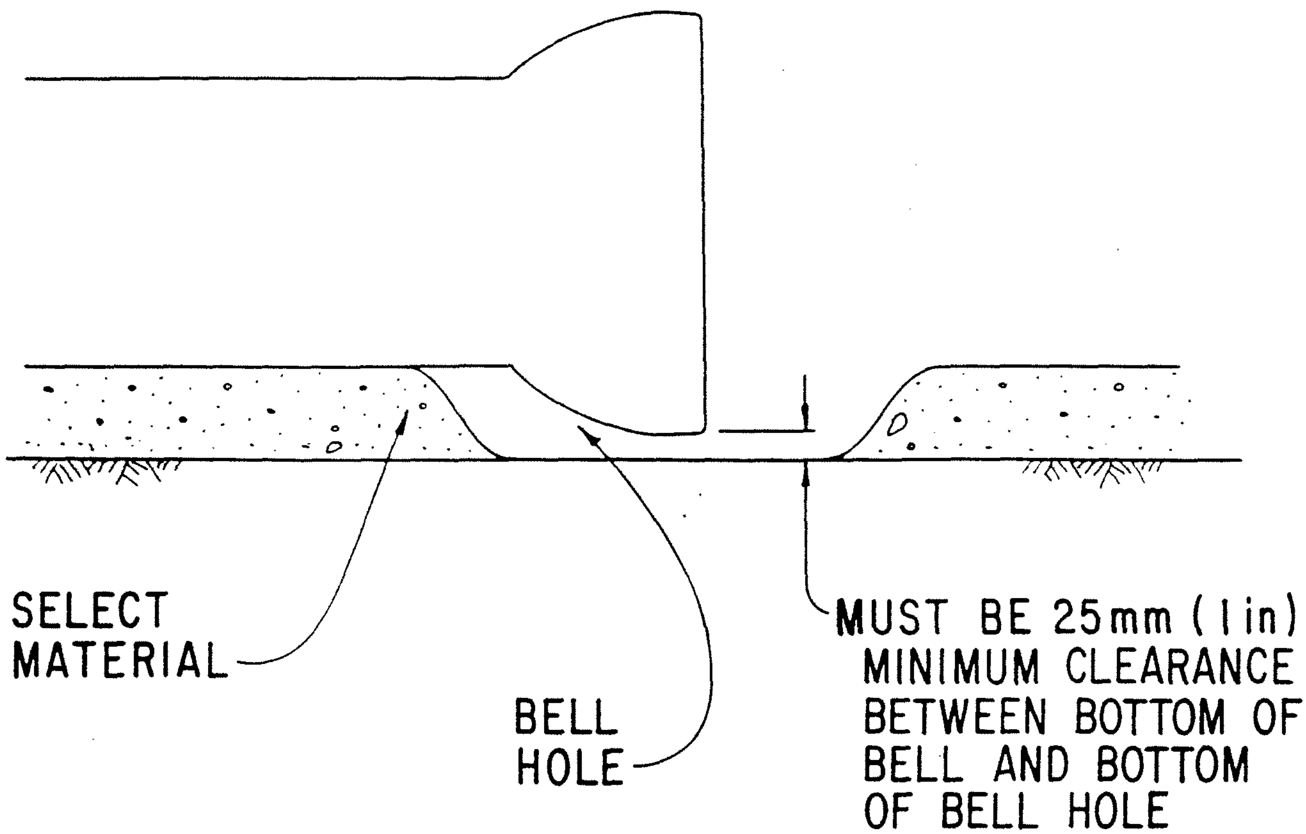
*For most types of pipe, the nominal (or design) diameter is equal to the inside diameter of the pipe. A pipe has an inside diameter (I.D.) and outside diameter (O.D.). In this manual, the nominal diameter may be used to determine pipe type (rigid versus flexible), pipe bedding thickness, and pipe deflection. Other pipe trench features, such as minimum thickness, trench width, and trench plugs, are based on the outside diameter.

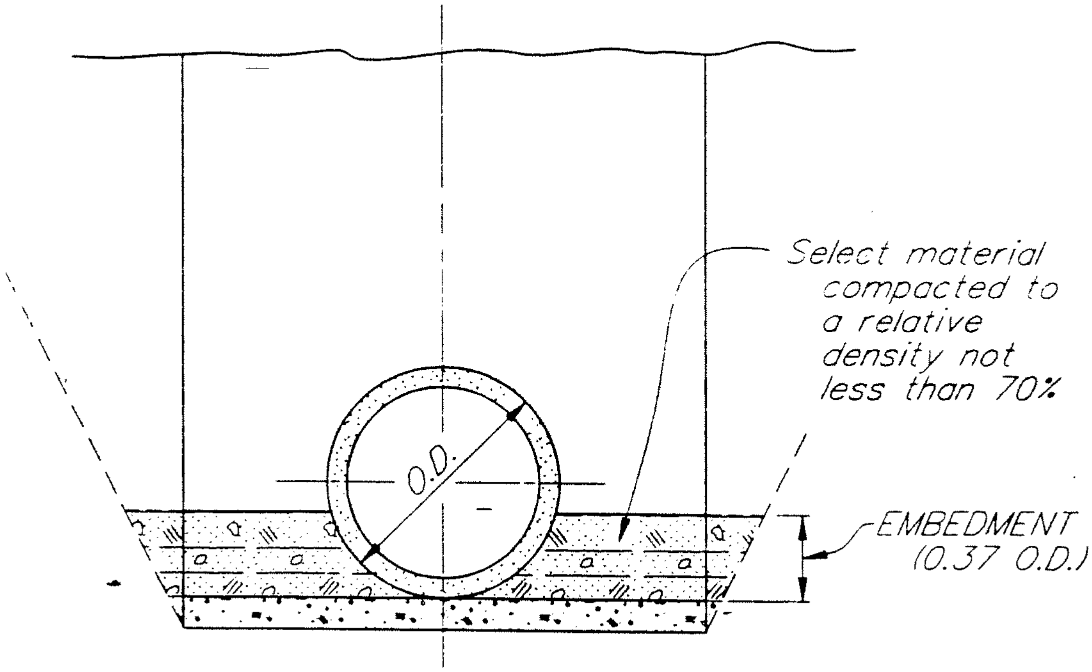
** For special designs of very large diameter pipe, a thicker bedding may be specified.


SELECT
MATERIAL
BELL
HOLE
MUST BE 25mm (1in)
MINIMUM CLEARANCE
BETWEEN BOTTOM OF
BELL AND BOTTOM
OF BELL HOLE

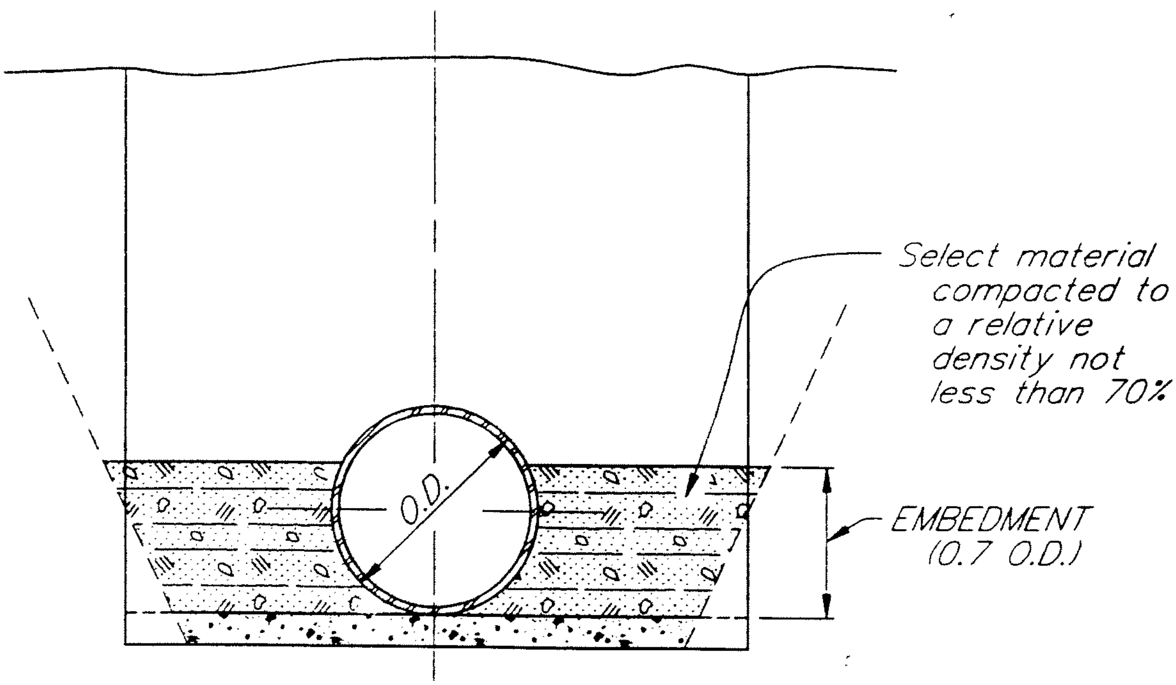
BELL HOLES

Following final grading, holes must be dug into the bedding at the ends of the pipe to provide a space between the bottom of the bell and any soil. This space will prevent a point loading on the bell end of the pipe. It may be necessary to excavate into the foundation for large bells.

Material may also need to be excavated for slings used in laying large pipe or for joints (other than the bell-and-spigot type) which require treatment of the outside of the joint, such as the taping of welded steel pipe joints or when mortar is placed in the joint space.



RIGID PIPE



FLEXIBLE PIPE

Embedment

After the pipe has been placed on the uncompacted layer of bedding material, embedment soil is compacted into place beside the pipe up to the specified height. PROPER CONSTRUCTION OF THE PIPE EMBEDMENT IS CRITICAL TO THE SUCCESSFUL INSTALLATION OF BURIED PIPE.

The soil for the embedment must be the select material as specified and must be compacted to a relative density not less than 70 percent. The most difficult task in pipeline installation is ensuring that the soil in the haunch area of the pipe receive sufficient compactive effort to meet the 70 percent relative density requirement.

Rigid pipe. - For rigid pipe, the embedment soil is placed to a height of 0.37 of the outside diameter of the pipe.

Flexible pipe. - For flexible pipe, the embedment soil is placed to a height of 0.7 of the outside diameter of the pipe.

Compaction of embedment. - The select material used must be a cohesionless, free-draining soil such as clean sands and gravels. Just as "percent Proctor" is used to control the compaction of cohesive soils (clays, etc.), relative density is used to control the compaction of cohesionless soils. The embedment may be compacted by any means as long as the 70 percent relative density criterion is met. If tampers or rollers are used, the compacted lift cannot exceed 150 mm (6 in). If crawler-type tractors or surface vibrators are used, the compacted lift cannot exceed 300 mm (12 in). Too much or too little moisture in the soil can hinder compaction. Adjustments may need to be made to the water content to find the best moisture condition for compaction. Saturation and internal vibration can be a very effective method of densifying the soil in the haunch area for large diameter pipe.

Drawing not necessary for this page

Saturation and internal vibration is the preferred method of compacting cohesionless, free-draining soils by many contractors. This method is particularly effective for densifying a lift several feet thick; however, the compacted lift thickness cannot exceed the length of the vibrator. For contractors unfamiliar with this method of compaction, it is not uncommon for them to expend considerable effort and time to experiment with finding the right combination of soil, water, equipment, and technique. In addition, if too much water is used, it is possible to float the pipe.

When saturation and internal vibration is used for flexible pipe larger than 1350 mm (54 in) in diameter or rigid pipe larger than 2700 mm (108 in) in diameter, the select material for the embedment shall be placed and compacted in two or more lifts. This may be done to ensure that the select material is getting compacted to at least 70 percent relative density in the haunches of the pipe. For a large diameter pipe, it is difficult to manually angle the vibrators under the haunches of the pipe. Several contractors have devised mechanical devices to ensure the haunch area is compacted. Another reason to limit the thickness of the lifts is that checking the density in the haunch after the embedment is several feet above the haunch area requires a major excavation.

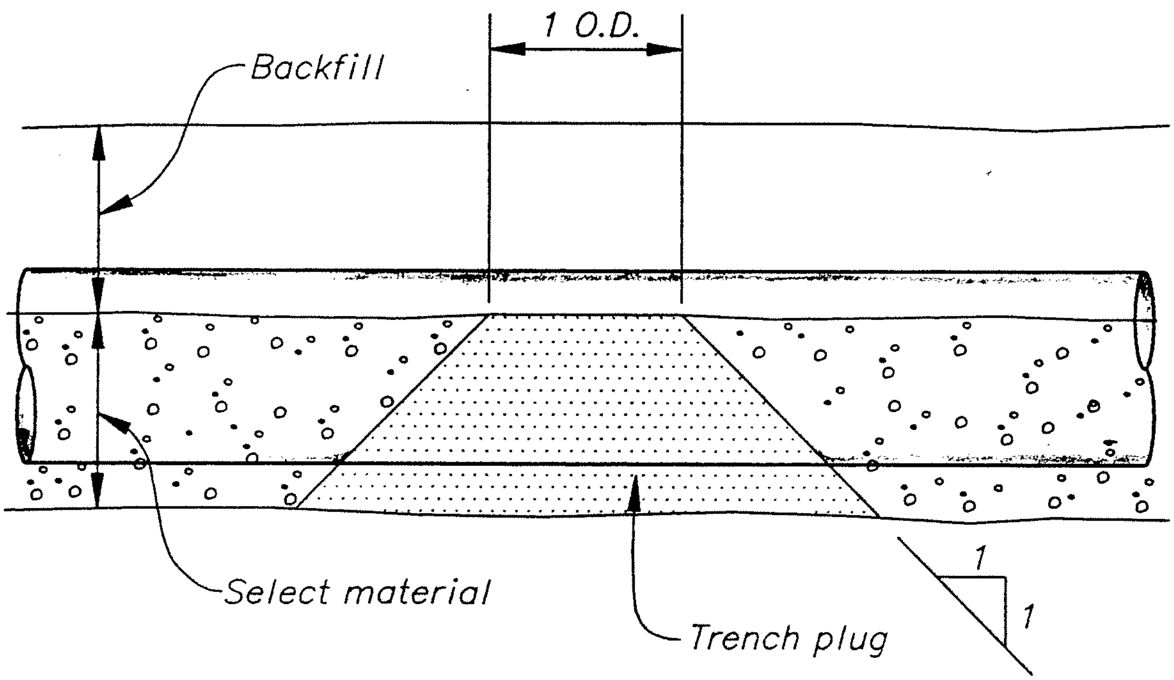
Pipelines on Slopes

Where the pipeline grade exceeds 0.3, silty or clayey material may be used instead of the specified select material for bedding and embedment. This change is allowed because of the difficulties of compacting some cohesionless soils on steep slopes. Silty or clayey soils must be compacted to a density not less than 95 percent compaction (95 percent standard Proctor). The inspector must be sure that the soil in the haunch areas is receiving sufficient compaction. The maximum particle size in the silty or clayey soil shall not exceed the size shown in the table on page 25. If the contractor elects to use an alternate method such as soil-cement or lean concrete as a bedding and embankment material on steep slopes (or anywhere else), the plans must be submitted for approval prior to construction.

GRADATION LIMITS FOR SELECT MATERIAL

SIZE *	PERCENT BY WEIGHT
Passing No. 200 sieve	5 or less
Passing No. 50 sieve	25 or less

* Maximum size shall not exceed 19 mm (¾").



TRENCH PLUG

Select Material

Select material used for the bedding and embedment must be a cohesionless, free-draining material (5 percent fines or less), and the maximum size shall not exceed 19 mm (¾ in). In addition, not more than 25 percent of the material can pass the No. 50 sieve. This latter requirement prevents the use of fine sands which can be difficult to compact. The requirement of 5 percent fines or less is particularly critical when the soil is to be compacted by saturation and vibration.

Rarely can soils from the trench excavation be used for select material without processing. In most cases, the select material used for the bedding and embedment is imported to the site from a processing plant.

Trench Plugs

Since the bedding and embedment are constructed using cohesionless, free-draining soils, a path is created for water to flow easily (french drain effect) alongside the pipe. In areas where there is high ground water, where the pipeline crosses streams or aquifers, or where the natural ground water flow would be affected or even diverted by the select material, trench plugs of compacted, cohesive, impervious soils should be constructed at intervals along the pipeline.

The trench plug area will have a bedding of compacted, cohesive soil, whereas the bedding on both sides of the trench plug will have a bedding of uncompacted, cohesionless soil. The bedding must be compressed equally when the pipe is lowered into the trench and onto the bedding. The first lift of cohesive soil may have to be at a moisture content considerably higher than the optimum moisture content so that the settlement of the compacted, cohesive soil will match the settlement of the uncompacted, cohesionless soil.

Checking Height of Embedment

The height of the compacted embedment, 0.37 O.D. for rigid pipe or 0.7 O.D. for flexible pipe, should be checked frequently during construction. Meeting this requirement is the contractor's responsibility, and the inspector shall not mark the pipe. The height should be checked after compaction of the embedment and before the backfill is placed.

Shored Trenches/Trench Boxes

If the bottom of a trench excavation will be 1.5 m (5 feet) or more below the ground surface, the trench walls must either be shored or sloped for safety reasons. Shoring is generally considered to be a wall support system that has to be disassembled and reassembled as the trench progresses. Trench boxes are allowed under the shoring requirement. Trench boxes (trench shields) are rigid structures that are pushed or pulled forward as the work progresses.

Where soil is to be compacted at the bottom of a shield or support system, the shield/support must be positioned so the soil can be compacted across the full trench width so a void is not created in the soil when the shield/support is moved.

Backfill

Most soils may be used for backfill over the pipe, except there are maximum particle size restrictions (as shown in the table below) in a zone 300 mm (12 in) around the pipe. These restrictions are necessary to prevent damage to the pipe or its coating from a hard, possibly sharp rock particle. Above this zone, any rock particle with a dimension greater than 450 mm (18 in) is not allowed in the backfill. Particles larger than this may easily penetrate through the 300-mm (12-in) zone around the pipe (from rolling down the trench wall slope or being dropped), impacting the pipe and damaging the pipe or its coating or lining. Frozen soils shall not be used. Where backfill is to be compacted to the ground surface (such as at road crossings) peat or other organic materials shall not be used. Local requirements for compacted backfill under roads must also be met. Backfill material must not be dropped on the pipe and large, hard clods should be prevented from rolling down slopes and impacting the pipe.

MAXIMUM PARTICLE SIZE ALLOWED IN BACKFILL WITHIN 300 MM (12 IN) OF PIPE	
PVC, fiberglass, ductile iron, or any pipe with a polyethylene sleeve	25 mm (1 in)
Coal-tar, enamel-coated and -wrapped or plastic-tape-coated steel pipe or any pipe with an approved bonded coating	38 mm (1½ in)
All other pipe (reinforced concrete, reinforced concrete cylinder, pretensioned concrete cylinder)	75 mm (3 in)

Soil-Pipe Contact

Soil placed against the pipe must be in firm, complete contact with the pipe.

Compacting soil in the haunch area of the pipe is the most difficult part of pipeline construction. This compaction must be carefully monitored during construction. To ensure that the soil is in complete contact with the pipe, a test pit must be dug at regular intervals to inspect the haunch area. The density of the soil in the haunch area must be determined. The area under the bottom of the pipe must be inspected to ensure that no space exists beneath the pipe. If too much water is used when saturation and internal vibration is used as a compaction method, it is possible to float the pipe. When the pipe floats, a gap is left between the pipe and the soil beneath the pipe. Pipe that has floated must be removed and re-installed.

Bell holes for bell-and-spigot pipe, sling holes for large diameter pipe, and spaces left for joint treatment for other than bell-and-spigot pipe must be filled with loose select material after the pipe is laid.

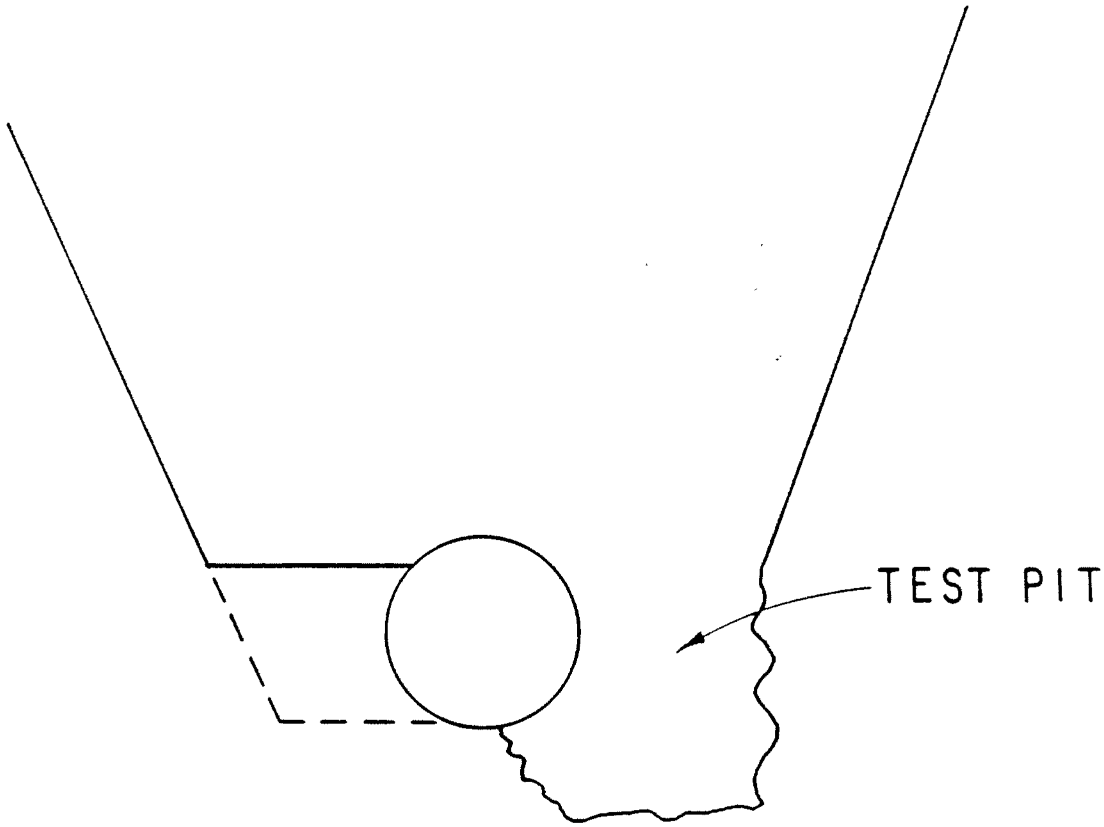
The embedment must be compacted for the full trench width regardless of the width of the trench. The soil shall be placed to about the same elevation on both sides of the pipe to prevent unequal loading and displacement of the pipe. The difference in elevation on either side of the pipe shall not exceed 150 mm (6 in) at any time.

Where trenches have been left open at pipe-structure junctions, the requirements as previously stated for pipe embedment must be continued right up to the structure when the excavation is to be filled.

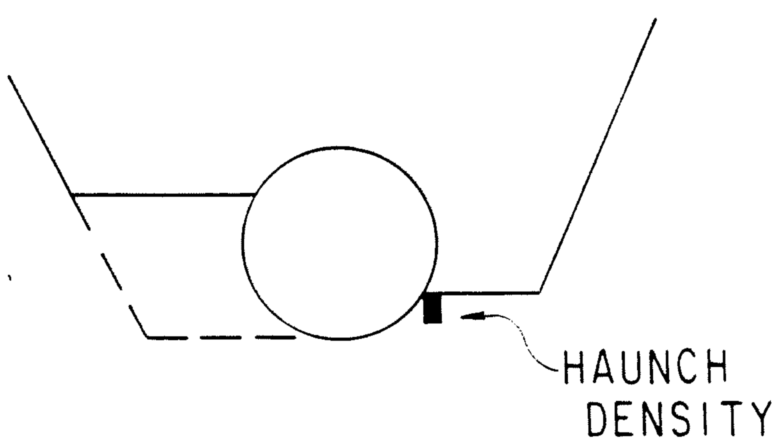
For silty or clayey soils, the thickness of each horizontal layer after compaction shall not be more than 150 mm (6 in). For cohesionless, free-draining material, such as clean sands and gravels, the thickness of the horizontal layer after compaction shall not be more than 150 mm (6 in) if compaction is performed by tampers or rollers; not more than 300 mm (12 in) if compaction is performed by treads of crawler-type tractors, surface vibrators, or similar equipment; and not more than the penetrating depth of the vibrator if compaction is performed by internal vibrators.

The backfill over the pipe should be placed to a minimum depth of 750 mm (30 in) or one-half the pipe diameter (whichever is greater) above the top of the pipe before power-operated hauling or rolling equipment is used over the pipe. In addition, limitations on weight of equipment traveling over the pipeline may be imposed.

Equipment crossings, detours, or haul roads crossing the pipeline must be approved prior to use.



LOOK FOR VOIDS
CHECK SOIL FIRMNESS



Test Pits

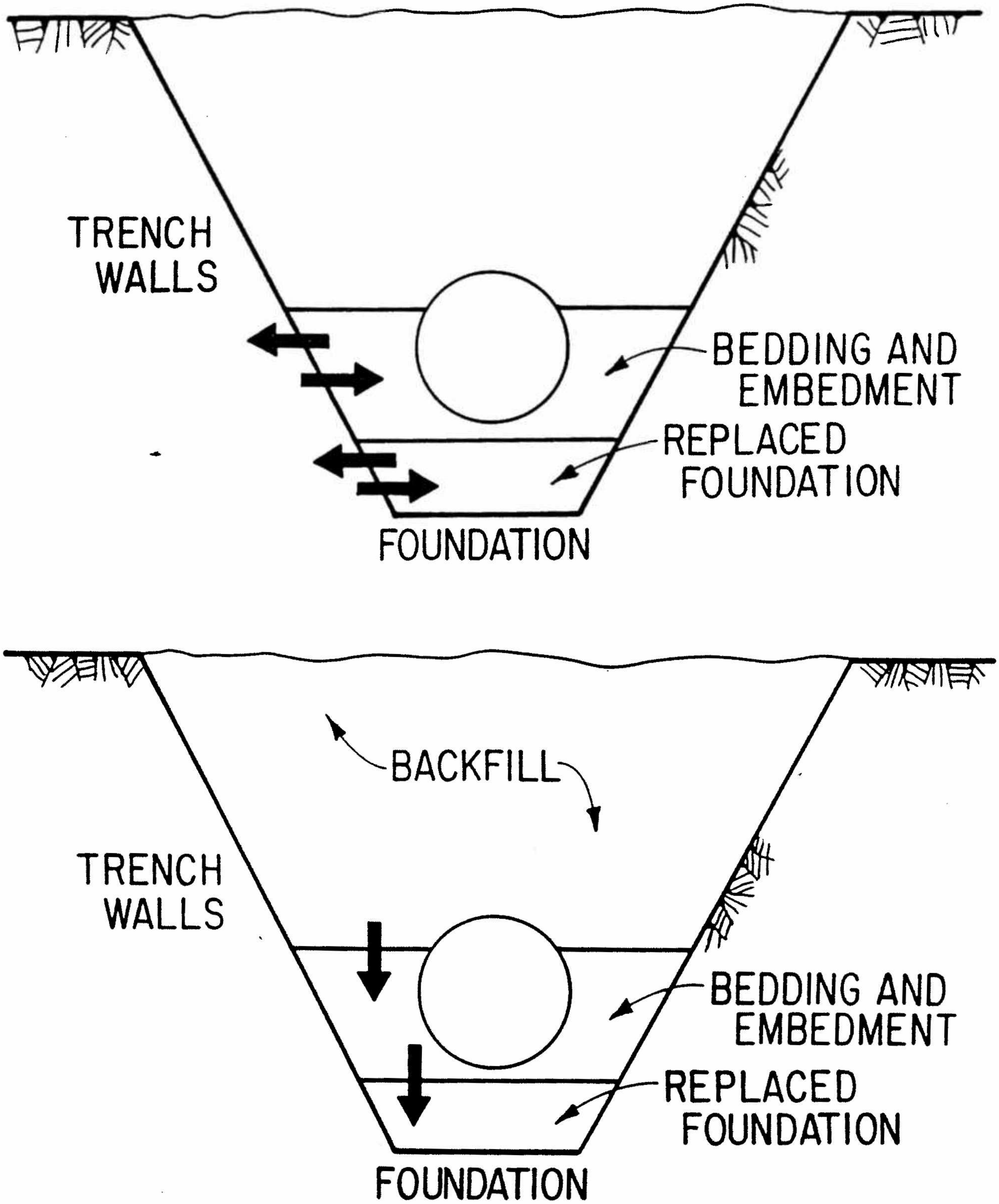
The soil in the haunch area of the pipe must be in firm contact with the pipe and compacted to the specified density. Test pits are required to obtain a field density test in the pipe haunch area and to visually examine the haunch area for voids or loose material next to the pipe. The area beneath the pipe invert must also be inspected for voids. Test pits also provide an opportunity to see if any oversize particles are contained in the embedment material.

Test pits to examine the haunch area should be excavated for all pipe 300 mm (12 in) or larger. About one-half of the test pits should be excavated on each side of the pipe. Field density tests are required in the haunch area for all pipe 1050 mm (42 in) and larger. The contractor should be discouraged from backfilling the pipe before the test pits have been excavated. All local, State, national, and Reclamation safety precautions must be followed for the test pit operation.

The test pit should initially be excavated deeply enough to permit the field density test to be performed. The haunch density test should be performed at an elevation 300 to 400 mm (12 to 16 in) above the bottom of the pipe and as close to the pipe as practical. Then, the test pit depth should be increased to allow visual examination beneath the pipe. The test pit excavation may be done in one stage if the excavated length alongside the pipe will permit both a field density test and the visual examination. Afterward, test pits must be refilled and recompacted to the specifications requirements.

The frequency of excavating test pits should be as follows:

1. For the first 1.5 kilometers or 1 mile of pipe installation by each compaction crew, a test pit should be excavated once for every 300 linear meters or 1000 linear feet of pipe placed. For pipelines shorter than 300 linear meters (1000 lin ft), at least one test pit should be excavated.


TRENCH WALLS
BEDDING AND EMBEDMENT
REPLACED FOUNDATION
FOUNDATION
BACKFILL
TRENCH WALLS
BEDDING AND EMBEDMENT
REPLACED FOUNDATION
FOUNDATION

MIGRATION

2. For the remainder of the operation by each compaction crew, a test pit should be excavated once for every 1000 linear meters or 3000 linear feet of pipe placed.

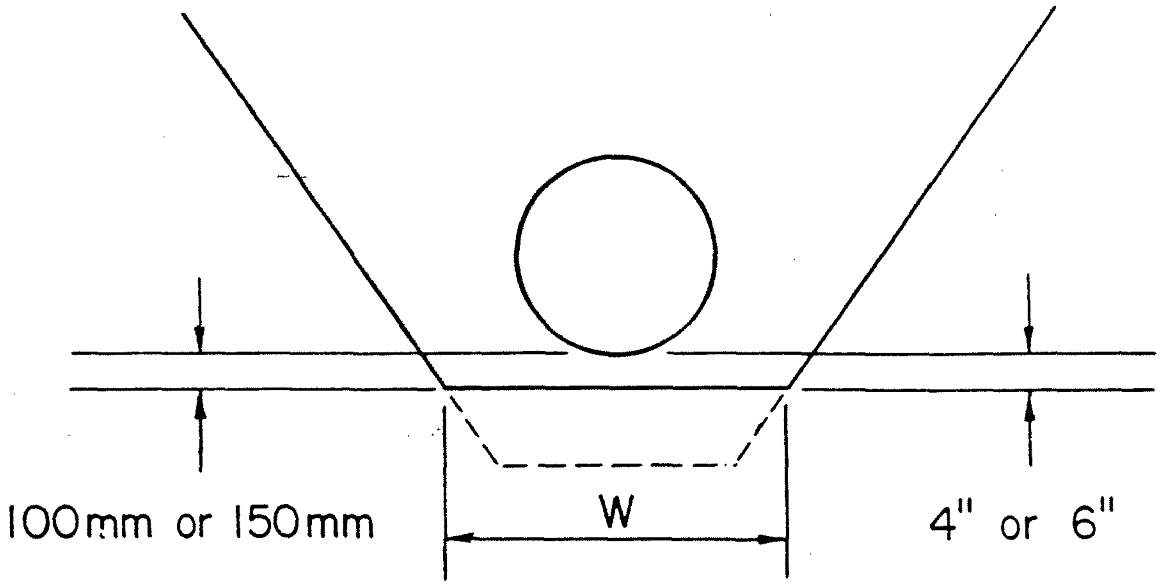
3. Additional test pits may be required for critical areas (such as steep slopes) when difficulty arises in obtaining the required density in the pipe haunch areas, or when voids are found. On steep slopes (> 0.3) where cohesive material is used, at least one test pit should be excavated for each slope or at a minimum frequency as noted in 1. or 2. above.

The location of the test pits and a brief comment on the observations and results should be included in the monthly L-29 construction report. The field density results should be included with the density results and noted in the remarks column as "pipe haunch density in test pit."

Migration of Soils

Reclamation specifications prohibit using soils that would allow the migration or movement of one soil into another. For example, a crushed rock material with all particles in the 19- to 37.5-mm (¾- to 1½-in) size would contain significant voids. If this material were placed next to a fine-grained soil, ground water movement could transport the finer sizes into the voids and cause loss of support for the pipe.

Compatibility of different soil materials can be evaluated using "filter criteria." These criteria establish what soil gradations can be placed next together without migration occurring. Filter criteria can be found in most soil mechanics textbooks or in the Earth Manual.



W = MIN. INSTALLATION WIDTH

PIPE I.D. mm	W in mm
150 or less	600
Over 150 thru 450	O.D. + 500
Over 450	O.D. + 900

PIPE I.D. (INCHES)	*W (FEET)*
6 and less	*2.0*
Over 6 thru 18	$\frac{1}{12}$ *(O.D. + 20)*
Over 18	$\frac{1}{12}$ *(O.D. + 36)*

O.D. = OUTSIDE DIAMETER IN mm (inches) OF PIPE ACTUALLY INSTALLED

CHAPTER 3

TRENCH DIMENSIONS

The trench dimensions, minimum installation width, slope of the trench walls, trench depth, and flexible pipe clearance must always be carefully checked.

Minimum Installation Width

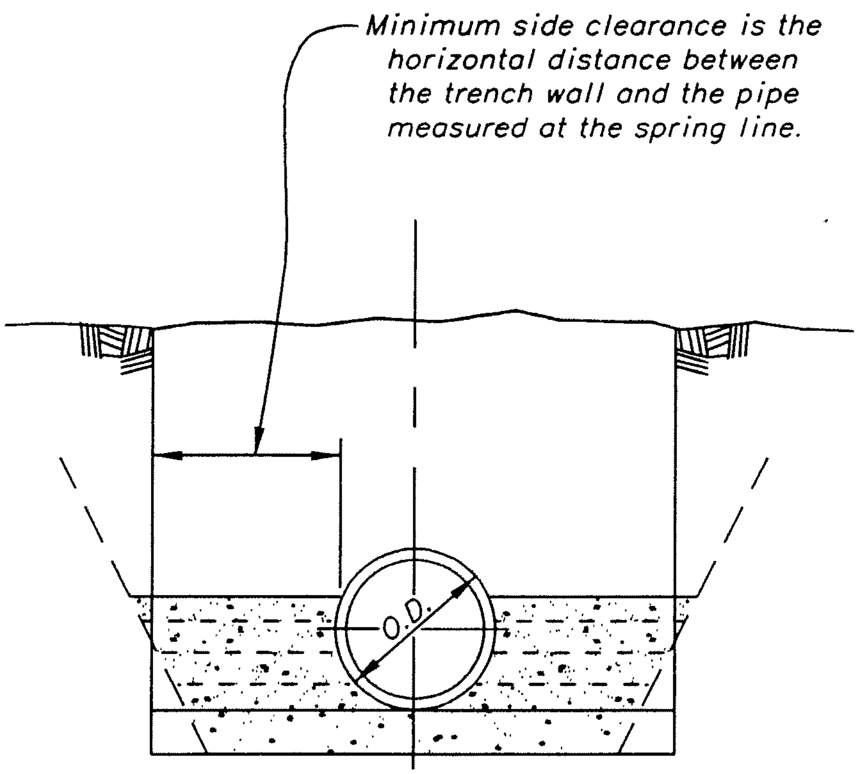
A minimum trench width, W, is specified to ensure a minimum distance between the pipe and the trench wall. There must be enough clearance to allow inspection of the pipe joints, to adequately compact the soil, and to perform field density tests in the embedment. This is particularly critical when the trench walls are vertical. The minimum installation width is measured at the top of the foundation. This is the elevation that is 100 mm (4 in) below the bottom of the pipe if the pipe has a nominal diameter or an (I.D.) between 100 and 1350 mm (4 and 54 in), or the elevation that is 150 mm (6 in) below the bottom of the pipe if the pipe has an I.D. larger than 1350 mm (54 in). The minimum installation width is measured to the nearest 30 mm or 0.1 ft.

Vertical trench walls can be used if the bottom of the trench excavation is less than 1.3 m (4.5 ft) below the ground surface or if the trench walls are shored. Otherwise, the trench wall slope must be a minimum of ¾ to 1 or the angle of repose of the trench wall material, whichever results in the flatter slope. However, State or local regulations may override this requirement. The trench wall slope <u>must</u> begin at the bottom of the excavation, which includes any excavation of the foundation material.

For flexible pipe, the clearance between the pipe at spring line and the trench wall must be checked. Both the clearance and the minimum installation width requirements must be met.

SIDE CLEARANCE TABLE

TRENCH TYPE	MINIMUM SIDE CLEARANCE
1	25 cm FOR 300 to 450 mm I.D. 45 cm FOR OVER 450 mm I.D. (10 INCHES FOR 12" TO 18" I.D.) (18 INCHES FOR OVER 18" I.D.)
2	ONE O.D.
3	TWO O.D.



FLEXIBLE PIPE

Flexible Pipe Clearance

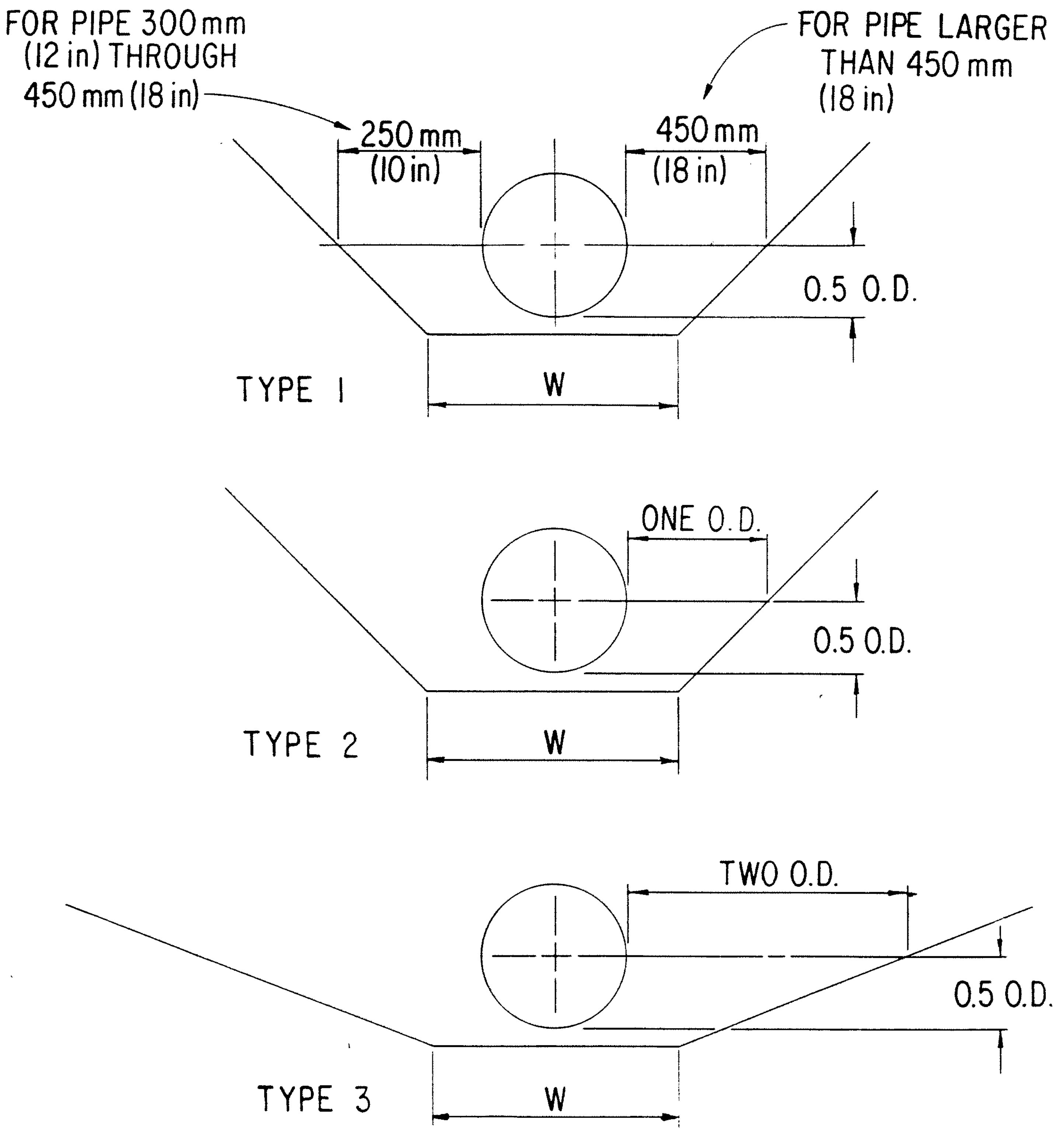
The performance of flexible pipe depends on the stiffness of the soil at the sides of the pipe. This side soil support is a combination of the embedment soil and the trench wall soil. The width of the trench depends on the relative firmness of the embedment and the trench wall material. If the trench walls are firmer than the embedment, the embedment is used to fill the space between the pipe and the trench walls. If the trench walls are soft and easily compressible, most of the resistance to deflection must come from the embedment soil. Accordingly, three types of trenches are specified. Each type requires a different minimum clearance between the pipe and the trench wall measured at the spring line of the pipe.

Trench type 1 is where the trench wall material is stronger or firmer than the compacted embedment. Typical trench wall materials would be rock; materials described as claystone, mudstone, or siltstone; highly cemented soils even though of low density; sands and gravels with inplace relative densities 70 percent or higher; and silty or clayey material with inplace densities 95 percent of Proctor maximum dry density or higher.

Trench type 2 is where the trench wall soil has a strength or firmness equivalent to the compacted embedment. These soils would include silty or clayey material with inplace densities 85 percent of Proctor maximum dry density or higher but less than 95 percent; or cohesionless soils with inplace relative densities between 40 and 70 percent.

Trench type 3 is where the trench walls are much softer than the compacted embedment. Soils falling into this category would be peat or other organic soils, elastic silts (MH), low-density silty or clayey material (below 85 percent of Proctor maximum dry density), or low-density cohesionless soils (below 40 percent relative density).

SLOPING TRENCH WALLS



FLEXIBLE PIPE CLEARANCE

During the investigation for a pipeline, it is important that areas be identified where trench type 2 or 3 may be required. Particular attention should be paid to stream crossings, old lakebeds, loessial deposits, talus slopes, and land fills. If problem areas are encountered along the pipeline during the trench excavation which were not identified during investigation, the contracting officer must be notified immediately.

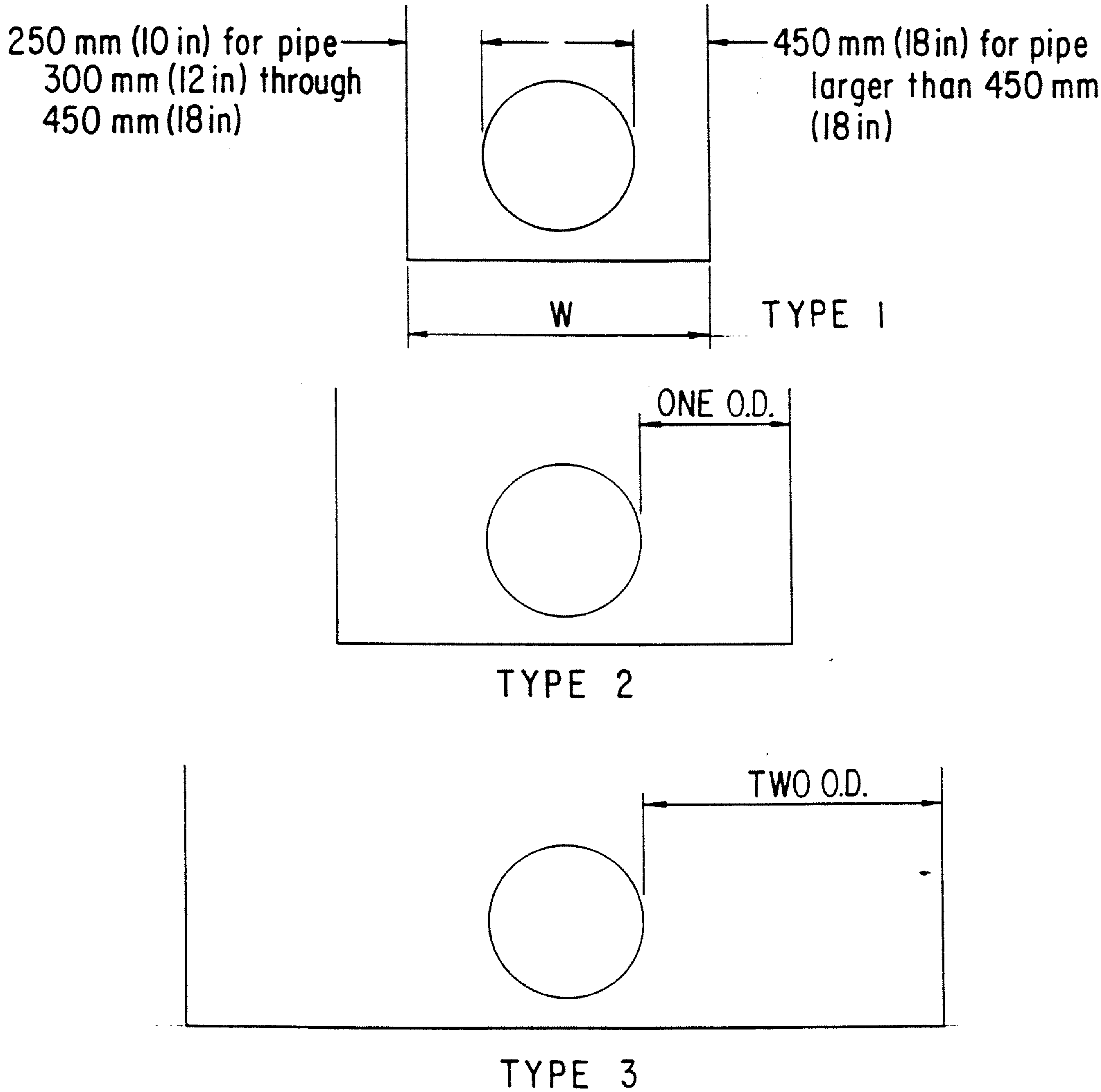
The minimum clearance between the pipe and the trench wall at the spring line of the pipe must be checked and maintained during construction.

For trench type 1, the minimum side clearance, measured at spring line, must be 450 mm (18 in) for pipe over 450 mm in nominal diameter and 250 mm (10 in) for pipe 300 to 450 mm (12 to 18 in) in nominal diameter. For trenches excavated with sloping sides, the minimum installation width ensures that the minimum clearance will be met. The minimum installation width must be checked and maintained.

For trench type 2, the minimum side clearance, measured at spring line, must be one pipe outside diameter on each side of the pipe. For sloping trench walls, this requires either a wider trench bottom width or a slope of about 1½ to 1 (horizontal to vertical) from the trench bottom to the spring line of the pipe if the trench bottom is the minimum width.

For trench type 3, the minimum side clearance, measured at spring line, must be two pipe outside diameters on each side of the pipe, resulting in a total trench width of five pipe diameters at the spring line. This is generally impractical, so in areas that would require trench type 3, either a rigid pipe or a flexible pipe with extra wall thickness (to make a stiffer pipe) may be specified. If unexpected areas of poor trench wall support are encountered, the contracting officer and the Technical Service Center must be notified immediately so proper action may be taken.

SHORED VERTICAL TRENCH WALLS



FLEXIBLE PIPE CLEARANCE

For areas along the pipeline excavation where it is uncertain which trench type may be required, inplace densities and classification of the trench wall materials should be performed and compared with the criteria previously stated for each trench type.

For the compacted embedment, it is essential that the full width of the soil placed between the pipe and the trench walls be compacted.

THE USE OF RELATIVE DENSITY VERSUS
PROCTOR COMPACTION FOR CONSTRUCTION CONTROL

EXAMPLE
FOR SOILS WITH LESS THAN 2 PERCENT PLUS NO. 4 MATERIAL

The method that results in the highest required inplace density (not the highest laboratory maximum density) should be selected for control.

EXAMPLE: The specifications require 95 percent of Proctor maximum dry density or 70 percent relative density. For a questionable soil, the relative density test was run.

Minimum dry density = 83 lb/ft^3
Maximum dry density = 118 lb/ft^3

The Proctor compaction test resulted in a laboratory maximum dry density of 114 lb/ft^3.

The relative density gave the highest maximum dry density.

However, 70 percent relative density is equal to 105 lb/ft^3 and 95 percent of Proctor maximum dry density is equal to 108 lb/ft^3.

Therefore, the Proctor method should be used for construction control since it gives the highest required inplace density.

Note: For illustrative purposes only, the inch-pound system of units is used. Soils containing more than 2 percent plus No. 4 material must be evaluated on a case by case basis.

CHAPTER 4

DENSITY OF COMPACTED SOIL

A certain degree of compaction must be obtained for the soil used as replaced foundation, embedment, and (sometimes) backfill. The density shall be measured at required intervals and locations. The applicable test procedures are presented in appendix A of this manual.

Degree of Compaction

Silty or clayey soils must be compacted to a minimum of 95 percent of the laboratory standard maximum soil dry density (Proctor compaction) as determined in Designation USBR 5500 in the Earth Manual, Third Edition, 1990.

Cohesionless, free-draining material (such as sands and gravels) must be compacted to a minimum of 70 percent relative density as determined by the relative density laboratory tests, Designations USBR 5525, 5530, and 7250 in the Earth Manual.

A field density test, Designation USBR 7205, 7220, 7206, or 7215 in the Earth Manual, is performed to measure the compaction of the inplace material. For silty or clayey soils, the degree of compaction may be determined by the rapid method, Designation USBR 7240 in the Earth Manual.

If in doubt as to which method to use, Proctor compaction or relative density, perform both methods and use the one that results in the highest inplace density in units of kilograms per cubic meter (pounds per cubic foot).

The moisture content of clayey or silty material should generally be between 2 percentage points dry of optimum and 2 percentage points wet of optimum, unless otherwise specified.

Location of Density Tests

1. For rigid pipe 450 to 1350 mm (18 to 54 in) in diameter, the field density test should be performed at the top of the compacted embedment (0.37 O.D.).

2. For rigid pipe greater than 1350 mm (54 in), the field density test should be performed at various elevations within the compacted embedment.

3. For flexible pipe 825 mm (33 in) and smaller, the field density test should be performed at the top of the compacted embedment (0.7 O.D.).

4. For flexible pipe 900 to 1350 mm (36 to 54 in) in diameter, one-half of the field density tests should be performed at the top of the compacted embedment (0.7 O.D.) and one-half at the spring line of the pipe.

5. For flexible pipe greater than 1350 mm (54 in), the field density test should be performed at various elevations within the compacted embedment with at least one-third of the tests performed at the spring line elevation.

6. The location of the density tests should vary in distance from the pipe and roughly one-half the tests should be performed on each side of the pipe.

Frequency of Density Tests

1. For the first 1.5 kilometers or 1 mile of the pipelaying operation by each compaction crew, a minimum of one field density test per lift should be performed for each 150 linear meters or 500 linear feet of pipe placed, or at least one test per shift for each crew.

2. For the remainder of the pipelaying operation by each compaction crew, a minimum of one field density test per lift should be performed for each 300 linear meters or 1000 linear feet of pipe placed, or at least one test per shift for each crew.

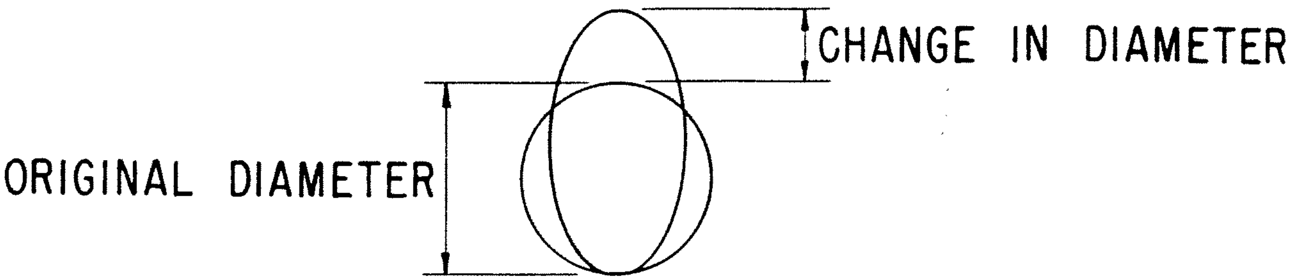
3. For compacted backfill over the pipe, such as at road crossings, one test is required for each 150 m^3 (200 yd^3) placed.

4. Additional density tests may be necessary in critical areas or when difficulty arises in obtaining the required compaction.

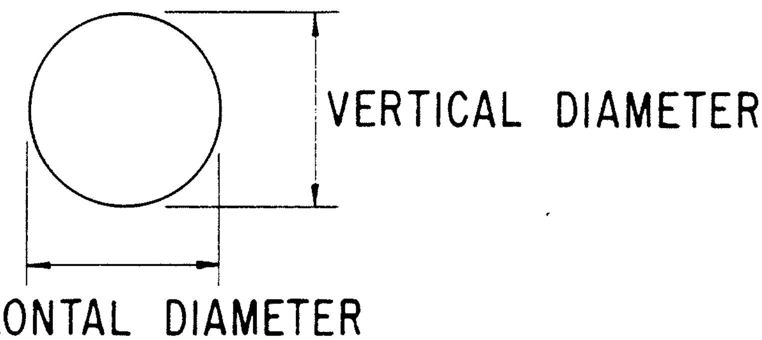
Reporting Field Densities

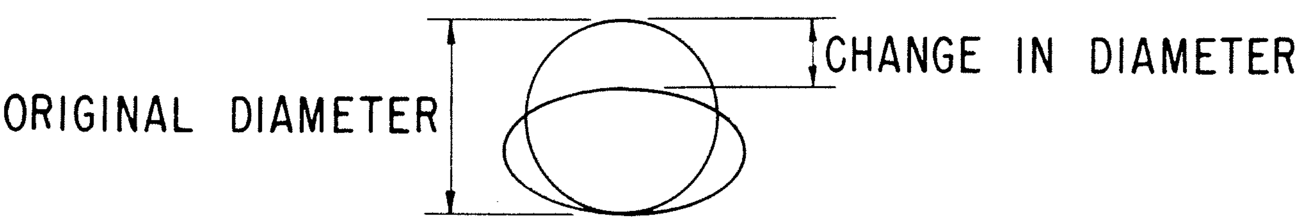
For the monthly L-29 construction report, the location of the field density tests should be reported in the remarks column as:

Top of 0.37 (or 0.7) embedment
Spring line
Pipe haunch (density in test pit)
Vertical distance from top of pipe if not at one of above locations



ELONGATION





DEFLECTION

CHAPTER 5

ELONGATION AND DEFLECTION OF BURIED FLEXIBLE PIPE

Flexible pipe can elongate (increase in the vertical diameter) due to compacting the embedment soil alongside the pipe and can deflect (decrease in the vertical diameter) due to the backfill load over the pipe.

<u>Elongation</u>. - For steel pipe with shop-applied cement mortar lining and/or coating, the elongation should not be more than 3 percent. For pretensioned concrete cylinder (PT) pipe, the allowable elongation is D/40 where D is the pipe inside diameter in inches (e.g., for 60-inch PT pipe, allowable elongation is D/40 = 60/40 = 1.5 percent). Other flexible pipe should not be elongated more than 5 percent. Excessive elongation might cause structural damage which could result in failure of the pipe.

<u>Deflection</u>. - Measuring the pipe deflection is an indirect way to check the adequacy of the compaction of the embedment soil. The initial deflection is the deflection immediately after backfilling is completed. The final deflection (the deflection after many years) can be 1.5 to 2.0 times the initial deflection. Excessive initial deflection can result in failure either of the pipe or of its coating or lining. The allowable <u>initial</u> deflections for flexible pipe are:

Factory cement-mortar-coated and/or cement-mortar-lined steel pipe	2 percent
Flexible lined and coated steel pipe	3 percent
Fiberglass pipe	3 percent
Ductile iron pipe	2 percent
PVC pipe	4 percent
Corrugated metal pipe	3 percent

Flexible pipe with a cover of 6 meters (or 20 feet) or less with the embedment compacted to either 70 percent relative density or 95 percent of Proctor maximum dry density will have an initial deflection of 2 percent or less.

Month JAN Year 1980 Page 1 of 4

MEASURED PIPE DEFLECTIONS

Project BIG TEWDUE Feature LAYUM AQUEDUCT Spec. No. ____

Type of Pipe STEEL, cement lined & coated Length of Pipe Unit 20 ft

How Diameters Measured steel tape measure

Station	Pipe class	Depth of cover (ft.)	Dia. V or H	ORIGINAL DIAMETER			ELONGATION				DEFLECTION				NET CHANGE (Net deflect)
				Diameter (inches)	Date	Read by	Diameter (inches)	Date	Read by	Percent elongation	Diameter (inches)	Date	Read by	Percent deflection	
				1			2			(1 - 2)/1 x 100	3			(2 - 3)/1 x 100	(1 - 3)/1 x 100
122+80	48B150	9.5	V	48 1/16	1-18	alh	48 1/4	1-22	alh	- 0.4	47 1/2	2-22	alh	+ 1.6	+ 1.2
132+05	48C150	13.0	V	48	1-20	alh	48 3/16	1-29	alh	- 0.4	47 9/16	3-1	alh	+ 1.3	+0.9
			H	48 1/8	1-20	alh	47 15/16	1-29	alh	+0.4	48 7/16	3-1	alh	- 1.0	-0.7

NON-STRUTTED PIPE

EXAMPLE

For pretensioned concrete cylinder pipe, the allowable deflection is D/40 where D is the pipe inside diameter in inches (e.g. for 48-inch PT pipe, allowable deflection is D/40 = 48/40 = 1.2 percent).

Elongations and deflections should be determined by measuring the pipe inside diameter during construction for flexible pipe 900 mm (36 in) in diameter and larger. The following equation is used:

$$\text{Percent deflection or elongation} = \frac{\text{change in diameter}}{\text{original diameter}} \times 100$$

The vertical deflection measurement should be compared to the allowable limits. Horizontal deflections should also be determined once for every tenth location of vertical deflection measurement.

The pipe must be marked at the points (both longitudinally and circumferentially) where the diameters are to be measured. The station number should be written on the pipe at the locations where readings are taken.

The diameters are measured and recorded to the nearest 2 mm ($^1/_{16}$ in or 0.05 in).

The measurements and calculations should be recorded on the appropriate form (see example) and submitted as part of the monthly Construction Report (L-29). A blank form is shown on the next page that may be copied and used.

The procedures for determining elongation and deflection are different for strutted and nonstrutted pipe.

Elongation and Deflection of Nonstrutted Pipe

For nonstrutted pipe, the points for diameter measurements should be marked on the pipe and the diameters measured after the pipe has been laid in the trench but before

Month ________ Year ________

Page ___ of ___

MEASURED PIPE DEFLECTIONS

Project ____________________ Feature ____________________ Spec. No. ____________

Type of Pipe ____________________ Length of Pipe Unit ____________

How Diameters Measured ____

Station	Pipe class	Depth of cover (ft.)	Dia. V or H	ORIGINAL DIAMETER			ELONGATION				DEFLECTION				NET CHANGE (Net deflect)
				Diameter (inches)	Date	Read by	Diameter (inches)	Date	Read by	Percent elongation	Diameter (inches)	Date	Read by	Percent deflection	
				1			2			$\frac{1-2}{1} \times 100$	3			$\frac{2-3}{1} \times 100$	$\frac{1-3}{1} \times 100$

any embedment operation begins. These diameter measurements are used as the "original diameter."

To determine the elongation, the diameters must again be measured and recorded following completion of the embedment operation (compacted up to 0.7 O.D.) and before any backfilling over the pipe is begun. The change in diameter needed to calculate the percent elongation is the original diameter minus the diameter measured at the completion of placing the embedment. A minus sign for the vertical change (plus for horizontal) indicates the pipe has been elongated.

To determine the deflection due to backfilling, the diameters are measured when the backfilling operation is complete (full depth of cover over pipe). These measurements must be made within 2 weeks (preferably within 1 or 2 days) after completion of the backfilling. The change in diameter to calculate deflection due to backfilling is the diameter measured at 0.7 O.D. embedment minus the diameter measurement following completion of backfilling. A plus value for the vertical change (minus for horizontal) indicates a decrease in vertical diameter due to backfilling.

The net deflection must also be calculated and compared to allowable values to determine the potential for structural damage to the pipe or damage to the coating or lining. The change in diameter for the net deflection is the original diameter minus the diameter measured after completion of the backfill. A negative value for the vertical change (plus for horizontal) indicates the deflection was less than the elongation and the pipe has not yet returned to its original diameter. This frequently occurs for pipe with low earth cover.

Even though the net deflection is compared to allowable values, the deflection due to backfilling must be measured. The deflection due to backfilling is the value that changes with time. Therefore, the deflection due to backfilling is required to predict what the net deflection value will be in 5 or 10 years.

Month MARCH Year 1981

MEASURED PIPE DEFLECTIONS

Project ______ Feature CLEARWATER CONDUIT Spec. No. ______

Type of Pipe pretensioned concrete cylinder (PT) Length of Pipe Unit 40 ft

How Diameters Measured telescoping metal tubing with piece of metal tape mounted on end

Station	Pipe class	Depth of cover (ft.)	Dia. V or H	ORIGINAL DIAMETER			ELONGATION				DEFLECTION				NET CHANGE (Net deflect)
				Diameter (inches)	Date	Read by	Diameter (inches)	Date	Read by	Percent elongation	Diameter (inches)	Date	Read by	Percent deflection	
				1			2			$\frac{1-2}{1} \times 100$	3			$\frac{2-3}{1} \times 100$	$\frac{1-3}{1} \times 100$
122+00	60D200	18.5	V	60 1/16	2-12	AKH					58 3/4	3-27	AKH		+ 2.2
158+75	60B150	8.0	V	60	2-14	AKH					59	3-28	AKH		+ 1.7
			H	60 3/8	2-14	AKH					61 1/8	3-28	AKH		– 1.2

STRUTTED PIPE

EXAMPLE

Elongation and Deflection of Strutted Pipe

The procedure for determining the elongation and deflection of strutted pipe is different because of the physical difficulties in obtaining measurements with the struts in place.

The original diameters should be measured after the pipe is laid but before any embedment operation begins. The specifications generally require the circularity of the pipe to be maintained (within ±1 percent of the nominal diameter) before and after laying the pipe in the trench. The contractor should check the circularity and adjust the struts, if necessary, after the pipe has been laid in the trench. The Reclamation inspector should also check the circularity. At this time, marks for diameter measurements could be established and the diameters measured for the deflection measurements. These diameter measurements would then serve as the "original diameter" values.

The specifications state that struts must stay in place until the embedment is compacted up to 0.7 O.D. If the struts are removed at this time, the procedure would be the same as described for nonstrutted pipe.

However, the contractor generally leaves the struts in place until after the backfilling is complete. In this case, the diameters are only measured after the struts are removed (within 2 weeks) and the net deflection calculated. The change in diameter to calculate the net deflection is the original diameter minus the diameter measured after the struts are removed.

If the elongation and the deflection due to backfilling are not determined by measurement, the pipe must be monitored visually. This requires an examination following compaction of the embedment and following backfilling before the struts are removed. Visually, the elongation and deflection can be monitored by looking for struts that may be loose, bent, broken, or crushed. If an elongation or deflection of more than 2 percent is apparent, the diameters must be measured and recorded.

Location

As a check on the adequacy of the compaction of the embedment, the vertical diameter must be measured at the vertical centerline of the pipe, and the horizontal diameter measured at the horizontal centerline of the pipe. The diameters should be measured at the midspan of the pipe sections. Markings should be made at the measurement points so subsequent readings can be made at the identical location, both longitudinally and circumferentially.

If the pipe shape is not symmetrical about the centerlines, the diameter measurements must still be made at the vertical and horizontal centerlines. If diameter changes other than the vertical and horizontal diameters seem excessive, they should be measured and compared with the allowable elongations and deflections.

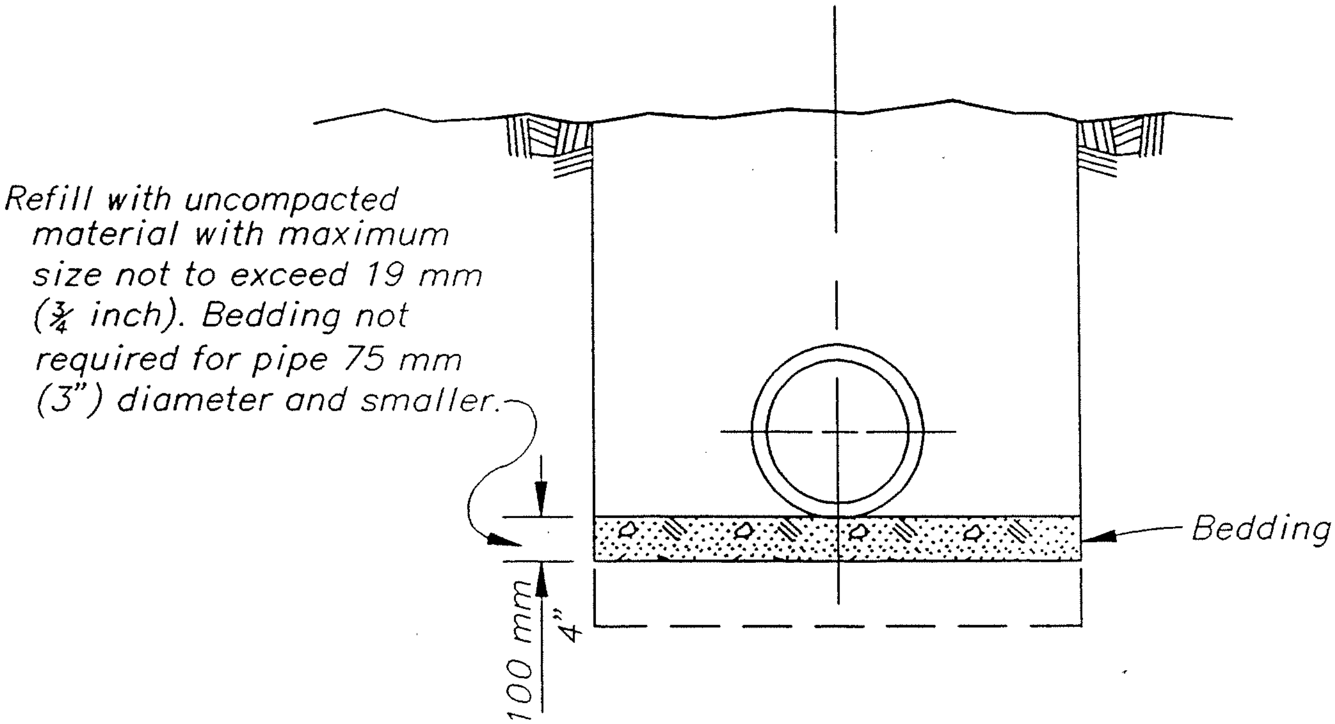
Frequency of Deflection Measurements

1. For the first 1.5 kilometers or 1 mile of the pipelaying operation by each compaction crew, the vertical elongation of the pipe due to compacting the embedment to 0.7 O.D. and the deflection due to backfilling over the pipe should be measured a minimum of once every 60 linear meters (200 linear feet). Some of the deflection measurements should be located opposite the location of accepted field density tests to establish a correlation between the embedment density and the pipe deflection.

2. For the remainder of the pipelaying operation by each compaction crew, the vertical elongation of the pipe due to compacting the embedment to 0.7 O.D. and the deflection due to backfilling over the pipe should be measured a minimum of once every 150 linear meters (500 linear feet).

3. Horizontal diameters should be measured once for every tenth location of vertical diameter measurements.

4. Additional deflection measurements should be made if the net deflection readings are close to 2 percent, where visual observation indicates excessive deflection, at road crossings, or where equipment crossings occur during construction.



PIPE 250 mm (10-INCH) DIAMETER AND SMALLER

PVC
STEEL
DUCTILE IRON

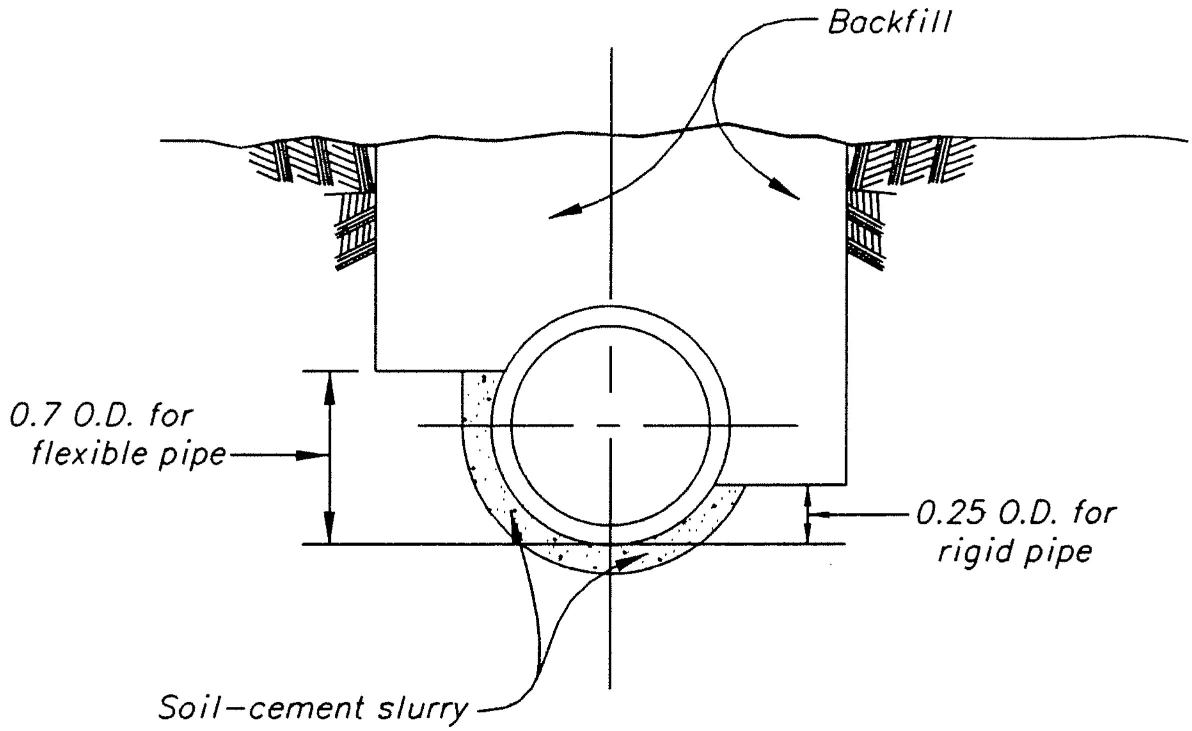
CHAPTER 6

INSTALLATION OF 250-MM (10-IN) AND SMALLER PIPE

Pipes smaller than 250 mm (10 in) in diameter are generally strong enough to support the mass of the backfill without any special soil support. Compacted soil is used around these pipes only on the outside of horizontal curves or where the pipe crosses under a roadway, another conduit, a canal, a ditch, or a structure. Previous comments on the adequacy of the foundation, however, still pertain to these pipes. The basic requirement for pipe 250 mm and smaller is the suitability of the foundation. Continuous, uniform support under the pipe prevents unequal settlement of the pipeline.

A bedding of 100 mm (4 in) of uncompacted material with a maximum particle size of 19 mm (¾ in) is required. The soil does not have to be the select material required for pipe 300 mm (12 in) and larger, but peat or other organic material must not be used. The uncompacted material can be imported and placed over the foundation or the material in the bottom of the trench can be loosened to a depth of 100 mm (4 in) by scarifying, if the inplace material is suitable. If loosened, the 100-mm thickness should be continually monitored and checked to be sure the pipe will not be laid on any shallow or unloosened areas that would be a hard spot.

The uncompacted bedding is not required for pipe 75 mm (3 in) and smaller.



SOIL–CEMENT TRENCH DETAILS

CHAPTER 7

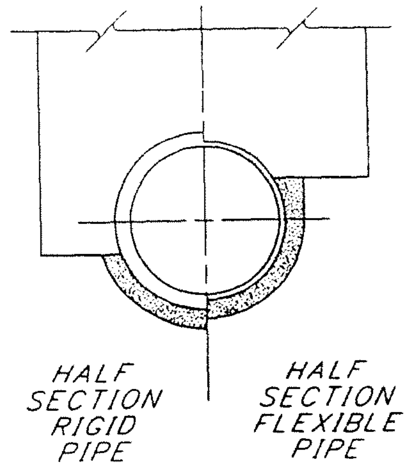
SOIL-CEMENT SLURRY

Soil-cement slurry is an optional method of installing pipe. The excavation of the trench and the installation of the pipe are completely different than the standard installation. For the soil-cement slurry construction, the bottom of the trench is excavated to a semicircular section about 150 mm (6 in) greater in diameter than the outside pipe diameter.

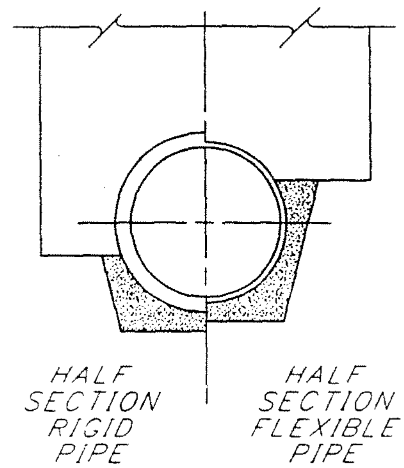
The soil-cement slurry is used to fill the gap between the pipe and the excavated trench and is only used to ensure complete contact between the pipe and the soil. The soil-cement transfers the load from the pipe to the in situ material; therefore, the native soil must be able to provide the necessary support for the pipe. This is particularly important for flexible pipe since the design of the pipe is based on the stiffness (or strength) of the soil at the sides of the pipe. The stiffness of the native soil may be different from the stiffness of an embedment using the select material. This must be considered in the design of pipe when soil-cement slurry is used as an option. If an area along the trench excavation is encountered of less stiffness than indicated on the drawings (for example, trench type 3 instead of trench type 1), the Technical Service Center must be consulted to see if soil-cement may be used. Soil-cement slurry may always be used for rigid or flexible pipe when in situ soils have been designated as trench type 1 or 2. The only exception would be when voids in the native soils might be so extensive that the slurry would drain away.

Trial mixes are usually tested before construction to determine the adequacy of the ingredients and the mixture.

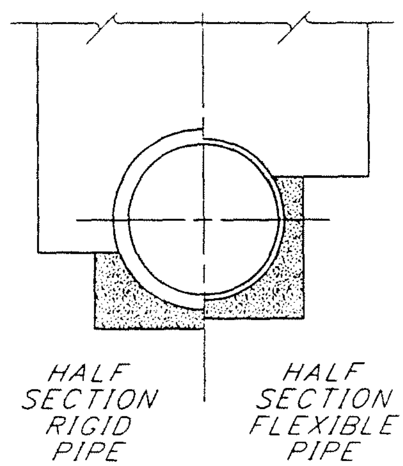
Soil-cement has been used by Reclamation since the early 1960's and has been used successfully for both rigid and flexible pipe from 300-mm (12-inch) diameter to 2400-mm (96-inch) diameter.



ALTERNATE A



ALTERNATE B



ALTERNATE C

ACCEPTABLE TRENCH BOTTOMS

FOR SOIL-CEMENT SLURRY

Excavation of trench

Typically, the trench is excavated to an elevation equal to 0.25 (rigid pipe) or 0.7 (flexible pipe) of the outside diameter of the pipe and then a circular shape is excavated, using a trenching machine or a specially shaped backhoe bucket, so that the excavated shape is about 150 mm (6 in) larger in diameter than the outside diameter of the pipe. This results in a 3-inch space between the pipe and the soil. The contractor may elect to use a rectangular or trapezoidal shape rather than the circular shape. While these shaped cuts require more soil-cement slurry to fill, the cost of fabricating special circular backhoe buckets is avoided, particularly when the pipeline consists of several different pipe diameters or when only a short reach of pipe is being constructed.

Materials

Any material and mix design can be used for the soil-cement slurry as long as two basic requirements are met:

1. The mixture is of a consistency such that it completely fills the space between the pipe and the in situ soil, and;

2. The hardened mixture has an unconfined compressive strength of at least 700 kPa (100-lb/in^2) but not more than 1400 kPa (200-lb/in^2) at 7 days.

Soil-cement slurry is typically a combination of soil, portland cement, and water. However, cementitious fly ash may be substituted for the cement, pozzolans may be added to reduce the amount of cement, and the consistency may range from a thick liquid to a high-slump material. If the soil-cement slurry is to be pumped, bentonite may be added to improve the flow characteristics of the slurry through the delivery hose. The most suitable soil to use is a silty sand with a fines content not exceeding about 30 percent. This allows use of native soils from the trench excavation or from the general area. The fines must be nonplastic or have a low plasticity. Clean concrete sands have often been used when the soil-cement was obtained from local ready-mix plants. Bleeding can occur when clean concrete sands are used and vibration is often necessary to keep the mixture in suspension as it is placed in the space between the pipe and the soil and to ensure that it flows completely around the pipe. The presence of fines can prevent the bleeding, result in higher compressive strengths, and reduce the need for vibration. The allowable maximum particle size is related to the annular space between the pipe and the in situ soil and must be small enough to prevent bridging as the mixture is poured into the space. The maximum particle size should not exceed ⅛ of the open distance between the pipe and the trench wall or 37.5 mm (1½ in), whichever is less. For the minimum 75-mm (3-in) gap, the maximum particle size should not exceed 9.5 mm (⅜ in). With a larger gap, the maximum particle size can increase as long as the larger particles stay in suspension. The soil used in the slurry must not contain organic impurities that would affect strength and the time of set. Any large clay balls in the sands must be removed because they do not become penetrated by cement and they become points of weakness in the hardened mixture. The maximum percentage of clay balls, on a wet mass basis, shall not exceed 10 percent. The maximum size of clay balls shall not exceed 13 mm (½ in) to prevent bridging of materials in small areas.

The cement shall meet the requirements for cement used in concrete as described in the specifications. Pozzolans, particularly fly ash, may be added to reduce the cement content to save costs. The cement content will typically be 5 to 10 percent by dry mass of soil (about one to three sacks per cubic yard). Cementitious fly ashes (type C) may be used in place of cement as long as the strength requirements are met. Fly ash sources can be extremely variable and close monitoring of the properties of the fly ash used may be required.

The water shall meet the requirements for water used in concrete as described in the specifications. In most cases, the mixture has the consistency of a thick liquid so that it flows readily into openings and fills any voids. Typically, the water-cement ratio is between 2 and 3. The water-cement ratio should not exceed 3.5. For installation on slopes or when pipe may be installed one section at a time (when a trench shield is used), a fluid consistency is not appropriate and the mixture should be placed with a slump of about 250 mm (10 in) to keep the slurry in place. Bleeding and keeping all the soil particles in suspension is not a problem with this consistency, although vibration will probably be required to work the material into complete contact with the pipe and the soil.

Mixing

Any method of mixing the materials can be used as long as the soil-cement slurry has a uniform consistency and appearance just before placement. If material excavated from the trench is used in the soil-cement, a trench-side traveling batch plant or a portable batch plant close to the site can be used. If a town is nearby, most contractors elect to obtain the soil-cement from a commercial ready-mix plant. Conventional concrete sand can be used in the batching operation.

Placement

In most cases, the pipe is laid on two soil pads (or sand bags) leveled to the proper grade. The soil-cement slurry is then placed under the pipe from one side until it appears on the other side. Soil-cement slurry is next added to both sides until the space between the pipe and the in situ soil is filled. Rodding or vibration may be needed to keep the soil particles in suspension so the material flows easily. Soil-cement slurry has the potential to float the pipe under the right circumstances. To prevent this, the soil-cement may need to be placed in two stages. The first placement should reach initial set before the remainder is placed.

Backfill should not be placed over the soil-cement until the soil-cement has reached its initial set. Since moisture is beneficial to curing of the soil-cement slurry, a 150-mm (6-in) cover of moist earth shall be placed over the soil-cement if the backfill is not to be placed over the soil-cement within 8 hours after placement. If the air temperature is 50 °F or less, the moist earth cover should be at least 450 mm (18 in) thick. Since hydration (hardening) of the soil-cement slurry would cease below 42 °F, soil-cement is not to be placed when the air temperature is below 40 °F unless the temperature is 35 °F or more and the temperature is rising. The soil-cement slurry must be protected from freezing. The soil-cement slurry is not to be placed when the trench bottom or walls are frozen or contain frozen materials. Before the initial set, an insulation blanket should be used, and after the initial set, an earth cover can be used.

Inspection

The placement of the soil-cement should be carefully monitored to see that the slurry is completely filling the gap between the pipe and the in situ soil. Vibration may be required to keep all the soil particles in suspension so the slurry will flow into all openings. Bleeding of water on the upper surface of the soil-cement is not a problem and neither is small surface cracking. The backfill (or a moist earth covering) must be placed over the soil-cement within 8 hours after placement. In the initial stages of a soil-cement slurry operation, it is recommended that a test pit be excavated to examine the soil-cement to see that all spaces were filled and that there is no shrinkage between the pipe and soil-cement or the soil and the soil-cement. A few chunks of soil-cement should be broken off to see if the hardened mixture is uniform and to see if segregation of particles has occurred.

02/22/1996

U.S. Bureau of Reclamation

Page 1

SUMMARY OF LABORATORY TESTS - SOIL-CEMENT SLURRY

PROJECT: Judge Roy Bean Reservior

SPECIFICATION NO: LWP-1870

PERIOD OF REPORT: 12/20/1995 - 01/10/1996

FEATURE: Pumping Plant

FILL NAME: PB - Pipe Backfill

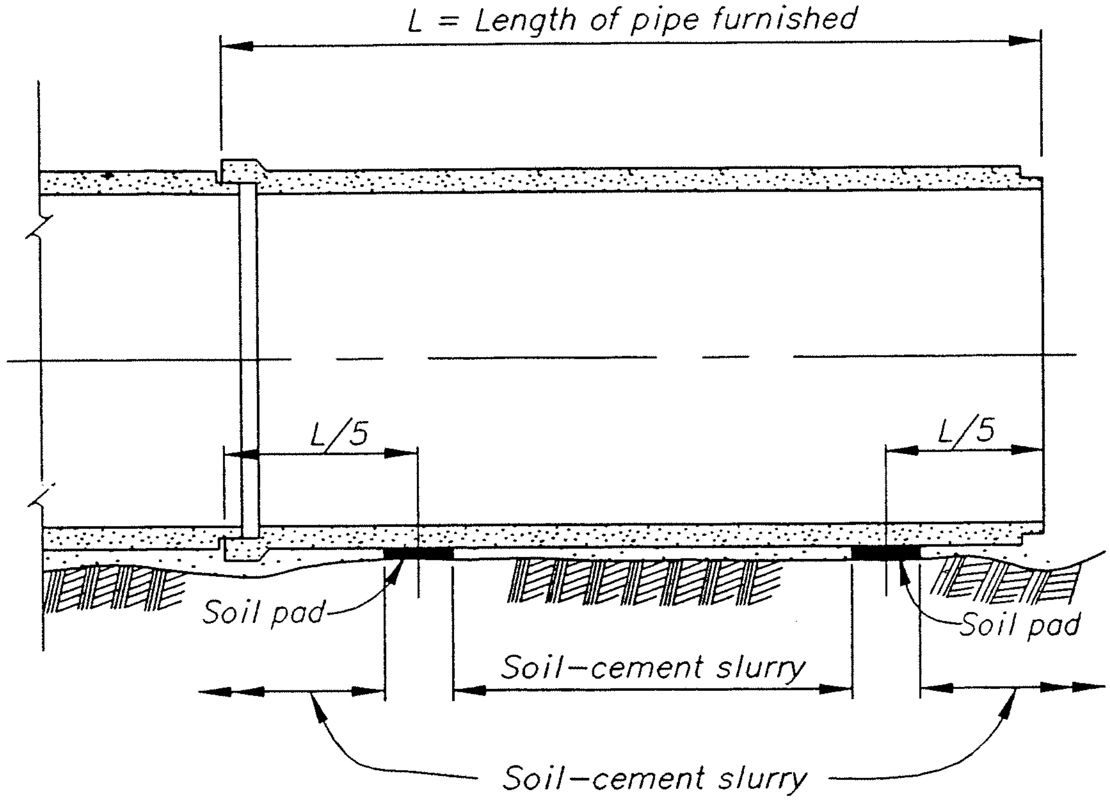
NUMBER (MONTH DAY SHIFT NUMBER)	BORROW	PAY	LOCATION START STATION	STOP STATION	OFF SET	STRUCTURE	GRADATION % PASSING 1 1/2	#4	#200	VISUAL SOIL CLASS	SPEC GRAV	BATCHED (LBS/CU YD) BATCHED (CUYD)	WATER	CEMENT	SOIL	W/C RATIO	PLACED PLACED (CUYD)	TOTAL CEMENT (LBS)	CEM (%)	PLACE TEMP (F)	COMPRESSIVE STRENGTH 7-DAY (PSI)	7-DAY (PSI)	REMARKS
12-20-A-01	AG	Y	3+29	3+10	RT	R.C.P. Culvert	100.0	97.1	2.9	SP	2.61	32.0	575	250	2734	2.30	32.0	8000	9.1	55.0	123	118	
12-21-A-01	AG	Y	3+10	3+00	L&R	C.M.P. Culvert	100.0	95.0	5.0	SP-SM	2.61	8.0	559	250	2734	2.24	8.0	2000	9.1	53.0	132	125	
12-23-A-01	AG	Y	3+00	2+94	LT	42" RCP	100.0	96.3	3.7	SP	2.61	8.0	560	250	2734	2.24	8.0	2000	9.1	55.0	105	135	
12-27-A-01	AG	Y	2+94	2+87	RT	42" RCP	100.0	93.9	6.1	SP-SM	2.61	16.0	610	250	2734	2.44	16.0	4000	9.1	59.0	96	112	
12-28-A-01	AG	Y	2+44	2+20	LT	42" RCP	100.0	96.1	3.9	SP	2.61	8.0	560	250	2734	2.24	8.0	2000	9.1	58.0	126	134	Road Crossing
12-29-A-01	AG	Y	2+20	2+00	L&R	42" RCP	100.0	96.4	3.6	SP	2.61	10.0	565	250	2734	2.26	10.0	2500	9.1	56.0	106	113	Drain Crossing
01-04-A-01	AG	Y	1+45	1+15	R&L	42" RCP	100.0	97.1	2.9	SP	2.61	32.0	595	250	2734	2.38	32.0	8000	9.1	60.0	93	107	
01-06-A-01	AG	Y	1+15	1+00	R&L	42" RCP	100.0	95.1	4.9	SP	2.61	14.0	580	250	2734	2.32	14.0	3500	9.1	55.0	117	134	
01-10-A-01	AG	Y	1+25	1+28	26R	13-15 Line/B-D Line	100.0	95.4	4.6	SP	2.61	15.0	587	250	2734	2.35	15.0	3750	9.1	62.0	121	121	Drain/Ejector
						AVG.	100.0	95.8	4.2		2.61	15.9	577	250	2734	2.31	15.9	3972	9.1	57.0	118		
						S.D.	0.0	1.1	1.1		0.00	9.6	18	0	0	0.07	9.6	2412	0.0	2.9	13		
						C.O.V.	0.0	1.1	25.4		0.00	60.7	3	0	0	3.09	60.7	61	0.0	5.1	11		

	Placed (Cu/Yd)	Cement Placed (Lbs)
NONPAY TOTALS:	0.0	0
PAY TOTALS:	143.0	35,750

Testing

A minimum of two 150- by 300-mm (6- by 12-in) compressive strength cylinders should be prepared to represent each sampled batch. In the initial stages, preparation of three cylinders is recommended to obtain representative data. The preparation and testing of the soil-cement slurry cylinders is to be performed in accordance with USBR 5807, "Preparing and Testing Soil Cement Slurry Test Cylinders," or ASTM D 4832, "Standard Test Method for Preparation and Testing of Soil Cement Slurry Test Cylinders." The compressive strength is to be determined at least once for every 150 linear meters (500 linear feet) of pipe placed, or at least twice per shift. The testing frequency should be increased in the initial stages and maintained until routine construction procedures and consistent test results are established.

The compressive strength tests are performed to check the adequacy and uniformity of the mixes. The soil-cement must have sufficient compressive strength to transfer the load directly from the pipe to the in situ soil. The minimum value of 100 lb/in^2 at 7 days for compressive strength has a built-in safety factor, since results are not available until 7 days. If strengths start falling below 700 kPa (100 lb/in^2), the soil-cement is still adequate but changes must be made to the mix to meet the minimum strength requirements. The compressive strength values should not be higher than 1400 kPa (200 lb/in^2). Higher strengths serve no purpose and mean an unnecessary amount of cement is being used. A low strength material would also be easier to remove if the pipe had to be repaired or replaced. Test results are to be reported in the monthly Construction Report (L-29). The example on the opposite page is from Reclamation's earthwork control program, PCEARTH.


L = Length of pipe furnished
L/5
L/5
Soil pad
Soil pad
Soil–cement slurry
Soil–cement slurry

SOIL PADS

Soil Pads

Soil pads are used to provide a space between the pipe and the trench bottom so the soil-cement slurry will flow under the pipe.

It is important that the soil-cement slurry flows completely beneath the pipe to ensure that all voids are filled and that the soil-cement is in complete contact with the pipe.

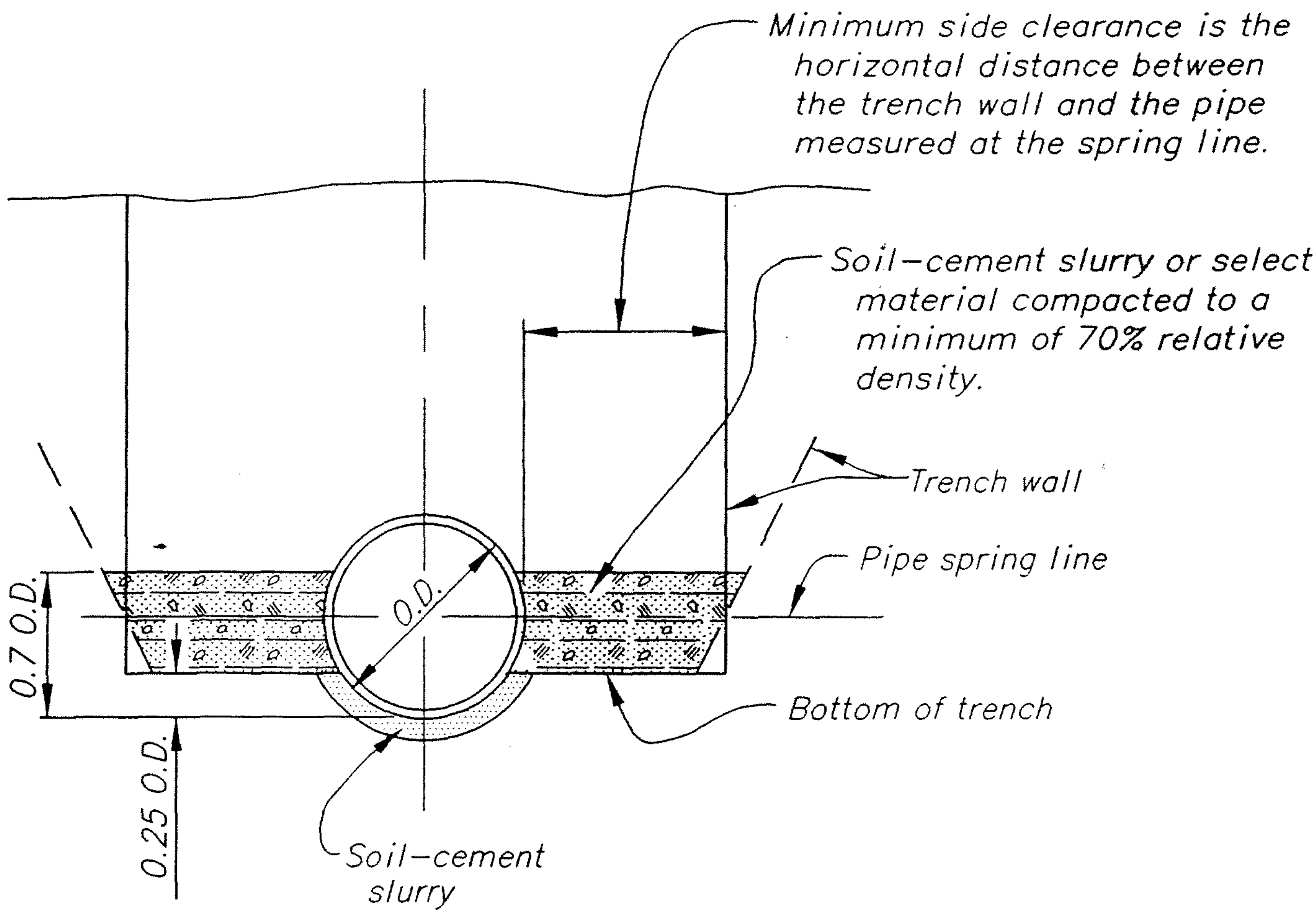
The soil pads can be of any material that will be "weaker" or of less stiffness than the cured soil-cement. This is necessary to avoid having two hard spots beneath the pipe which may result in concentrated point loads.

The soil may be loose or compacted. Sand bags have been used effectively. Compacted soil is convenient in that the pipeline grade is easier to maintain than with uncompacted soil. In wide trenches, stability of the pipe may be a problem and must be considered.

When the pipe is on slopes greater than 0.3, or for pipe 3050 mm (120 in) in diameter and larger, the pipe is laid on the trench bottom without soil pads. For these cases it is important that visual inspection verify that the soil-cement is filling all spaces around the pipe. The trench width or the space between the pipe and the soil, or both, may have to be increased to allow for visual observation. When the pipe is laid directly on the bottom, the contractor must submit the trench dimensions for approval.

Soil pads are located at a distance of L/5 from the ends of the pipe, where L is the pipe length. The length of the soil pad is related to the pipe diameter as follows:

Pipe Diameter	Length of Soil Pad
300 to 675 mm (12 to 27 in)	0.05 L (L = length of pipe)
750 to 1650 mm (30 to 66 in)	0.10 L
1800 to 2850 mm (72 to 114 in)	0.15 L



TRENCH TYPE 2
MAY BE USED FOR TRENCH TYPE 1

SIDE CLEARANCE TABLE

TRENCH TYPE	MINIMUM SIDE CLEARANCE
1	30 cm (12 inches)
2	ONE O.D.

For location of Trench Types, see Specifications.

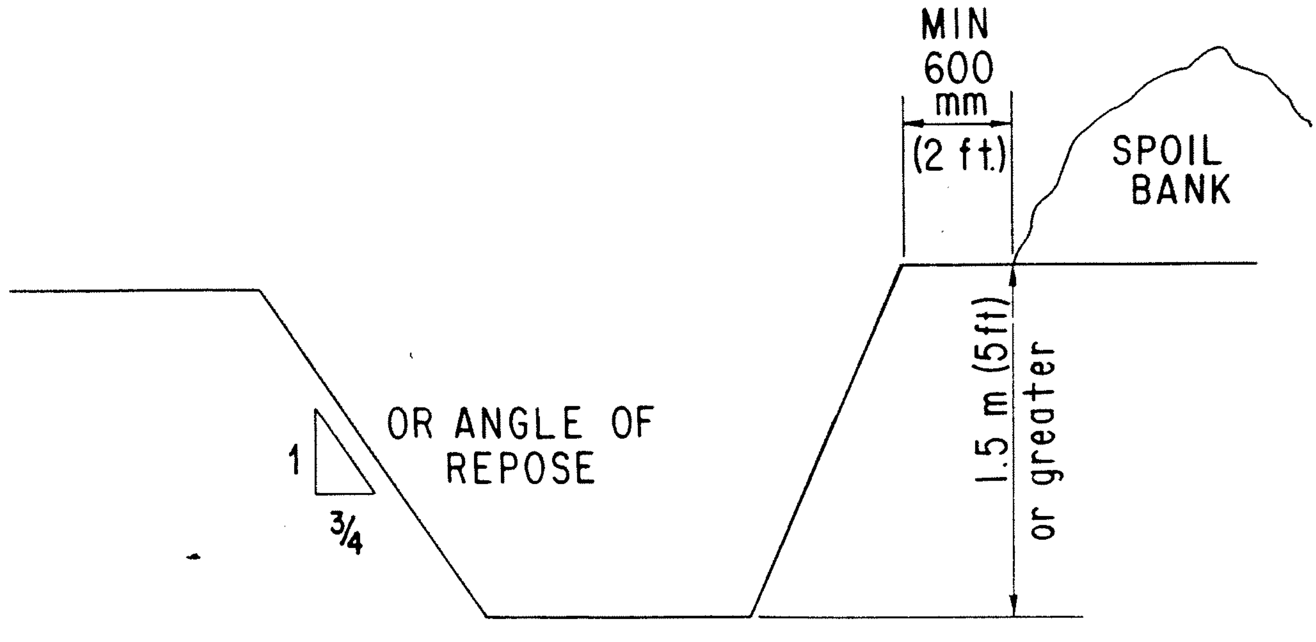
USE OF SOIL−CEMENT SLURRY FOR TRENCH TYPE 2

Trench Type 2 Construction

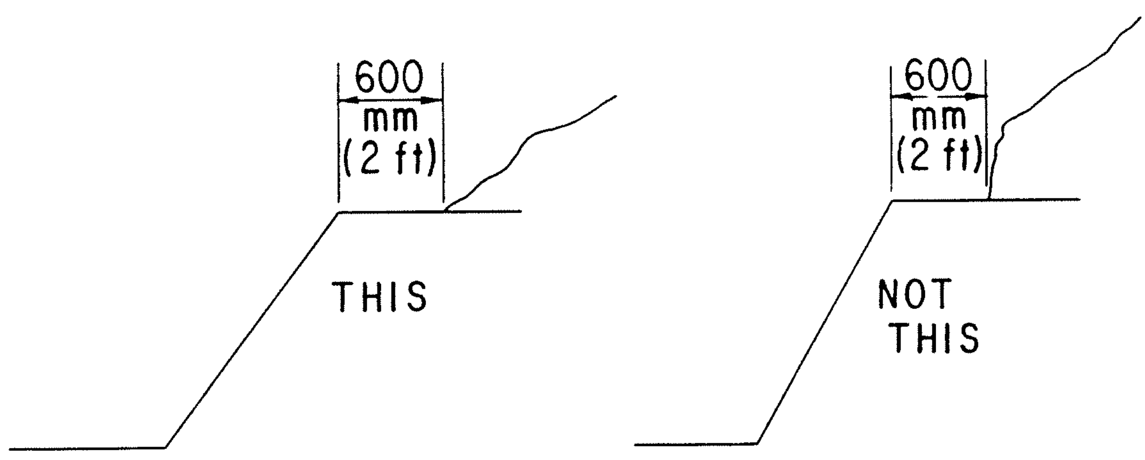
As discussed in chapter 3, if the in situ soil has been designated as trench type 2, at least one diameter of compacted select material must be constructed beside the pipe. Trench type 2 material does not provide enough side support to allow construction using the soil-cement slurry with the 3-inch annular space. However, the soil-cement slurry can be used in the haunch area of the pipe and select material used for embedment above the haunch area. A circular (or trapezoidal, etc.) shape can be excavated so the soil-cement would be in the haunch from 0.25 of the outside diameter and below. This saves some excavation and eliminates compacting the select material into the haunch area.
The select material can be placed after the slurry has initially set and must be compacted to 70 percent relative density.

The select material that can be used in the trench type 2 section is slightly different than the select material used in the standard installation. In the standard installation, the select material has a maximum particle limit of ¾ inch and a limit of 5 percent fines so it can be easily compacted by saturation and vibration into the haunch area of the pipe. With the soil-cement slurry installation, the trench type 2 uses the soil-cement slurry in the haunch area. The requirements for the select material can be different. A clean, coarse-grained material is still required to provide the necessary soil resistance at the sides of the pipe, but the fines content can increase up to 12 percent and the maximum particle size depends on the pipe type and coating as follows:

PVC, fiberglass, ductile iron, or any pipe with a polyethylene sleeve	25 mm (1 in)
Coal-tar, enamel-coated and wrapped or plastic-tape-coated steel pipe; or any pipe with an approved bonded coating	38 mm (1-1/2 in)



TRENCH REQUIREMENT



SPOIL BANK PLACEMENT

TRENCH SAFETY

CHAPTER 8
SAFETY REQUIREMENTS

Refer continuously and often to Reclamation construction safety standards, OSHA requirements, and State and local regulations. These change, and some may be stricter than others depending on location. Only a few of the safety requirements are highlighted here.

Trench Wall Slope

For trench excavations 1.5 m (5.0 ft) deep or more, the trench wall slope should normally be a minimum of ¾ horizontal to 1 vertical starting at the bottom of the trench. The trench wall slope shall not be steeper than the angle of repose of the native material.

Spoil Bank

The toe of the spoil bank of the excavation from a trench shall be at least 600 mm (2 ft) from the edge of the trench. This shall be the natural toe of the spoil bank slope, not a 600-mm cut in the toe.

Cobbles and Boulders on Slope

There shall be no loose clods or rock particles larger than 75 mm (3 in) left on the trench wall slopes or on the edge of the excavation.

Cables and Slings

The cables and slings used to lower the pipe into the trench must be of adequate strength and in a safe working condition.

Overhead Powerlines

Overhead powerlines must be deenergized or the boom of the crane must be physically restrained to prevent contact with the powerlines.

7-1336-A (1-86) Bureau of Reclamation	LOG OF TEST PIT OR AUGER HOLE	HOLE NO.

FEATURE ______ PROJECT ______

AREA DESIGNATION ______ GROUND ELEVATION ______

COORDINATES N ______ E ______ METHOD OF EXPLORATION ______

APPROXIMATE DIMENSIONS ______ LOGGED BY ______

DEPTH WATER ENCOUNTERED 1/ ______ DATE ______ DATE(S) LOGGED ______

CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME) 3 - 5 in	5 - 12 in	PLUS 12 in
CL in-place unit weight 4.3 ft	0.0 to 4.3 ft LEAN CLAY: About 90% fines with medium plasticity, high dry strength, medium toughness; about 10% predominantly fine sand; maximum size, coarse sand; no reaction with HCl. IN-PLACE CONDITION: Firm, homogeneous, moist, reddish-brown In-place dry unit weight and moisture from test at 3.0 to 3.7 ft: 112.0 lbf/ft^3, 11.7%.			
GC in-place unit weight 8.2 ft	4.3 to 8.2 ft CLAYEY GRAVEL WITH SAND: About 55% coarse to fine, hard, angular to subangular gravel (1/4 of gravel particles are flat or elongated); about 25% fines with medium plasticity, no dilatancy, high dry strength, medium toughness; about 20% predominantly fine sand; maximum size, 75 mm; weak to strong reaction with HCl. IN-PLACE CONDITION: homogeneous, moist, brown In-place dry unit weight and moisture from test at 6.2 to 7.0 ft Total: 129.7 lbf/ft^3, 13.2% Minus No. 4: 107.8 lbf/ft^3, 12.1% (90% compaction) Max. Unit Weight, Opt.: 119.7 lbf/ft^3, 11.0%			

REMARKS:

REPORTING IN-PLACE UNIT WEIGHT TESTS
AND PERCENT COMPACTION

1/ Report to nearest 0.1 foot

GPO 849-280

CHAPTER 9

INVESTIGATIONS FOR PIPELINES

Subsurface investigations, usually test pits or auger holes, for pipelines must relate the in situ soil conditions to the following pipe installation requirements:

1. Stable pipe foundation - during construction
   - over lifetime of pipeline

2. Adequacy of trench walls for flexible pipe. Soil classifications and the percent compaction or percent relative density must be determined and reported on log forms.

3. Suitability of material excavated from trench for backfill or for select material for embedment or both.

4. Noninterference with natural ground water movement

In addition, native soils should be evaluated for potential use for soil-cement slurry pipe bedding. Report any potential or anticipated future construction in the right-of-way over the pipe, such as new roads.

Pipe Foundation

Unsuitable pipe foundations were discussed in chapter 2. The stability of the foundation during construction must be considered as well as the future stability.

If materials in the foundation area are identified as potentially expansive, they should be evaluated by laboratory soils tests. Samples of these materials may be sent to the Technical Service Center geotechnical laboratories for determination of their expansion potential.

If there is a possibility of rock being close to the proposed pipeline, the depth to rock should be determined. This can affect the pipeline grade and alignment as well as the estimated costs of blasting.

Artesian water pressures can create unstable trench bottoms for construction, so ground water levels in auger holes should be monitored.

Trench Walls

If flexible pipe is an option for the proposed pipeline, the trench type as discussed in chapter 3 must be delineated along the alignment. Evaluation of the trench type is based on the soil classification and the percent compaction or percent relative density in the area of the spring line of the pipe.

Determinations of trench type usually require that a test pit be excavated to classify the soil and to measure the inplace density of the soil. For cohesive soils, a laboratory compaction test must be performed to evaluate the percent compaction. For cohesionless soils, a minimum index unit weight and a maximum index unit weight test must be performed to determine the percent relative density. If oversize particles are encountered in the native soils, the total dry density should also be determined. The percentage of cobbles and boulders encountered must be included in the field log of the excavation.

Backfill

Backfill material is usually the soil excavated from the trench. This material should be evaluated against the particle size limitations of the backfill as discussed in chapter 2 for the area around the pipe. There is also a requirement that any rock particles with a dimension greater than

450 mm (18 in) cannot be used in the backfill. This is to prevent damage from large rocks falling against the pipe during construction. These size limitations may

require processing of the soils from the trench excavation before they may be used for backfill.

If the backfill is to be compacted above the pipe to the ground surface, the maximum rock particle size is 125 mm (5 in), since 150-mm (6-in) compacted lifts are normally used. In addition, organic soils should not be used for compacted backfill.

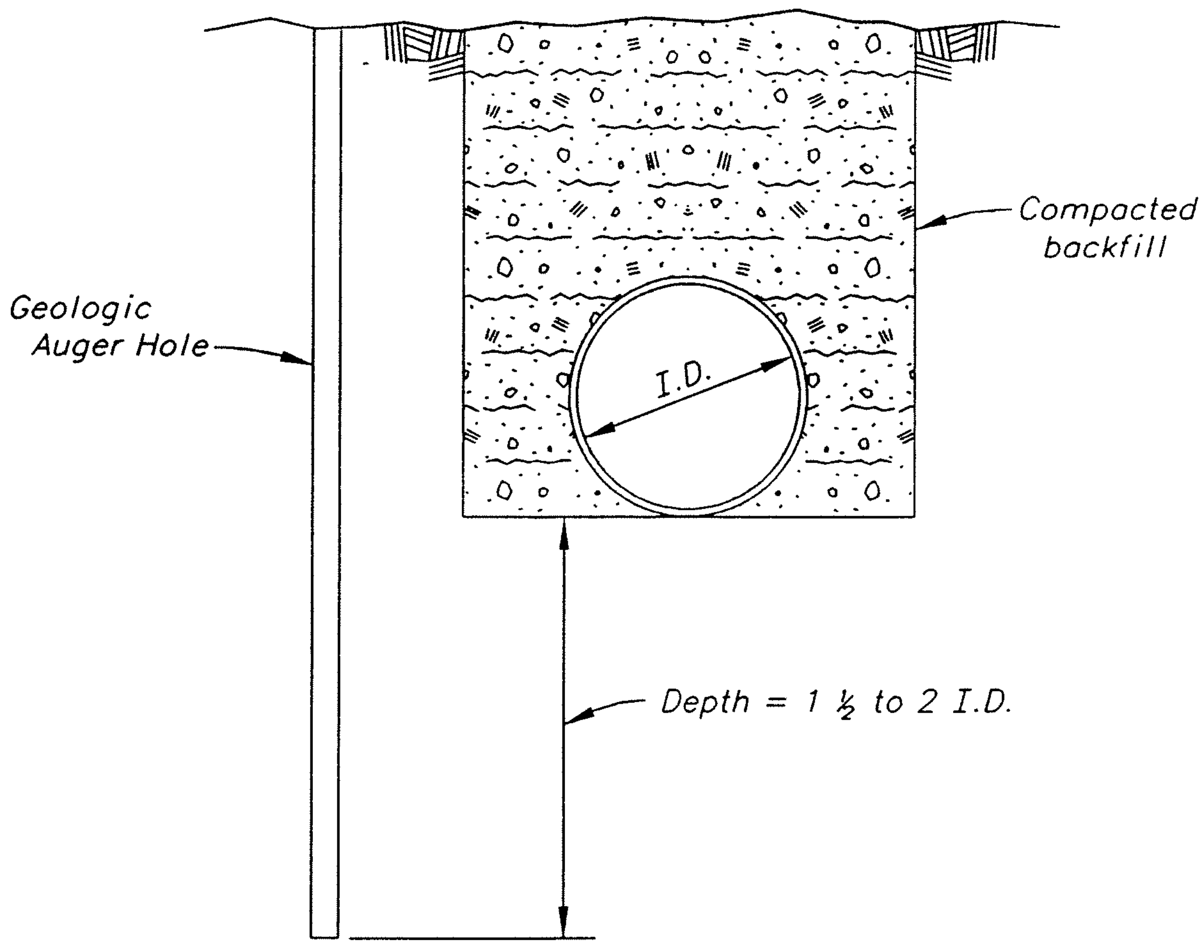
For compacted backfill under roads, any potentially expansive soil, such as fat clays (CH), should not be used.

Ground Water

The select material specified is a cohesionless, free-draining soil (see Select Material in chapter 2). Water passes through this pervious soil easily. Use of the select material in the bottom of the trench creates a drainage path for water along the pipeline alignment. This "drain" can divert or interrupt natural ground water movement. If this is a possibility, trench plugs may be required. A trench plug is compacted, cohesive, impervious soil compacted into place along the pipeline for short lengths as both pipe bedding and embedment at designated intervals (see discussion on page 23). Trench plugs prevent water flow through the select material along the pipe alignment.

Soil-Cement Slurry

For pipelines with trench type 1 in situ soil, the soil-cement slurry, as discussed in chapter 7, may be an economical alternative to using the select material. Silty sand soil from the trench excavation may be used for the soil-cement slurry without special processing. Additional auger holes may be useful along the alignment to identify the extent of the soil that could be used.



DEPTH OF INVESTIGATION
FOR PIPELINES

Frequency of Exploratory Test Pits or Auger Holes

During the planning stages, the in-situ soils should be investigated about once per mile. In the design stage, investigations should be conducted about once per 650 m (2000 ft). Additional exploration may be warranted at sharp changes in geologic conditions, water crossings, faults, and existing or potential landslides or flows. Area geologic conditions may be more important than the soil conditions in the trench.

Auger holes should extend to a depth of about 1½ to 2 pipe diameters below the anticipated bottom of the pipe.

Test pits should extend to a depth below the pipe invert of 1 pipe diameter or 1.5 m (5 ft), whichever is less.

Future Development

Pipe is designed for specific depths of burial and vehicular load (when appropriate). Any future construction that would affect the height of cover over the pipe, whether removal or additional, can have serious consequences on the structural behavior of the pipe. Any potential future use of the right-of-way, such as housing or commercial developments or road crossings, should be investigated and reported.

APPENDIX A
SOIL TESTING PROCEDURES

The applicable soil testing procedures listed below shall be performed in accordance with the U.S. DEPARTMENT OF THE INTERIOR, BUREAU OF RECLAMATION, EARTH MANUAL, PART 2, THIRD EDITION or the comparable *ASTM ANNUAL BOOK* of ASTM STANDARDS.

Procedure		USBR	ASTM
Soil classification	Laboratory visual	USBR 5000 USBR 5005	D 2487 D 2488
Gradation analysis		USBR 5325, 5330, 5335	D 422
Atterberg limits		USBR 5350, 5360, 5365	D 4318 D 4943
Moisture content		USBR 5300	D 2216
Specific gravity		USBR 5320	D 854 C 127
"Proctor" compaction		USBR 5500	D 698 METHOD A
Relative density of cohesionless soils		USBR 5525, 5530, 7250	D 4253 D 4254
In-place unit weight	Sandcone	USBR 7205	D 1556 but use minimum hole volume from USBR 7205
	Test pits	USBR 7220 USBR 7221	D 4914 D 5030
	Rubber balloon	USBR 7206	D 2167 but use minimum volume hole from USBR 7205 D 4564
	Sleeve	USBR 7215	
Rapid construction control		USBR 7240	D 5080

NOTES: 1. Other test procedures, not listed in the above table, must also be performed, since they are an integral part of the procedures (i.e., calibration). Refer to the "Applicable" or "Referenced" documents paragraph(s) of the individual procedure for these requirements.

2. All ASTM standards can be found in Vols. 04.08 and 04.09 "Soil and Rock(I and II)" except for C127 on specific gravity which is in Vol. 04.02 "Concrete and Aggregates."

3. Both USBR and ASTM standards that are in effect on the day the contract is awarded are to be used for the duration of the contract.

APPENDIX B

TABLE OF SI METRIC PIPE SIZES

Reclamation every now and again tries using a system of measurement called SI (International System of Units). The following table gives the SI pipe sizes that will be specified. For example, if a design required a 90-inch pipe for a pipeline system, the metric size specified would be 2250 mm.

Nominal metric (mm)	Equivalent inch-pound system (in)	Nominal inch-pound system (in)
100	3.94	4
150	5.91	6
200	7.87	8
250	9.84	10
300	11.81	12
350	13.78	14
375	14.76	15
400	15.75	16
450	17.72	18
500	19.68	20
525	20.67	21
600	23.62	24
675	26.57	27
750	29.53	30
825	32.48	33
900	35.43	36
975	38.39	39
1050	41.34	42
1125	44.29	45
1200	47.24	48
1275	50.20	51
1350	53.13	54
1500	59.06	60
1650	64.96	66
1800	70.87	72
1950	76.77	78
2100	82.68	84
2250	88.58	90
2400	94.49	96
2550	100.39	102
2700	106.30	108

APPENDIX C

DENSITY VS. UNIT WEIGHT

"Density" is how much stuff (mass) is packed together while "unit weight" is the force (weight) created by the stuff. In the inch-pound system, "pound" is used for both mass and force and we don't care which is what.

However, in the SI (metric) system, the force (in kilonewtons per cubic meter, kN/m^3) is about 10 times larger than the density (in kilograms per cubic meter, kg/m^3). It is <u>very</u> important how density and unit weight are used.

Density is measured and unit weight is calculated. Specifications and literature may use the term unit weight but "DENSITY" is used in this manual, since it is the measured value. When calculating forces using SI, the density <u>must</u> be converted to unit weight.

H O W A R D ' S   L A W

<u>PART I</u>

ONLY 1% OF PIPELINES

NOT PROPERLY CONSTRUCTED AND INSPECTED

WILL FAIL

<u>PART II</u>

100% OF THE TIME

<u>YOUR</u> PIPELINE WILL

BE IN THE 1%