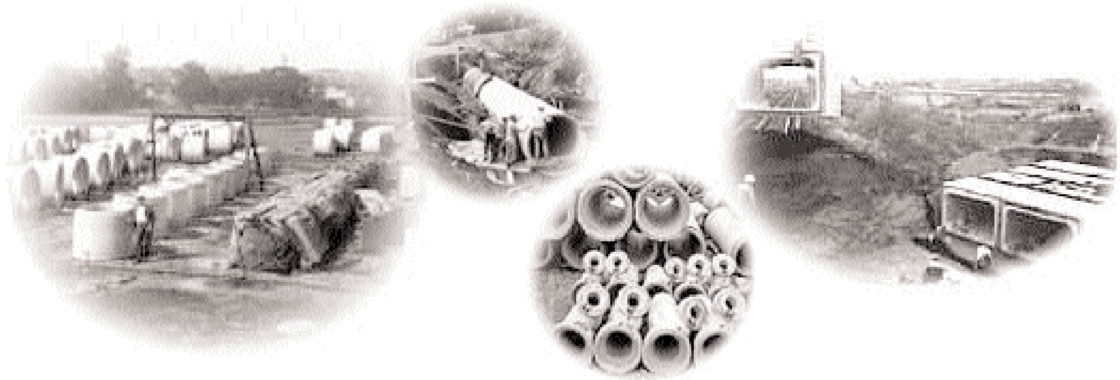
OCPA CONCRETE PIPE DESIGN MANUAL



Ontario
Concrete Pipe
Association



1900
Steel reinforcement in pipe wall represents the single most important advance in concrete pipe technology. Larger diameter pipe with much greater load capacity can now be produced.

1960
Changes to the joint geometry lead to the use of a variety of rubber gaskets for bottle tight joints that significantly reduce leakage and infiltration (advances continue today).

1970
Shorter plant-manufactured junctions used for service connections to facilitate hook-up.

1980
New specifications for precast concrete box culverts and sewers provide pre-approved drainage systems for environmentally sensitive areas, roadways, and mature neighbourhoods. Cost and time-effective solutions!

1990 - 2000
On the leading edge of software development for engineers and purchasers of drainage systems, the OCPA continues to advance life cycle costing analysis, trench material estimating and load analysis software. (Now available through concrete pipe industry home pages and web sites.) Through public/private sector partnering initiatives, the OCPA participates in milestone research projects, including developing new codes for application of materials for highway drainage in Ontario, and defining performance and durability for all pipe material across Canada.

History

Historical records include many references to engineering feats undertaken by ancient civilizations to collect and convey water. Archeological explorations indicate that an understanding of drainage principles existed very early in history. For example, a sewer arch constructed about 3750 B.C. was unearthed in an excavation at Nippur, India. Another excavation in Tell Asmar, near Baghdad, exposed a sewer constructed in 2600 B.C.

Most renowned of these early construction efforts were the aqueducts of Rome. The water carried by these aqueducts was used primarily for drinking. The aqueducts were also used to carry sewage through Rome's main sewer, the Cloaca Maxima. Built in 800 B.C., and constructed mainly of stone masonry and natural cement, the Cloaca Maxima was the first known man-made waterborne method of sewage disposal. After 2800 years, sections of this concrete sewer are still being utilized.

Crude, but functional, sewers also existed in the ancient cities of Babylon, Jerusalem, Byzantium, and Paris. Not surprisingly, these cities were noted for their peculiarly bitter and offensive odour.

Early cities tended to develop around waterways. Used at first for drinking water, the rivers became so polluted with sewage that the residents had to go elsewhere. These natural streams became open sewers and were often arched over with masonry. This universal pattern has been followed by mankind throughout the ages.

As the great cities grew and people built permanent homes, increasingly greater amounts of sewage, garbage and refuse were deposited in the streets. When the piles became high, and the odour nuisance great enough, the filth was removed using picks, shovels and carts. This condition existed until the early part of the 19th century when water distribution systems made it possible to use water to carry off the sewage. Many cities like Paris, London and Baltimore tried cesspools with disastrous results.

These cesspools became breeding areas for disease. From health and aesthetic standpoints, it took the development of waterborne sewage disposal systems to clean up the large cities.

During the first 5000 years of recorded history, the need for sewers, water supply, and drainage was recognized and practical methods of handling the flow of water were developed. From the remains of the ancient structures, it is apparent that the building materials progressed from relatively simple applications of natural materials to cast concrete. In many applications, permanency was a major requirement and concrete was one of the earliest substitutes for natural stone. While not all stone and concrete structures were able to survive the ravages of time, weather and warfare, concrete has an ancient and noble heritage.

Very little theoretical pipeline technology existed prior to the 19th century. The precursor of the modern formula for relating velocity of flow and head loss due to friction in open channel flow was developed by Antoine Chezy, a French engineer and mathematician. Principles of sanitation developed by Edwin Chadwick, an Englishman, were refined by engineers of that time and contributed to the design of properly sized and aligned sewers, with adequate facilities for cleaning and maintenance.

1.1 Birth of an Industry

Public health requirements for water and sewage treatment set the beginnings of the concrete pipe industry in the late 19th and early 20th centuries. Plants were established to manufacture pipe for sewers, transportation facilities, irrigation and drainage of agricultural land, and urban stormwater drainage.

Sewage disposal methods did not improve until the early 1840s when the first modern sewer was built in Hamburg, Germany. It was modern in the sense that houses were connected to a sewer system. For the first time, sanitary sewers were separate from storm sewers. Paris officials had begun to design sewers at the start of the 19th century to protect its citizens from cholera. The cholera epidemics that ravaged England in 1854 led authorities there, to design and construct a sewer system in 1859.

Many of the early sewers in North America were built in small towns, and financed with local funds. Details of these early sewerage projects are generally unknown because of the lack of accurate records. The oldest recorded concrete pipe sanitary sewer installation was in 1842 at Mohawk, New York. The initial conception of engineered sewer systems in America has been credited to Julius W. Adams who designed the sewers in Brooklyn, New York in 1857. His designs were used as a model for years.

The growing concern for public health peaked in North America with the yellow fever epidemic that broke out in Memphis, Tennessee in 1873. It caused more than 2,000 deaths. In 1878 there were 5,150 deaths from this disease. These epidemics were largely responsible for the formation of the National Board of Health, the forerunner of the U.S. Public Health Service. After the Board assisted Memphis in the design and construction of a sanitary sewer system, 20 major cities in North America had concrete pipe sewer lines.

Although concrete pipe manufacturing processes have changed throughout the years, each process ensured a durable product. Concrete pipe that is manufactured today is dense, strong and durable. As the demand for concrete pipe continued to grow, so did the need to increase output and productivity. Equipment manufacturers were pressed to develop new machines with the capability of producing quality concrete pipe at a faster rate.

Early concrete sewer systems, such as the Roman aqueducts, were cast in place, with high slump concrete. This method was slow, but the quality was good ó some aqueducts are more than 2,000 years old.

The precast concrete pipe that was installed in the late 19th century, and the early 20th century was produced by the wet cast method. High slump concrete was poured into a pipe form. When the concrete was set, the core and jacket were removed. This system was expensive, because one form set was required for each piece of pipe.

During the first half of the 20th century, tamping machinery was developed to manufacture concrete pipe. This process utilized either wooden or steel tamping sticks to compact the zero slump concrete that was placed into the form. The form was removed from the machine, stripped from the pipe, and returned to the machine to make another piece of pipe. Because the forms could be immediately reused, output was significantly greater than the wet cast method.

Subsequently, both the packerhead and vibration processes (utilizing zero slump concrete) were introduced to the industry. Both of these systems have evolved into the high output, state-of-the-art machines that are currently in use.

Packerhead pipe is made by feeding concrete onto a rotating roller head that shapes the inside diameter of the pipe. The concrete is thrown against the outer jacket, and packed by the roller head as it slowly rises up the inside of the pipe. The finished product is removed from the machine and placed in a curing area. The jacket is returned to the machine to produce the next piece of pipe.

Vibration processes utilize electric, hydraulic or pneumatic vibrators on either the steel jacket, or core (or both) that are used to form the product. The vibration forces fluidize the concrete so that it can be consolidated. The pipe is removed and placed in a curing area. The form is returned to the machine for another cycle.

1.2 Ontario's Concrete Pipe Industry

There was unprecedented growth in residential and industrial development in the early 1900s, as people migrated to the cities to work. It was during this era that engineers began the task of building water supply and treatment systems, as well as sewage collection and treatment systems for Ontario's towns and cities. Sanitary and storm sewers were constructed for public health requirements and transportation, just as the Americans had done decades before.

Although there is evidence of earlier concrete pipe installations, precast concrete pipe manufacturing in Ontario became a recognizable industry sometime in the late 1890s.

There are photographic records of a concrete pipe manufacturer in the Kitchener area circa 1898. From that time onward, precast concrete pipe has been installed in Ontario's urban areas.

Photos taken in 1924 show a well-organized pipe production facility at Weston Road in north Toronto. Storm and sanitary sewers were constructed of brick, wood and clay, prior to the use of precast concrete systems.

In 1979, a section of 60 year old, 750 mm reinforced concrete storm sewer pipe was excavated in the City of Oshawa and tested for strength. The city was undertaking local improvement work and did not wish to replace the system. Tests of core specimens revealed a concrete compressive strength of 33.5 MPa. A section of pipe was removed and tested to an 85-D classification by today's standards. This concrete pipe system is one of the oldest documented installations in the province. It remains intact and continues to function as originally designed.

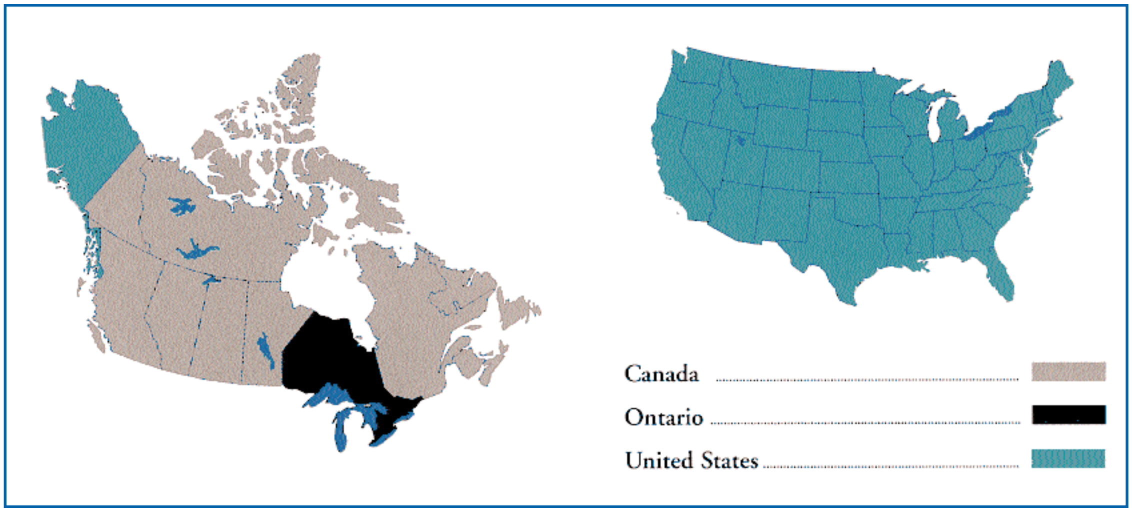
In 1990, the Town of Richmond Hill replaced two adjacent storm drainage culverts running beneath a railroad bed after 63 years of service. One culvert was a 2100 mm reinforced concrete pipe with a flat invert that had been originally designed as a cattle crossing. The second culvert was an 1800 mm reinforced concrete pipe. After removal, the pipe was inspected and found to be in excellent condition.

As the industry matured, the owners of nine pipe plants founded the Ontario Concrete Pipe Association (OCPA) in 1957, to establish standards for the manufacture of high quality products. The nine producers were joined by six associate suppliers, and they became the first members. In 1997, there are eight producer and nineteen associate supplier members. Some members still have their roots in the founding organizations.

In its forty years of service to industry, the Ontario Concrete Pipe Association has joined with industry and government agencies to improve the quality and performance of precast concrete products. Changes were made to the joint geometry of concrete pipe that has led to the use of a variety of gaskets for watertight joints. A standard for the manufacture of concrete pipe and maintenance holes was developed through the Canadian Standards Association with significant input from the OCPA. A Plant Prequalification Program was established in 1965 to certify plants and the testing procedures of products. The Program is still in effect and now serves as a vital component of ISO registration for member producers. A specification for nine standard sizes of precast box units was developed through the 1980s and published in 1993. Industry is now drafting a specification for larger standard box units and updating guidelines for microtunneling pipe.

In the nineties, the OCPA entered into partnerships with the federal and provincial governments to develop new guidelines for the use of drainage pipe materials, taking into consideration performance, durability, and life cycle costing. To support the new research, the Association led the development of a unique software called PipePac that performs simultaneous analysis of different pipe materials for embedment costs and life cycle costing. It includes a third program to compute loads on concrete pipe. To facilitate distribution, the OCPA and Canadian Concrete Pipe Association developed a home page (www.ccpa.com) on the Internet, and made the software freely available.

In 1997, the OCPA continues to work with government and industry to improve and create standards for precast concrete drainage products. With a strong Plant Prequalification Program, and partnerships for research and development, the Ontario concrete pipe industry is poised to break into the twenty-first century on a sound foundation of performance and achievement that has lasted a hundred years.



2 Standards

Standardization plays an essential role in the manufacture of a product. It enables industries to produce large runs of component parts that are guaranteed to be compatible and interchangeable. This contributes to increased productivity and reduced costs, while ensuring a steady supply of readily available drainage system components.

Standard drawings and specifications are one of the most efficient methods of recording and sharing technical knowledge, providing for a significant reduction in duplication of efforts at all stages of engineering and manufacturing processes.

Specifications usually include extensive terminology listings, detailed descriptions of ingredients and materials and, in many cases, formulae and illustrative drawings, allowing for clear communications between all interested parties. These parties include manufacturers and their suppliers, as well as designers and owners of projects.

In addition, standard drawings and specifications define the physical and dimensional properties of a product, and the testing methods required to establish its optimal characteristics and performances, as well as allowable tolerances.

To meet these standard requirements, manufacturers impose upon themselves comprehensive fabrication procedures and quality assurance programs that enable them to guarantee a consistent high level of quality for their products.

Various standardization agencies around the world have issued standard drawings and specifications which deal specifically with concrete pipe and other sewer, drainage and watermain items (i.e., maintenance holes, catchbasins, ditch inlets, valve chambers, and precast box units).

Ranking among the most prominent in Ontario and North America, we can list

PPP - Plant Prequalification Program

OPS - Ontario Provincial Standards

OHBDC - Ontario Highway Bridge Design Code

CSA - Canadian Standards Association.

ASTM - American Society for Testing and Materials.

AASHTO - American Association of State Highway and Transportation Officials.

2.1 Plant Prequalification Program

The concrete pipe Plant Prequalification Program is a unique program that maintains manufacturing standards, procedures and quality controls for concrete pipe plants and products in the province of Ontario. Started in 1965, the program is administered by a committee comprised of representatives of the Ontario Concrete Pipe Association (OCPA), the Municipal Engineers Association (MEA), the Ministry of Transportation Ontario (MTO), and the Ontario Provincial Standards (OPS). The committee ensures that products are manufactured in accordance with a rigorous quality assurance and testing program. This program is the only quality assurance program of its kind in Ontario, and producers are using the standards of the program for ISO 9000 registration.

Several advantages are realized through the Prequalification Program. The direct link with specifiers through the MEA makes the industry more responsive to market needs and changes. The inspection and testing of pipe plants and products are performed by an independent consulting engineering firm that reports directly to the Prequalification Committee. This program is in addition to the stringent requirements of CAN/CSA A257 Series M92 for manufacturing concrete pipe and maintenance holes. Joint dimension tolerances are confirmed for each pipe produced. In addition, structural and hydrostatic performances are verified.

Inspection of plants is carried out annually by the independent inspection engineer. The program now covers all sizes and shapes of pipe, and precast concrete box units up to 3000 mm x 2400 mm. Plants that are prequalified must identify products covered by their certification, with the symbol shown below. The right to use the stamp is issued by the Plant Prequalification Committee.

2.2 Ontario Provincial Standards

In Ontario, the process towards standardization at a provincial level was initiated in 1977, with the intent of improving the administration and cost-effectiveness of road building and other municipal services, such as sewers and watermains.

The resulting Ontario Provincial Standards for Roads and Municipal Services (OPS) is a comprehensive set of standard drawings and specifications which currently contain the following manuals:

OPS - SPECIFICATIONS

Vol.#1 General Conditions of Contract and Specifications for Construction

Vol.#2 Specifications for Materials

OPS - DRAWINGS

Vol.#3 Drawings for Roads, Barriers, Drainage, Sanitary Sewers, Watermains and Structures.

Vol.#4 Drawings for Electrical Work.

The co-ordinating and ruling body of the Ontario Provincial Standards process is the Joint Committee composed of five members, three from the Municipal Engineers Association (MEA), one from the Ontario Ministry of the Environment and Energy (MOEE) and one from the Ministry of Transportation, Ontario (MTO). The Ontario Concrete Pipe Association (OCPA) is cited as one of several contributors to the development of the Standards.

The following Ontario Provincial Standard Specifications (OPSS) are of particular significance for concrete pipe producers, road builders and sewer contractors:

OPSS No.	TITLE
Construction Specifications - Drainage and Tunnels	
405	Pipe Subdrains
407	The Construction of Manholes, Catch Basins, Ditch Inlets and Valve Chambers
408	Adjusting or Rebuilding Manholes, Catch Basins, Ditch Inlets and Valve Chambers
410	Pipe Sewer Construction by Open Cut Method
415	Tunneling
416	Jacking and Boring
421	Pipe Culverts
422	Precast Reinforced Concrete Box Culverts and Box Sewers
Material Specifications - Cement and Concrete	
1350	Material Specification for Concrete - Materials and Production
1351	Components for Precast Reinforced Concrete Catch Basins, Manholes, Ditch Inlets and Valve Chambers
Material Specifications - Pipes and Associated Drainage Items	
1820	Circular Concrete Pipe
1821	Precast Reinforced Concrete Box Culverts and Box Sewers
1002	Aggregates - Concrete
1440	Steel Reinforcement For Concrete

2.3 CSA and ASTM Standards:

The following are the CSA and ASTM standards for precast concrete pipe and associated items:

CAN/CSA A 257 Series M92

A 257.0	Methods for Determining Physical Properties of Concrete Pipe;
A 257.1	Concrete Culvert, Storm Drain and Sewer Pipe;
A 257.2	Reinforced Concrete Culvert, Storm Drain and Sewer Pipe;
A 257.3	Joints for Circular Concrete Sewer and Culvert Pipe Using Rubber Gaskets
A 257.4	Precast Circular Concrete Manhole Sections, Catchbasins & Fittings

2.4 American Society For Testing And Materials

C 14M-95	Specification for Concrete Sewer, Storm Drain, and Culvert Pipe
C 76M-95	Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe
C 118M-95	Specification for Concrete Pipe for Irrigation or Drainage
C 361M-95	Specification for Reinforced Concrete Low-Head Pressure Pipe
C 443M-94	Specification for Joints for Circular Concrete Sewer and Culvert Pipe Using Rubber Gaskets
C 478M-95a	Specification for Precast Reinforced Concrete Manhole Sections
C 665M-95a	Specification for Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe
C 497M-95a	Test Methods for Concrete Pipe, Manhole Sections, or Tile
C 507M-95a	Specification for Reinforced Concrete Elliptical Culvert , Storm drain, and Sewer Pipe
C 789M-95a	Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers
C 850M-95b	Specification for Precast reinforced concrete Box Sections for culverts, Storm Drains, and Sewers with Less Than 0.6 m of Cover Subjected to Highway Loadings
C 1131-95	Practice for Least cost (Life Cycle) Analysis of Concrete Culvert, Storm sewer, and Sanitary Sewer Systems

2.5 American Association of State Highway and Transportation Officials

Section 17,	Division 1 Soil-Reinforced Concrete Structure Interaction Systems

3 Materials Manufacture and Testing

Many factors have contributed to the success of the concrete pipe industry. The use of readily available raw materials in production plants, located close to major urban areas, is not the least of these. From manufacturing plants, personal services are regularly provided by the manufacturer to engineers, contractors and public officials. Included in these services are design and specification assistance, seminars, plant tours and the ability to quickly accommodate the changing requirements of projects.

High quality precast concrete pipe is manufactured using state-of-the-art facilities, processes and equipment, integrated under controlled conditions. Several different processes are used, each capable of producing precast concrete pipe that conforms to the requirements of applicable standards. This chapter provides an overview of the materials, techniques and equipment used to produce a concrete product of consistently high quality.

3.1 Materials

Materials used to manufacture precast concrete pipe consist of locally available aggregates and manufactured products, such as portland cement and reinforcing steel. Each of the component materials has a CSA standard specifying its properties and methods of testing.

Portland Cement

Portland cement, is a closely controlled chemical combination of calcium, silicon, aluminum, iron, and small amounts of other compounds. Gypsum, which regulates the setting time of the concrete, is added during the final process of grinding.

For practical purposes, portland cements may be considered as being composed of four principal compounds with chemical formulae and abbreviations as shown in Table 3.1. Most of the strength developing characteristics are controlled by the tricalcium silicate, C_3S, and dicalcium silicate, C_2S. Together, these two compounds usually comprise more than 70 percent of the cement.

Table 3.1 Four Principal Compounds of Portland Cement

Compound	Chemical Formula	Abbreviation
Tricalcium silicate	$3CaO\text{-}SiO_2$	C_3S
Dicalcium silicate	$2CaO\text{-}SiO_2$	C_2S
Tricalcium aluminate	$3CaO\text{-}Al_2O_2$	C_3A
Tetracalcium aluminoferrite	$4CaO\text{-}Al_2O_2\text{-}Fe_2O_3$	C_4AF

Portland cements are produced to meet CAN/CSA A 5 and classified into five types described in the following paragraphs. This standard sets limits for chemical composition, fineness of grind, setting time, strength at certain ages, resistance to chemical attack, and rate of development of heat of hydration. Not all types of cements are available in all market areas, and it is recommended that local pipe manufacturers be consulted regarding available cement types.

Type 10. Normal Portland Cement

Type 10 cement is a general purpose cement suitable for all uses where the special properties of the other types are not required. It is used in pavement and sidewalk construction, concrete buildings and bridges, railway structures, tanks and reservoirs, sewers, culverts, water pipe, masonry units, soil-cement mixtures, and any use not subject to sulphates, or where the heat of hydration is not critical.

Type 20. Moderate Portland Cement

Type 20 cement has a lower heat of hydration than Type 10, improved resistance to sulphate attack, and is intended for use in structures of considerable size, to minimize temperature rise. Applications include large piers, heavy abutments and heavy retaining walls when the concrete is placed in warm weather. In cold weather when heat generation is an advantage, Type 10 cement may be preferred. Type 20 cement is also intended for places where protection against sulphate attack is required, as in drainage structures where soil sulphate concentrations are higher than normal but not unusually severe. Type 20 cement has a maximum allowable C_3A content of 8 percent. Concrete produced with predetermined quantities of slag cement and portland cement can result in a sulphate resistance equivalent to Type 20.

Type 30. High-Early-Strength Portland Cement

Type 30 cement is used where high early strengths are desired, such as when forms need to be removed as soon as possible, or when the concrete must be placed in service as quickly as possible. Other uses include cold weather construction so that the required period of protection against low temperatures can be reduced.

Type 40. Low-Heat-of-Hydration Portland Cement

Type 40 cement is used where the amount and rate of heat generated must be kept to a minimum, but strength development also proceeds at a slower rate. It is intended for use only in mass concrete, such as large gravity dams, where temperature rise is a critical factor.

Type 50. Sulphate-Resistant Portland Cement

Type 50 cement is a special cement intended for use in structures exposed to severe sulphate action. It has a slower rate of strength development than normal portland cement. Type 50 cement has a maximum allowable C_3A content of 5 percent, which provides better sulphate resistance than Type 20 cement. Concrete produced with predetermined quantities of slag cement and portland cement can result in sulphate resistance equivalent to Type 50 cement.

Blended Hydraulic Cements

Blended hydraulic cements are blends of portland cements or lime and one or more natural or manufactured pozzolans which, in the presence of moisture, chemically react with calcium hydroxide to form compounds possessing cementitious properties. There are three kinds of blended hydraulic cements manufactured to meet the requirements of CSA A362:

- Type 10S - Portland-Blast-Furnace-Slag Cement
- Type 10P - Portland-Pozzolan Cement
- Type 10SM - Slag-Modified Portland Cement

Type 10S. Portland-Blast-Furnace-Slag Cement consists of a uniform blend of portland cement and finely granulated blast-furnace slag. Blast-furnace slag is a non-metallic product consisting essentially of silicates and aluminosilicates of calcium and other bases that is developed in a molten condition simultaneously with iron in a blast furnace.

Type 10P. Portland-Pozzolan Cement consists of a uniform blend of portland cement or portland blast-furnace slag cement and fine pozzolan. Pozzolans are siliceous and aluminous materials which possess little or no cementitious value but will chemically react, in finely divided form and in the presence of moisture, with calcium hydroxide to form compounds possessing cementitious properties.

Type 10SM. Slag-Modified Portland Cement is a blend of portland cement and finely ground, granulated blast furnace slag in which the slag portion is less than 25% by mass of the total portland blast furnace slag cement.

Reinforcement

Concrete pipe is manufactured with or without reinforcing steel according to applicable specifications and project requirements. Most concrete pipe is manufactured with steel reinforcement. The amount of steel reinforcement is suggested by CSA standards or determined by special design. The type of reinforcement used depends on production processes and availability.

Supplementary Cementing Materials

Supplementary cementing materials are materials that, when used in conjunction with Portland cement, contribute to the properties of the hardened concrete through hydraulic or pozzolanic activity, or both. Typical examples are natural pozzolans, fly ash, ground granulated blast-furnace slag and silica fume.

Natural Pozzolans

A pozzolan is a siliceous or aluminosiliceous material that, in finely divided form and in the presence of moisture, chemically reacts with the calcium hydroxide released by the hydration of Portland cement to form compounds possessing cementing properties. Type N pozzolans are classified in CSA A23.5 as raw or calcined natural pozzolans. A number of these occur as natural materials such as volcanic glass, diatomaceous earth, opaline cherts, shales, tuffs, and pumices. Others may be produced from calcined clays or shales.

Fly Ash

Fly ash is the finely divided residue that results from the combustion of pulverized coal, and is carried from the combustion chamber of a furnace by exhaust gases. Most commercially available fly ash is a by product of thermal-power-generating stations. CSA A23.5 recognizes two types of fly ash, Type F and Type C.

Type F fly ash is normally produced from the burning of pulverized anthracite or bituminous coal. It is removed by mechanical collectors, or electrostatic precipitators, as a fine particular residue from the combustion gasses before they are discharged into the atmosphere.

Type C fly ash is normally produced from burning pulverized lignite or subbituminous coal. The particles, which are collected in a manner similar to that described for Type F, usually have some cementitious properties.

Blast-Furnace Slag

Blast-furnace slag, or iron ore blast-furnace slag, is the nonmetallic product consisting essentially of silicates, aluminosilicates of calcium, and other bases and that is developed in a molten condition simultaneously with iron in a blast furnace. The granulated slag group contains two types, Type G and Type H.

Type G ground granulated blast-furnace slag is the glassy granular material formed when molten blast-furnace slag is chilled rapidly. This type, in the absence of an activator, displays little or no cementitious action.

Type H cementitious hydraulic slag meets the requirements of Type G and also meets the requirements of CSA A363. Cementitious hydraulic slag is the product obtained by pulverizing granulated iron blast-furnace slag and displays some hydraulic activity when mixed with water alone.

Silica Fume

Condensed silica fume is the finely divided residue resulting from the production of silicon, or silicon-containing alloys that is carried from the furnace by exhaust gasses. The type of silica fume covered in the CSA standard is Type U, which results from the production of silicon or ferro-silicon alloys, containing at least 75% silicon. It is collected by filtering the gases escaping from the electric arc furnaces and consists of very fine spherical particles.

Welded Wire Fabric

Welded wire fabric is prefabricated from high-strength, cold drawn wires and consists of longitudinal wires welded to transverse wires to form rectangular grids. Each wire intersection is electric resistance-welded by automatic welders. Smooth wires, deformed wires, or a combination of both may be used. Welded wire fabric is manufactured to CSA G30.5 or CSA G30.15. The positive mechanical anchorage at each wire intersection of welded smooth wire fabric provides the concrete to steel bond characteristics. Welded deformed wire fabric utilizes wire deformations in addition to the welded intersections to improve bond characteristics.

Illustration 3.1 Mesh roller curves welded wire fabric to proper diameter for cage.

Cross-sectional area is the basic measure used in specifying wire sizes. Smooth wire sizes are identified by the letters MW followed by a number indicating the cross-sectional area of the wire in square millimeters. For example, MW103.2 denotes a smooth wire with cross-sectional area of 103.2 mm2. Similarly, metric deformed wire sizes are identified by the letters MD followed by a number which also indicates the cross-sectional area in square millimeters. For example, MD 64.5 is a deformed wire with a cross-sectional area of 64.5 mm2.

Spacing and sizes of wires in welded wire fabric are identified by style designation. A typical style designation is 51 x 203 - MW25.8 x MW16.0. This denotes a welded wire fabric in which:

Spacing of longitudinal wires = 51 mm

Spacing of transverse wires = 203 mm

Size of longitudinal wires (MW25.8) = 25.8 mm2.

Size of transverse wires (MW16) = 16.0 mm2.

Cold Drawn Wire

Cold drawn steel wire is produced from hot rolled rods by one or more cold reduction processes that produce the size desired. The cold-drawn process changes the physical properties and increases the tensile strength while improving the surface finish. CSA G30.3-M and CSA G 30.14-M cover cold-drawn reinforcement wire used in the manufacture of concrete pipe.

Reinforcing Bars

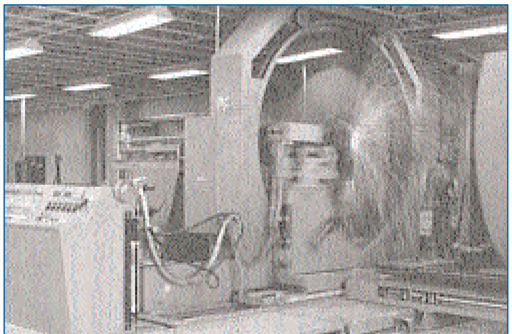


Illustration 3.2 Automatic Cage Machine.

Reinforcing bars (rebar) are hot-rolled from billets made from ingots of properly identified heats of open hearth, basic oxygen, or electric furnace steel. There are two types of deformed bar: designated regular (R) and weldable (W), and one type of plain bar (R) produced in the rolling process. All bars used as reinforcement in concrete should conform to CAN/CSA-G30.18. These reinforcing bars are generally arranged in grid patterns to provide the necessary steel areas. Rebar is typically used as reinforcement for some maintenance hole components and some precast box units, although it can be used elsewhere.

Aggregates

Aggregates are granular material of mineral composition, such as sand, gravel or crushed stone. Aggregates are combined with a cementing medium to form concrete. Aggregates should have sufficient strength to develop the full strength of the cementing matrix and be of such character that the binding material will adhere to the surface.

Aggregates are classified by the general terms fine and coarse aggregate. Fine aggregate consists of material ranging from a size passing 9.5 mm seive down to material just passing the 150 µm sieve. Coarse aggregate ranges from the maximum size for sand to a varying upper limit, determined by the pipe wall thickness and production considerations. The maximum size ordinarily used in pipe manufacture is 19-25 mm.

Aggregates for concrete pipe meet the requirements of CAN/CSA A23.1, except for gradation requirements. This standard limits the amount of deleterious substances, and also covers requirements for grading, strength and soundness.

Water

Water added to cement produces a chemical reaction known as hydration. The physical characteristic of this reaction is the formation of a gel when the cement is exposed to water. This gel is formed by the penetration of water into the cement particles causing softening, and establishing a colloidal suspension. The absorption of water by the clusters of cement particles is the actual hydration.

Only a small amount of water is required for hydration, but additional water is required to produce a workable mix. There is, however, a relation between the amount of water used and the strength of the resulting concrete. The amount of water must be limited to that which will produce concrete of the quality required. This is seldom a factor in the concrete used to precast concrete pipe because most manufacturing processes utilize relatively dry mixes

Water used for mixing concrete should be free of acids, alkalis and oil, unless tests or experience indicate that water being considered for use and containing any of these materials is satisfactory. Water containing organic matter, which may interfere with the hydration of the cement, should be avoided. Most specifications require that the water for mixing be suitable for drinking.

Admixtures

Admixtures for concrete are available in several classifications. Those commonly used in concrete pipe, maintenance holes and box units belong to the classifications of water reducers and air-entraining admixtures which are covered by CSA Standards, CAN/CSA3-A226.1 and CAN/CSA3-A226.2. Other admixtures may be used in the production of these products, and should conform to the appropriate standard.

3.2 Manufacture of Precast Concrete Pipe

The basic materials for concrete pipe are fine aggregate, coarse aggregate, portland cement, water and, in most cases, reinforcement. These are combined in a systematic manner, using quantities and proportions specially designed for each product. Fine and coarse aggregates are mixed with cement and water to provide a concrete mix which is formed into pipe by one of several methods. The newly formed pipe is cured and then moved into a storage area until shipment to the construction site. The manufacturing process includes:

- Storage of Materials
- Materials Handling
- Concrete Batching
- Reinforcement Fabrication
- Pipe Production Methods
- Offbearing and Curing
- Yarding and Storage
- Storage of Materials

Aggregates of varying gradations are stored in sufficient quantities to enable the continuous operation of the facilities, most often in large bins either inside or outside of the plant. The gradations used at a plant are dependent on the methods of manufacture, the thickness of the pipe wall being produced, and local aggregate sources.

Portland cement is normally stored in silos located above the manufacturing plant floor, which enables the cement to flow by gravity into the weighing bins. Some plants use augers or air to transport cement. The cement is pneumatically pumped into the silo by delivery trucks, or by pumping apparatus directly from railroad cars. The capacity of cement storage at any plant is dependent on the size of the plant, the number of types of cement used, and the frequency of delivery.

Steel reinforcement is usually stored near the reinforcement fabricating equipment. The reinforcement inventory is dependent on the various sizes and classes of pipe being produced, and the pipe manufacturerís cage fabrication facilities.

Material Handling

Aggregates are transferred from the storage areas to the weighing bins by loading equipment, a series of conveyor belts, gravity, or some combination of these. Cement is commonly fed by gravity, air, or auger from the silo into a weighing bin. Weighing bins for cement and aggregates can be controlled manually or electronically. Water is piped directly to the mixer, and controlled by a manual or electronic system. After the concrete has been batched, it is delivered directly to the pipe machine, or a holding bin, by conveyor belt, skip hoist, or travelling bucket.

Concrete Batching

Concrete batching is preceded by design of the mix which determines the proportion of cement, fine aggregate, coarse aggregate, water and admixtures, if used.

Cement and both fine and coarse aggregates are fed into weighing bins and then discharged into the mixer. In most processes the materials are mixed and then the proper amount of water and admixture added.

Ribbon mixers and pan mixers are the two most common types used in the concrete pipe industry. A ribbon mixer consists of a spiral blade that is welded around a horizontal shaft. The pan mixer consists of a vertical short cylinder resembling a pan, hence the name. Inside the pan, paddles are mounted vertically and rotate to mix the concrete. Components are added from above and the concrete is removed from the bottom. Both ribbon and pan mixers are efficient in converting the components of the concrete into a homogenous mixture.

The slump test is the most common means of measuring the relative water content of cast-in-place concrete mixes. It cannot be effectively applied to the dry mixes used in concrete pipe machines, because the slump of these mixes is always zero. In fact, concrete mixes for pipe have what is called a negative slump in that additional water could be added to the mix before any slump would occur.

Reinforcement Fabrication

Cage machines, mandrels, and wire rollers are the three most common means of fabricating reinforcing cages in a concrete pipe plant. A cage is an assembled unit of steel reinforcement consisting of circumferential and longitudinal bars or wires.

A cage machine uses reels or spools of cold drawn steel wire. By means of adjusting guides, it positions the longitudinal wires while wrapping the circumferential wire in a helix around the longitudinals. Intersections of the circumferential and longitudinal wires are automatically welded. The process produces a continuous cage. When the desired cage length has been reached, the longitudinals and circumferentials are cut with shears.

In using mandrels to fabricate cages, the mandrel is adjusted to the required diameter. The longitudinal steel is placed on the mandrel, and the circumferential steel is helically wrapped around the turning mandrel. The intersections of the longitudinals and the circumferentials are welded manually.

Wire rollers use welded wire fabric in rolls or flat mats with the desired size and spacing of longitudinal and circumferential wires. When the proper length of fabric has been formed by the roller, it is cut and spot welded to form the cage.

Four cage configurations are in common use: single circular cage, double circular cage, single elliptical cage, and a combination of an elliptical cage and one or more circular cages, Figure 3.1. Alternatively, quadrant reinforcement can be used to provide increased steel areas in the tensile zones of the pipe, Figure 3.2.

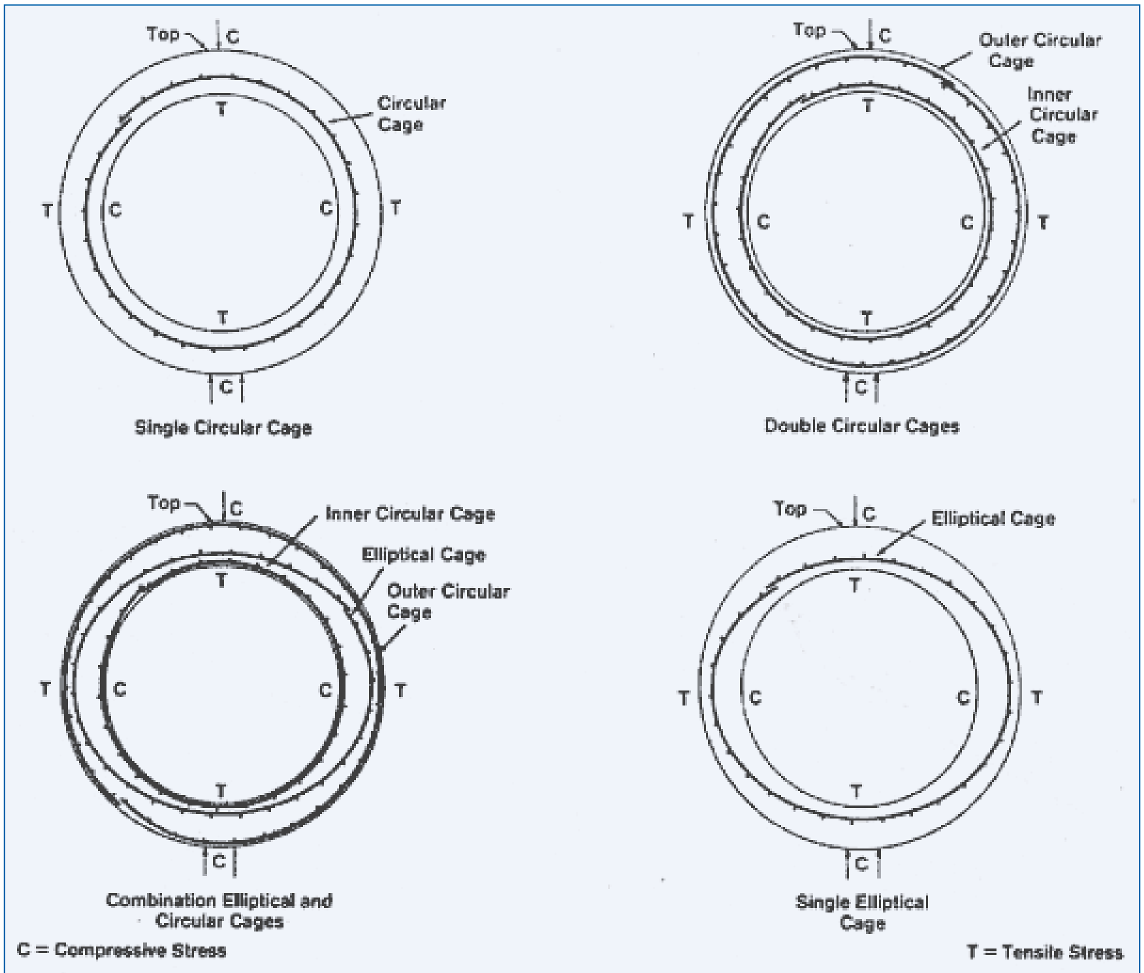


Figure 3.1 Four cage Configurations Commonly Employed in the Manufacture of Reinforced Concrete Pipe.

Steel area is a commonly used term for describing the reinforcement in concrete pipe. When the term is used, it refers to the square millimetres of circumferential steel per linear metre; that is, if a section of pipe were to be cut lengthwise, the steel area is the sum of the cross-sectional areas of the exposed circumferential wires in one linear metre of pipe.

Pipe Production Methods

There are five basic methods of producing concrete pipe. Four of the methods, Figure 3.1, use mechanical means to place and compact a dry concrete mix into the form. The fifth method uses a more conventional wet mix and casting procedure. The methods are:

- Centrifugal
- Dry cast/Vibration
- Packerhead
- Tamp
- Wet cast

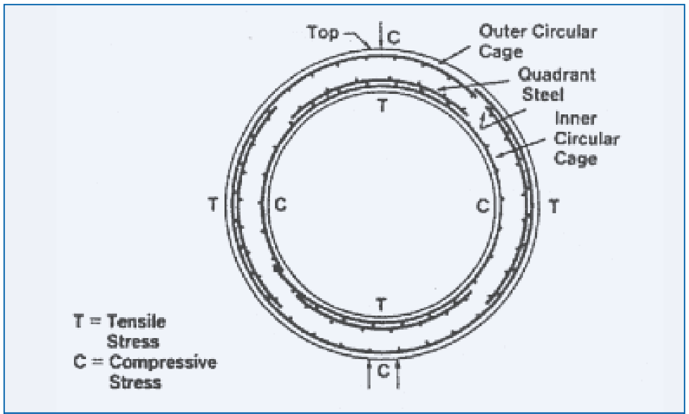


Figure 3.2 Quadrant Reinforcement Provides Additional Reinforcement in Tension Zones of Pipe Wall.

Centrifugal Method

The centrifugal method, which is no longer used in Canada, uses an outer form that is rotated in a horizontal position during the pipe making process. Vibration and compaction can be used in combination with centrifugation to consolidate the concrete mix. While the mix used in this process is wetter than that for some others, water is extracted from the concrete by the centrifugal forces which develop as the pipe is spinning. As the form is rotated, concrete is fed into the form by a conveyor system that is capable of distributing concrete throughout the form length. The finished pipe, still in the form, is moved to the curing area and cured in the form.

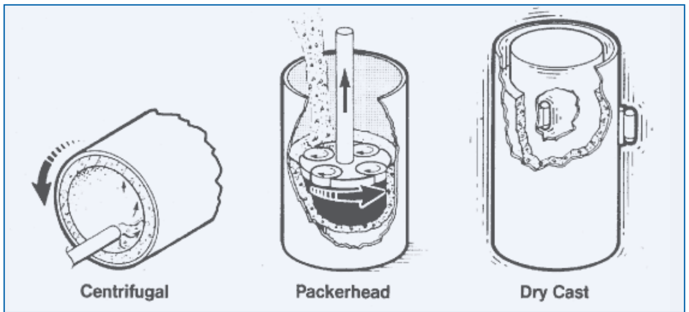


Figure 3.3 Three Commonly Used Manufacturing Methods for Production of Precast Concrete Pipe.

Dry Cast / Vibration Process

This method has several variations, but all use low frequency-high amplitude vibration to distribute and densely compact the dry mix in the form. The form is removed immediately, as the newly formed pipe can support itself. To get the desired vibration at all points, several different techniques are utilized.

In one method, individual vibrators are attached directly to the exterior form or internal core (or both). The mix is fed into the form and the vibrators are operated at various stages during this process. At the completion of the process, the pipe and form are lifted off the machine and moved to the curing area where the form is removed.

Vibrators on the exterior forms of a two station vibration machine.

Another variation of the dry cast method has a central core that moves up and down and provides vibration and compaction. In this method, when the process is completed, the core retracts and the pipe is lifted and moved to the curing area.

This vibration machine utilizes an internal vibrating core that rises as the concrete mix is fed into the forms.

Packerhead Method

The packerhead process uses a vertical shaft with a circular packing head on the bottom. It rotates at a high speed as it forms the interior surface of the pipe. It is drawn up through the inside as mix is fed from above. This head has rollers or deflectors mounted on the top which compact the mix. When compaction is complete, the form and pipe are moved to a curing area where the exterior form is removed.

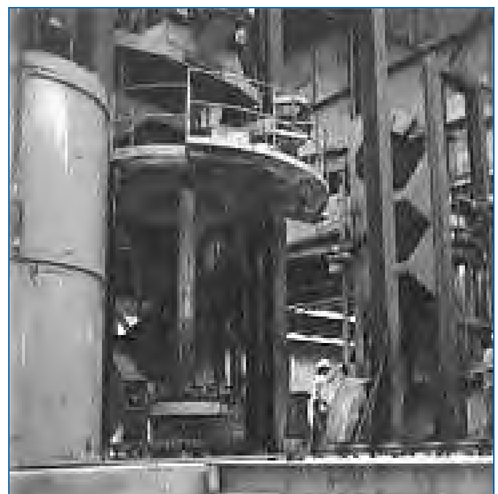
In some packerhead processes, a vibrating core follows the packerhead through the pipe making sequence. The core is mounted in a pit below the pipe machine and is retracted before the pipe is moved.

In other packerhead processes a counter rotating rollerhead is used. This counter rotating head is effectively two heads rotating in opposite directions to neutralize any torque transferred to the pipe during the casting process.

This vibration machine utilizes an internal vibrating core that rises as the concrete mix is fed into the forms.

Tamp Method

The tamp process, which is no longer used in Canada, uses direct mechanical compaction to consolidate the concrete mix. Inner and outer forms are placed on a rotating table, and the concrete mix is fed into the forms. As the form is rotated and filled, the tamper rises automatically. There are usually multiple tampers so that the mix on each side of any reinforcement can be compacted. The pipe is removed from the machine, with either the inner or outer form, and moved to the curing area where the form is removed.



Pipe in outer form is removed from machine and packerhead begins forming another section.

Wet Cast Method

Wet casting of concrete pipe, as the name implies, uses a concrete mix that is wet, relative to the mixes used in the other processes. The mix usually has a slump of more than 25 mm. The wet cast process is most commonly used for production of large diameter pipe where it is manufactured, cured and stripped at one location. Inner and outer forms are most commonly mounted in a vertical position, but some pipe is cast with forms placed horizontally.

With vertical forms, a cone attached to the inner form is used to direct the concrete mix. The mix can be transported to the form by crane, conveyor or similar equipment. As the mix is placed in the form it is vibrated using internal, and in many cases, external vibrators. After the form has been filled, the cone is removed, and the pipe cured in the form. Following the curing period, usually overnight, the forms are removed and the pipe moved to the storage area.

Offbearing and Curing

Removal of the pipe from the machine is called offbearing and is accomplished in a variety of ways ranging from manual to fully automated. Fork lifts, overhead cranes and automated systems are used to lift pipe from the machine. The freshly made pipe is transported to the curing kiln by fork lifts, hand trucks, overhead cranes or moving floors. Moving floors are used by some plants for efficient transport of the pipe into the curing area. A section of moving floor, referred to as a kiln car, usually consists of a concrete slab, or steel deck, supported on steel trucks. It runs on rails installed in a trench in the floor of the plant. The moving floor passes adjacent to the pipe machine and into the kiln.

Depending on the production method, the pipe is either cured while in the form, or immediately removed from the form and then cured. Curing is accomplished by a variety of procedures. In some cases, the pipe is placed in a permanent kiln, and in other cases, the pipe is covered by canvas, plastic, or other material which functions as a kiln.

As soon as the concrete pipe is formed, the curing process begins. Curing is optimized by control of kiln conditions and thus, the rate of hydration of the cement. There are three basic methods for curing: steam, water and sealing membranes. In the concrete pipe industry, low pressure steam predominates as a curing method. The principle of low pressure steam curing is that an accelerated rate of hydration produces concrete pipe of required strength in shorter time than is possible when curing at ambient temperatures.

The three essential factors in all known methods of properly curing concrete are time, temperature and moisture. For equivalent strengths, an increase in temperature usually permits a shorter curing period. The time-temperature relationship is not the same for all mixtures, materials, and conditions and is determined by experience.

In low pressure steam curing, it is essential that the relative humidity surrounding the pipe be high, and as near as possible to saturation. High humidity, in excess of 80%, is provided when the curing temperature is obtained by direct injection of saturated steam into the kiln. With systems combining moisture and hot air, radiant heat, or other forms of dry heat it is necessary to maintain a closer check on the humidity in the kiln. Drying of the concrete can cause damage to the surface. A concrete pipe is sensitive to moisture loss because of the large surface area for the volume of concrete. A moist atmosphere is not necessary when the concrete is entirely encased in a pipe mold. In such cases the water in the concrete mixture is sealed inside the forms.

Concrete pipe can be cured in the open air, provided temperatures are high and constant. It is necessary under these conditions to maintain the pipe in a moist condition. A sprinkler system is most commonly used to provide such an environment.

Pipe has been efficiently cured in a chamber by maintaining a constant, warm temperature achieved by the addition of heat, or by the heat generated from the hydration of the cement. Moisture is usually provided in the form of a warm spray.

Yarding and Storage

At the completion of the curing cycle the pipe is removed from the kiln and moved to the storage area. Small diameter pipe is frequently moved in groups of four or more, depending on the size of the pipe and capacity of the equipment. Before moving to the storage area, the pipe receives a final visual inspection to ensure a consistent quality of product. Marking of the pipe to indicate strength class, manufacturing date, manufacturer and other information to conform to CSA standards is done as the pipe is yarded.

3.3 Pipe Shapes

Concrete pipe is manufactured in four standard shapes: circular, horizontal elliptical, vertical elliptical, and rectangular as shown in Figure 3.4.

Circular pipe is the most common shape manufactured. The sizes produced range from 150 mm to 3600 mm. The limitation on the size of concrete pipe is usually not a problem of the capability of the producer, but a problem of transportation from the plant to the job site. There are many advantages to a round cross section, from the self-centering joint to highly efficient hydraulic characteristics.

Elliptical pipe is manufactured for special applications. Horizontal elliptical pipe is sometimes called lo-head because the pipe can be placed where the available headroom precludes the use of a standard round section. Where lateral clearance is limited, a vertical elliptical pipe can be provided. There is a major difference between horizontal and vertical elliptical pipe in the placement and amount of reinforcement required to resist vertical loading on the pipe.

Rectangular pipe is also produced by pipe manufacturers, and referred to as box units. The precast concrete box unit was developed in the early 1970s to provide an alternative to cast-in-place structures. Precast boxes have the advantage of in-plant quality control. Box units have the further advantage of being quickly installed, thus reducing time delays during construction.

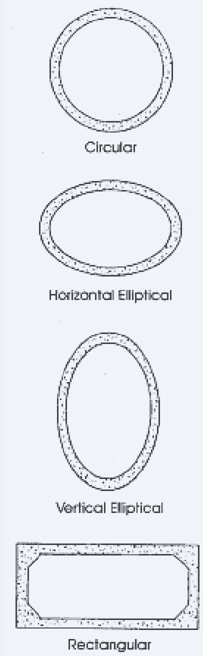


Figure 3.4 *Concrete Pipe is Manufactured in Four Common Shapes. Regional Custom and Demand Usually Determine Availability*

Circular Concrete Pipe

Tables 3.2 and 3.3 show the approximate mass and the wall thickness of common sizes of concrete pipe. This mass is based on concrete having a density of 2400 kg/m3. Concrete pipe may be produced which conforms to the requirements of the respective specifications, but with increased wall thickness and different concrete density.

Table 3.2 Dimensions and Approximate Mass of Concrete Pipe

CSA A257.1M - Non-reinforced Sewer and Culvert Pipe, Bell and Spigot Joint				
	CLASS 2		CLASS 3	
Nominal Internal Diameter mm	Minimum Wall Thickness mm	Approx. Mass kg/m	Minimum Wall Thickness mm	Approx. Mass kg/m
100	19	19	19	22
150	19	30	22	36
200	22	46	29	54
250	25	63	32	74
300	35	101	44	134
375	41	149	47	179
450	50	238	57	253
525	57	313	69	387
600	75	476	94	521
675	100	670	100	670
750	107	804	107	804
825	113	923	113	923
900	119	1042	119	1042

Table 3.3 *Dimensions and Approximate Mass of Concrete Pipe*

CSA A257.2M - Reinforced Concrete Culvert, Storm Drain, Drain and Sewer Pipe, Bell and SpigotWALL				
	Wall B		Wall C	
Nominal Internal Diameter mm	Minimum Wall Thickness mm	Approx. Mass kg/m	Minimum Wall Thickness mm	Approx. Mass kg/m
300	50	162		
375	57	216		
450	63	253		
525	69	327		
600	75	430	94	545
675	82	500	100	625
750	88	598	107	708
825	94	695	113	821
900	100	832	119	973
975	113	923	125	1090
1050	117	1057	132	1207
1200	125	1324	144	1504
1350	138	1589	157	1798
1500	150	1927	169	2192
1650	163	2295	182	2582
1800	175	2695	194	2998
1950	188	3125	207	3586
2100	200	3585	219	3958
2250	213	4078	232	4494
2400	225	4598	244	4993
2550	238	5179	257	5595
2700	250	5752	269	6190
3000	279	6344	298	7401
3600	330	9921	349	9117

Note: *This Table is based on concrete having a density of 2400 kg/m^3 .*
Actual unit masses will vary depending upon concrete density.

Elliptical Concrete Pipe

Elliptical pipe, installed with the major axis horizontal or vertical, represents two different products from the standpoint of structural strength, hydraulic characteristics and type of application. Table 3.4 includes the dimensions and approximate weights of elliptical concrete pipe.

***Table 3.4** Dimensions and Approximate Mass of Elliptical Concrete Pipe*

ASTM C507M - Reinforced Concrete Elliptical Culvert, Storm Drain and Sewer Pipe

Nominal Equivalent Round size	Minor Axis mm	Major Axis mm	Minimum Wall Thickness mm	Waterway Area m^2	Approx. Mass kg/m
450	365	575	69	.17	290
600	490	770	82	.31	446
675	550	865	88	.38	543
750	610	960	94	.47	640
825	670	1055	94	.59	707
900	730	1150	113	.68	930
975	795	1250	119	.82	1071
1050	855	1345	125	.95	1213
1200	975	1535	138	1.20	1488
1350	1095	1730	150	1.55	1838
1500	1220	1920	163	1.90	2195
1650	1340	2110	175	2.30	2597
1800	1465	2305	188	2.73	3036
1950	1585	2495	200	3.21	3497
2100	1705	2690	213	3.73	3988
2250	1830	2880	225	4.28	4538
2400	1950	3070	238	4.87	5089
2550	2075	3265	244	5.49	5543
2700	2195	3455	250	6.17	6026
3000	2440	3840	275	7.63	7336
3600	2925	4610	325	11.00	10416

***Note:** Some sizes may not be available in certain areas. This table is based on concrete having a density of 2400 kg/m3. Actual unit masses will vary depending upon concrete density.*

Horizontal Elliptical (HE) Pipe

Horizontal elliptical concrete pipe is installed with the major axis horizontal and is extensively used for minimum cover conditions, or where vertical clearance is limited by existing structures. It offers the hydraulic advantage of greater capacity for the same depth of flow than most other structures of equivalent water-way area. Under most embankment conditions, its wide span results in greater earth loadings for the same height of cover than for the equivalent size circular pipe and, at the same time, there is a reduction in effective lateral support due to the smaller vertical dimension of the section. Earth loadings are normally greater than for the equivalent circular pipe in the trench condition, since a greater trench width is usually required for HE pipe. For shallow cover, where live load requirements control the design, loading is almost identical to that for an equivalent size circular pipe with the same invert elevation.

Vertical Elliptical (VE) Pipe

Vertical elliptical concrete pipe is installed with the major axis vertical and is useful where minimum horizontal clearances are encountered, or where unusual strength characteristics are desired. Hydraulically, it provides higher flushing velocities under minimum flow conditions and carries equal flow at a greater depth than equivalent HE or circular pipe. For trench conditions, the smaller span requires less excavation than an equivalent size circular pipe, and the pipe is subjected to less vertical earth load due to the narrower trench. The structural advantages of VE pipe are particularly applicable in the embankment condition where the greater height of the section increases the effective lateral support, while the vertical load is reduced due to the smaller span.

Concrete Box Units

Precast concrete box units are useful in minimum cover and width situations, or other conditions where clearance problems are encountered for special waterway requirements or designer preference. Table 3.5 includes the dimensions and approximate mass of standard precast concrete box units. Special design precast concrete box units may be produced which conform to the requirements of the respective specifications, but in different size and cover conditions.

Table 3.5 *Dimensions and Approximate Mass of OPSS 1821 Precast Concrete Box Units*

OPSS 1821 - Precast Reinforced Concrete Box Culverts and Box Sewers

Box Size (mm)		Thickness (mm)				
Span	Rise	Top Slab	Bottom Slab	Wall	Waterway Area m^2	Approx. Mass kg/m
180	900	200	200	200	1.54	3280
1800	1200	200	200	200	2.08	3575
2400	1200	200	200	200	2.80	4170
2400	1500	200	200	200	3.52	4470
2400	1800	200	200	200	4.24	4765
3000	1500	250	250	250	4.38	6517
3000	1800	250	250	250	5.28	6889
3000	2100	250	250	250	6.18	7261
3000	2400	250	250	250	7.08	7635

Note: *Additional sizes may be available. Check with your local supplier.*

3.4 Special Sections

Special Sections are those precast concrete products other than standard pipe sections, that are used in the construction of a sewer system or culvert. Concrete pipe manufacturers can fabricate almost any size and shape of special product needed. Commonly used special sections include tees, wyes, reducers, increasers, plugs, bends and radius pipe. The use of such special sections permits a contractor to complete a pipeline more rapidly than if built-in-place structures are used.

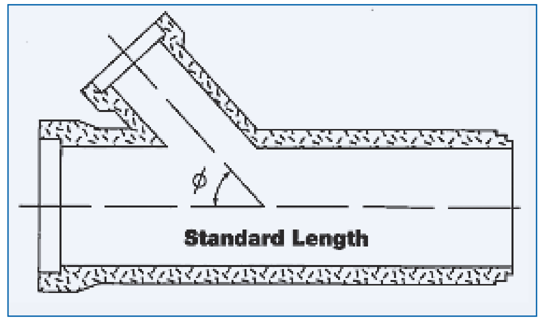
Tees and Wyes (fittings)

Special sections known as tees and wyes are used when a connection to the main line sewer must be made. These manufactured fittings are made with a branch of the connecting pipe attached to the main line at 90o for a tee and angle less than 90o for a wye, commonly 45o. These fittings allow for a watertight gasketed connection to be made at a location other than at a maintenance hole. Minimum angles possible for fittings are listed and shown in Table 3.6 and Figure 3.7

Table 3.6 Minimum Fitting Angles

Branch ID (mm)	Minimum Angle ø (deg.)	Branch ID (mm)	Minimum Angle ø (deg.)
150	22	750	34
200	22	825	38
250	22	900	42
300	22	975	46
375	22	1050	47
450	22	1200	56
525	24	1350	67
600	27	1500	90
675	30		

Figure 3.7



Note: *This table has been provided as guide only.*
For actual angles available check with local manufactures

Increasers, Reducers, Plugs

Special sections such as increasers and reducers can be manufactured and used to make a transition from a larger line to smaller at a location other than a maintenance hole. These units can be made in a variety of ways; all have the bell of one pipe size and the spigot of the other, to provide a watertight gasketed seal.

Plugs are another special section that can be provided by pipe manufacturers. These can be made to plug either the bell or spigot end of a pipe to temporarily close a pipe line during construction, or to allow for staged construction where the pipe line will be continued at a future date.

Radius Pipe

Radius, beveled or mitred pipe incorporate a specific deflection angle into the joint to allow changes in direction of sewer lines, without the installation of a maintenance hole. The radius of curvature which may be obtained by beveled pipe is a function of the deflection angle per joint, diameter of the pipe, length of the pipe sections and wall thickness.

Since the maximum permissible bevel of any pipe is dependent on the manufacturing process, the specification must be co-ordinated with the pipe manufacturer. Many manufacturers have standardized joint configurations and deflections for specific radii, and economies can be realized by utilizing standard sections.

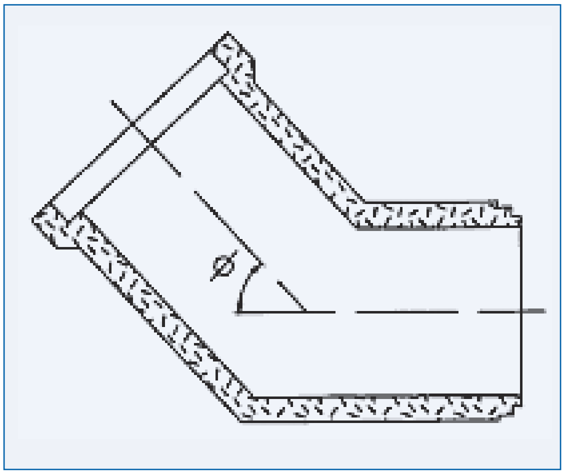
Table 3.7 *Curved Alignment Using Concrete Radius Pipe*

Pipe Diameter (mm)	Minimum Radius (m)
675 -1500	40
1650	45
1800-2400	50
2550-3600	60

Bends - Radius Pipe Alternate

Bends can also be used to accommodate a change in alignment of a pipe line. They can be manufactured to fit the radius curves as a suitable alternate for radius pipe and may be used when a shorter radius of curvature is required. Bends of any angle can be manufactured within the limitations set out below.

Figure 3.8 *Bend Angle*



Standard Bend Angles

1/4 Bend - 90˚

1/8 Bend - 45˚

1/16 Bend - 22.5˚

Table 3.8 *Maximum Bend Angles*

Pipe Diameter (mm)	Maximum Angle ø (deg.)	Pipe Diameter (mm)	Maximum Angle ø (deg.)
150	90	1200	90
200	90	1350	90
250	90	1500	84
300	90	1650	78
375	90	1800	74
450	90	1950	71
525	90	2100	67
600	90	2250	63
675	90	2400	60
750	90	2550	57
825	90	2700	54
900	90	3000	50
975	90	3600	42
1050	90		

Note: *Maximum Bend Angles have been calculated from dimensional data only. It is left to the designer to investigate hydraulic considerations. This table has been provided as a guide only. For actual angles available check with local manufactures.*

3.5 Maintenance Holes

Precast maintenance holes are universally accepted for use in sanitary and storm sewers. Precast reinforced concrete maintenance hole sections are available throughout Canada, and are generally manufactured in accordance with the provisions of CAN/CSA A257 Series M 92 specification.

A typical precast concrete maintenance hole, as shown in Figure 3.9 consists of riser sections, a top section and grade rings and, in many cases, precast base sections or tee sections. The riser sections vary in diameter, and are available in sizes from 1200 mm to 3600 mm. A number of sections may be joined vertically on top of the base or junction chamber. Most precast maintenance holes employ a tapered top section instead of a cap. These reinforced cone sections effect the transition from the inside diameter of the riser sections to the specified size of the top access. Flat caps are normally used for very shallow maintenance holes, and consist of a reinforced circular slab at least 200 mm thick for 1200 mm diameter risers, and 300 mm thick for larger riser sizes. The slab, which rests on top of the riser sections, is cast with an access opening.

Precast adjustment units, that are placed on top of either the cap or taper top section, are used for close adjustment of top elevation. Cast iron maintenance hole frames and covers are normally placed on top of the adjustment units.

The maintenance hole assembly usually includes steps inserted into the walls of the sections. Reinforcement required is primarily designed to resist handling stresses incurred before and during installation, and is more than adequate for that purpose. Such stresses are more severe than those encountered in the vertically installed maintenance hole. In normal installations, the magnitude of horizontal loads transmitted to maintenance hole risers is a fraction of that transmitted by vertical loads.

The maximum allowable depth of a typical precast concrete maintenance hole is in excess of 100 m or, for all practical purposes, unlimited. This critical or limiting factor for maintenance hole depth is the supporting strength of the base structure, or the resistance to crushing of the ends of the riser section. This phenomena, which is dependent on the relative settlement of the adjacent soil mass, does not lend itself to precise analysis. Even with extremely conservative values for soil weights, lateral pressure and friction coefficients, it may be concluded that over 100 m can be safely supported by the riser sections without end crushing, based on the assumption that provision is made for uniform bearing at the ends of the riser sections and the elimination of localized stress concentrations.

When confronted with maintenance hole depths greater than those commonly encountered, there may be a tendency to specify additional circumferential reinforcement in the maintenance hole riser sections. Such requirements are completely unnecessary and only result in increasing the cost of the maintenance hole structure.

Maintenance holes are also available in rectangular components.

A number of joint sealants may be used for maintenance hole risers and tops, including mortar, mastic, rubber gaskets or combinations of these three basic types for sealing purposes. Consideration should be given to maintance hole depth, the presence of groundwater and the minimum allowable leakage rates in the selection of specific joint requirements.

Precast concrete maintenance holes are usually installed by the same crew that is installing the pipeline, and a maintenance hole of any depth can be constructed in the field by combining various length sections. Standard maintenance hole riser sections are 1200 mm, 1500 mm, 1800 mm, 2400 mm, 3000 mm and 3600 mm in diameter, varying in length. The riser section may be cast with an

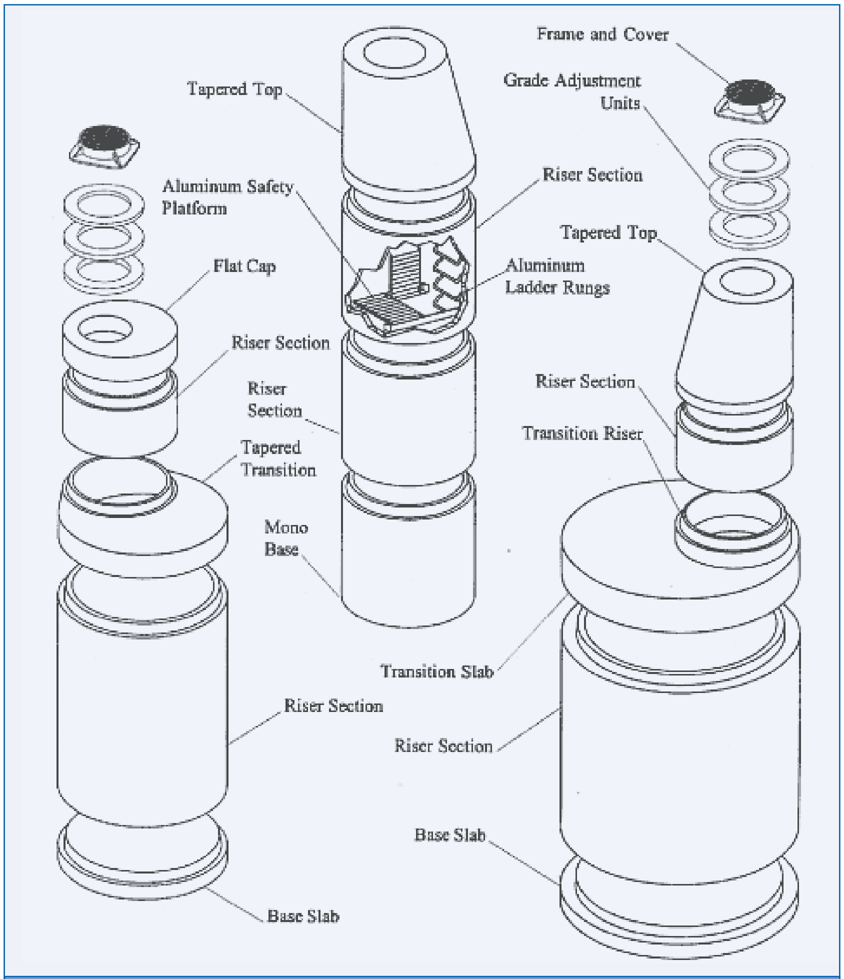


Figure 3.9 *Typical Configuration of PrecastManhole Sections*

integral base as part of the maintenance hole section, or the maintenance hole section may be placed on a precast or cast-in-place base. Maintenance holes are used at changes in size, alignment, or grade of the pipeline, as well as for convenience in maintenance.

For pipelines of 1200 mm in diameter or larger, a precast maintenance hole tee may be used. Subsequent riser sections could be placed on top of the precast tee. This allows installation of the pipeline to proceed with less delay or interruption. It also eliminates the need to use special lengths of pipe to accommodate the maintenance hole. Maintenance hole tees may not be appropriate where changes in elevation or direction exist.

3.6 Quality Assurance

Comprehensive testing and quality assurance programs are maintained by manufacturers to ensure that the precast concrete pipe available today meets the high standards necessary for construction and replacement of today's infrastructure. Through the OCPA, an industry regulated Plant Prequalification Program is implemented to certify each manufacturing plant for the production of precast concrete pipe and box units.

Testing of the raw materials and finished products is carried out in accordance with applicable standards such as CAN/CSA-A257 Series-M92, CAN/CSA-A23.1-M90, OPSS 1821, ASTM C507 and the Prequalification Requirements For Manufacturers of Concrete Sewer Pipe and Precast Reinforced Box Units. A complete listing of standards relating to precast concrete pipe, maintenance holes and box units is presented in Chapter 2.

The manufacturing process involves testing and verification of raw materials, monitoring of the concrete mixing and casting processes, verification of concrete properties and tests to verify performance of the finished product. There are several tests that can be performed in situ to verify the integrity of the installed pipeline.

Raw Materials

The first step in the process of manufacturing concrete pipe is to ensure that the raw materials used are of high quality, consistent and within the requirements established by the manufacturer.

Coarse and fine aggregates are sampled and run through a sieve analysis on a regular basis to ensure that they conform to the gradation established by the manufacturer. In addition, these materials should meet any requirements established by the Ministry of Transportation Ontario for concrete aggregates, as well as those set out in the Plant Prequalification Program.

Process Control

Manufactures routinely check several aspects of the manufacturing process as part of their quality control and testing program. Batching scales for raw materials are checked and certified yearly to ensure accuracy. Measured raw material proportions, moisture content and mixing times are checked against design. Placement and spacing of reinforcement are verified prior to placement of fresh concrete.

Concrete specimens either cast from fresh concrete or obtained from cured product are tested for compressive strength and absorption. Some specimens may be subjected to freeze-thaw or salt scaling tests to verify durability of the cured concrete.

Equipment used to form concrete pipe are gauged against strict tolerances on a regular basis. All joint forming rings are checked when received new, and at least once yearly, or prior to use, if not used for a period of time. Records of all such dimensional checks are kept as part of the prequalification requirements.

Finished Product

The final stage in the process of manufacturing precast concrete pipe involves performing checks and tests on the finished product itself. All products are checked visually for flaws, or other obvious defects. Pipe joints are checked with gauges to ensure dimensional accuracy.

Pipe strength is verified through the use of the Three-Edge Bearing test (TEB). The TEB test applies a linear load to a pipe section set in a special test frame. The pipe is placed on two rubber bearing strips spaced a specified distance apart on the base of the test machine. A loading beam, with a third rubber bearing strip, is lowered onto the top of the pipe.

A specified load is applied by the test frame through the three rubber bearing strips to the pipe, hence the name Three-Edge Bearing. A predetermined proportion of pipe are subjected to this TEB test to ensure that the load bearing capacity of the finished product meets the requirements of the pipe strength classification.

Watertightness of pipe and maintenance holes is verified through the use of hydrostatic testing. Representative sections of product are assembled with gasketed joints, bulkheaded and filled with water. A specified pressure is placed on the assembly and held for a predetermined period of time for which there must be no evidence of leakage.

In addition to the hydrostatic test, vacuum testing is used as a means of rapid verification of the integrity of single pipe. Currently, all pipe supplied for sanitary sewers from OCPA prequalified suppliers are being vacuum tested and marked for identification, with the previous symbol.

Field Testing

Once pipe have been installed, there are several tests that can be performed to verify the integrity of the line. One test commonly used where the ground water level is above the pipe obvert, is the infiltration test. This test measures the volume of ground water infiltrating, and is measured as the volume of infiltration per unit length of pipe per unit of pipe diameter, for a given period of time.

An exfiltration test can be used where ground water levels are below the pipe obvert, or other factors make it more suitable. The pipe line is filled with water, and the drop in water level is measured over time.

Low pressure air testing may be conducted by pressurizing a section of the installed pipe line and recording loss in pressure over time, compared to allowable limits. Finally, testing of individual joints with air pressure in a manner similar to the low pressure test may be performed to indicate proper joint assembly.

These test methods are covered in detail in Chapter 6, Construction and Field Testing. For more information please refer to the appropriate section within that chapter.

Reference Publications

CSA	- Canadian Standards Association
CAN/CSA-A5-M88	- Canadian Standards Association
	- Portland Cement
CAN/CSA-A362-M88	- Canadian Standards Association
	- Blended Hydraulic Cement
G30.5-M1983	- Canadian Standards Association
	- Welded Wire Fabric for Concrete Reinforcement
G30.15-M1983	- Canadian Standards Association
	- Welded Deformed Steel Wire Fabric For Concrete Reinforcement
CAN/CSA-A23.1/A23.2-M90	- Canadian Standards Association
	- Concrete Materials & Methods of Concrete Construction/
	Methods of Test for Concrete
G30.3-M1983	- Canadian Standards Association
	- Cold-Drawn Steel Wire for Concrete Reinforcement
G30.14-M1983	- Canadian Standards Association

4 Structural Design

This chapter deals with the design of buried pipe systems using PipePac software developed by the OCPA in partnership with others, and the traditional Spangler and Marston method (called SAMM) outlined in the software and developed by the American Concrete Pipe Association. Both approaches to pipe design are valid. It is left to the choice of the designer which approach will be used. The OCPA encourages the use of PipePac since it introduces Cost Analysis of Pipe Envelope (CAPE) and Life Cycle Analysis (LCA) sub-programs into the design process, and provides for comparisons of flexible and rigid systems.

4.1 Glossary and Equation

Glossary and Load Terms

A a constant corresponding to the shape of the pipe

A_{LL} distributed live load area on subsoil plane at outside top of pipe, square metres

B_c outside horizontal span of the pipe, metres

B'_c outside vertical height of the pipe, metres

B_d width of trench at top of pipe, metres

$B_{d\,t}$ transition width at top of pipe, metres

B'_d average of the width of trench at top of pipe Bc and the outside horizontal span of the pipe Bd for negative projecting embankment installations, metres

B_f bedding factor

$B_{f\,e}$ bedding factor, embankment

Bf_{LL} bedding factor, live load

Bf_o minimum bedding factor, trench

Bf_t fixed bedding factor, narrow trench

Bf_v variable bedding factor, trench

B_t maximum width of excavation ahead of pipe or tunnel, metres

C pressure coefficient for rail loads

C_c load coefficient for positive projecting embankment installations

C_d load coefficient for trench installations

C_n load coefficient for negative projecting embankment installations

C_t load coefficient for jacked or tunneled installations

c coefficient of cohesion of undisturbed soil, Newtons per square metre (Pascals)

D inside diameter of circular pipe, millimetres

D-load the supporting strength of a pipe loaded under three-edge-bearing test conditions expressed in Newtons per linear metre per millimetre of inside diameter or horizontal span

$D_{0.3}$ the maximum three-edge-bearing test load supported by a concrete pipe before a crack occurs having a width of 0.3 mm measured at close intervals, throughout a length of at least 300 mm, expressed as D-load

D_o outside diameter of the pipe, millimetres

D_{ult} the maximum three-edge-bearing test load supported by a pipe, expressed as a D-load

d depth of bedding material below pipe, millimetres

d_c deflection of the vertical height of the pipe

e base of natural logarithms (2.718)

F.S. factor of safety

g gravitational constant, metres per second per second

H height of backfill or fill material above top of pipe, metres

H_e height of the plane of equal settlement above top of pipe, metres

I_f impact factor for live loads

K lateral pressure ratio for backfill or backfill material

L length of ALL parallel to longitudinal axis of pipe, metres

L_e effective live load supporting length of pipe, metres

μ coefficient of internal friction of fill material

μ' coefficient of sliding friction between the backfill material and the trench walls

m	lateral pressure fraction is the fractional part or ratio of the outside diameter of the pipe over which the lateral pressure is effective
N	a parameter which is a function of the distribution of the vertical load and vertical reaction
P	wheel load, kilograms
p	projection ratio for positive projecting embankment installations; equals vertical distance between the top of the pipe and the natural ground surface, divided by the outside vertical height of the pipe
p'	projection ratio for the negative projecting installations; equals vertical distance between the top of the pipe and the top of the trench, divided by the trench width
p_o	live load pressure at the surface, Pascals
q	the ratio of total lateral pressure to the total vertical load
R	inside vertical rise of the elliptical pipe or box sections, millimetres
r_{sd}	settlement ratio
S	inside horizontal span of elliptical pipe or box sections, millimetres
S_L	outside horizontal span of pipe Bc or width of ALL transverse to longitudinal axis of pipe, whichever is less, metres
s_d	compression of the fill material in the trench within the height p¥Bd for negative projecting embankment installations
s_f	settlement of the pipe into its bedding foundation
s_g	settlement of the natural ground or compacted fill surface adjacent to the pipe
s_m	settlement of the adjacent soil of p¥B¥c height for positive projecting embankment conditions
$T.E.B$	three-edge-bearing strength, kilonewtons per metre
W_E	earth load, Newtons per metre
W_L	live load on pipe, Newtons per metre
W_T	total live load on pipe, Newtons
w	density of backfill material, kilograms per cubic metre
w_L	average pressure intensity of live load on sub soil plane at outside top of pipe, Pascals
x	a parameter which is a function of the area of the vertical projection of the pipe over which active lateral pressure is effective

Glossary of Economic Terms

AC	annualized costs
FV	future value
PV	present value
C	initial cost
I	inflation rate
i	interest rate
i¥	discount rate (I-i)
n	number of years or periods

Equations

(4.1) Variable Bedding Factor, Trench - 3 Edge Bearing

$$B_{fv} = \frac{(B_{fe} - B_{fo})(B_d - B_c)}{B_{d_t} - B_c} + B_{fo}$$

(4.2) Trench Variable Bedding Factor - Spangler and Marston

$$B_{fv} = (B_{fe} - B_{ft}) \left[\frac{B_d - (B_c + 0.3)}{B_{dt} - (B_c + 0.3)} \right] + B_{ft}$$

(4.3) Three-Edge-Bearing Strength

$$T.E.B. = \left[\frac{W_L}{B_{fLL}} + \frac{W_E}{B_{fe}} \right] F.S.$$

(4.4) D-Load

$$D\text{-}load = \left[\frac{W_L}{B_{fLL}} + \frac{W_E}{B_{fe}} \right] \frac{F.S.}{S}$$

(4.5) D-Load

$$D\text{-}load = \left[\frac{W_L + W_E}{B_{fe}} \right] \frac{F.S.}{S}$$

(4.6) Trench Backfill Load

$$W_E = C_d \, wg \, B_d^2$$

(4.7) Trench Load Coefficient

$$C_d = \frac{1 - e^{-2K\mu' \frac{H}{B_d}}}{2K\mu'}$$

(4.8) Positive Projecting Embankment Fill Load

$$W_E = C_c\, Wg\, B_c^{2}$$

(4.9) Positive Projecting Embankment Load Coefficient (Complete Condition)

$$C_c = \frac{e^{2K\mu\frac{H}{B_c}} - 1}{2K\mu} \quad when\ H \leq H_e$$

(4.10) Positive Projecting Embankment Load Coefficient (Incomplete Condition)

$$C_c = \frac{e^{2K\mu\frac{H_e}{B_c}} - 1}{2K\mu} + \left(\frac{H}{B_c} - \frac{H_e}{B_c}\right) e^{2K\mu\frac{H_e}{B_c}} \quad when\ H > H_e$$

(4.11) Settlement Ratio for Positive Projecting Embankment

$$r_{sd} = \frac{(s_m + s_g) - (s_f + d_c)}{s_m}$$

(4.12) Negative Projecting Embankment fill Load

$$W_E = C_n\, w\, g\, B_d^{2}$$

(4.13) Negative Projecting Embankment Load Coefficient (Complete Condition)

$$C_n = \frac{e^{-2K\mu\frac{H}{B_d}} - 1}{-2K\mu} \quad when\ H \leq H_e$$

(4.14) Negative Projecting Embankment Load Coefficient (Incomplete Condition)

$$C_n = \frac{e^{-2K\mu\frac{H_e}{B_d}} - 1}{-2K\mu} + \left(\frac{H}{B_d} - \frac{H_e}{B_d}\right)e^{-2K\mu\frac{H_e}{B_d}} \quad when\ H > H_e$$

(4.15) Settlement Ratio for Negative Projecting Embankment

$$r_{sd} = \frac{s_g - (s_d + s_f + d_c)}{s_d}$$

(4.16) Jacked or Tunneled Earth Load

$$W_E = C_t w g B_t^2 - 2cC_t B_t$$

(4.17) Jacked or Tunneled Load Coefficient

$$C_t = \frac{1 - e^{-2K\mu'\frac{H}{B_t}}}{2K\mu'}$$

(4.18) Average Live Load Pressure Intensity on Subsoil Plain

$$w_L = \frac{Pg\,(I_f)}{A_{LL}}$$

(4.19) Total Live Load

$$W_T = w_L L S_L$$

(4.20) Live Load on Pipe

$$W_L = \frac{W_T}{L_e}$$

(4.21) Effective Supporting Length

$$L_e = L + 1.75\,(0.75\,B_c)$$

(4.22) Railroad Live Load

$$W_L = C p_o B_c I_f$$

(4.23) Bedding Factor for Positive Projecting Embankment and Induced Trench

$$B_f = \frac{A}{N - xq}$$

(4.24) Lateral Pressure Term (Circular Pipe)

$$q = \frac{pK}{C_c}\left(\frac{H}{B_c} + \frac{p}{2}\right)$$

(4.25) Lateral Pressure Term (Elliptical Pipe)

$$q = \frac{pB'_c K}{C_c B_c^{\,2}}\left(H + \frac{pB'_c}{2}\right)$$

(4.26) Three-Edge Bearing Strength

$$T.E.B. = \frac{W_L + W_E}{B_f}\,F.S.$$

(4.27) D-Load (Circular Pipe)

$$D\text{-}load = \frac{W_L + W_E}{B_f D}\,F.S.$$

(4.28) D-Load (Elliptical Pipe)

$$D\text{-}load = \frac{W_L + W_E}{B_f S}\,F.S.$$

(4.29) Present Value

$$PV = C \left[\frac{1}{(1 + i')}\right]^n$$

(4.30) Annualized Costs

$$AC = PV \left[\frac{i'(1 + i')^n}{(1 + i')^{n-1}}\right]$$

(4.31) Future value

$$FV = PV(1 + i')^n$$

4.2 PipePac

PipePac is a software package developed for designers of buried infrastructure systems. Specifiers and purchasers of materials are responsible for selecting the appropriate material for a drainage system. A complete manual for operating the program is built into the Help menu to guide you through the analysis.

LCA (Life Cycle Analysis), CAPE (a windows version of Cost Analysis of Pipe Envelope) and SAMM (Spangler & Marston Method)/3EB (Three Edge Bearing) have been combined in PipePac. The software is designed to share input data and results among each of the three independent sub-programs (e.g., 3EB results are used to estimate pipe embedment costs in CAPE). PipePac is designed for a Windows environment on a PC, with analysis produced in metric or imperial units, and a choice of either English or French language text. It is available on the Internet for easy downloading. The OCPA has produced the software in cooperation with the American Concrete Pipe Association, Canadian Concrete Pipe Association, and TubÈcon (the association of QuÈbec concrete pipe producers).

Standards built into the program are those used throughout North America. Data can be selected from default tables, or entered manually. The following are the features of PipePac that are expected to be of great interest to planners and engineers:

- Easy comparison of flexible and rigid systems,
- Integrated analysis using LCA, CAPE and SAMM/3EB,
- LCA, CAPE and SAMM/3EB programs can be run independently of each other,
- Choice of analysis in metric or imperial units,
- Choice of language - English or French,
- Choice of standards to follow CSA or ASTM,
- Technical support,
- Software can be copied and accessed free of charge,
- Built-in support manual and instructions using Windows context sensitive help,
- Calculates earth loads and pipe classes for concrete pipe,
- Compares installation costs and life cycle cost,
- User friendly Microsoft™ Windows™ based program.

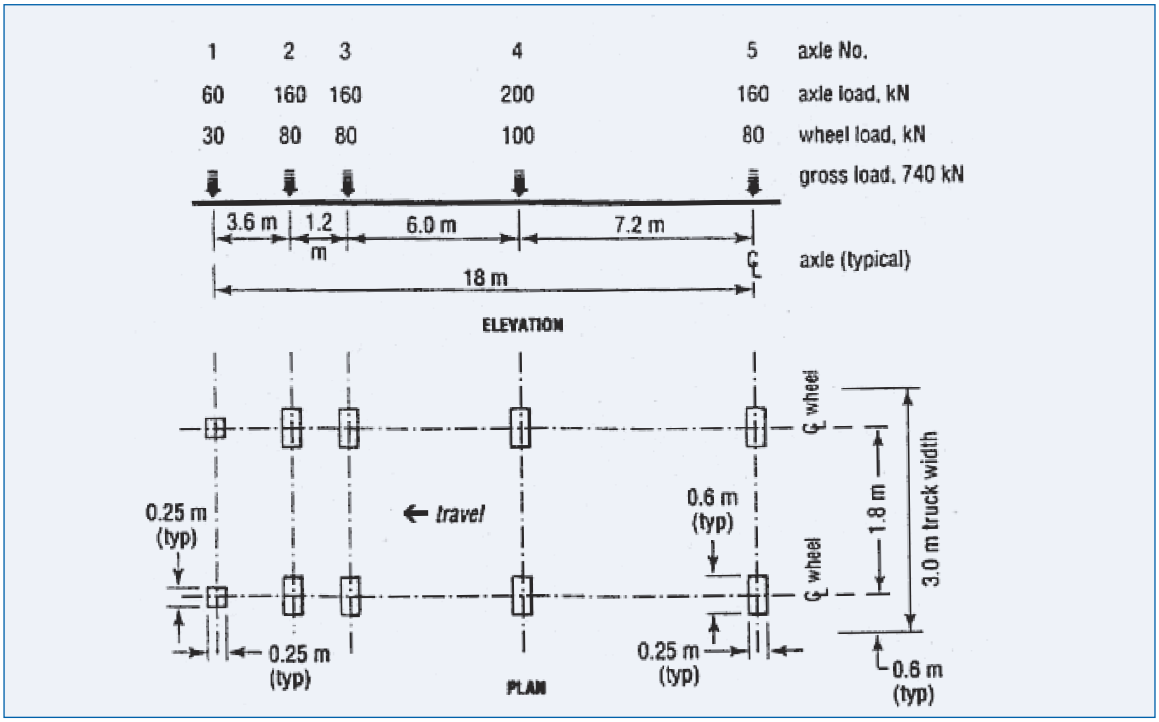
The program offers the following modules.

4.2.1 Earth Loads - 3EB
The program 3EB computes earth loads on concrete pipe in accordance with the methods presented in the Concrete Pipe Design Manuals of the Ontario Concrete Pipe Association and American Concrete Pipe Association. 3EB analyzes underground pipelines for standard installation conditions, including trench, positive and negative projecting embankments, as well as jacked and tunneled pipe.

3EB computes earth loads on concrete pipe in accordance with the methods presented in the American Concrete Pipe Associationís publications, Design Data 40: Standard Installations and Bedding Factors for the Indirect Design Method (September, 1995) and Concrete Pipe Handbook (January, 1988). The acronym 3EB stands for three-edge bearing load test as specified in CAN/CSA-A257.0-M92 (Methods for Determining Physical Properties of Circular Concrete Pipe, Manhole Sections, Catch Basins and Fittings). These loads are derived by using the indirect design method, which relates the supporting strength of buried pipe to the strength obtained in a three-edge-bearing test through the use of bedding factors.

The program analyzes all standard live loads, such as aircraft and railroad loadings, as well as AASHTO and OHBD Truck (Figure 4.1). 3EB utilizes standard CAN/CSA-A257.2-M92 safety factors for dead and live loads, which may be overridden by the user. The program also allows the user to perform calculations in either metric or imperial units.

Figure 4.1 *OHBD Truck*



The installations incorporated in the program are consistent with research and field tests performed over the last 30 years, by the American Concrete Pipe Association. The research results provided the basis for the more advanced beddings where pipe-soil interaction, based on the direct design of the pipe for the installed condition, is taken into account. This resulted in the acceptance of the four Standard Installations, and a direct design procedure by the American Society of Civil Engineers. The standard entitled, ASCE Standard Practice for Direct Design of Buried Concrete Pipe in Standard Installations, SIDD, was published in 1993.

This procedure is modern and practical for designing pipe interactions based on the state-of-the-art knowledge about the structural behaviour of buried concrete pipe. When utilizing these installations, care must be taken to ensure that the soil and compaction requirements for the design of a particular type of installation can be achieved in the field.

In addition, Section 17, Division 1 of the American Association of State Highway and Transportation Officials (AASHTO), Standard Specifications for Highway Bridges, has recently been modified so that both indirect and direct design methods are based on the same beddings.

The Indirect Design Method is the most commonly used procedure for specifying concrete pipe. In this approach, the engineer determines the required strength of pipe and then chooses a class of pipe under CAN/CSA-A257 that meets the requirement.

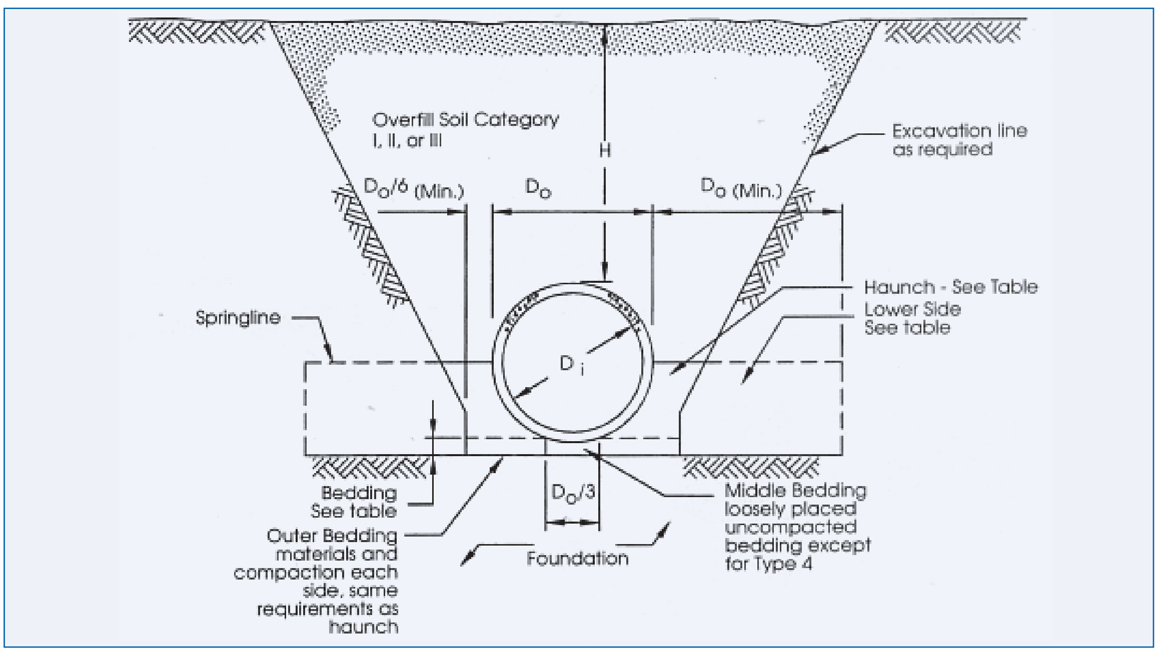
In some extreme cases, the strength requirements may exceed the established pipe classifications of CAN/CSA-A257, and a more exacting design may be appropriate. In this situation, the engineer can use the Direct Design Method to determine the reinforcement required to meet the specific project criteria.

4.2.2 Trench

This type of installation is used in relatively narrow excavations, and the pipeline is covered with earth backfill. The backfill extends to the original ground surface. The trench load theory is based upon certain applied mechanics assumptions concerning the properties of the materials involved. These assumptions are:

Earth loads on the pipe develop as the backfill settles,
The resulting earth load on the pipe is equal to the weight of the material in the trench above the top of the pipe minus the shearing (frictional) forces on the sides of the trench,
Cohesion is negligible because with cohesive soils, considerable time must elapse before effective cohesion between the backfill material and the sides of the trench can develop. Therefore, the assumption is no cohesion, which yields the maximum probable load on the pipe,
For a rigid pipe, the sidefills may be relatively compressible and the pipe will carry a large portion of the load developed over the entire width of the trench,
Active lateral pressure against the pipe is usually neglected, but it should be taken into account if the trench width exceeds the defined narrow trench widths.
The type of bedding is one of the factors that determines the supporting strength of buried pipe. Types of bedding for the trench condition are shown in Figure 4.2 and Table 4.1

Figure 4.2 *Standard Trench Installation*



Other beddings can be selected for conditions other than those defined above. When another bedding is selected, the designer must specify the bedding factor to be used.

The original research for the standard installations was performed for circular pipe, and all the resulting design parameters specifically apply to circular pipe. However, the desire to have quantifiable beddings with detailed soil and compaction requirements applies to all pipe in general. Therefore, arch and elliptical pipe also use Type 2 and Type 3 installations instead of the previous Class B and Class C beddings. Although the Standard Installations beddings are used, the Marston/Spangler bedding factors and design equations are still used for computing the D-load for arch and elliptical pipe, since no specific research has been done for these shapes. This is a conservative approach to the design of arch and elliptical pipe since a Type 2 installation provides slightly more support than a Class B bedding. Similarly, a Type 3 installation provides slightly more support than a Class C bedding. The input screens used for arch and elliptical pipe are somewhat different than those used for circular pipe, to reflect the difference in the design theory used.

In early publications of the Iowa Engineering Experiment Station, both Spangler and Schlick postulated that some active lateral pressure is developed in trench installations, before transition width is reached. Experience indicates that the active lateral pressure increases as the trench width increases, from a very narrow width to the transition width, provided the sidefill is compacted.

For circular pipe beddings, the ìminimumî bedding factor (for a trench width equal to the outside pipe diameter) represents the condition at the interface of the pipe wall and soil. A conservative linear variation is assumed between the minimum bedding factor and the bedding factor for the embankment condition, which begins at transition width. The equation for the variable trench bedding factor used with the standard installation is:

(4.1)

$$B_{fv} = \frac{(B_{fe} - B_{fo})(B_d - B_c)}{B_{d_t} - B_c} + B_{fo}$$

For arch and elliptical pipe, the minimum bedding factor for a given bedding is the ìfixedî bedding factor. This bedding factor is based on a narrow trench installation where no lateral pressure is developed. Defining the narrow trench width as a trench having a width at the top of the pipe equal to, or less than the outside horizontal span plus 300 mm, and assuming a conservative linear variation to the transition width, the variable trench bedding factor can be determined by:

(4.2)

$$B_{fv} = (B_{fe} - B_{ft})\left[\frac{B_d - (B_c + 0.3)}{B_{dt} - (B_c + 0.3)}\right] + B_{ft}$$

Table 4.1 *Standard Installation Soils and Minimum Compaction Requirements*

INSTALLATION TYPE	BEDDING THICKNESS	HAUNCH AND OUTER BEDDING**	LOWER SIDE*
Type 1	D_0 / 24 minimum not less than 75 mm. If rock foundation, use D_0 / 12 minimum not less than 150 mm.	95% CATEGORY I	90% CATEGORY I, 95% CATEGORY II or 100% CATEGORY III
Type 2	D_0 / 24 minimum not less than 75 mm. If rock foundation, use D_0 / 12 minimum not less than 150 mm.	90% CATEGORY I or 95% CATEGORY II	85% CATEGORY I, 90% CATEGORY II or 95% CATEGORY III
Type 3	D_0 / 24 minimum not less than 75 mm. If rock foundation, use D_0 / 12 minimum not less than 150 mm.	85% CATEGORY I,	85% CATEGORY I, 90% CATEGORY II or 95% CATEGORY III
Type 4	D_0 / 24 minimum not less than 75 mm. If rock foundation, use D_0 / 12 minimum not less than 150 mm.	No compaction required, except if CATEGORY III, use 85% CATEGORY III	No compaction required, except if CATEGORY III, use 85% CATEGORY III

NOTES:

1. *Compaction and soil symbols - i.e. "95% CATEGORY" - refers to Category I soil material with minimum Standard Proctor compaction of 95%. See Table 4.2 for equivalent Modified Proctor values.*
2. *The trench top elevation shall be no lower than 0.1H below finished grade or, for roadways, its top shall be no lower than an elevation of 0.3 m below the bottom of the pavement base material.*
3. *Soil in bedding and haunch zones shall be compacted to at least the same compaction as specified for the majority of soil in the backfill zone.*
4. *The trench width shall be wider than shown if required for adequate space to attain the specified compaction in the haunch and bedding zones.*
5. *For trench walls that are within 10 degrees of vertical, the compaction or firmness of the soil in the trench walls and lower side zone need not be considered.*
6. *For trench walls with greater than 10 degree slopes that consist of embankment, the lower side shall be compacted to at least the same compaction as specified for the soil in the backfill zone.*

* * *For soil Category Description and Comparison see Table 4.2*

Table 4.2 Equivalent USCS and AASHTO Soil Classifications for SIDD Soil Designations

SIDD SOIL	REPRESENTATIVE SOIL TYPES		PERCENT COMPACTION	
	USCS	ASHTO	STANDARD PROCTOR	MODIFIER PROCTOR
GRAVELLY SAND (CATEGORY I)	SW, SP GW, GP	A1, A3	100 95 90 85 80 61	95 90 85 80 75 59
SANDY SILT (CATEGORY II)	GM, SM, ML Also GC, SC with less than 20% passing #200 sieve	A2, A4	100 95 90 85 80 49	95 90 85 80 75 46
SILTY CLAY (CATEGORY III)	CL, MH GC, SC	A5, A6	100 95 90 85 80 45	90 85 80 75 70 40
	CH	A7	100 95 90 45	90 85 80 40

Soil Type Legend

AASHTO . . . . .American Association of State Highway and Transportation Officials
USCS . . . . .United Soil Classification System
SW . . . . .well graded sand
SP . . . . .poorly graded sand
GW . . . . .well graded gravel
GP . . . . .poorly graded gravel
ML . . . . .sandy silt
SM . . . . .silty sand
GM . . . . .silty gravel
GC . . . . .clayey gravel, with less than 20% passing #200 sieve
SC . . . . .clayey sand, with less than 20% passing #200 sieve
CL . . . . .silty clay
MH . . . . .inorganic elastic silt
GC . . . . .clayey gravel
SC . . . . .clayey sand
CH . . . . .plastic clay

4.2.3 Embankment

These installations are subdivided into two groups:

Positive projection, where pipe is installed with the top of the pipe projecting above the surface of the natural ground, or compacted fill, and then covered with earth fill. This type also includes pipe installed in extremely wide trenches. This installation is also referred to as transition width design.

Negative projection, where pipe is installed in relatively shallow trenches of such depth that the top of the pipe is below the level of the natural ground surface or compacted fill, and then covered with earth fill to a height appreciably greater than the distance from the natural ground surface, or original compacted fill surface, to the top of the pipe.

Types of bedding for the embankment condition are shown in Figure 4.3 and Table 4.3. In determining the loading on embankment installations, 3EB utilizes the projection ratio, settlement ratio, lateral pressure ratio, and lateral pressure fraction.

For positive projecting pipe, the projection ratio, p, is the vertical distance between the outside top of the pipe and the natural ground surface, divided by the outside horizontal diameter of the pipe.

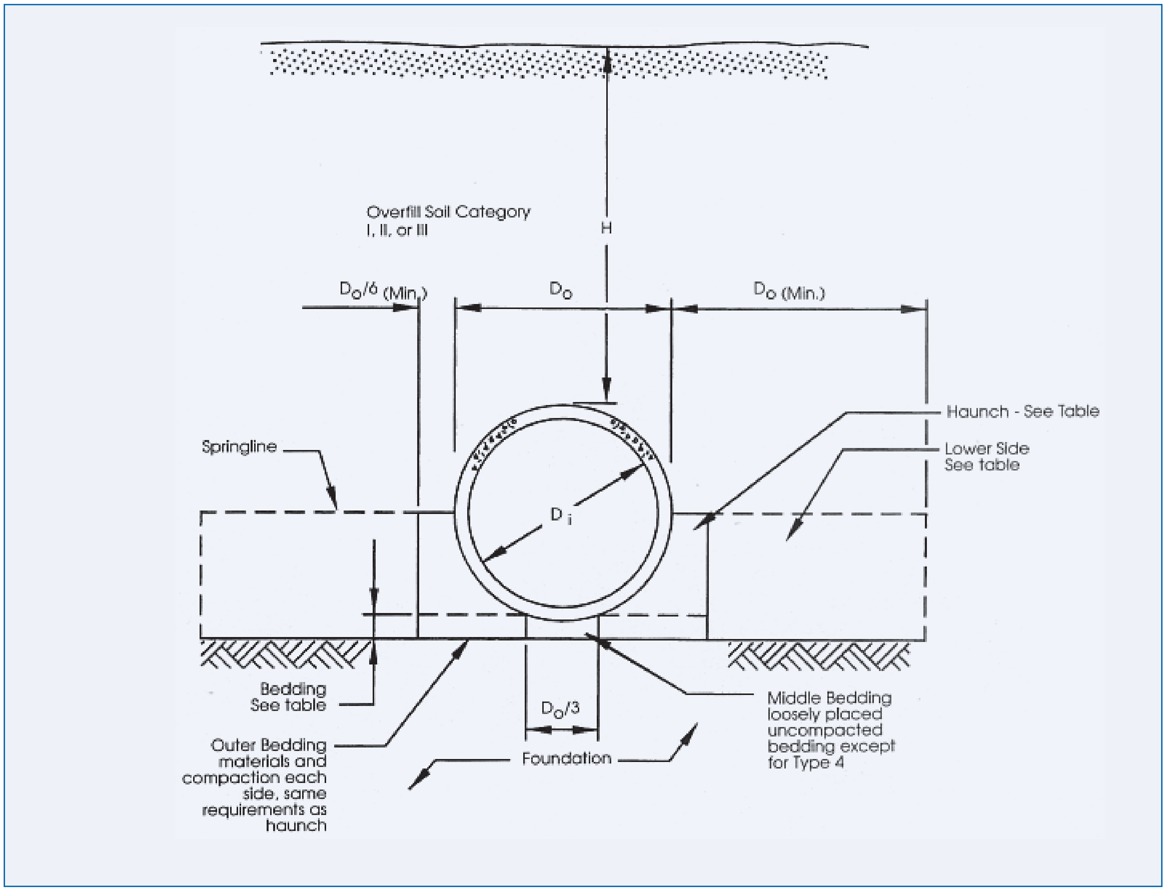


Figure 4.3 *Standard Embankment Installation*

The settlement ratio, rsd, is the factor which determines the direction of action of the frictional forces. It is dependent upon the settlement and deflection of the pipe, and the compression of the soil adjacent to the pipe. These values range from 0.0 to 1.0 for positive projection conditions and -1.0 to 0.0 for negative projection conditions.

The lateral pressure ratio, K, is the ratio of the unit lateral soil pressure to unit vertical soil pressure, and is commonly referred to as the Rankineís Coefficient of Active Earth Pressure. For positive projecting embankment installations using the Marston/Spangler beddings, a value of 0.33 is usually sufficiently accurate for design. When using Standard Installation beddings, the lateral pressure ratio does not need to be input.

The lateral pressure fraction, m, is the fractional part, or ratio of the outside diameter of the pipe over which the lateral pressure is effective.

Since the fill material can be compacted more readily in embankment installations, the effect of active lateral pressure in a positive projection condition is considered in evaluating the bedding factor. The supporting strength of the pipe is a function of the distribution of the vertical load, the class or type of bedding, the magnitude of the active soil pressure against the sides of the pipe and the area of the pipe over which the active lateral pressure is effective.

The 3EB computer program requires the user to input the projection ratio, settlement ratio, lateral pressure ratio, and lateral pressure fraction for the arch and elliptical pipe beddings, before it will calculate a bedding factor. For circular pipe, using the Standard Installations design procedures, these parameters already have default values associated with them and need not be input by the user.

Table 4.3 Standard Embankment Installation Soils and MinimumCompaction Requirements

INSTALLATION TYPE	BEDDING THICKNESS	HAUNCH AND OUTER BEDDING**	LOWER SIDE*
Type 1	D_0 / 24 minimum not less than 75 mm. If rock foundation, use D_0 / 12 minimum not less than 150 mm.	95% CATEGORY I	90% CATEGORY I, 95% CATEGORY II or 100% CATEGORY III
Type 2	D_0 / 24 minimum not less than 75 mm. If rock foundation, use D_0 / 12 minimum not less than 150 mm.	90% CATEGORY I or 95% CATEGORY II	85% CATEGORY I, 90% CATEGORY II or 95% CATEGORY III
Type 3	D_0 / 24 minimum not less than 75 mm. If rock foundation, use D_0 / 12 minimum not less than 150 mm.	85% CATEGORY I,	85% CATEGORY I, 90% CATEGORY II or 95% CATEGORY III
Type 4	D_0 / 24 minimum not less than 75 mm. If rock foundation, use D_0 / 12 minimum not less than 150 mm.	No compaction required, except if CATEGORY III, use 85% CATEGORY III	No compaction required, except if CATEGORY III, use 85% CATEGORY III

NOTES:

1. *Compaction and soil symbols - i.e. "95% CATEGORY I" refers to Category I soil material with a minimum Standard Proctor compaction of 95%. See Table 4.2 for equivalent Modified Proctor values.*
2. *Soil in the outer bedding, haunch, and lower side zones, except within Do/3 from the pipe springline, shall be compacted to at least the same compaction as the majority of soil in the overfill zone.*

3. Subtrenches

3.1 A subtrench is defined as a trench with its top below finished grade by more than 0.1H or, for roadways, its top is at an elevation lower than 0.3 m below the bottom of the pavement base material.

3.2 The minimum width of a subtrench shall be 1.33 Do, or wider if required for adequate space to attain the specified compaction in the haunch and bedding zones.

3.3 For subtrenches with walls of natural soil, any portion of the lower side zone in the subtrench wall shall be at least as firm as an equivalent soil placed to the compaction requirements specified for the lower side zone. It shall also be as firm as the soil in the overfill zone, or shall be removed and replaced with soil compacted to the specified level.

** * For soil Category Description and Comparison see Table 4.2*

4.2.4 Trenchless - Jacking and Tunneling

Two types of loads are imposed upon concrete pipe installed by tunneling and jacking methods; axial and earth loads. The axial load is due to jacking pressures applied during installation. The earth load is due to the overburden, with some possible influence from live loadings.

Axial loadings are not considered by the program in the design analysis. 3EB will only calculate the loads due to earth and live loadings. Refer to section 4.3 for further information on axial loads.

Major factors influencing the vertical earth load on pipe installed by jacking are:

- Weight of the prism of earth directly above the bore
- Upward shearing or frictional forces between the prism of earth directly above the bore and the adjacent earth
- Cohesion of soil

The vertical earth load on the horizontal plane at the top of the bore, within the width of the excavation, is equal to the weight of the prism of earth above the bore minus the upward frictional forces, and minus the cohesion of the soil along the limits of the prism of the soil over the bore. The user must select an appropriate value for cohesion for the type of soil being jacked through. These values range from 0 to 48 kPa for soils classified as loose dry sand to hard clay, respectively.

Since the jacking method of construction has the potential to allow positive contact around the lower exterior surface of the pipe and the surrounding earth, an ideal bedding condition can be provided. This positive contact can be obtained by close control of the bore excavation to the outside dimensions and shape of the pipe or, if the bore is over-excavated, the space between the pipe and the bore can be filled with sand, grout, concrete, or other suitable material. For this type of installation, a bedding factor of 3.0 is recommended. If the bore is slightly over-excavated, and the space between the pipe and the bore is not filled, a minimum bedding factor of 1.9 is recommended. 3EB defaults to a bedding factor of 3.0 for a grouted bore, and 1.9 for a non-grouted bore.

Pipe Strength
Pipe strengths in 3EB are calculated in terms of either the 0.3 mm crack strength ($D_{0.3}$) or ultimate strength in the three-edge bearing test for reinforced concrete pipe (D_{ult}). For non-reinforced pipe, it is in terms of ultimate strength. The strength of non-reinforced pipe is given in terms of a three-edge bearing load (D_{ult}). The equation for three-edge bearing load on a non-reinforced pipe using Standard Installations is:

(4.3)

$$T.E.B. = \left[\frac{W_L}{B_{f_{LL}}} + \frac{W_E}{B_{f_e}}\right] F.S.$$

For reinforced pipe, three-edge bearing strength is divided by the inside span of the pipe to obtain a strength classification termed the D-load.

The **D-load** strength for circular reinforced pipe using Standard Installation beddings is determined by the equation:

(4.4)

$$D\text{-}load = \left[\frac{W_L}{B_{f_{LL}}} + \frac{W_E}{B_{f_e}}\right] \frac{F.S.}{S}$$

In the 3_{EB} program for the B and C beddings, and for arch and elliptical pipe, there is a common bedding factor for earth and live loads. Therefore, the D-load equation is:

(4.5)

$$D\text{-}load = \left[\frac{W_L + W_E}{B_{f_e}}\right] \frac{F.S.}{S}$$

B and C beddings are applicable for earth cover 0.6 m or greater. For installations with less than 0.6 m of cover, use the Type 2 and Type 3 trench and embankment installations as shown in Sections 4.2.2 and 4.2.3.

4.2.5 Cost Analysis of Pipe Envelope - CAPE

CAPE is a design aid for estimating the material costs of the embedment zones for both rigid and flexible pipe, and allows for the comparison of different embedment scenarios.

When developing a design for sewer works, municipal engineers must take into account numerous factors that affect the cost of the job. These may include sewer layout, availability of materials, cost of materials, material strength, material service life, installation effort (including inspection), importation or exportation of additional materials, environmental concerns, and public safety.

Information generated by the CAPE module helps designers develop a realistic picture of the true cost of the project. Once the designer has determined the diameter of the pipe, all that remains is for the user to accept or modify various default input parameters. The program will then proceed to calculate the relative bedding costs of both rigid and flexible pipe by taking into account.

- The bedding type selected for rigid pipe
- The bedding type selected for flexible pipe
- The trench geometry (i.e., whether the trench side slopes are vertical or sloped)
- Rigid or flexible trench dimensions (i.e., bottom width, bedding depth or thickness)
- The cost of imported granular material (dollars per cubic metre)
- The haulage cost for removal of native material (dollars per cubic metre)
- The tipping fee for disposal of native material (dollars per cubic metre)
- The resulting bedding diagrams, and total bedding costs, are then displayed on a summary screen that compares scenarios for flexible and rigid pipe. Another useful feature of the module is the creation of a graph summarizing the embedment cost versus the pipe size, by bedding type.

4.2.6 Life Cycle Analysis - LCA

Municipalities and governmental agencies have to deal with restricted budgets while continuing to build, operate, maintain, repair and rehabilitate their buried infrastructure. These restrictions can explain why it is so appealing for them to reduce, as much as possible, the initial cost of a project. Tenders are often written allowing the use of alternative materials. This does not ensure the quality and the durability of buried infrastructure, such as sewer systems. Storm and sanitary sewers are the most expensive utilities to replace because they are installed beneath all the other infrastructure (watermain, gas, telephone, electric services, paved roads). Consequently, sewer systems should be designed and installed to last at least 100 years. Durability of the specified piping materials becomes a design parameter that has to be taken into account.

Least Cost Analysis (LCA) or Life Cycle Analysis (LCA) considers the durability of products, and the design life of the project. The most cost-effective product for the design life of a project should be selected. LCA can compare three different pipe materials for a specific project. Careful consideration should be given to design life, interest rate, and material service life, since they can have dramatic effects on the final analysis. Several inputs are required to perform the economic calculations. The user enters a description of the project. This description appears in the printed output.

Project Design

The user chooses the type of project such as sanitary or storm sewers, or different kinds of culverts. Based on the type of project, a design life has to be established. Table 4.4 shows some guidelines concerning the design life of various drainage systems. In some parts of the world, there is a trend towards a design life of 150 years.

Table 4.4 *Design Life*

Storm Sewer	>100 Years
Sanitary Sewer	>100 Years
Expressway Culvert	>100 Years
Urban Culvert	>100 Years
Arterial Culvert	50-75 Years
Collector Culvert	50-75 Years
Rural Culvert	25-50 Years

Economic Factors

LCA applies time value analysis for money, which makes it possible to compare alternative materials with different service lives. LCA can perform this analysis using three different methods, the most common of which is net present value, or present value.

Present value analysis indicates the total amount of funds required to-day to finance initial and future costs over the total project design life. LCA considers all future costs in its calculations. These can include:

- rehabilitation
- maintenance
- repairs
- social costs due to traffic disruption

The calculations can be performed using real discount rate, or nominal discount rate. The nominal discount rate uses current dollars and directly includes an inflation value in its analysis. The real discount rate uses constant dollars and, although it takes inflation into account, a value for inflation does not directly enter into the calculations. For example, if the interest rate was six percent (6%) and inflation was four percent (4%), the nominal discount rate would use the specific values of the interest and inflation rates, whereas, the real discount rate would be the differential between the two rates, or two percent (2%). Choosing one method over another does not significantly affect the final analysis since both yield essentially the same results. However, since LCA is concerned with long term results, the real discount rate is recommended. The University of Western Ontario studied the long term interest/inflation relationship in Canada for the period of 1960 to 1989. Table 4.5 shows the results:

Table 4.5 *Real Discount Rate (i-l) 1960-1989*

Federal	3.63
Provincial	4.36
Private	4.56

Table 4.5 also indicates that the type of funding influences the discount rate. Federal and provincial investments can usually benefit from lower interest rates than private investments. This results in lower discount rates.

A Government of Canada project would use the federal rate. For provincial and municipal government projects, the provincial rate would be used. For private projects use the private rate. The differences in these rates reflect the degree of risk.

Material Service Life

Different pipe materials have different service lives that depend on the material, environmental, and functional conditions of the installation. There are numerous reports on the durability of pipe manufactured from all available materials. The reports should be reviewed carefully and the results thoroughly compared before making conclusions. The data must be credible and able to withstand critical review.

The service life of the selected pipe materials are very important data for least cost analysis. Materials with a shorter service life will have to be replaced or rehabilitated over the life of the project. When calculated, these replacement or rehabilitation costs have a major impact on the investment needed.

The suggested service lives used as defaults, were derived from the Ohio Culvert Durability Study (Comparative Study #11); the most comprehensive study available at this time.

Economic Analysis

At this point, all the necessary inputs are entered into the LCA program, and the user has to choose the type of economic analysis to be conducted. LCA accommodates three different methods of economic analysis: present value, annualized costs and future value.

Present value is calculated based on the equivalent cost for future expenditures at the current or present time.

(4.29)

$$PV = C \left[\frac{1}{(1+i')}\right]^n$$

In other words, this is the amount of money that would have to be set aside today to meet all costs for the life of the desired design project. Present value calculations are made by first inflating the estimates of cost expenditures, made in original dollar terms, into the future to the time they will be made. These inflated costs are then discounted to present value terms using an appropriate interest rate.

Annualized costs represent the costs that would have to be paid every year for the life of the project.

(4.30)

$$AC = PV \left[\frac{i'(1+i')^n}{(1+i')^{n-1}}\right]$$

Future value is the future cost of the project at a future date.

(4.31)

$$FV = PV(1+i')^n$$

Costs can be discounted to a future value by the above equation. This is often used to analyze the cost of deferring a project.

4.3 Spangler and Marston

During the first three decades of the 20th century, researchers at Iowa State University developed and tested a theory for estimating loads on buried pipe. The original concept was advanced by Marston-Talbot, and the theory was developed by Marston and Anderson, and published in 1913. A. Marston was joined by M.G. Spangler and W.J. Schlick, and continued the work on evaluation of design loads. In 1930, Marston published *The Theory of External Loads on Closed Conduits in the Light of the Latest Experiments*, which presents the theory in its present form. During this same period, the three-edge bearing test was developed as a method for evaluating the strength of rigid pipe. Other Iowa reports include Schlickís tests of pipe on concrete cradles, and Spanglerís classic report on the supporting strength of rigid pipe culverts, which still serves as the principal design theory. *(ACPA Handbook, 1988)*

Many designers of concrete pipe systems still prefer to use the Spangler Marston method of estimating loads on buried pipe. The following information is presented to assist designers favouring traditional methods.

The design procedure for the selection of pipe strength requires:

- Determination of Earth Load
- Determination of Live Load
- Selection of Bedding
- Determination of Bedding Factor
- Application of Factor of Safety
- Selection of Pipe Strength
- Determination of Earth Load

The earth load transmitted to a pipe is largely dependent on the type of installation. The three common types are Trench, Positive Projecting Embankment and Negative Projecting Embankment. Pipe are also installed by jacking or tunneling methods, where deep installations are necessary, or where conventional open excavation and backfill methods may not be feasible. The essential features of each of these installations are shown in Figure 4.13.

Trench

This type of installation is normally used in the construction of sewers, drains and water mains. The pipe is installed in a relatively narrow trench excavated in undisturbed soil and then covered with backfill extending to the ground surface.

The backfill load on pipe installed in a trench condition is computed by the equation:

(4.6)

$$W_E = C_d\, wg\, B_d^2$$

Cd is further defined as:

(4.7)

$$C_d = \frac{1 - e^{-2K\mu' \frac{H}{B_d}}}{2K\mu'}$$

Tables 4.6 through 4.32 are based on Equation (4.6) and list backfill loads in newtons per linear metre for various heights of backfill and trench widths. There are four tables for each circular pipe size based on different soil types having the following values of $K\mu'$; 0.165, 0.150, 0.130 and 0.110. The “Transition Width” column gives the trench width at which the backfill load on the pipe is a maximum and remains constant, regardless of any increase in the width of the trench. For any given height of backfill, the maximum load at the transition width is shown by bold type.

4.3.1 Positive Projecting Embankment

This type of installation is normally used when the culvert is installed in a relatively flat stream bed, or drainage path. The pipe is installed on the original ground, or compacted fill, and then covered by an earth fill or embankment. The fill load on a pipe installed in a positive projecting embankment condition is computed by the equation:

(4.8)

$$W_E = C_c\, Wg\, B_c^2$$

C_c is further defined as:

(4.9)

$$C_c = \frac{e^{2K\mu\frac{H}{B_c}} - 1}{2K\mu} \quad when\ H \leq H_e$$

and

(4.10)

$$C_c = \frac{e^{2K\mu\frac{H_e}{B_c}} - 1}{2K\mu} + \left(\frac{H}{B_c} - \frac{H_e}{B_c}\right) e^{2K\mu\frac{H_e}{B_c}} \quad when\ H > H_e$$

The settlements which influence loads on positive projecting embankment installations are shown in Figure 4.4. To evaluate the H_e term in Equation (4.10), it is necessary to determine, numerically, the relationship between the pipe deflection and the relative settlement between the prism of fill directly above the pipe, and the adjacent soil. This relationship is defined as a settlement ratio, expressed as:

(4.11)

$$r_{sd} = \frac{(s_m + s_g) - (s_f + d_c)}{s_m}$$

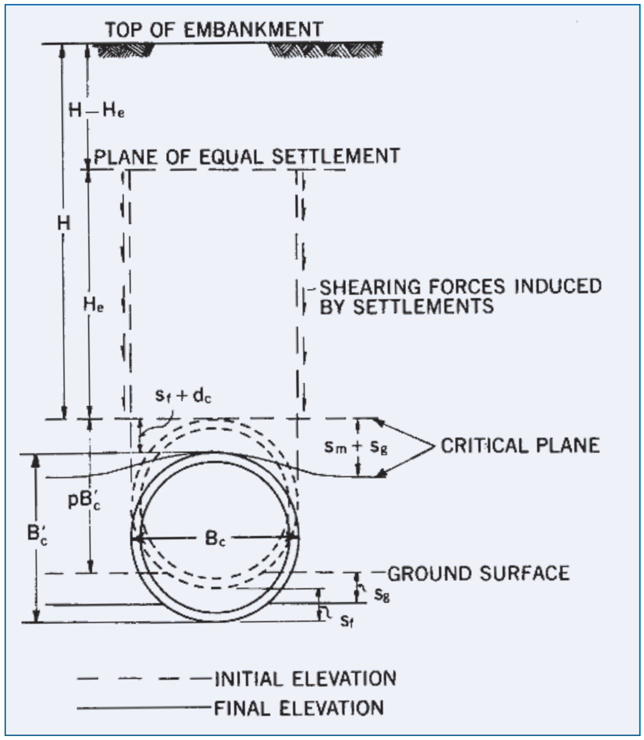
The fill load on a pipe installed in a positive projecting embankment condition is influenced by the product of the settlement ratio, r_{sd}, and the projection ratio, p. The projection ratio p is the vertical distance the pipe projects above the original ground, divided by the outside vertical height of the pipe (B'_c). Recommended settlement ratio design values are listed in Table 4.33.

Figure 4.14 is a solution by Spangler1 which permits reasonable estimates of C_c for various conditions of $H/B_c r_{sd}$ and p. Since the effect of μ' is nominal, $K\mu'$ was assumed to be 0.19 for the projection condition, and 0.13 for the trench condition. Figure 4.14 will provide an estimate for C_c that is well within the accuracy of the theoretical assumptions.

In Figures 4.14, 4.15 and 4.16, the family of straight lines represent the incomplete conditions, while the curves represent the complete conditions. The straight lines intersect the curves where H_e equals H. These diagrams can, therefore, be used to determine the minimum height of fill for which the plane of equal settlement will occur, within the soil mass.

Where the $r_{sd}\,p$ product is zero, the load coefficient term C_c is equal to H/B_c. Substituting this value in equation (4.6) results in the load, W_E, being equal to the weight of fill above the pipe, $wgHB_c$. For positive values of $r_{sd}\,p$ the load on the pipe will be greater than the weight of fill above the pipe, and for negative values, the load will be less than the weight of fill above the pipe.

Figure 4.4 *Settlements Which Influence Loads Positive Projecting Embankment Installation*



4.3.2 Negative Projecting Embankment

This type of installation is normally used when the culvert is installed in a relatively narrow and deep stream bed, or drainage path. The pipe is installed in a shallow trench of such depth that the top of the pipe is below the natural ground surface, or compacted fill, then covered with an earth fill or embankment which extends above the original ground level. The fill load on a pipe installed in a negative projecting embankment, condition is computed by the equation:

(4.12)

$$W_E = C_n w g B_d^2$$

C_n is further defined as:

(4.13)

$$C_n = \frac{e^{-2K\mu \frac{H}{B_d}} - 1}{-2K\mu} \quad when\ H \leq H_e$$

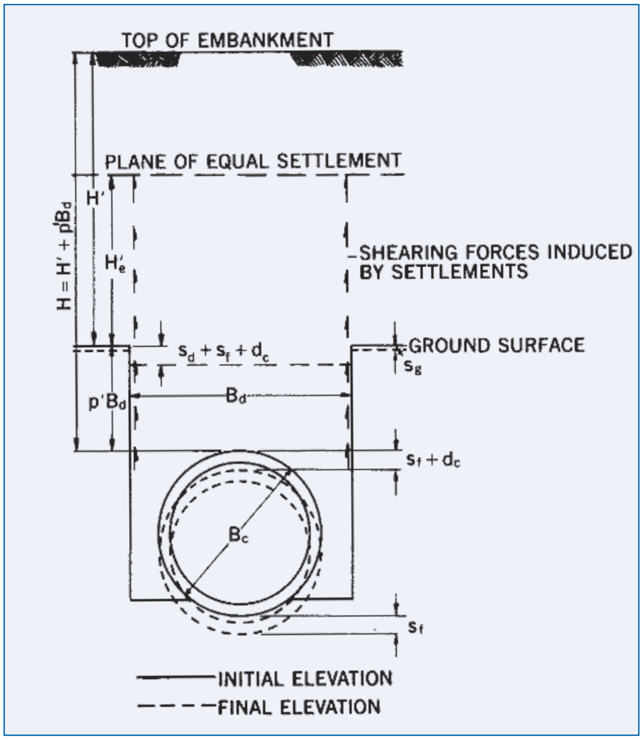
and

(4.14)

$$C_n = \frac{e^{-2K\mu \frac{H}{B_d}} - 1}{-2K\mu} \quad when\ H \leq H_e$$

When the material within the subtrench is densely compacted, Equation 4.12 can be expressed as $W_E = C_c\, wgB_d\, B'_d$ where B'_d is the average of the trench width and the outside diameter of the pipe.

Figure 4.5 *Settlements Which Influence Loads Negative Projecting Embankment Installation*



The settlements which influence loads on negative projecting embankment installations are shown in Figure 4.5. As in the case of the positive projecting embankment installation, it is necessary to determine the settlement ratio, by relating the deflection of the pipe and the total settlement of the prism of fill above the pipe, to the settlement of the adjacent soil. This relationship is defined as a settlement ratio:

(4.15)

$$r_{sd} = \frac{s_g - (s_d + s_f + d_c)}{s_d}$$

Recommended settlement ratio design values are listed in Table 4.33. The projection ratio, *p'*, for this type of installation is the distance from the top of the pipe to the surface of the natural ground, or compacted fill, at the time of installation, divided by the width of the trench. Where the ground surface is sloping, the average vertical distance from the top of the pipe to the original ground should be used in determining the projection ratio, *p'*.

In general, the notation follows that given the positive projection condition, the depth of the top of the pipe below the critical plane is defined by *p'Bd*, in which *p'* is defined as the negative projection ratio. If the natural ground surface is on a transverse slope, the vertical distance may be taken as the average distance from the top of the pipe to the top of the trench, at both sides of the trench. Furthermore, s_d is defined as the compression within the fill, for height *p'Bd*.

Values of *Cn* versus *H/Bd* for various values of *rsd* are provided in Figures 4.17 through 4.20 for values of *p'* equal to 0.5 (4.17), 1.0 (4.18), 1.5 (4.19) and 2.0 (4.20). For other values of *p'* between 0.5 and 2.0, values of C_n may be obtained by interpolation.

Only one value of Kμ is used, as with the trench condition for positive projection. The family of straight lines representing the incomplete condition intersects the curve for the complete condition. At these intersections, the height of the plane of equal settlement, He, equals the height of the top of embankment, H . These intersecting points can be used to determine the height of the plane of equal settlement above the top of the pipe.

4.3.3 Trenchless - Jacked or Tunneled

This type of installation is used where surface conditions make it difficult to install the pipe by conventional open excavation and backfill methods, or where it is necessary to install the pipe under an existing embankment. The earth load on a pipe installed by these methods is computed by the equation:

(4.16)

$$W_E = C_t w g B_t^2 - 2cC_t B_t$$

C_t is further defined as:

(4.17)

$$C_t = \frac{1 - e^{-2K\mu' \frac{H}{B_t}}}{2K\mu'}$$

Axial Loads
For axial loads normally encountered, it is necessary to provide for a uniform distribution of the jacking force around the periphery of the pipe, to prevent localized stress concentrations. This is accomplished by ensuring that the pipe ends are parallel, within the tolerances prescribed by CSA for reinforced concrete pipe and the Microtunneling Pipe Guidelines of the Ontario Concrete Pipe Association; by the use of a spacer made from plywood, or rubber placed between the pipe sections; and by ensuring the jacking forces applied are properly distributed through the jacking frame to the pipe, and parallel to the axis of the pipe. Under most circumstances, the cross sectional area of the pipe wall is adequate to resist the pressures encountered.

To calculate the jacking force required, the forces that arise from the site conditions, and construction methods have to be analyzed.

The forces determined by the site conditions are:

- Size, shape, mass and external pipe surface
- The length of the jacking/microtunneling operation
- Type of soil, or soils that will be encountered over the length of the drive
- Position of the water table
- Stability of the soil immediately and during construction
- The depth and mass of the overburden
- Vibratory loading

The factors that affect the forces due to the construction process are:

- Amount of overcut of the bore
- The use of lubricants, such as bentonite
- Misalignment of the pipeline along the length of the project
- The rate of advancement of the pipeline
- The frequency and duration of stoppages

Once the jacking forces have been calculated, the forces relating to the advancement of the cutting head and shield must be added. The information must be given to the pipe manufacturer to ensure pipe of proper concrete compressive strength and joint end area are supplied. To do this, the manufacturer will select a compressive strength based on methods that add a safety margin to required concrete compressive strength, or apply a safety factor to axial load capacity.

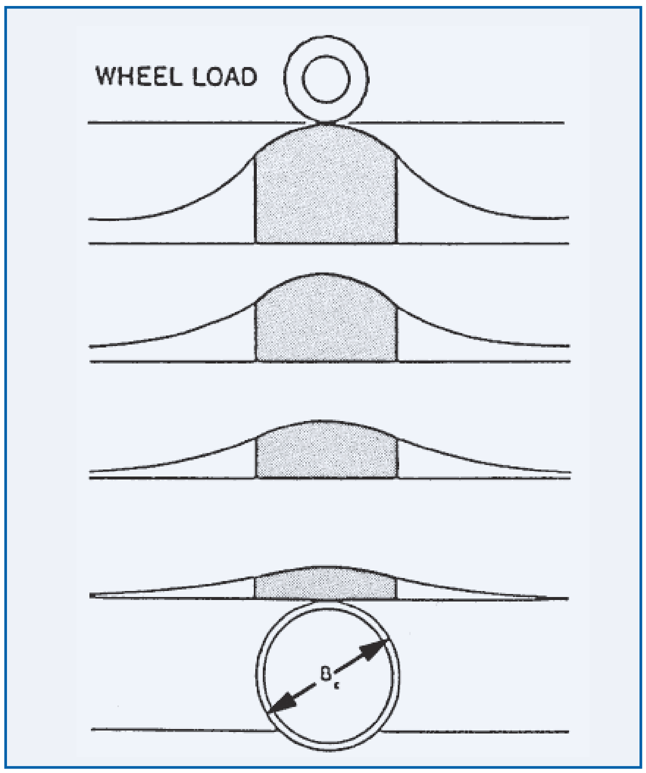
In Equation 4.16 the CtwgBt2 term is similar to the trench Equation 4.6 for trench loads and the 2cCtBt term accounts for the cohesion of undisturbed soil. Conservative design values of the coefficient of cohesion for various soils are listed in Table 4.34.

To obtain the total earth load for any given height of cover, width of bore or tunnel and type of soil, the value of the cohesion term is subtracted from the value of the trench load term.

4.4 Determination of Live Load

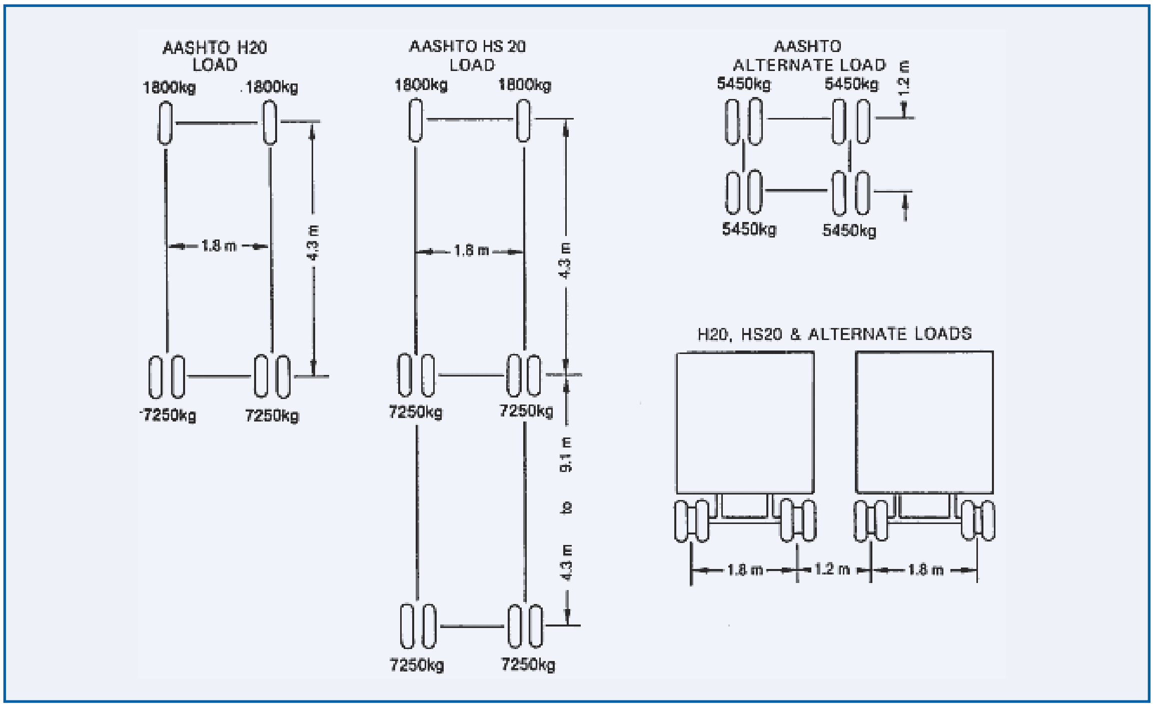
In the selection of pipe, it is necessary to evaluate the effect of live loads. Live load considerations are necessary in the design of pipe installed with shallow cover under railroads, airports and unsurfaced highways. The distribution of a live load at the surface on any horizontal plane in the subsoil is shown in Figure 4.6. The intensity of the load on any plane in the soil mass is greatest at the vertical axis directly beneath the point of application, and decreases in all directions outward from the center of application. As the distance between the plane and the surface increases, the intensity of the load at any point on the plane decreases.

Figure 4.6 *Live Load Distribution*



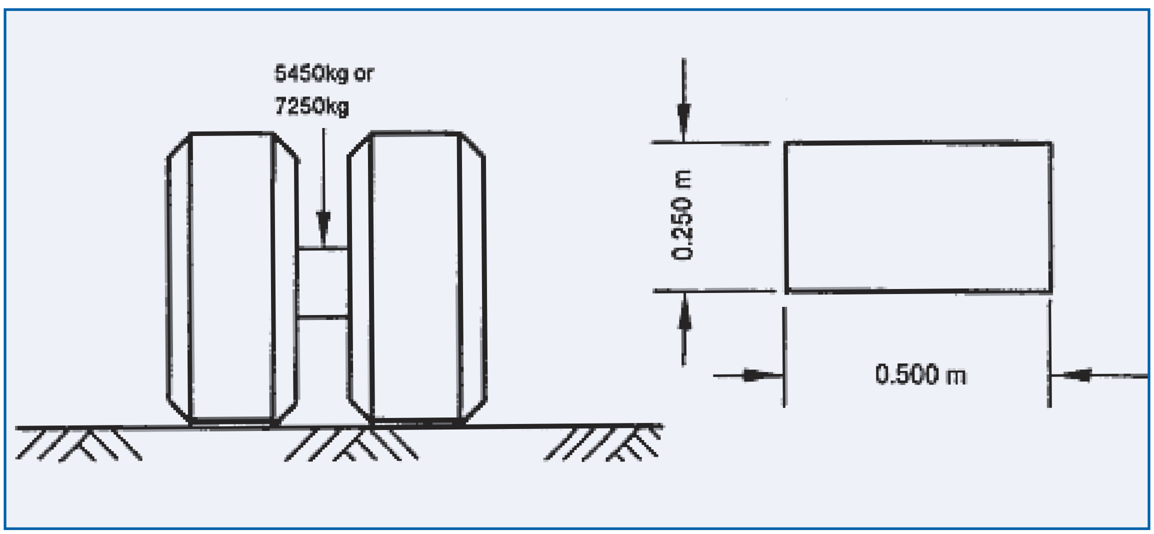
Highways
If a rigid or flexible pavement designed for heavy duty traffic is provided, the intensity of a truck wheel load is usually reduced sufficiently so that the live load transmitted to the pipe is negligible. In the case of flexible pavements designed for light duty traffic but subjected to heavy truck traffic, the flexible pavement should be considered as fill material over the top of the pipe. In analysis, the most critical AASHTO (American Association of State Highway Transportation Officials) loadings shown in Figure 4.7 are used in either the single mode, or passing mode.

Figure 4.7 AASHTO Live Loads



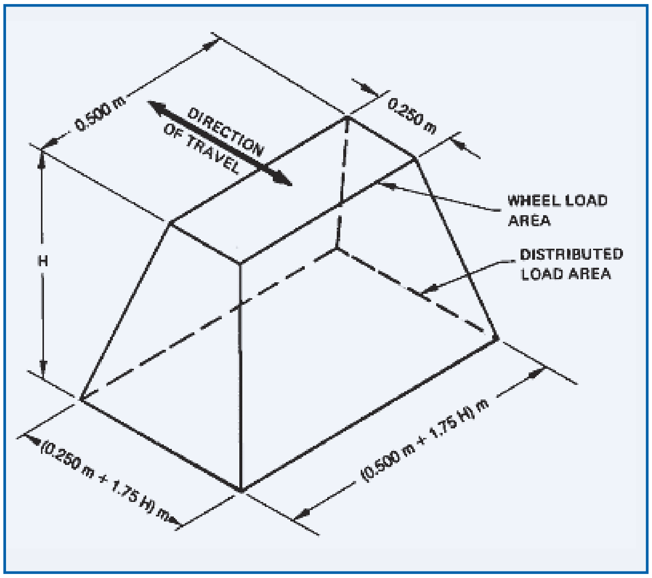
Each of these loadings is assumed to be applied through dual wheel assemblies uniformly distributed over a surface area of 0.200 m by 0.500 m, as shown in Figure 4.8.

Figure 4.8 Wheel Load Surface Contact Area



As recommended by AASHTO, the total wheel load is then assumed to be transmitted and uniformly distributed over a rectangular area on a horizontal plane at the depth, H, as shown in Figure 4.9 for a single HS-20 dual wheel.

Figure 4.9 *Distributed Load Area, Single Dual Wheel*



Distributed load areas for the alternate load, and the passing mode for either loading, are developed in a similar manner.

The average pressure intensity of the subsoil plane at the outside top of the pipe at depth, H, is determined by the equation:

(4.18)

$$w_L = \frac{Pg\,(I_f)}{A_{LL}}$$

Recommended impact factors, If , to be used in determining live loads imposed on pipe with less than 0.900 m of cover, when subjected to dynamic traffic loads, are listed in the accompanying table.

Impact Factors For Highway Truck Loads

***H*, HEIGHT OF COVER (m)**	**I_f IMPACT FACTOR**
0.000 to 0.300	1.3
0.301 to 0.600	1.2
0.601 to 0.900	1.1
0.901 and greater	1.0

NOTE: *Impact Factors recommended by the American Association of State Highway and Transportation Officials in Standard Specifications for Highway Bridges.*

As the depth, H, increases, the critical loading configuration can be either one HS-20 wheel load, two HS-20 wheel loads in the passing mode, or the alternate load in the passing mode. Since the exact geometric relationship of individual or combinations of surface wheel loads cannot be anticipated, the most critical loading configurations, and the outside dimensions of the distributed load areas within the indicated cover depths, are summarized in the following table.

Critical Loading Configurations

H (m)	P (kg)	A LL, Distributed Load Area
H< 0.400	7,250	(0.200 + 1.75 H) (0.500 + 1.75 H)
0.400 < H< 1.250	14,500	(0.200 + 1.75 H) (1.700 + 1.75 H)
1.250 < H	21,750	(1.450 + 1.75 H) (1.700 + 1.75 H)

The total live load acting on the pipe is determined by the following formula:

(4.19)

$$W_T = w_L L S_L$$

The live load acting on the pipe in newtons per linear metre is determined by the following equation:

(4.20)

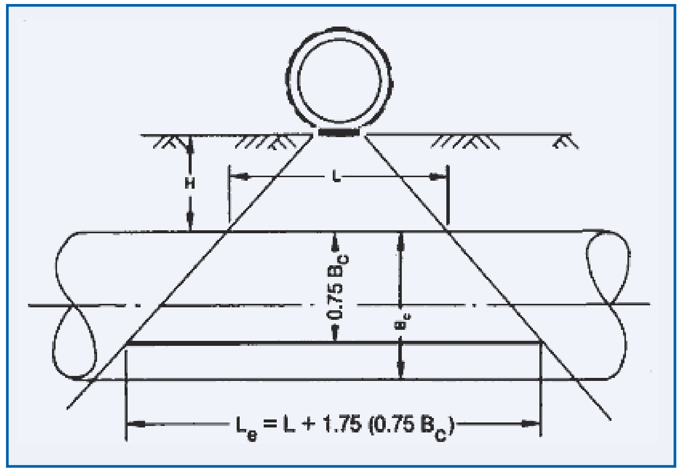
$$W_L = \frac{W_T}{L_e}$$

Since the buried concrete pipe is similar to a beam on continuous supports, the effective supporting live load length of the pipe is assumed as in Figure 4.10 and determined by the following equation:

(4.21)

$$L_e = L + 1.75\,(0.75\,B_c)$$

Figure 4.10 *Effective Supporting Length of Pipe*



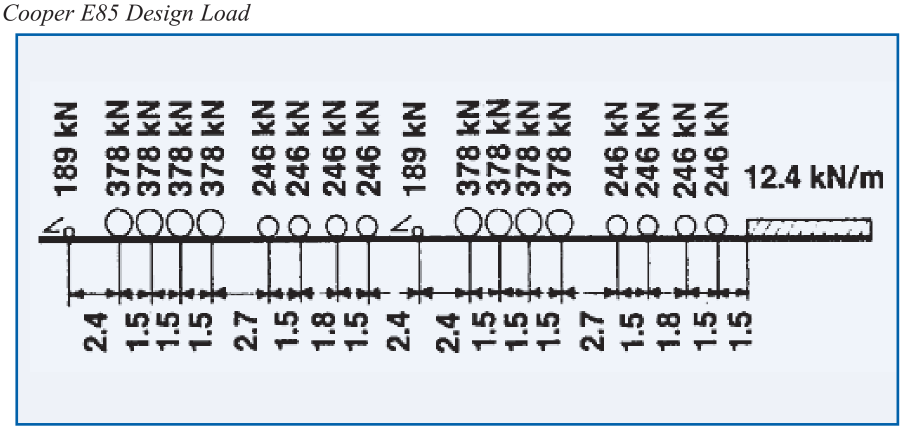
Analysis of possible pipe alignments relative to load orientation, confirms the most critical loading can occur when the longitudinal pipe axis is either parallel or transverse to the direction of travel, and centred under the distributed load area. Tables 4.35 through 4.37 present the maximum highway loads in kilonewtons per linear metre imposed on circular(4.35), horizontal elliptical(4.36) and vertical elliptical(4.37) pipe, with impact included.

4.4.1 Railroads

In determining the live load transmitted to a pipe installed under railroad tracks, the weight on the locomotive drive axles plus the weight of the track structure, including ballast, is considered to be uniformly distributed over an area equal to the length occupied by the drivers, multiplied by the length of ties.

Canadian Rail Authorities presently use a Cooper E85 loading with axle loads, and axles spacing as shown in the following figure.

Figure 4.11 *Cooper E85 Design Load*



Based on a uniform load distribution at the bottom of the ties and through the soil mass, the live load to a pipe underground is computed by the equation:

(4.22)

$$W_L = C p_o B_c I_f$$

Tables 4.38 and 4.39 present live loads in kilonewtons per linear metre, based on Equation 4.22, with a Cooper E85 equivalent design loading, track structure weighing 2.9 kN/m and the locomotive load uniformly distributed over an area 2.4 m x 6.0 m yielding a uniform live load of 106 kPa. In accordance with the American Railway Engineering Association (AREA) Manual of Recommended Practice, an impact factor of 1.4 at zero cover decreasing to 1.0 at 3 m of cover is included in the table.

4.4.2 Construction Loads

During grading operations, it may be necessary for heavy construction equipment to travel over an installed pipe. Unless adequate protection is provided, the pipe may be subjected to load concentrations in excess of the design loads. Before heavy construction equipment is permitted to cross over a pipe, a temporary earth fill should be constructed to an elevation of a least 0.9 m over the top of the pipe. The fill should be of sufficient width to prevent possible lateral displacement of the pipe.

4.5 Selection of Bedding

A bedding is provided to distribute the vertical reaction around the lower exterior surface of the pipe, and to reduce stress concentrations within the pipe wall. The load that a concrete pipe will support depends on the width of the bedding contact area, and the quality of the contact between the pipe and bedding. The OCPA recommends that no matter what bedding is used, the centre third of the bedding is to remain uncompacted for pipe settlement and initiation of haunch support. An important consideration in selecting a material for bedding is to be sure that positive contact can be obtained between the bed and the pipe. Since most granular materials will shift to attain positive contact as the pipe settles, an ideal load distribution can be attained through the use of clean coarse sand, or well-graded crushed stone.

To ensure that the in-place supporting strength of the pipe is adequate, the width of the band of contact between the pipe and the bedding material should be in accordance with the specified class of bedding. With the development of mechanical methods for subgrade preparation, pipe installation, backfilling and compaction, the flat bottom trench with granular foundation is generally the more practical method of bedding. If the pipe is installed in a flat bottom trench, it is essential that the bedding material, directly under the pipe, be loosely compacted over a width equal to one third of the outside diameter of the pipe, and be uniformly compacted under the haunches of the pipe.

The following are two types of embankment conditions:

1) Positive Projecting Embankment

A positive projecting embankment condition exists where the top of the pipe is projecting above the surface of the natural ground, or compacted fill, before backfilling. This condition also applies to pipe installed in very wide trenches (i.e., beyond the transition width).

2) Negative Projecting Embankment

This condition exists where the pipe is installed in a relatively narrow trench of such depth that the top of the pipe is below the level of the natural ground surface, or compacted fill, before backfilling occurs.

Beddings for Trench Conditions

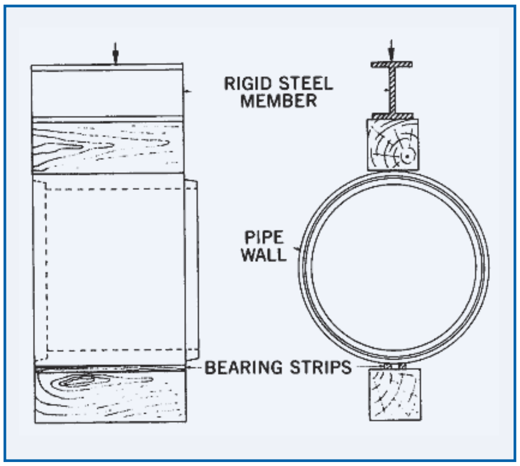
Three general classes of bedding for the installation of circular pipe in a trench condition are illustrated in Figures 4.21A and 4.21B. Trench bedding for horizontal elliptical, and vertical elliptical pipe are shown in Figure 4.22.

Beddings for Embankment
Three general classes of bedding for the installation of circular pipe in an embankment condition are shown in Figure 4.23. Embankment beddings for horizontal elliptical and vertical elliptical pipe are shown in Figure 4.24. Class B through D bedding classifications are presented as a guideline, which should be reasonably attainable under field conditions.

4.5.1 Determination of Bedding Factor

Under installed conditions, the vertical load on a pipe is distributed over its width, and the reaction is distributed in accordance with the type of bedding. When the pipe strength used in design has been determined by plant testing, bedding factors must be developed to relate the in-place supporting strength to the more severe plant test strength. The bedding factor is the ratio of the strength of pipe, under the installed conditions of loading and bedding, to the strength of the pipe in the plant test. This same ratio is defined originally by Spangler as the load factor. This latter term, however, was subsequently defined in the ultimate strength method of reinforced concrete design, with an entirely different meaning. To avoid confusion, therefore, Spanglerís term was renamed the bedding factor. The three-edge bearing test shown in Figure 4.12 is the normally accepted plant test; all bedding factors described relate the in-place supporting strength to the three-edge bearing strength.

Figure 4.12 *Three-Edge Bearing Test*



The bedding factor for a particular pipeline, and consequently the supporting strength of the buried pipe, depends upon two characteristics of the installation:

Width and quality of contact between the bedding and the pipe
Magnitude of the lateral pressure, and the portion of the vertical area of the pipe over which it is effective.
Since the sidefill material can be more readily compacted for pipe installed in a positive projection embankment condition, the effect of lateral pressure is considered in evaluating the bedding factor. For trench installations, the effect of lateral pressure was neglected in development of bedding factors. Instead of a general theory as for the embankment condition, Spangler, from analysis of test installations, established conservative fixed bedding factors for each of the standard classes of bedding used for trench installations.

Trench Bedding Factors
In early Iowa Engineering Experiment Stations, both Spangler and Schlick postulated that some active lateral pressure is developed in trench installations, before the transition width is reached. As the trench width is increased for a given height of cover and pipe diameter, a point is reached at which no additional load is transmitted to the pipe, and an embankment condition applies. This limiting value of the trench width is defined as the transition width. Experience indicates that the active lateral pressure increases as the trench width increases, from a very narrow width to the transition width, provided the sidefill is compacted. Defining the narrow trench width as a trench having a width at the top of the pipe equal to or less than the outside horizontal span plus 300 mm, and assuming a conservative linear variation between this narrow trench width and the transition width, the variable trench bedding factor can be determined by:

(4.2)

$$B_{fv} = (B_{fe} - B_{ft}) \left[\frac{B_d - (B_c + 0.3)}{B_{dt} - (B_c + 0.3)} \right] + B_{ft}$$

The six-step design procedure for determining the trench variable bedding factor is:

- Determine the trench fixed bedding factor, B_{ft}
- Determine the trench width, B_d
- Determine the transition width for the installation conditions, B_{dt}
- Determine H/B_c ratio, settlement ratio, r_{sd}, projection ratio, p, and the product of the settlement and projection ratios, $r_{sd}\,p$
- Determine positive projecting embankment bedding factor, B_{fe}
- Calculate the trench variable bedding factor, B_{fv}
- Positive Projecting Embankment Bedding Factors
- For pipe installed in a positive projecting embankment condition, active lateral pressure is exerted against the sides of the pipe. Bedding factors for this type of installation are computed by the equation:

(4.23)

$$B_f = \frac{A}{N - xq}$$

For circular pipe q is further defined as:

(4.24)

$$q = \frac{pK}{C_c}\left(\frac{H}{B_c} + \frac{p}{2}\right)$$

For elliptical pipe q is further defined as:

(4.25)

$$q = \frac{pB'_cK}{C_cB_c^2}\left(H + \frac{pB'_c}{2}\right)$$

Tables 4.40 through 4.42 list bedding factors for circular (4.40A, 4.40B), vertical elliptical (4.41), horizontal elliptical (4.42) pipe.

Negative Projecting Embankment Bedding Factors
The trench bedding factors listed in Figures 4.21 A and 4.21 B should be used for negative projecting embankment installations.

Jacked or Tunneled Bedding Factor
Since the jacking method of construction affords positive contact around the lower exterior surface of the pipe and the surrounding earth, an ideal bedding condition is provided. This positive contact can be obtained by close control of the bore excavation to the outside dimensions and shape of the pipe or, if the bore is over-excavated, the space between the pipe and the bore can be filled with sand, grout, concrete or other suitable material. For this type of installation a bedding factor of 3.0 is recommended. If the bore is slightly over-excavated, and the space between the pipe and the bore is not filled, a minimum bedding factor of 1.9 is recommended.

The usual procedure in tunnel construction is to complete excavation of the tunnel bore first, then install the pipe. If the pipe is designed to carry the earth load, or a portion of the load, the bedding factor should be in accordance with the particular type of bedding provided. The bedding factors listed in Figures 4.21 A and 4.21 B are recommended.

Application of Factor of Safety

The total earth and live load on a buried concrete pipe is computed, and multiplied by a factor of safety to determine the pipe supporting strength required. The safety factor is defined as the relationship between the ultimate strength *D-load (Dult)* and the 0.3 mm crack D-load (D0.3). This relationship is specified in the CSA standards on reinforced concrete pipe. Therefore, for reinforced concrete pipe, a factor of safety of 1.0 should be applied if the 0.3 mm crack strength is used as the design criterion. For non-reinforced concrete pipe, a factor of safety of 1.25 to 1.5 is normally used.

Selection of Pipe Strength

The Canadian Standards Association (CSA) and the American Society for Testing and Materials (ASTM) have developed standard specifications for precast concrete pipe. Each specification contains design, manufacturing and testing criteria.

CAN/CSA-A257.1-M92 for circular concrete culvert, storm drain and sewer pipe specifies three strength classes for nonreinforced concrete pipe. These classes are specified to meet minimum ultimate loads, expressed in terms of three-edge-bearing strength in kilonewtons per linear metre.

CAN/CSA-A257.2-M92 for circular reinforced concrete culvert, storm drain and sewer pipe specifies strength classes based on D-load at 0.3 mm crack (D0.3) and/or ultimate load (Dult). The 0.3 mm crack D-load (D0.3) is the maximum three-edge-bearing test load supported by a concrete pipe, before a crack occurs having a width of 0.3 mm measured at close intervals, throughout a length of at least 300 mm. The ultimate D-load (Dult) is the maximum three-edge-bearing test load supported by a pipe. D-loads are expressed in newtons per linear metre per millimetre of inside diameter.

ASTM Standard C 507M, for reinforced concrete elliptical culvert, storm drain and sewer pipe, specifies strength classes for both horizontal elliptical and vertical elliptical pipe based on D-load at 0.3 mm crack and/or ultimate load in newtons per linear metre per millimetre of inside span.

ASTM Standard C 655M for reinforced concrete D-load culvert, storm drain and sewer pipe covers acceptance of pipe design to meet specific D-load requirements.

ASTM Standard C 985M, for nonreinforced concrete specified strength culvert, storm drain, and sewer pipe, covers acceptance of pipe designed for specified strength requirements.

Since numerous reinforced concrete pipe sizes are available, three-edge-bearing test strengths are classified by D-loads. The D-load concept provides strength classification of pipe, independent of pipe diameter. For reinforced circular pipe, the three-edge-bearing test load in newtons per linear metre equals D-load multiplied by inside diameter in millimetres. For horizontal elliptical and vertical elliptical pipe, the three-edge-bearing test load in newtons per linear metre equals D-load multiplied by nominal inside span in millimetres.

The required three-edge-bearing strength of nonreinforced concrete pipe is expressed in newtons per linear metre, not a a D-load, and is computed by the equation:

(4.26)

$$T.E.B. = \frac{W_L + W_E}{B_f} F.S.$$

The required three-edge-bearing strength of circular reinforced concrete pipe is expressed as D-load and is computed by the equation:

(4.27)

$$D\text{-}load = \frac{W_L + W_E}{B_f D} F.S.$$

The determination of required strength of elliptical concrete pipe is computed by the equation:

(4.28)

$$D\text{-}load = \frac{W_L + W_E}{B_f S} F.S.$$

4.6 Precast Concrete Box Units

In Ontario, there are two specifications for precast reinforced box units. Ontario Provincial Standard Specification (OPSS) 1821, is the Material Specification for Precast Concrete Box Culverts and Box Sewers, and OPSS 422 is the Construction Specification for Precast Reinforced Concrete Box Culverts and Box Sewers. OPSS 1821 covers box units up to 3000 mm span, with a minimum earth cover of 0.6 metres. For box culverts or box sewers with fill heights less than 0.6 m, or greater than the maximum shown in Table 1 of OPSS 1821 for the various sizes, the Ontario Highway Bridge Design Code (OHBDC) is the governing specification. This specification is also the criterion for the design of box units with spans greater than 3000 mm. Precast reinforced concrete box units are designed for installed conditions rather than for test conditions.

Other standard designs are presented in ASTM C 789M, Precast Reinforced Concrete Box Sections for Culverts, Storm Drains and Sewers (0.6 m and greater); and C 850M, Precast Reinforced Concrete Box Sections with less than 0.6 m of cover subjected to highway loadings.

ASTM C 789M covers box sections with 0.6 m or more of earth cover for both the AASHTO H20 and HS20 truck plus dead load conditions and the AASHTO alternate load plus dead load conditions.

ASTM C 850M covers box units with less than 0.6 m of earth cover for the same AASHTO conditions as C 789M.

Special designs for sizes and conditions other than as presented in the ASTM Standards are also available. Both C 789M and C 850M have been accepted and published as AASHTO standards M 259M and M 273M respectively.

Trench and embankment beddings for the precast concrete box units are shown in Figure 4.24.

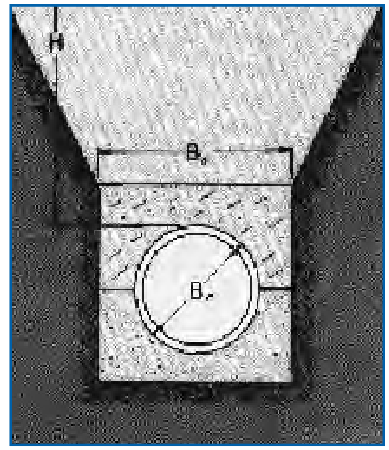
4.7 Example Problems

The following examples do not consider the effect of rigid or flexible pavement. With flexible pavement, it is always a good idea to consider it as fill material over the top of the pipe.

In the following examples the answers have been rounded to the nearest whole number.

Example 4.7.1

TRENCH INSTALLATION



Given: A 1200 mm circular pipe is to be installed in a 2.60 m wide trench with 11.0 m of cover over the top of the pipe. The pipe will be backfilled with sand and gravel having a density of 1900 kg/m3.

Find: The required pipe strength in terms of 0.3 mm crack *D-load*.

Solution:

1. Determination of Earth Load (W_E)

From Table 4.20A, Sand and Gravel, the backfill load based on 1900 kg/m3 backfill is 289.8 kg/m3.

$W_E = 289,800$ N/m

2. Determination of Live Load (W_L)

From Table 4.35, live load is negligible at a depth of 11.0 m.

$W_L = 0$

3. Selection of Bedding

A class B bedding as shown in Figure 4.21A will be assumed for this example. In actual design, it may be desirable to consider other types of bedding in order to arrive at the most economical overall installation.

4. Determination of Bedding Factor (B_f)

The trench variable bedding factor, B_{fv}, is given by:

(4.2)

$$B_{fv} = (B_{fo} - B_{ft}) \left[\frac{B_d - (B_c + 0.3)}{B_{dt} - (B_c + 0.3)} \right] + B_{ft}$$

Step i

From Figure 4.21A for circular pipe installed on a class *B* bedding, the trench fixed bedding factor, B_{ft}, is 1.9.

Step ii

A trench width, B_d, of 2.60 metres is specified.

Step iii

The transition width, $Bd\ t$, determined from Table 4.20A is 3.50m

Step iv

$H/B_c = 11.0/1.5 = 7.3$

From Table 4.33 the design range of values for ordinary soil is +0.5 to +0.8. Assume an r_{sd} value of +0.5. For a granular class B bedding $p = 0.5$, then = 0.5 x 0.5 = 0.25.

Step v

From Table 4.40A for $H/Bc = 7.3$, $p = 0.5$, $r_{sd}\,p = 0.25$ and a (class B) bedding, $B_{fe} = 2.19$, is interpolated.

Step vi

The trench variable bedding factor is:

$B_{fv} = 2.04$

Use a variable bedding factor, B_{fv}, of 2.04 to determine the required *D-load* pipe strength.

5. **Application of Factor of Safety (F.S.)**

   A factor of safety of 1.0 based on the 0.3 mm crack will be applied.

6. **Selection of Pipe Strength**

   The *D-load* is defined by:

   (4.27)

$$D\text{-}load = \frac{W_L + W_E}{B_f D} F.S.$$

$= 119\ \mathrm{N / m / mm}$

Answer:

A pipe which would withstand a minimum three-edge-bearing test load for the 0.3 mm crack of 119N/m/mm of inside diameter would be required.

Example 4.7.2

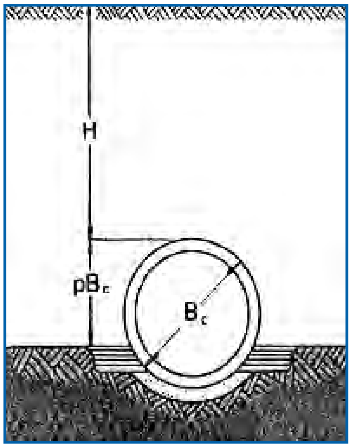
POSITIVE PROJECTING EMBANKMENT INSTALLATION

Given: A 1200 mm circular pipe is to be installed in a positive projecting embankment condition in ordinary soil. The pipe will be covered with 10.0 m of 1760 kg/m3 overfill.

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

Solution:

1. **Determination of Earth Load (W_E)**



A settlement ratio must first be assumed. In Table 4.33 values of settlement ratio from +0.5 to +0.8 are given for positive projecting installations, on a foundation of ordinary soil. A conservative value for settlement ratio of 0.7 will be used, with an assumed projection ratio of 0.7. The product of the settlement ratio and the projection ratio will be 0.49 ($r_{sd}\,p$ » 0.5).

$B_c = 1.5m,\ H = 10.0$

$H/B_c = 6.7$

From Figure 4.14 For $H / B_c = 6.7$

and using curve marked $r_{sd}\,p = 0.5$

$C_c = 10.1$

Weight of soil is given by:

(4.8) $$W_E = C_c\,Wg\,B_c^2$$

= 10.1 x 1760 x 9.81 x 1.52

= 392,400 N/m

2. Determination of Live Load (W_L)

From Table 4.35, live load is negligible at a depth of 10.0 m,

$W_L = 0$

3. Selection of Bedding

A Class B bedding as shown in Figure 4.23 will be assumed for this example. In actual design, it may be desirable to consider other types of bedding in order to arrive at the most economical over all installation.

4. Determination of Bedding Factor (Bf)

The outside diameter for a 1200 mm diameter pipe is 1.5 metres. From Table 4.40A, for an H/B ratio of 6.7, rsd p value of 0.5, p value of 0.7 and class B bedding, a bedding factor of 2.34 is inter polated.

5. Application of Factor of Safety (F.S.)

A factor of safety of 1.0 based on the 0.3 mm crack will be applied.

6. Selection of Pipe Strength

The D-load is given by:

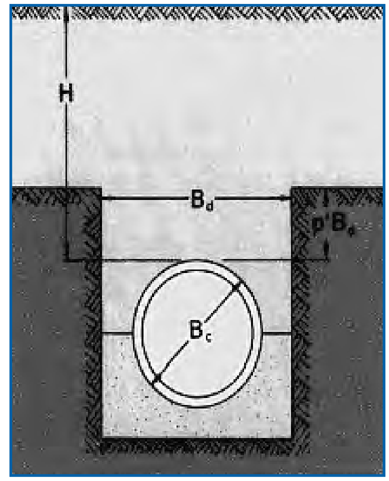
(4.27) $$D\text{-}load = \frac{W_L + W_E}{B_f D} F.S.$$

= 140 $N / m / mm$

Answer: A pipe which would withstand a minimum three-edge-bearing test load for the 0.3 mm crack of 140 N/m/mm of inside diameter would be required.

Example 4.7.3

NEGATIVE PROJECTING EMBANKMENT INSTALLATION



Given: A 1200 mm circular pipe is to be installed in a negative projecting embankment condition in ordinary soil. The pipe will be covered with 11.0 m of 1900 kg/m3 overfill. A 2.0m trench width will be constructed with a 2.0 m depth from the top of the pipe to the natural ground surface.

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

Solution:

1. **Determination of Earth Load (W_E)**

A settlement ratio must first be assumed. In Table 4.33 for a negative projection ratio, p´ = 1.0, the design value of the settlement ratio, r_{sd} , is -0.3

$B_d = 2.0\ m,\ H = 11.0\ m,\ B_c = 1.5$

From Figure 4.18, For $H/B_d = 5.5$

and using curve marked $r_{sd}\,p = -0.3$

$C_n = 3.50$

Weight of soil is given by:

(4.12) $$W_E = C_n\, w\, g\, B_d^2$$

= 3.50 x 1900 x 9.81 x 2.0
= 261,000 N/m

2. **Determination of Live Load (W_L)**

From Table 4.35 live load is negligible at a depth of 11.0 m.
$W_L = 0$

3. **Selection of Bedding**

A class B bedding as shown in Figure 4.21A will be assumed for this example. In actual design, it may be desirable to consider other types of bedding in order to arrive at the most economical overall installation.

4. **Determination of Bedding Factor ()**

The trench variable bedding factor, , is given by:

(4.2)

$$B_{fv} = (B_{fe} - B_{ft})\left[\frac{B_d - (B_c + 0.3)}{B_{dt} - (B_c + 0.3)}\right] + B_{ft}$$

Step i
From Figure 4.21A for circular pipe installed on a class B bedding, the trench fixed bedding factor, B_{ft} , is 1.9.

Step ii
A trench width, B_d , of 2.0 m is specified.

Step iii
The transition width, $B_d t$, determined from Table 4.20 is 3.50m.

Step iv
$H/B = 11.0/1.5 = 7.3$
From Table 4.33 the design range of values for ordinary soil is +0.5 to +0.8. Assume an r_{sd} value of +0.5. For a granular class B bedding p = 0.5, then $r_{sd} p$ = 0.5 x 0.5 = 0.25.

Step v
From Table 4.40A for $H/B_c = 7.3$, $p = 0.5$, $r_{sd} p = 0.25$
and a class B bedding, $B_f e = 2.19$ is interpolated.

Step vi
The trench variable factor is:
$B_f v = 1.93$
Use a variable bedding factor, Bf v , of 1.93 to determine the required D-load pipe strength.

5. **Application of Factor of Safety (*F.S.*)**
A factor of safety of 1.0 based on the 0.3 mm crack will be applied.

6. **Selection of Pipe Strength**
The D-load is given by:
(4.27)

$$D\text{-}load = \frac{W_L + W_E}{B_f D} F.S.$$

= 133 N / m / mm

Answer:

A pipe which would withstand a minimum three-edge-bearing test load for the 0.3 mm crack of 113 N/m/mm of inside diameter would be required.

Example 4.7.4

JACKED OR TUNNELED INSTALLATION

Given: A 1200 mm circular pipe is to be installed by the jacking method of construction with a height of cover over the top of the pipe of 11.0 m. The pipe will be jacked through ordinary clay material weighing 1900 kg/m3. The limit of excavation will be 1.5 m.

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

Solution:

1. **Determination of Earth Load (W_E)**

A coefficient of cohesion value must first be assumed. In Table 4.34 values of the coefficient of cohesion from 1900 to 48000 are given for clay. A conservative value of 4800 Pascals will be used.

Earth load is computed by:

(4.16) $$W_E = C_t w g B_t^2 - 2cC_t B_t$$

C_t is further defined as:

(4.17) $$C_t = \frac{1 - e^{-2K\mu' \frac{H}{B_t}}}{2K\mu'}$$

Assume Kμ´ value of 0.13 for ordinary clay
H = 11.0m
Bt = 1.5m

Substituting values we arrive at C_t = 3.27

To determine the earth load:

(4.16) $$W_E = C_t w g B_t^2 - 2cC_t B_t$$

= 3.27 x 1900 x 9.81 x 1.52 - 2 x 4800 x 3.27 x 1.5

= 90,100 N/m

2. **Determination of Live Load (W_L)**

From Table 4.35 live load is negligible at a depth of 11.0 m,
$W_L = 0$

3. **Selection of Bedding**
   The annular space between the pipe and limit of excavation will be filled with grout.

4. **Determination of Bedding Factor (B_f)**
   Since the space between the pipe and the bore will be filled with grout, there will be positive contact of bedding around the entire periphery of the pipe. Because of this ideal bedding condition, little or no flexural stresses should be induced in the pipe wall. A conservative bedding factor of 3.0 will be used.

5. **Application of Factor of Safety (*F.S.*)**
   A factor of safety of 1.0 based on the 0.3 mm crack will be applied.

6. **Selection of Pipe Strength**
   the D-load is given by:
   (4.27)

$$D\text{-}load = \frac{W_L + W_E}{B_f D} F.S.$$

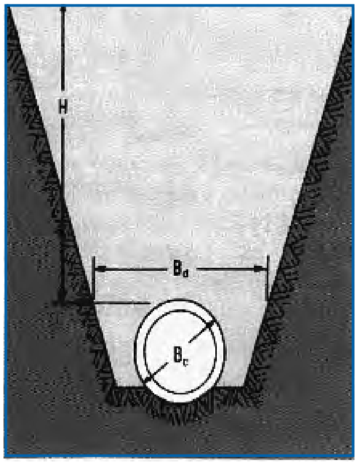
= 25 N / m / mm

Answer:

A pipe which would withstand a minimum three-edge-bearing test load for the 0.3 mm crack of 25 N/m/mm of inside diameter would be required.

Example 4.7.5

WIDE TRENCH INSTALLATION



Given: A 300 mm circular pipe is to be installed in a 1.7 m wide trench with 2.0 m of cover over the top of the pipe. The pipe will be backfilled with ordinary clay having a density of 1900 kg/m3.

Find: The required three-edge-bearing test strength for nonreinforced pipe and the ultimate D-load for reinforced pipe.

Solution:

1. **Determination of Earth Load (W_E)**
   From Table 4.9C the transition width for H = 2.0 m is 0.85 m. Since the actual 1.7 m trench width exceeds the transition width, the backfill load based on 1900 kg/m3 backfill is 22.5 kN/m.

   $W_E = 22{,}500\ N/m$

2. **Determination of Live Load (WL)**
From Table 4.35, the live load is interpolated to be 3.1 kN/m.

$W_L = 3,100\ N/m$

3. **Selection of Bedding**
A class B bedding as shown in Figure 4.21A will be assumed for this example.

4. **Determination of Bedding Factor (B_f)**
Since the trench is beyond transition width, a bedding factor for embankment condition is required. The outside diameter for a 300 mm diameter pipe is 0.4 m.

From Table 4.40A, for an *H/B* ratio of 5.0, $r_{sd}\,p$ value of 0.5, *p* value of 0.7 and Class B bedding, a bedding factor of 2.35 is obtained.

5. **Application of Factor of Safety (*F.S.*)**
A factor of safety of 1.5 based on the three-edge-bearing strength for nonreinforced pipe and ultimate D-Load for reinforced pipe will be applied.

6. **Selection of Pipe Strength**
The three-edge-bearing strength for nonreinforced pipe is given by:

(4.26)
$$T.E.B. = \frac{W_L + W_E}{B_f} F.S.$$

= 16 kN / m

The D-Load for reinforced pipe is given by:

(4.27)
$$D\text{-}load = \frac{W_L + W_E}{B_f D} F.S.$$

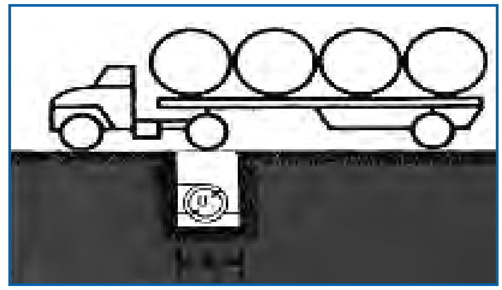
= 55 N / m / mm

Answer:
A nonreinforced pipe which would withstand a minimum three-edge bearing test load of 16 kN/m would be required.

A reinforced pipe which would withstand a minimum three-edge bearing test load for the ultimate load of 55 N/m/mm of inside diameter would be required.

Example 4.7.6

HIGHWAY LIVE LOAD



Given: A 300 mm circular pipe is to be installed in a narrow trench, $B_d \leq (B_c + 0.3)$, under a roadway and covered with 0.3 m of 1900 kg /m3 backfill material.

Find: The required pipe strength in terms of 0.3 mm crack *D-load.*

Solution:

1. **Determination of Earth Load (W_E)**

   For pipe installed with less than 0.9 m of cover, it is sufficiently accurate to calculate the backfill or fill load as being equal to the weight of the prism of earth on top of the pipe.

   $W_E = wgHB_c$

   = 1900 x 9.81 x 0.3 x 0.4

   = 2200 *N/m*

2. **Determination of Live Load (W_L)**

   Since the pipe is being installed under an unsurfaced roadway with shallow cover, a truck loading based on legal load limitations should be evaluated. From Table 4.35, for D = 300 mm, $H = 0.3\ m$ and AASHTO loading a live load of 33.0 kN/m is obtained. This live load value includes impact.

   W_L = 33,000 N/m

3. **Selection of Bedding**

   A class B bedding will be assumed for this example.

4. **Determination of Bedding Factor (B_f)**

   From Figure 4.21A for circular pipe installed on a class B bedding, a bedding factor of 1.9 is obtained.

5. **Application of Factor of Safety (*F.S.*)**

   A factor of safety of 1.0 based on 0.3 mm crack will be applied.

6. **Selection of Pipe Strength**

   The D-load is given by:

   (4.27)

   $$D\text{-}load = \frac{W_L + W_E}{B_f D} F.S.$$

   = 62 N / m / mm

Answer:
A pipe which would withstand a minimum three-edge-bearing test load for the 0.3 mm crack of 62 N/m/mm of inside diameter would be required.

b)
Given: All data will remain the same as above except that the pipe size will be increased from 300 mm circular pipe to 1200 mm circular pipe.

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

Solution:

1. **Determination of Earth Load (W_E)**

WE = wgHBc

= 1900 x 9.81 x 0.3 x 1.5

= 8400 N/m

2. **Determination of Live Load (W_L)**

From Table 4.35, for D = 1200 mm, H = 0.3 m and AASHTO loading a live load of 34 kN/m is obtained. This live load value includes impact.

WL = 34,000 N/m

3. **Selection of Bedding**

A class B bedding will be assumed for this example.

4. **Determination of Bedding Factor (B_f)**

From Figure 4.21A, for circular pipe installed on a class B bedding, a bedding factor of 1.9 is obtained.

5. **Application of Factor of Safety (F.S.)**

A factor of safety of 1.0 based on the 0.3 mm crack will be applied.

6. **Selection of Pipe Strength**

The D-load is given by:

(4.27)

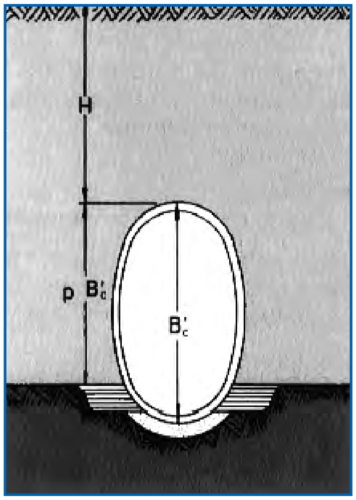
$$D\text{-}load = \frac{W_L + W_E}{B_f D} F.S.$$

= 19 N / m / mm

Answer:
A pipe which would withstand a minimum three-edge-bearing test load for the 0.3 mm crack of 19 N/m/mm of inside diameter.

Example 4.7.7

POSITIVE PROJECTING EMBANKMENT INSTALLATION VERTICAL ELLIPTICAL PIPE



Given: A 1920 mm x 1220 mm vertical elliptical pipe is to be installed in a positive projecting embankment condition in ordinary soil. The pipe will be covered with 15 m of 1900 kg/m3 overfill.

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

Solution:

1. Determination of Earth Load (WE)

A settlement ratio must first be assumed. In Table 4.33, values of settlement ratio from +0.5 to +0.8 are given for positive projecting installations on a foundation of ordinary soil. A value of 0.5 will be used, with an assumed projection ratio of 0.7. The product of the settlement ratio and the projection ratio will be 0.35 ($r_{sd}\,p$ » 0.3).

The outside horizontal span $B_c = 1.55\ m,\ H = 15.0\ m,\ H/B_c = 9.70$

From Figure 4.16, for $H/B_c = 9.70$ and using curve marked $r_{sd}\,p = 0.3$,

$C_c = 14.1$

Weight of soil is given by:

(4.8) $$W_E = C_c\, Wg\, B_c^2$$

= 14.1 x 1900 x 9.81 x 1.55 2

= 631,400 N/m

2. Determination of Live Load (W_L)

From Table 4.37, live load is negligible at a depth of 15 m

$W_L = 0.$

3. Selection of Bedding

A class B bedding will be assumed for this example.

4. Determination of Bedding Factor (B_f)

From Table 4.41 for an H/Bc ratio of 9.7, rsd pvalue of 0.3, p value of 0.7 and a class B Bedding, a bedding factor of 2.80 is obtained.

5. Application of Factor of Safety (*F.S.*)
A factor of safety of 1.0 based on the 0.3 mm crack will be applied.

6. Selection of Pipe Strength
The D-load is given by:

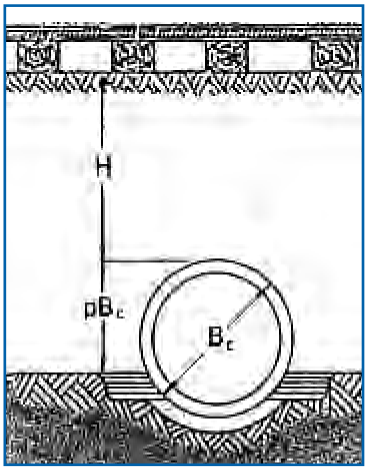
(4.28)
$$D\text{-}load = \frac{W_L + W_E}{B_f S} F.S.$$

= 185 N / m / mm

Answer:
A pipe which would withstand a minimum three-edge bearing test load for the 0.3 mm crack of 185 N/m/mm of inside horizontal span would be required.

Example 4.7.8

RAILROAD LIVE LOAD



Given: A 375 mm circular pipe is to be installed under a railroad in a positive projecting embankment condition, in ordinary soil. The pipe will be covered with 1.0 m of 1900 kg/m3 overfill (measured from top of pipe to bottom of ties.)

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

Solution:

1. Determination of Earth Load (W_E)
For pipe installed with 0.9 m of cover or less, it is sufficiently accurate to calculate the backfill, or fill load, as being equal to the weight of the prism of earth on top of the pipe.

$W\text{E} = wgHB_c$

= 1900 x 9.81 x 1.0 x 0.5

= 9300 N/m

2. Determination of Live Load (W_L)

From Table 4.38, for a 375 mm diameter pipe with H = 1.0 m and a COOPER E85 design load, a live load of 55.4 kN/m is interpolated.

WL = 55,400 N/m

3. Selection of Bedding

A class B bedding will be assumed for this example.

4. Determination of Bedding Factor (B_f)

The outside diameter for a 375 mm pipe is 0.5 m. H/Bc = 2.0. From Table 4.33 the design range of values for ordinary soils is +0.5 to +0.8. Assume an r_{sd} value of +0.7, for class B bedding $p = 0.7$, then $r_{sd}\,p = 0.49$. From Table 4.40A, a bedding factor of 2.39 is obtained.

5. Application of Factor of Safety (*F.S.*)

A factor of safety of 1.0 based on the 0.3 mm crack will be applied.

6. Selection of pipe strength

The D-load is given by:

(4.27)

$$D\text{-}load = \frac{W_L + W_E}{B_f D} F.S.$$

= 72 N / m / mm

Answer:

A pipe which would withstand a minimum three-edge-bearing test load for 0.3 mm crack of 72 N/m/mm of internal diameter would be required.

List of Figures

Figures 4.13 to 4.24

Tables 4.6 to 4.42

Figure 4.13 - **Essential Features of Types of Installations**

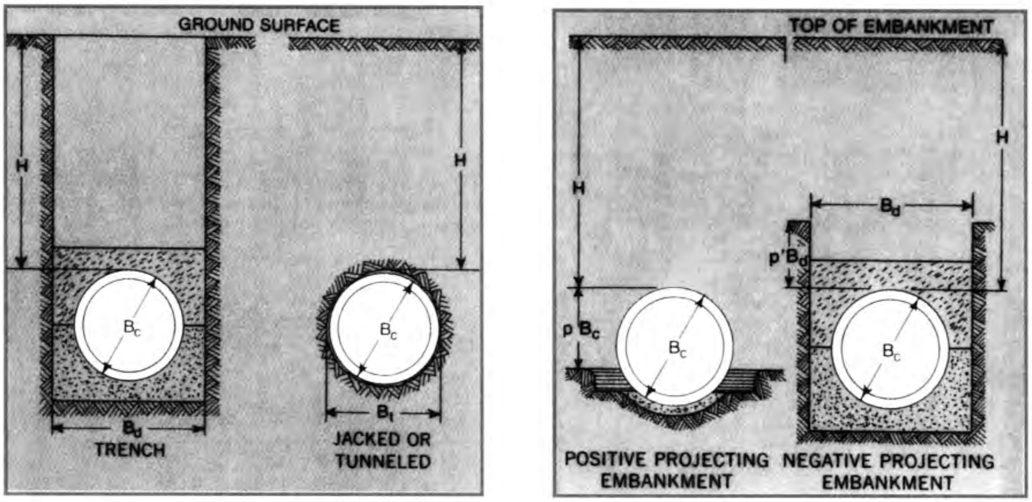


Figure 4.14 - **Load Coefficient for Positive Projection Embankment Condition**

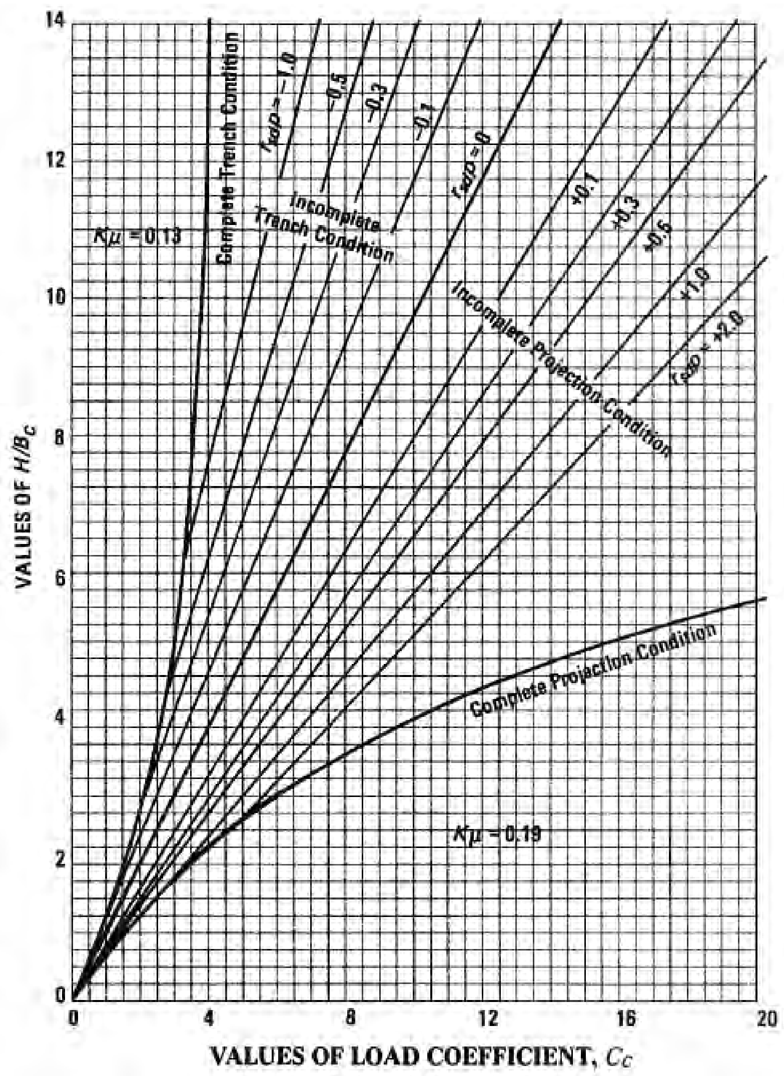


Figure 4.15 - Load Coefficient for Horizontal Elliptical Pipe

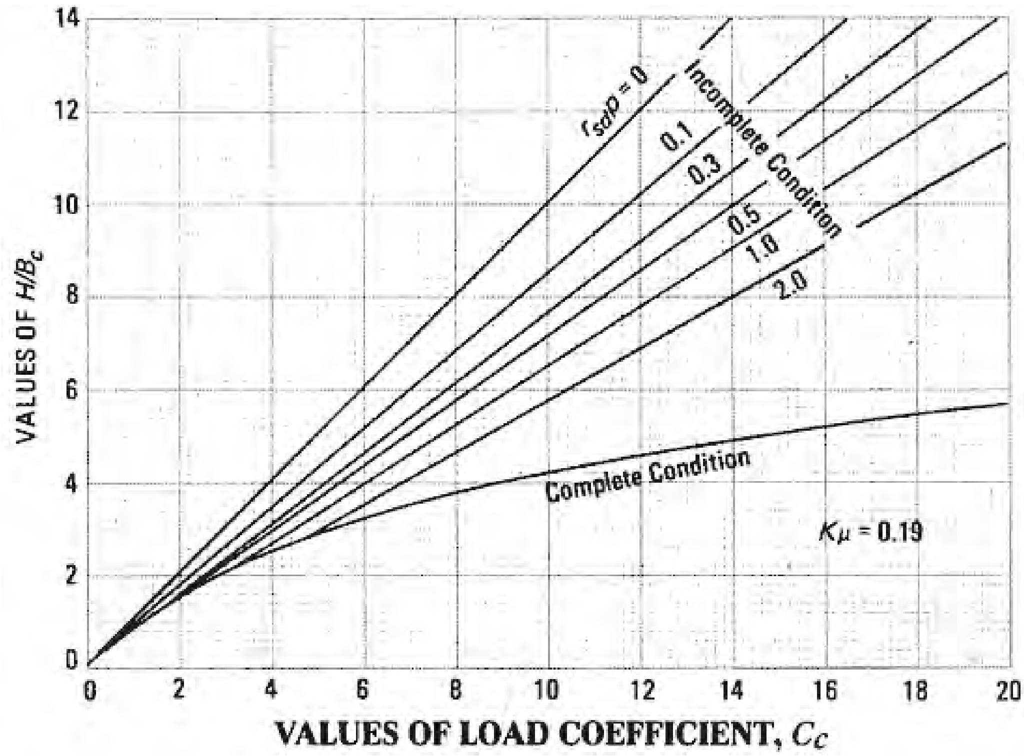


Figure 4.16 - Load Coefficient for Vertical Elliptical Pipe

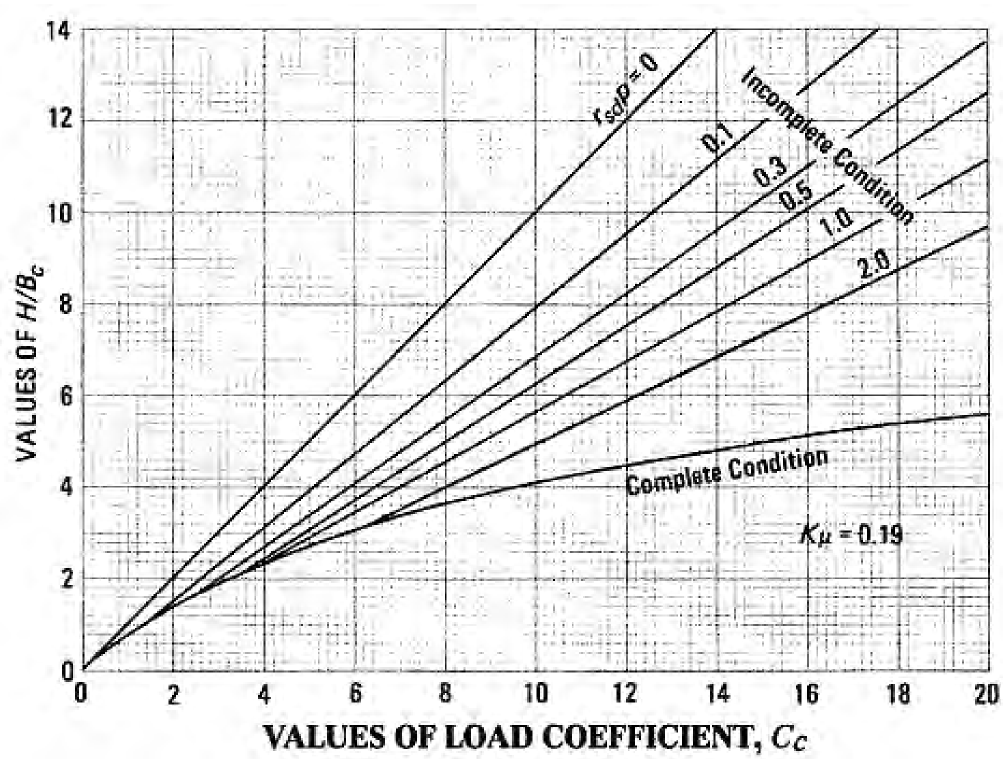


Figure 4.17 - Load Coefficient for Negative Projection Condition (p′ = 0.5)

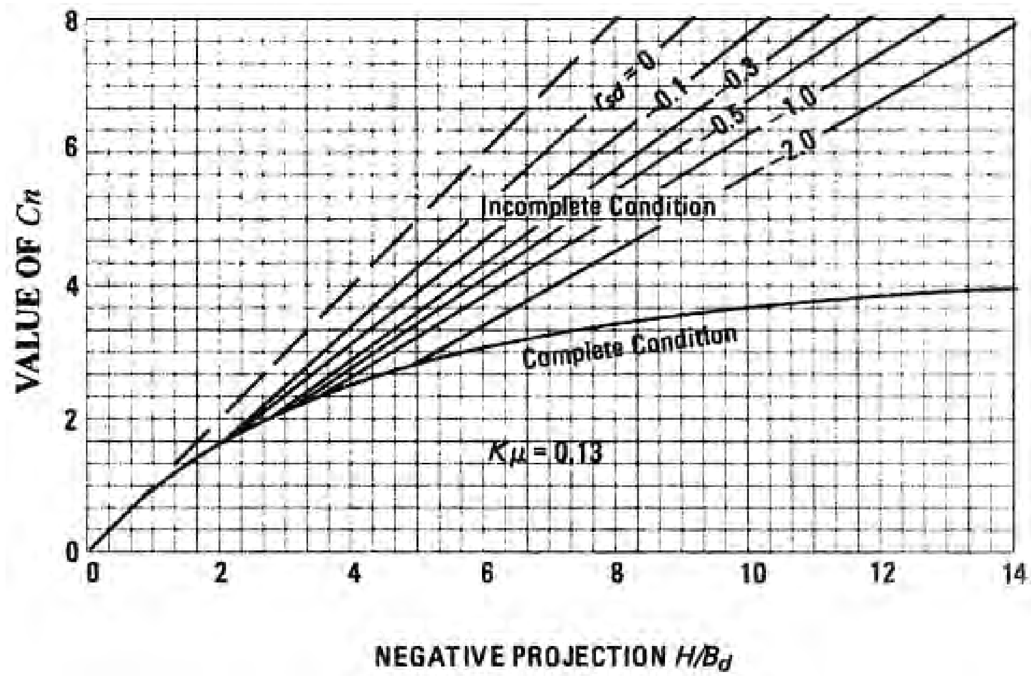


Figure 4.18 - Load Coefficient for Negative Projection Condition (p′ = 1.0)

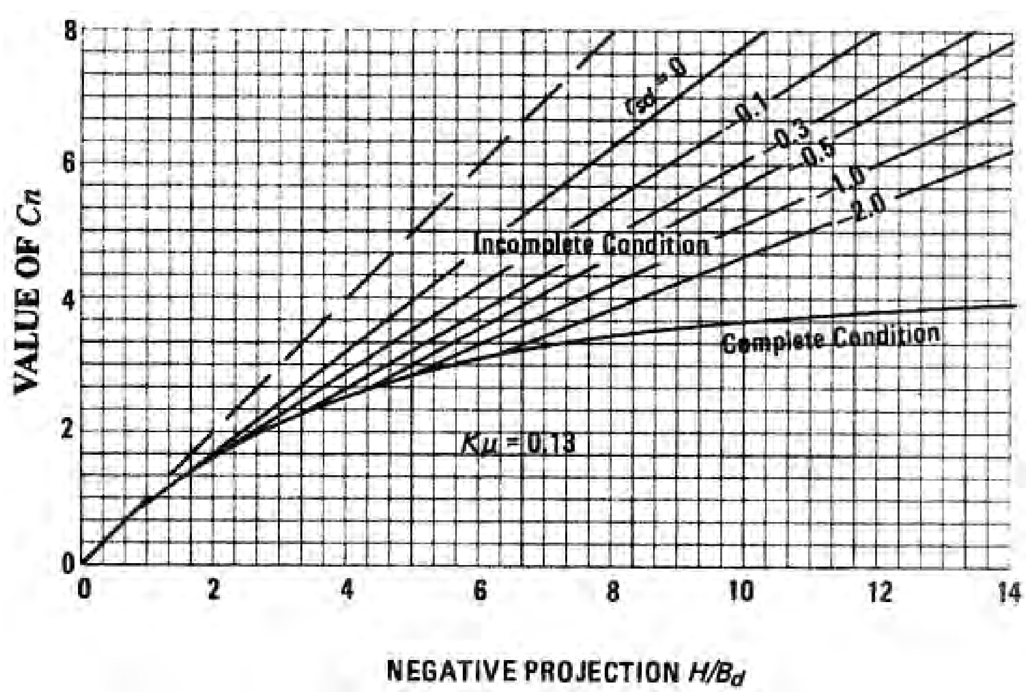


Figure 4.19 - Load Coefficient for Negative Projection Condition (p´ = 1.5)

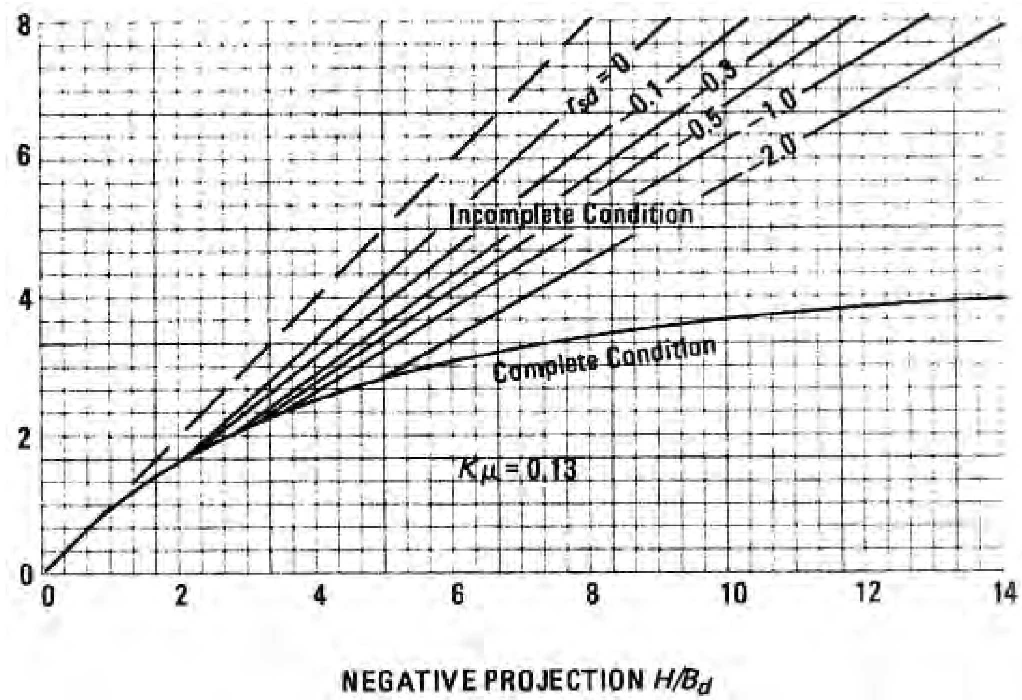


Figure 4.20 - Load Coefficient for Negative Projection Condition (p´ = 2.0)

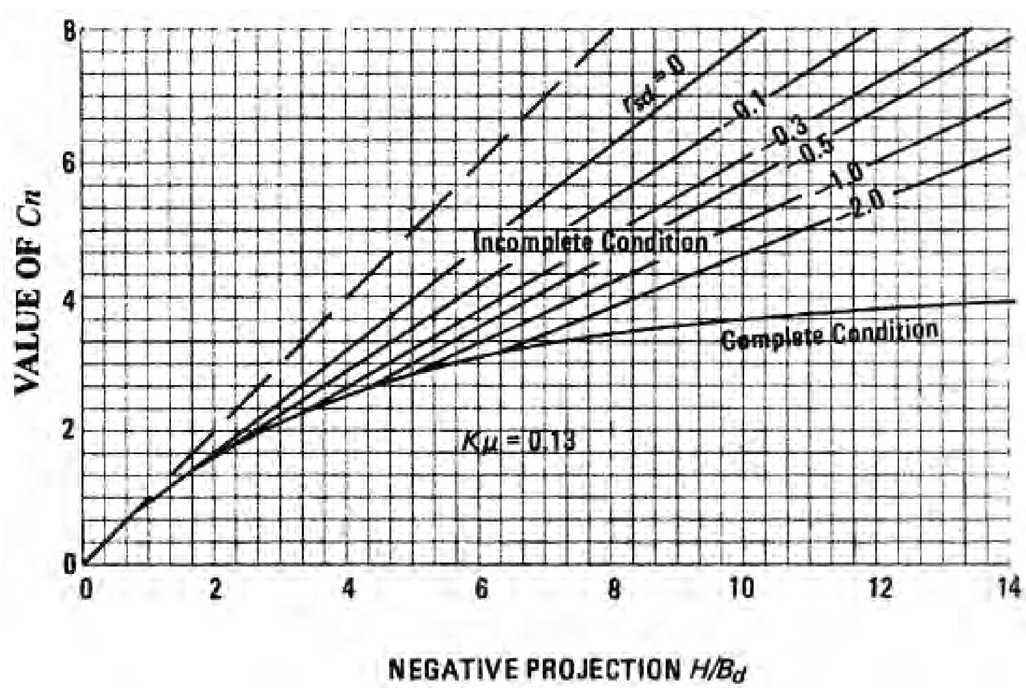


Figure 4.21A - Trench Beddings, Circular Pipe

Notes:

1. The minimum dimension shall be 0.150, except in an unyielding foundation where the minimum dimension shall be 0.250. In no case shall the min. dimension be less than 150mm, or the max dimension exceed 300mm.

2. Bedding Types:
   A. (Class B) - Bft = 1.9
      1. Bedding compacted to 90% using SW.
   B. (Class C) - Bft = 1.5
      1. Bedding compacted to 80% SW or 85% ML or CL

2. Lower Haunch 80% SW or 85% ML or CL

3. A 300mm layer of cover material to O.P.S.S 410 shall be provided before using a mechanical compactor on top of the pipe. Power operated tractors, or rolling equipment shall not be used.

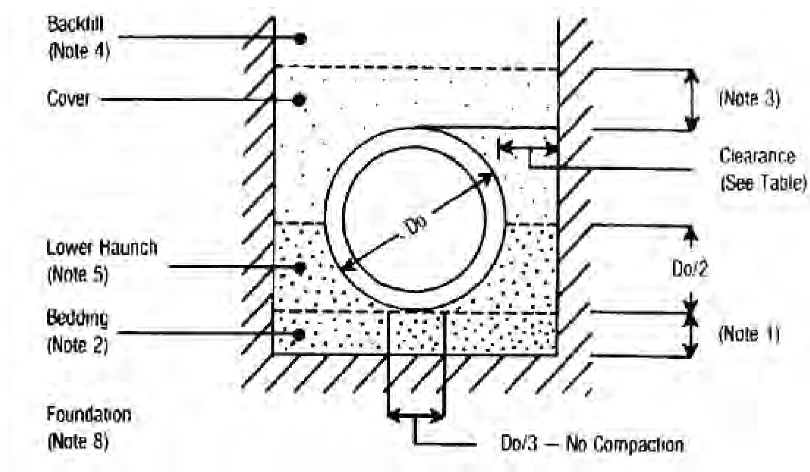
4. Backfill according to O.P.S.S B03.04.

5. When installation is designed for wheel loads, compaction of soil in lower haunch zones shall not be less than that specified for backfit.

6. Compaction presented as modified proctor values.

7. Soils represented per United Soil Classification System.

8. This detail to be applied in stable conditions or after trench has been brought to stable condition.



Pipe Inside Diameter (mm)	Clearance (mm)
150-900	300
975-3600	500

Legend
D = inside diameter
DO = outside
SW = well grade sand
CL = lean clay
ML = silt
= Bedding factor used for calculating of the variable bedding factor

Figure 4.21B - Trench Beddings, Circular Pipe

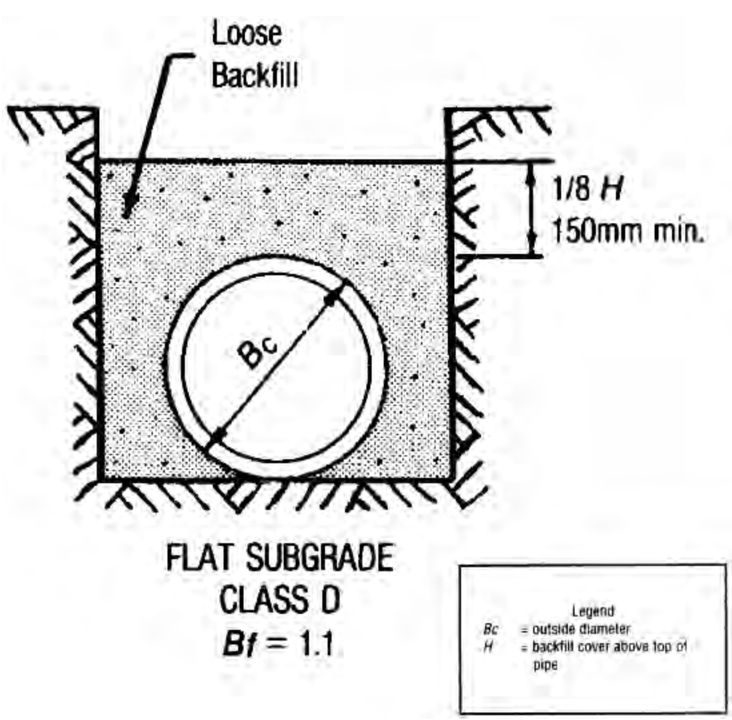


Figure 4.22 - **Trench Beddings**

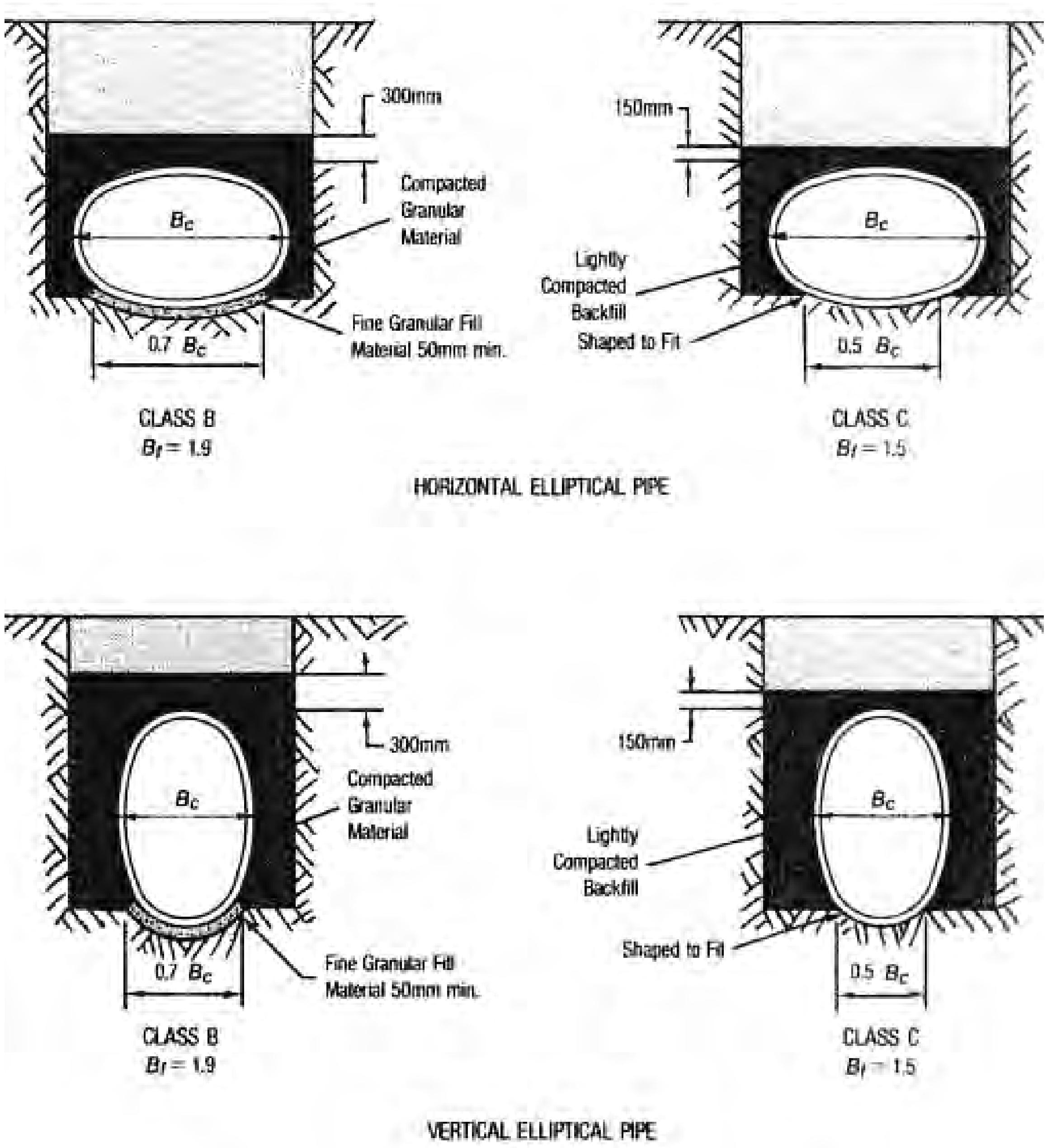
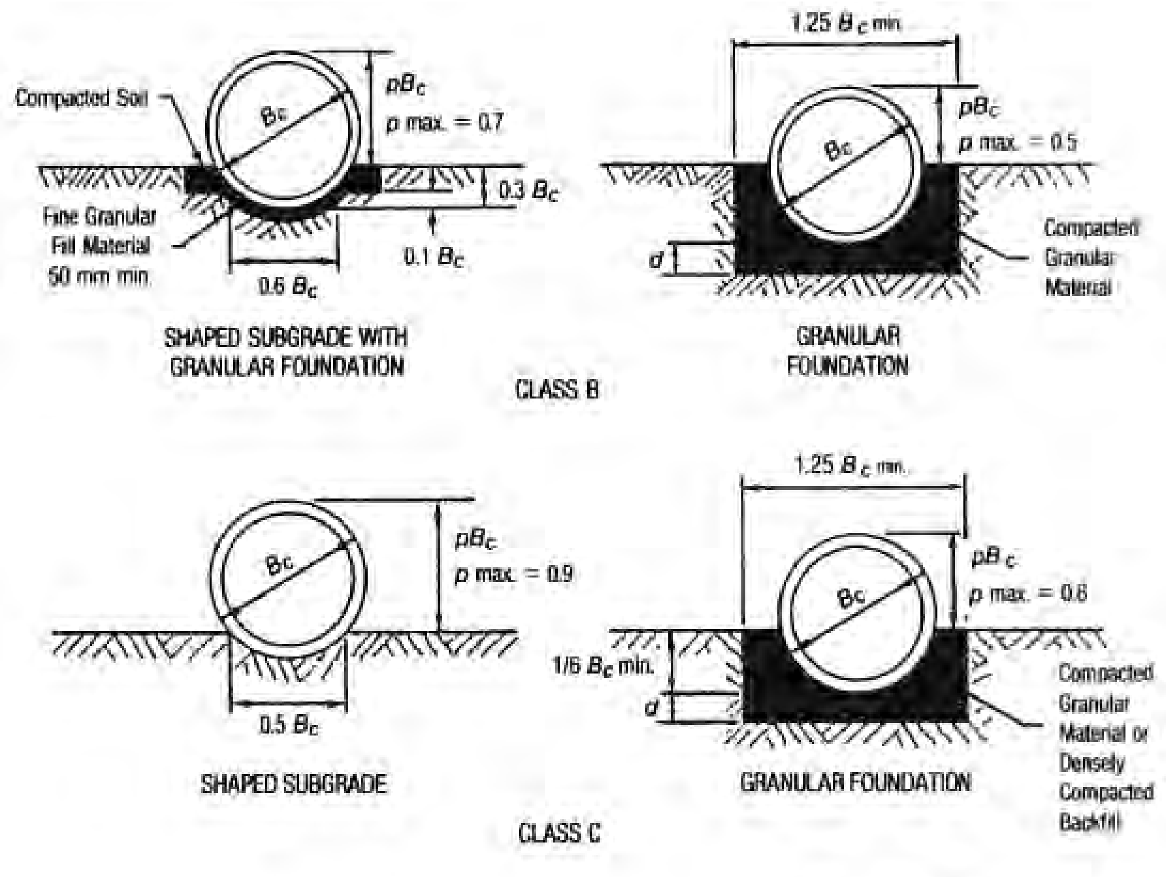
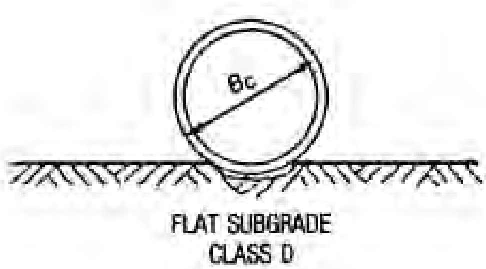


Figure 4.23 - Embankment Beddings, Circular Pipe





Depth of Bedding
Material Below Pipe

D	d(min.)
675mm & smaller	75mm
750 to 1500mm	100mm
1650mm & larger	150mm

Legend
B_c = outside diameter
H = backfill cover above top of pipe
D = inside diameter
d = depth of bedding material below pipe

Figure 4.24 - **Trench Beddings**

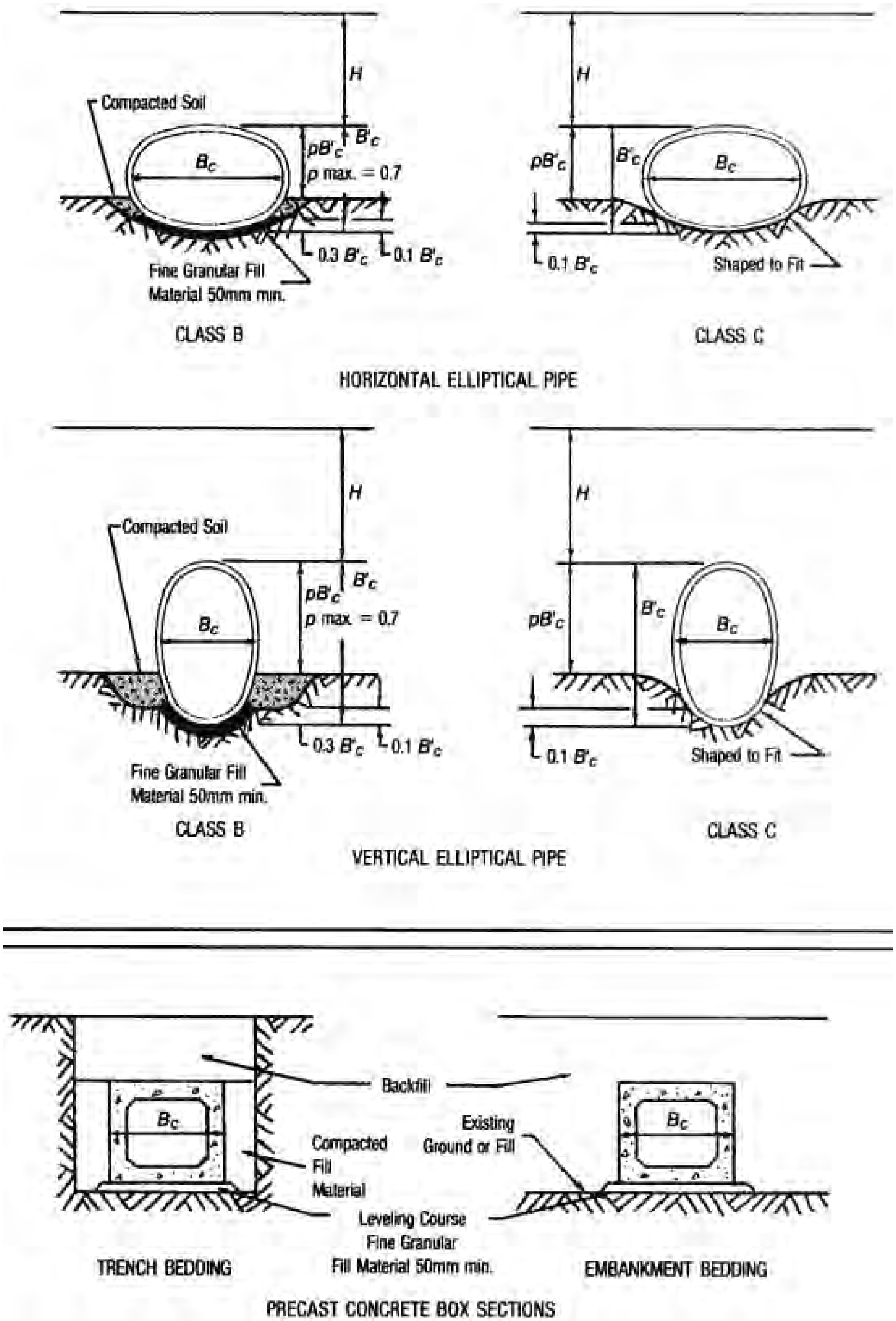


Table 4.6 - Backfill Loads On Circular Pipe In Trench Installation (kN/m)

150 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.20	
1.5	2.1	4.1	6.5	8.0							0.50
2.0	2.2	4.6	7.4	10.4	10.7						0.55
2.5	2.2	4.8	8.0	11.5	13.4						0.55
3.0	2.3	4.9	8.3	12.3	16.1						0.60
3.5	2.3	5.0	8.6	12.8	17.5	18.7					0.65
4.0	2.3	5.1	8.8	13.2	18.2	21.4					0.70
4.5	2.3	5.1	8.9	13.5	18.8	24.1					0.70
5.0	2.3	5.1	9.0	13.7	19.2	25.3	26.8				0.75
5.5	2.3	5.1	9.0	13.9	19.5	25.8	29.5				0.80
6.0	2.3	5.1	9.1	14.0	19.8	26.3	32.2				0.80
6.5	2.3	5.1	9.1	14.0	19.9	26.6	34.0	34.8			0.85
7.0	2.3	5.1	9.1	14.1	20.1	26.9	34.4	37.5			0.85
7.5	2.3	5.1	9.1	14.1	20.2	27.1	34.8	40.2			0.90
8.0	2.3	5.1	9.1	14.2	20.3	27.3	35.1	42.9			0.90
8.5	2.3	5.1	9.1	14.2	20.3	27.4	35.4	44.1	45.6		0.95
9.0	2.3	5.1	9.1	14.2	20.4	27.5	35.6	44.4	48.3		0.95
9.5	2.3	5.1	9.1	14.2	20.4	27.6	35.7	44.7	50.9		1.00
10.0	2.3	5.1	9.1	14.2	20.4	27.7	35.9	45.0	53.6		1.00
10.5	2.3	5.1	9.1	14.2	20.4	27.7	36.0	45.2	55.2	56.3	1.05
11.0	2.3	5.1	9.1	14.2	20.5	27.8	36.1	45.3	55.5	59.0	1.05
11.5	2.3	5.1	9.1	14.2	20.5	27.8	36.1	45.5	55.7	61.7	1.10
12.0	2.3	5.1	9.1	14.2	20.5	27.8	36.2	45.6	55.9	64.4	1.10
12.5	2.3	5.1	9.1	14.2	20.5	27.8	36.3	45.7	56.0	67.0	1.10
13.0	2.3	5.1	9.1	14.2	20.5	27.9	36.3	45.8	56.2	69.7	1.15
13.5	2.3	5.1	9.1	14.2	20.5	27.9	36.3	45.8	56.3	72.4	1.15
14.0	2.3	5.1	9.1	14.2	20.5	27.9	36.3	45.9	56.4	75.1	1.20
14.5	2.3	5.1	9.1	14.2	20.5	27.9	36.4	45.9	56.5	77.8	1.20
15.0	2.3	5.1	9.1	14.2	20.5	27.9	36.4	46.0	56.6	80.5	1.20

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.20	
1.5	2.2	4.4	6.8	8.0							0.45
2.0	2.4	4.9	7.8	10.7							0.50
2.5	2.4	5.2	8.5	12.2	13.4						0.55
3.0	2.5	5.4	9.0	13.1	16.1						0.60
3.5	2.5	5.5	9.3	13.7	18.6	18.7					0.65
4.0	2.5	5.5	9.5	14.2	19.5	21.4					0.65
4.5	2.5	5.6	9.7	14.6	20.2	24.1					0.70
5.0	2.5	5.6	9.8	14.9	20.7	26.8					0.70
5.5	2.5	5.6	9.9	15.1	21.1	27.8	29.5				0.75
6.0	2.5	5.6	9.9	15.2	21.4	28.4	32.2				0.80
6.5	2.5	5.6	10.0	15.3	21.7	28.8	34.8				0.80
7.0	2.5	5.6	10.0	15.4	21.9	29.2	37.2	37.5			0.85
7.5	2.5	5.6	10.0	15.5	22.0	29.5	37.7	40.2			0.85
8.0	2.5	5.6	10.0	15.5	22.1	29.7	38.1	42.9			0.90
8.5	2.5	5.6	10.0	15.6	22.2	29.9	38.5	45.6			0.90
9.0	2.5	5.6	10.0	15.6	22.3	30.1	38.7	48.2	48.3		0.95
9.5	2.5	5.6	10.0	15.6	22.4	30.2	39.0	48.6	50.9		0.95
10.0	2.5	5.6	10.0	15.6	22.4	30.3	39.2	48.9	53.6		0.95
10.5	2.5	5.6	10.0	15.6	22.4	30.4	39.3	49.2	56.3		1.00
11.0	2.5	5.6	10.0	15.6	22.5	30.4	39.5	49.5	59.0		1.00
11.5	2.5	5.6	10.0	15.7	22.5	30.5	39.6	49.7	60.7	61.7	1.05
12.0	2.5	5.6	10.0	15.7	22.5	30.5	39.7	49.8	61.0	64.4	1.05
12.5	2.5	5.6	10.0	15.7	22.5	30.6	39.7	50.0	61.2	67.0	1.05
13.0	2.5	5.6	10.0	15.7	22.5	30.6	39.8	50.1	61.4	69.7	1.10
13.5	2.5	5.6	10.0	15.7	22.5	30.6	39.9	50.2	61.6	72.4	1.10
14.0	2.5	5.6	10.0	15.7	22.5	30.6	39.9	50.3	61.7	75.1	1.15
14.5	2.5	5.6	10.0	15.7	22.5	30.6	39.9	50.4	61.9	77.8	1.15
15.0	2.5	5.6	10.0	15.7	22.5	30.7	40.0	50.4	62.0	80.5	1.15

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.20	
1.5	2.5	4.7	7.2	8.0							0.45
2.0	2.7	5.4	8.4	10.7							0.50
2.5	2.8	5.8	9.3	13.2	13.4						0.55
3.0	2.8	6.0	9.9	14.3	16.1						0.55
3.5	2.9	6.2	10.4	15.1	18.7						0.60
4.0	2.9	6.3	10.7	15.8	21.4						0.60
4.5	2.9	6.4	10.9	16.3	22.3	24.1					0.65
5.0	2.9	6.4	11.1	16.7	23.0	26.8					0.70
5.5	2.9	6.5	11.2	17.0	23.6	29.5					0.70
6.0	2.9	6.5	11.3	17.3	24.1	31.6	32.2				0.75
6.5	2.9	6.5	11.4	17.5	24.5	32.3	34.8				0.75
7.0	2.9	6.5	11.4	17.6	24.8	32.8	37.5				0.80
7.5	2.9	6.5	11.5	17.7	25.0	33.2	40.2				0.80
8.0	2.9	6.5	11.5	17.8	25.2	33.6	42.8	42.9			0.85
8.5	2.9	6.5	11.5	17.9	25.4	33.9	43.4	45.6			0.85
9.0	2.9	6.5	11.5	17.9	25.5	34.2	43.8	48.3			0.85
9.5	2.9	6.5	11.5	17.9	25.6	34.4	44.2	50.9			0.90
10.0	2.9	6.5	11.6	18.0	25.7	34.6	44.5	53.6			0.90
10.5	2.9	6.5	11.6	18.0	25.8	34.7	44.8	55.7	56.3		0.95
11.0	2.9	6.5	11.6	18.0	25.8	34.8	45.0	56.1	59.0		0.95
11.5	2.9	6.5	11.6	18.0	25.9	34.9	45.2	56.5	61.7		0.95
12.0	2.9	6.5	11.6	18.0	25.9	35.0	45.3	56.7	64.4		1.00
12.5	2.9	6.5	11.6	18.0	25.9	35.1	45.5	57.0	67.0		1.00
13.0	2.9	6.5	11.6	18.1	25.9	35.1	45.6	57.2	69.7		1.00
13.5	2.9	6.5	11.6	18.1	26.0	35.2	45.7	57.4	70.1	72.4	1.05
14.0	2.9	6.5	11.6	18.1	26.0	35.2	45.8	57.5	70.4	75.1	1.05
14.5	2.9	6.5	11.6	18.1	26.0	35.3	45.9	57.7	70.6	77.8	1.10
15.0	2.9	6.5	11.6	18.1	26.0	35.3	45.9	57.8	70.8	80.5	1.10

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.20	
1.5	2.8	5.1	7.7	8.0							0.45
2.0	3.0	5.9	9.1	10.7							0.45
2.5	3.2	6.5	10.2	13.4							0.50
3.0	3.3	6.8	11.0	15.7	16.1						0.55
3.5	3.3	7.1	11.7	16.8	18.7						0.55
4.0	3.4	7.3	12.2	17.7	21.4						0.60
4.5	3.4	7.4	12.6	18.4	24.1						0.60
5.0	3.4	7.5	12.8	19.0	25.6	26.8					0.65
5.5	3.4	7.6	13.0	19.6	26.7	29.5					0.65
6.0	3.4	7.6	13.2	19.8	27.4	32.2					0.70
6.5	3.4	7.6	13.3	20.1	27.9	34.8					0.70
7.0	3.4	7.6	13.4	20.4	28.4	37.2	37.5				0.75
7.5	3.4	7.7	13.5	20.6	28.8	37.9	40.2				0.75
8.0	3.4	7.7	13.5	20.7	29.1	38.6	42.9				0.75
8.5	3.4	7.7	13.5	20.9	29.4	39.0	45.6				0.80
9.0	3.4	7.7	13.6	21.0	29.6	39.4	48.3				0.80
9.5	3.4	7.7	13.6	21.0	29.8	39.8	50.7	50.9			0.85
10.0	3.4	7.7	13.6	21.1	30.0	40.1	51.2	53.6			0.85
10.5	3.4	7.7	13.6	21.2	30.1	40.3	51.6	56.3			0.85
11.0	3.4	7.7	13.6	21.2	30.2	40.6	52.0	59.0			0.90
11.5	3.4	7.7	13.6	21.2	30.3	40.7	52.4	61.7			0.90
12.0	3.4	7.7	13.7	21.3	30.4	40.9	52.7	64.4			0.90
12.5	3.4	7.7	13.7	21.3	30.4	41.0	52.9	66.0	67.0		0.95
13.0	3.4	7.7	13.7	21.3	30.5	41.2	53.2	66.3	69.7		0.95
13.5	3.4	7.7	13.7	21.3	30.5	41.3	53.4	66.7	72.4		0.95
14.0	3.4	7.7	13.7	21.3	30.6	41.4	53.5	67.0	75.1		1.00
14.5	3.4	7.7	13.7	21.3	30.6	41.4	53.7	67.2	77.8		1.00
15.0	3.4	7.7	13.7	21.3	30.6	41.5	53.8	67.4	80.5		1.00

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, rsd p = 0.5 in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.7 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

200 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.20	1.40	TRANSITION WIDTH (m)
1.5	4.1	6.5	9.0	10.3							0.60
2.0	4.6	7.4	10.4	13.7	13.7						0.65
2.5	4.8	8.0	11.5	15.3	17.2						0.65
3.0	4.9	8.3	12.3	16.6	20.6						0.70
3.5	5.0	8.6	12.8	17.5	22.6	24.1					0.75
4.0	5.1	8.8	13.2	18.2	23.7	27.5					0.80
4.5	5.1	8.9	13.5	18.8	24.6	30.8	31.0				0.85
5.0	5.1	9.0	13.7	19.2	25.3	31.8	34.4				0.85
5.5	5.1	9.0	13.9	19.5	25.8	32.7	37.9				0.90
6.0	5.1	9.1	14.0	19.8	26.3	33.4	41.0	41.3			0.95
6.5	5.1	9.1	14.0	19.9	26.6	34.0	41.9	44.8			0.95
7.0	5.1	9.1	14.1	20.1	26.9	34.4	42.6	48.2			1.00
7.5	5.1	9.1	14.1	20.2	27.1	34.8	43.2	51.7			1.00
8.0	5.1	9.1	14.2	20.3	27.3	35.1	43.7	52.9	55.1		1.05
8.5	5.1	9.1	14.2	20.3	27.4	35.4	44.1	53.5	58.6		1.10
9.0	5.1	9.1	14.2	20.4	27.5	35.6	44.4	54.0	62.0		1.10
9.5	5.1	9.1	14.2	20.4	27.6	35.7	44.7	54.5	65.5		1.15
10.0	5.1	9.1	14.2	20.4	27.7	35.9	45.0	54.9	68.9		1.15
10.5	5.1	9.1	14.2	20.4	27.7	36.0	45.2	55.2	72.4		1.20
11.0	5.1	9.1	14.2	20.5	27.8	36.1	45.3	55.5	75.8		1.20
11.5	5.1	9.1	14.2	20.5	27.8	36.1	45.5	55.7	78.6	79.3	1.25
12.0	5.1	9.1	14.2	20.5	27.8	36.2	45.6	55.9	79.0	82.7	1.25
12.5	5.1	9.1	14.2	20.5	27.8	36.3	45.7	56.0	79.4	86.2	1.30
13.0	5.1	9.1	14.2	20.5	27.9	36.3	45.8	56.2	79.7	89.6	1.30
13.5	5.1	9.1	14.2	20.5	27.9	36.3	45.8	56.3	80.0	93.1	1.30
14.0	5.1	9.1	14.2	20.5	27.9	36.3	45.9	56.4	80.3	96.5	1.35
14.5	5.1	9.1	14.2	20.5	27.9	36.4	45.9	56.5	80.5	100.0	1.35
15.0	5.1	9.1	14.2	20.5	27.9	36.4	46.0	56.6	80.7	103.4	1.40

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.20	1.40	TRANSITION WIDTH (m)
1.5	4.4	6.8	9.3	10.3							0.55
2.0	4.9	7.8	10.9	13.7							0.60
2.5	5.2	8.5	12.2	16.1	17.22						0.65
3.0	5.4	9.0	13.1	17.5	20.6						0.70
3.5	5.5	9.3	13.7	18.6	23.9	24.1					0.75
4.0	5.5	9.5	14.2	19.5	25.2	27.5					0.75
4.5	5.6	9.7	14.6	20.2	26.2	31.0					0.80
5.0	5.6	9.8	14.9	20.7	27.1	34.0	34.4				0.85
5.5	5.6	9.9	15.1	21.1	27.8	35.0	37.9				0.85
6.0	5.6	9.9	15.2	21.4	28.4	35.9	41.3				0.90
6.5	5.6	10.0	15.3	21.7	28.8	36.6	44.8				0.90
7.0	5.6	10.0	15.4	21.9	29.2	37.2	45.6	48.2			0.95
7.5	5.6	10.0	15.5	22.0	29.5	37.7	46.6	51.7			1.00
8.0	5.6	10.0	15.5	22.1	29.7	38.1	47.2	55.1			1.00
8.5	5.6	10.0	15.6	22.2	29.9	38.5	47.8	57.8	58.6		1.05
9.0	5.6	10.0	15.6	22.3	30.1	38.7	48.2	58.5	62.0		1.05
9.5	5.6	10.0	15.6	22.4	30.2	39.0	48.6	59.0	65.5		1.10
10.0	5.6	10.0	15.6	22.4	30.3	39.2	48.9	59.5	68.9		1.10
10.5	5.6	10.0	15.6	22.4	30.4	39.3	49.2	60.0	72.4		1.15
11.0	5.6	10.0	15.6	22.5	30.4	39.5	49.5	60.4	75.8		1.15
11.5	5.6	10.0	15.7	22.5	30.5	39.6	49.7	60.7	79.3		1.20
12.0	5.6	10.0	15.7	22.5	30.5	39.7	49.6	61.0	82.7		1.20
12.5	5.6	10.0	15.7	22.5	30.6	39.7	50.0	61.2	86.2		1.20
13.0	5.6	10.0	15.7	22.5	30.6	39.8	50.1	61.4	86.7	89.6	1.25
13.5	5.6	10.0	15.7	22.5	30.6	39.9	50.2	61.6	87.2	93.1	1.25
14.0	5.6	10.0	15.7	22.5	30.6	39.9	50.3	61.7	87.5	96.5	1.30
14.5	5.6	10.0	15.7	22.5	30.6	39.9	50.4	61.9	87.8	100.0	1.30
15.0	5.6	10.0	15.7	22.5	30.7	40.0	50.4	62.0	88.1	103.4	1.35

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.20	1.40	TRANSITION WIDTH (m)
1.5	4.7	7.2	9.8	10.3							0.55
2.0	5.4	8.4	11.7	13.7							0.60
2.5	5.8	9.3	13.2	17.2							0.60
3.0	6.0	9.9	14.3	18.9	20.6						0.65
3.5	6.2	10.4	15.1	20.3	24.1						0.70
4.0	6.3	10.7	15.8	21.4	27.4	27.5					0.75
4.5	6.4	10.9	16.3	22.3	28.8	31.0					0.75
5.0	6.4	11.1	16.7	23.0	29.9	34.4					0.80
5.5	6.5	11.2	17.0	23.6	30.8	37.9					0.80
6.0	6.5	11.3	17.3	24.1	31.6	39.7	41.3				0.85
6.5	6.5	11.4	17.5	24.5	32.3	40.7	44.8				0.85
7.0	6.5	11.4	17.6	24.8	32.8	41.5	48.2				0.90
7.5	6.5	11.5	17.7	25.0	33.2	42.2	51.7				0.90
8.0	6.5	11.5	17.8	25.2	33.6	42.8	52.8	55.1			0.95
8.5	6.5	11.5	17.9	25.4	33.9	43.4	53.5	58.6			0.95
9.0	6.5	11.5	17.9	25.5	34.2	43.8	54.2	62.0			1.00
9.5	6.5	11.5	17.9	25.6	34.4	44.2	54.8	65.5			1.00
10.0	6.5	11.6	18.0	25.7	34.6	44.5	55.3	66.9	68.9		1.05
10.5	6.5	11.6	18.0	25.8	34.7	44.8	55.7	67.6	72.4		1.05
11.0	6.5	11.6	18.0	25.8	34.8	45.0	56.1	68.2	75.8		1.10
11.5	6.5	11.6	18.0	25.9	31.9	45.2	56.5	68.7	79.3		1.10
12.0	6.5	11.6	18.0	25.9	35.0	45.3	56.7	69.1	82.7		1.15
12.5	6.5	11.6	18.0	25.9	35.1	45.5	57.0	69.5	86.2		1.15
13.0	6.5	11.6	18.1	25.9	35.1	45.6	57.2	69.8	89.6		1.15
13.5	6.5	11.6	18.1	26.0	35.2	45.7	57.4	70.1	93.1		1.20
14.0	6.5	11.6	18.1	26.0	35.2	45.8	57.5	70.4	96.5		1.20
14.5	6.5	11.6	18.1	26.0	35.3	45.9	57.7	70.6	99.6	100.0	1.25
15.0	6.5	11.6	18.1	26.0	35.3	45.9	57.8	70.8	100.1	103.4	1.25

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.20	1.40	TRANSITION WIDTH (m)
1.5	5.1	7.7	10.3								0.50
2.0	5.9	9.1	12.5	13.7							0.55
2.5	6.5	10.2	14.3	17.2							0.60
3.0	6.8	11.0	15.7	20.5	20.6						0.65
3.5	7.1	11.7	16.8	22.2	24.1						0.65
4.0	7.3	12.2	17.7	23.7	27.5						0.70
4.5	7.4	12.5	18.4	24.9	31.0						0.70
5.0	7.5	12.8	19.0	25.8	33.2	34.4					0.75
5.5	7.6	13.0	19.5	26.7	34.4	37.9					0.75
6.0	7.6	13.2	19.8	27.4	35.5	41.3					0.80
6.5	7.6	13.3	20.1	27.9	36.4	44.8					0.80
7.0	7.6	13.4	20.4	28.4	37.2	46.7	48.2				0.85
7.5	7.7	13.5	20.6	28.8	37.9	47.7	51.7				0.85
8.0	7.7	13.5	20.7	29.1	38.5	48.6	55.1				0.90
8.5	7.7	13.5	20.9	29.4	39.0	49.4	58.6				0.90
9.0	7.7	13.6	21.0	29.6	39.4	50.1	61.5	62.0			0.95
9.5	7.7	13.6	21.0	29.8	39.8	50.7	62.4	65.5			0.95
10.0	7.7	13.6	21.1	30.0	40.1	51.2	63.2	68.9			0.95
10.5	7.7	13.6	21.2	30.1	40.3	51.6	63.9	72.4			1.00
11.0	7.7	13.6	21.2	30.2	40.6	52.0	64.5	75.8			1.00
11.5	7.7	13.6	21.2	30.3	40.7	52.4	65.1	78.6	79.3		1.05
12.0	7.7	13.7	21.3	30.4	40.9	52.7	65.5	79.4	82.7		1.05
12.5	7.7	13.7	21.3	30.4	41.0	52.9	66.0	80.0	86.2		1.05
13.0	7.7	13.7	21.3	30.5	41.2	53.2	66.3	80.6	89.6		1.10
13.5	7.7	13.7	21.3	30.5	41.3	53.4	66.7	81.1	93.1		1.10
14.0	7.7	13.7	21.3	30.6	41.4	53.5	67.0	81.5	96.5		1.10
14.5	7.7	13.7	21.3	30.6	41.4	53.7	67.2	81.9	100.0		1.15
15.0	7.7	13.7	21.3	30.6	41.5	53.8	67.4	82.3	103.4		1.15

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads (White -on -black values) and widths are based upon $K\mu' = 0.19$, rsd p = 0.5 in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.8 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

250 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.20	1.40	1.60	
1.5	6.5	9.0	11.5	12.7							0.65
2.0	7.4	10.4	13.7	16.9							0.70
2.5	8.0	11.5	15.3	19.3	21.2						0.75
3.0	8.3	12.3	16.6	21.1	25.4						0.80
3.5	8.6	12.8	17.5	22.6	27.9	29.7					0.85
4.0	8.8	13.2	18.2	23.7	29.5	34.0					0.90
4.5	8.9	13.5	18.8	24.6	30.8	37.3	38.2				0.95
5.0	9.0	13.7	19.2	25.3	31.8	38.8	42.5				1.00
5.5	9.0	13.9	19.5	25.8	32.7	40.0	46.7				1.00
6.0	9.1	14.0	19.8	26.3	33.4	41.0	49.1	51.0			1.05
6.5	9.1	14.0	19.9	26.6	34.0	41.9	50.3	55.3			1.10
7.0	9.1	14.1	20.1	26.9	34.4	42.6	51.3	59.5			1.10
7.5	9.1	14.1	20.2	27.1	34.8	43.2	52.2	63.8			1.15
8.0	9.1	14.2	20.3	27.3	35.1	43.7	52.9	68.0			1.20
8.5	9.1	14.2	20.3	27.4	35.4	44.1	53.5	72.3			1.20
9.0	9.1	14.2	20.4	27.5	35.6	44.4	54.0	75.1	76.6		1.25
9.5	9.1	14.2	20.4	27.6	35.7	44.7	54.5	76.0	80.8		1.25
10.0	9.1	14.2	20.4	27.7	35.9	45.0	54.9	76.8	85.1		1.30
10.5	9.1	14.2	20.4	27.7	36.0	45.2	55.2	77.5	89.3		1.30
11.0	9.1	14.2	20.5	27.8	36.1	45.3	55.5	78.1	93.6		1.35
11.5	9.1	14.2	20.5	27.8	36.1	45.5	55.7	78.6	97.8		1.40
12.0	9.1	14.2	20.5	27.8	36.2	45.6	55.9	79.0	102.1		1.40
12.5	9.1	14.2	20.5	27.8	36.3	45.7	56.0	79.4	105.8	106.4	1.45
13.0	9.1	14.2	20.5	27.9	36.3	45.8	56.2	79.7	106.4	110.6	1.45
13.5	9.1	14.2	20.5	27.9	36.3	45.8	56.3	80.0	107.0	114.9	1.50
14.0	9.1	14.2	20.5	27.9	36.3	45.9	56.4	80.3	107.5	119.1	1.50
14.5	9.1	14.2	20.5	27.9	36.4	45.9	56.5	80.5	108.0	123.4	1.55
15.0	9.1	14.2	20.5	27.9	36.4	46.0	56.6	80.7	108.4	127.7	1.55

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.20	1.40	1.60	
1.5	6.8	9.3	11.9	12.7							0.65
2.0	7.8	10.9	14.3	16.9							0.70
2.5	8.5	12.2	16.1	20.2	21.2						0.75
3.0	9.0	13.1	17.5	22.2	25.4						0.80
3.5	9.3	13.7	18.6	23.9	29.3	29.7					0.85
4.0	9.5	14.2	19.5	25.2	31.2	34.0					0.85
4.5	9.7	14.6	20.2	26.2	32.7	38.2					0.90
5.0	9.8	14.9	20.7	27.1	34.0	41.2	42.5				0.95
5.5	9.9	15.1	21.1	27.8	35.0	42.6	46.7				1.00
6.0	9.9	15.2	21.4	28.4	35.9	43.9	51.0				1.00
6.5	10.0	15.3	21.7	28.8	36.6	44.9	53.8	55.3			1.05
7.0	10.0	15.4	21.9	29.2	37.2	45.8	55.0	59.5			1.05
7.5	10.0	15.5	22.0	29.5	37.7	46.6	56.1	63.8			1.10
8.0	10.0	15.5	22.1	29.7	38.1	47.2	57.0	68.0			1.15
8.5	10.0	15.6	22.2	29.9	38.5	47.8	57.8	72.3			1.15
9.0	10.0	15.6	22.3	30.1	38.7	48.2	58.5	76.6			1.20
9.5	10.0	15.6	22.4	30.2	39.0	48.6	59.0	80.8			1.20
10.0	10.0	15.6	22.4	30.3	39.2	48.9	59.5	82.8	85.1		1.25
10.5	10.0	15.6	22.4	30.4	39.3	49.2	60.0	83.7	89.3		1.25
11.0	10.0	15.6	22.5	30.4	39.5	49.5	60.4	84.5	93.6		1.30
11.5	10.0	15.7	22.5	30.5	39.6	49.7	60.7	85.1	97.8		1.30
12.0	10.0	15.7	22.5	30.5	39.7	49.8	61.0	85.7	102.1		1.35
12.5	10.0	15.7	22.5	30.6	39.7	50.0	61.2	86.3	106.4		1.35
13.0	10.0	15.7	22.5	30.6	39.8	50.1	61.4	86.7	110.6		1.40
13.5	10.0	15.7	22.5	30.6	39.9	50.2	61.6	87.2	114.9		1.40
14.0	10.0	15.7	22.5	30.6	39.9	50.3	61.7	87.5	116.7	119.1	1.45
14.5	10.0	15.7	22.5	30.6	39.9	50.4	61.9	87.8	117.3	123.4	1.45
15.0	10.0	15.7	22.5	30.7	40.0	50.4	62.0	88.1	117.9	127.7	1.50

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.20	1.40	1.60	
1.5	7.2	9.8	12.4	12.7							0.65
2.0	8.4	11.7	15.1	16.9							0.70
2.5	9.3	13.2	17.2	21.2							0.70
3.0	9.9	14.3	18.9	23.8	25.4						0.75
3.5	10.4	15.1	20.3	25.8	29.7						0.80
4.0	10.7	15.8	21.4	27.4	33.7	34.0					0.85
4.5	10.9	16.3	22.3	28.8	35.6	38.2					0.85
5.0	11.1	16.7	23.0	29.9	37.2	42.5					0.90
5.5	11.2	17.0	23.6	30.8	38.5	46.6	46.7				0.95
6.0	11.3	17.3	24.1	31.6	39.7	48.2	51.0				0.95
6.5	11.4	17.5	24.5	32.3	40.7	49.6	55.3				1.00
7.0	11.4	17.6	24.8	32.8	41.5	50.8	59.5				1.00
7.5	11.5	17.7	25.0	33.2	42.2	51.9	62.0	63.8			1.05
8.0	11.5	17.8	25.2	33.6	42.8	52.8	63.3	68.0			1.05
8.5	11.5	17.9	25.4	33.9	43.4	53.5	64.4	72.3			1.10
9.0	11.5	17.9	25.5	34.2	43.8	54.2	65.3	76.6			1.10
9.5	11.5	17.9	25.6	34.4	44.2	54.8	66.2	80.8			1.15
10.0	11.6	18.0	25.7	34.6	44.5	55.3	66.9	85.1			1.15
10.5	11.6	18.0	25.8	34.7	44.8	55.7	67.6	89.3			1.20
11.0	11.6	18.0	25.8	34.8	45.0	56.1	68.2	93.6			1.20
11.5	11.6	18.0	25.9	34.9	45.2	56.5	68.7	95.5	97.8		1.25
12.0	11.6	18.0	25.9	35.0	45.3	56.7	69.1	96.4	102.1		1.25
12.5	11.6	18.0	25.9	35.1	45.5	57.0	69.5	97.2	106.4		1.30
13.0	11.6	18.1	25.9	35.1	45.6	57.2	69.8	97.9	110.6		1.30
13.5	11.6	18.1	26.0	35.2	45.7	57.4	70.1	98.5	114.9		1.35
14.0	11.6	18.1	26.0	35.2	45.8	57.5	70.4	99.1	119.1		1.35
14.5	11.6	18.1	26.0	35.3	45.9	57.7	70.6	99.6	123.4		1.35
15.0	11.6	18.1	26.0	35.3	45.9	57.8	70.8	100.1	127.7		1.40

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.20	1.40	1.60	
1.5	7.7	10.3	12.7								0.60
2.0	9.1	12.5	16.0	16.9							0.65
2.5	10.2	14.3	18.5	21.2							0.70
3.0	11.0	15.7	20.5	25.4							0.70
3.5	11.7	16.8	22.2	27.9	29.7						0.75
4.0	12.2	17.7	23.7	30.0	34.0						0.80
4.5	12.5	18.4	24.9	31.7	38.2						0.80
5.0	12.8	19.0	25.8	33.2	40.9	42.5					0.85
5.5	13.0	19.5	26.7	34.4	42.6	46.7					0.85
6.0	13.2	19.8	27.4	35.5	44.2	51.0					0.90
6.5	13.3	20.1	27.9	36.4	45.5	55.1	55.3				0.95
7.0	13.4	20.4	28.4	37.2	46.7	56.7	59.5				0.95
7.5	13.5	20.6	28.8	37.9	47.7	58.2	63.8				1.00
8.0	13.5	20.7	29.1	38.5	48.6	59.4	68.0				1.00
8.5	13.5	20.9	29.4	39.0	49.4	60.6	72.3	72.3			1.05
9.0	13.6	21.0	29.6	39.4	50.1	61.5	73.7	76.6			1.05
9.5	13.6	21.0	29.8	39.8	50.7	62.4	74.9	80.8			1.05
10.0	13.6	21.1	30.0	40.1	51.2	63.2	76.0	85.1			1.10
10.5	13.6	21.2	30.1	40.3	51.6	63.9	77.0	89.3			1.10
11.0	13.6	21.2	30.2	40.6	52.0	64.5	77.9	93.6			1.15
11.5	13.6	21.2	30.3	40.7	52.4	65.1	78.6	97.8			1.15
12.0	13.7	21.3	30.4	40.9	52.7	65.5	79.4	102.1			1.20
12.5	13.7	21.3	30.4	41.0	52.9	66.0	80.0	106.4			1.20
13.0	13.7	21.3	30.5	41.2	53.2	66.3	80.6	110.6			1.20
13.5	13.7	21.3	30.5	41.3	53.4	66.7	81.1	112.7	114.9		1.25
14.0	13.7	21.3	30.6	41.4	53.5	67.0	81.5	113.6	119.1		1.25
14.5	13.7	21.3	30.6	41.4	53.7	67.2	81.9	114.4	123.4		1.30
15.0	13.7	21.3	30.6	41.5	53.8	67.4	82.3	115.2	127.7		1.30

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.9 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

300 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 0.50	0.60	0.70	0.80	0.90	1.00	1.20	1.40	1.60	1.80	TRANSITION WIDTH (m)
1.5	9.0	11.5	14.2	16.8	16.8						0.85
2.0	10.4	13.7	17.0	20.5	22.5						0.90
2.5	11.5	15.3	19.3	23.5	27.7	28.2					0.95
3.0	12.3	16.6	21.1	25.9	30.8	33.9					1.00
3.5	12.8	17.5	22.6	27.9	33.4	39.0	39.5				1.05
4.0	13.2	18.2	23.7	29.5	35.5	41.8	45.2				1.10
4.5	13.5	18.8	24.6	30.8	37.3	44.1	50.9				1.10
5.0	13.7	19.2	25.3	31.8	38.8	46.0	56.6				1.15
5.5	13.9	19.5	25.8	32.7	40.0	47.7	62.3				1.20
6.0	14.0	19.8	26.3	33.4	41.0	49.1	66.3	67.9			1.25
6.5	14.0	19.9	26.6	34.0	41.9	50.3	68.3	73.6			1.30
7.0	14.1	20.1	26.9	34.4	42.6	51.3	70.1	79.3			1.30
7.5	14.1	20.2	27.1	34.8	43.2	52.2	71.6	85.0			1.35
8.0	14.2	20.3	27.3	35.1	43.7	52.9	72.9	90.7			1.40
8.5	14.2	20.3	27.4	35.4	44.1	53.5	74.1	96.3			1.40
9.0	14.2	20.4	27.5	35.6	44.4	54.0	75.1	98.3	102.0		1.45
9.5	14.2	20.4	27.6	35.7	44.7	54.5	76.0	99.8	107.7		1.50
10.0	14.2	20.4	27.7	35.9	45.0	54.9	76.8	101.1	113.4		1.50
10.5	14.2	20.4	27.7	36.0	45.2	55.2	77.5	102.3	119.1		1.55
11.0	14.2	20.5	27.8	36.1	45.3	55.5	78.1	103.3	124.7		1.60
11.5	14.2	20.5	27.8	36.1	45.5	55.7	78.6	104.2	130.4		1.60
12.0	14.2	20.5	27.8	36.2	45.6	55.9	79.0	105.1	133.6	136.1	1.65
12.5	14.2	20.5	27.8	36.3	45.7	56.0	79.4	105.8	134.8	141.8	1.65
13.0	14.2	20.5	27.9	36.3	45.8	56.2	79.7	106.4	135.9	147.5	1.70
13.5	14.2	20.5	27.9	36.3	45.8	56.3	80.0	107.0	136.8	153.1	1.75
14.0	14.2	20.5	27.9	36.3	45.9	56.4	80.3	107.5	137.7	158.8	1.75
14.5	14.2	20.5	27.9	36.4	45.9	56.5	80.5	108.0	138.5	164.5	1.80
15.0	14.2	20.5	27.9	36.4	46.0	56.6	80.7	108.4	139.2	170.2	1.80

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 0.50	0.60	0.70	0.80	0.90	1.00	1.20	1.40	1.60	1.80	TRANSITION WIDTH (m)
1.5	9.3	11.9	14.6	16.8							0.80
2.0	10.9	14.3	17.7	21.2	22.5						0.85
2.5	12.2	16.1	20.2	24.4	28.2						0.90
3.0	13.1	17.5	22.2	27.1	32.1	33.9					0.95
3.5	13.7	18.6	23.9	29.3	35.0	39.5					1.00
4.0	14.2	19.5	25.2	31.2	37.4	43.8	45.2				1.05
4.5	14.6	20.2	26.2	32.7	39.4	46.4	50.9				1.10
5.0	14.9	20.7	27.1	34.0	41.2	48.7	56.6				1.15
5.5	15.1	21.1	27.8	35.0	42.6	50.6	62.3				1.15
6.0	15.2	21.4	28.4	35.9	43.9	52.3	67.9				1.20
6.5	15.3	21.7	28.8	36.8	44.9	53.8	72.5	73.6			1.25
7.0	15.4	21.9	29.2	37.2	45.8	55.0	74.6	79.3			1.25
7.5	15.5	22.0	29.5	37.7	46.6	56.1	76.4	85.0			1.30
8.0	15.5	22.1	29.7	38.1	47.2	57.0	78.0	90.7			1.35
8.5	15.6	22.2	29.9	38.5	47.8	57.8	79.5	96.3			1.35
9.0	15.6	22.3	30.1	38.7	48.2	58.5	80.7	102.0			1.40
9.5	15.6	22.4	30.2	39.0	48.6	59.0	81.8	106.8	107.7		1.45
10.0	15.6	22.4	30.3	39.2	48.9	59.5	82.8	108.4	113.4		1.45
10.5	15.6	22.4	30.4	39.3	49.2	60.0	83.7	109.9	119.1		1.50
11.0	15.6	22.5	30.4	39.5	49.5	60.4	84.5	111.2	124.7		1.50
11.5	15.7	22.5	30.5	39.6	49.7	60.7	85.1	112.4	130.4		1.55
12.0	15.7	22.5	30.5	39.7	49.8	61.0	85.7	113.4	136.1		1.60
12.5	15.7	22.5	30.6	39.7	50.0	61.2	86.3	114.4	141.8		1.60
13.0	15.7	22.5	30.6	39.8	50.1	61.4	86.7	115.3	146.4	147.5	1.65
13.5	15.7	22.5	30.6	39.9	50.2	61.6	87.2	116.0	147.7	153.1	1.65
14.0	15.7	22.5	30.6	39.9	50.3	61.7	87.5	116.7	148.8	158.8	1.70
14.5	15.7	22.5	30.6	39.9	50.4	61.9	87.8	117.3	149.8	164.5	1.70
15.0	15.7	22.5	30.7	40.0	50.4	62.0	88.1	117.9	150.8	170.2	1.75

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 0.50	0.60	0.70	0.80	0.90	1.00	1.20	1.40	1.60	1.80	TRANSITION WIDTH (m)
1.5	9.8	12.4	15.1	16.8							0.80
2.0	11.7	15.1	18.6	22.1	22.5						0.85
2.5	13.2	17.2	21.4	25.7	28.2						0.90
3.0	14.3	18.9	23.8	28.8	33.9						0.90
3.5	15.1	20.3	25.8	31.4	37.3	39.5					0.95
4.0	15.8	21.4	27.4	33.7	40.1	45.2					1.00
4.5	16.3	22.3	28.8	35.6	42.6	49.9	50.9				1.05
5.0	16.7	23.0	29.9	37.2	44.8	52.6	56.6				1.05
5.5	17.0	23.6	30.8	38.5	46.6	55.0	62.3				1.10
6.0	17.3	24.1	31.6	39.7	48.2	57.1	67.9				1.15
6.5	17.5	24.5	32.3	40.7	49.6	59.0	73.6				1.15
7.0	17.6	24.8	32.8	41.5	50.8	60.6	79.3				1.20
7.5	17.7	25.0	33.2	42.2	51.9	62.0	83.6	85.0			1.25
8.0	17.8	25.2	33.6	42.8	52.8	63.3	85.7	90.7			1.25
8.5	17.9	25.4	33.9	43.4	53.5	64.4	87.6	95.3			1.30
9.0	17.9	25.5	34.2	43.8	54.2	65.3	89.3	102.0			1.35
9.5	17.9	25.6	34.4	44.2	54.8	66.2	90.8	107.7			1.35
10.0	18.0	25.7	34.6	44.5	55.3	66.9	92.2	113.4			1.40
10.5	18.0	25.8	34.7	44.8	55.7	67.6	93.4	119.1			1.40
11.0	18.0	25.8	34.8	45.0	56.1	68.2	94.5	123.3	124.7		1.45
11.5	18.0	25.9	34.9	45.2	56.5	68.7	95.5	125.0	130.4		1.45
12.0	18.0	25.9	35.0	45.3	56.7	69.1	96.4	126.5	136.1		1.50
12.5	18.0	25.9	35.1	45.5	57.0	69.5	97.2	127.8	141.8		1.50
13.0	18.1	25.9	35.1	45.6	57.2	69.8	97.9	129.0	147.5		1.55
13.5	18.1	26.0	35.2	45.7	57.4	70.1	98.5	130.2	153.1		1.55
14.0	18.1	26.0	35.2	45.8	57.5	70.4	99.1	131.2	158.8		1.60
14.5	18.1	26.0	35.3	45.9	57.7	70.6	99.6	132.1	164.5		1.60
15.0	18.1	26.0	35.3	45.9	57.8	70.8	100.1	133.0	168.9	170.2	1.65

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 0.50	0.60	0.70	0.80	0.90	1.00	1.20	1.40	1.60	1.80	TRANSITION WIDTH (m)
1.5	10.3	13.0	15.7	16.8							0.75
2.0	12.5	16.0	19.5	22.5							0.80
2.5	14.3	18.5	22.8	27.2	28.2						0.85
3.0	15.7	20.5	25.6	30.7	33.9						0.90
3.5	16.8	22.2	27.9	33.8	39.5						0.90
4.0	17.7	23.7	30.0	36.5	43.2	45.2					0.95
4.5	18.4	24.9	31.7	38.8	46.2	50.9					1.00
5.0	19.0	25.8	33.2	40.9	48.8	56.6					1.00
5.5	19.5	26.7	34.4	42.6	51.2	60.0	62.3				1.05
6.0	19.8	27.4	35.5	44.2	53.3	62.6	67.9				1.10
6.5	20.1	27.9	36.4	45.5	55.1	65.0	73.6				1.10
7.0	20.4	28.4	37.2	46.7	56.7	67.1	79.3				1.15
7.5	20.6	28.8	37.9	47.7	58.2	69.0	85.0				1.15
8.0	20.7	29.1	38.5	48.6	59.4	70.8	90.7				1.20
8.5	20.9	29.4	39.0	49.4	60.6	72.3	96.3				1.20
9.0	21.0	29.6	39.4	50.1	61.5	73.7	99.4	102.0			1.25
9.5	21.0	29.8	39.8	50.7	62.4	74.9	101.5	107.7			1.25
10.0	21.1	30.0	40.1	51.2	63.2	76.0	103.4	113.4			1.30
10.5	21.2	30.1	40.3	51.6	63.9	77.0	105.1	119.1			1.30
11.0	21.2	30.2	40.6	52.0	64.5	77.9	106.7	124.7			1.35
11.5	21.2	30.3	40.7	52.4	65.1	78.6	108.1	130.4			1.35
12.0	21.3	30.4	40.9	52.7	65.5	79.4	109.4	136.1			1.40
12.5	21.3	30.4	41.0	52.9	66.0	80.0	110.6	141.8			1.40
13.0	21.3	30.5	41.2	53.2	66.3	80.6	111.7	145.8	147.5		1.45
13.5	21.3	30.5	41.3	53.4	66.7	81.1	112.7	147.4	153.1		1.45
14.0	21.3	30.6	41.4	53.5	67.0	81.5	113.6	148.9	158.8		1.50
14.5	21.3	30.6	41.4	53.7	67.2	81.9	114.4	150.3	164.5		1.50
15.0	21.3	30.6	41.5	53.8	67.4	82.3	115.2	151.6	170.2		1.50

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.10 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

375 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	0.60	0.70	0.80	0.90	1.00	1.20	1.40	1.60	1.80	2.00	(m)
1.5	11.5	14.2	16.8	19.5	20.4						0.95
2.0	13.7	17.0	20.5	24.0	27.4						1.00
2.5	15.3	19.3	23.5	27.7	32.0	34.3					1.10
3.0	16.6	21.1	25.9	30.8	35.8	41.2					1.15
3.5	17.5	22.6	27.9	33.4	39.0	48.1					1.20
4.0	18.2	23.7	29.5	35.5	41.8	54.7	55.1				1.25
4.5	18.8	24.6	30.8	37.3	44.1	58.2	62.0				1.30
5.0	19.2	25.3	31.8	38.8	46.0	61.3	68.9				1.30
5.5	19.5	25.8	32.7	40.0	47.7	64.0	75.8				1.35
6.0	19.8	26.3	33.4	41.0	49.1	66.3	82.7				1.40
6.5	19.9	26.6	34.0	41.9	50.3	68.3	87.5	89.7			1.45
7.0	20.1	26.9	34.4	42.6	51.3	70.1	90.2	96.6			1.50
7.5	20.2	27.1	34.8	43.2	52.2	71.6	92.6	103.5			1.50
8.0	20.3	27.3	35.1	43.7	52.9	72.9	94.7	110.4			1.55
8.5	20.3	27.4	35.4	44.1	53.5	74.1	96.6	117.4			1.60
9.0	20.4	27.5	35.6	44.4	54.0	75.1	98.3	123.1	124.3		1.65
9.5	20.4	27.6	35.7	44.7	54.5	76.0	99.8	125.3	131.2		1.65
10.0	20.4	27.7	35.9	45.0	54.9	76.8	101.1	127.3	138.1		1.70
10.5	20.4	27.7	36.0	45.2	55.2	77.5	102.3	129.1	145.0		1.75
11.0	20.5	27.8	36.1	45.3	55.5	78.1	103.3	130.8	152.0		1.75
11.5	20.5	27.8	36.1	45.5	55.7	78.6	104.2	132.2	158.9		1.80
12.0	20.5	27.8	36.2	45.6	55.9	79.0	105.1	133.6	164.1	165.8	1.85
12.5	20.5	27.8	36.3	45.7	56.0	79.4	105.8	134.8	165.9	172.7	1.85
13.0	20.5	27.9	36.3	45.8	56.2	79.7	106.4	135.9	167.6	179.6	1.90
13.5	20.5	27.9	36.3	45.8	56.3	80.0	107.0	136.8	169.0	186.6	1.95
14.0	20.5	27.9	36.3	45.9	56.4	80.3	107.5	137.7	170.4	193.5	1.95
14.5	20.5	27.9	36.4	45.9	56.5	80.5	108.0	138.5	171.6	200.4	2.00
15.0	20.5	27.9	36.4	46.0	56.6	80.7	108.4	139.2	172.8	207.3	2.00

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	0.60	0.70	0.80	0.90	1.00	1.20	1.40	1.60	1.80	2.00	(m)
1.5	11.9	14.6	17.3	20.0	20.4						0.95
2.0	14.3	17.7	21.2	24.7	27.4						1.00
2.5	16.1	20.2	24.4	28.7	33.1	34.3					1.05
3.0	17.5	22.2	27.1	32.1	37.2	41.2					1.10
3.5	18.6	23.9	29.3	35.0	40.7	48.1					1.15
4.0	19.5	25.2	31.2	37.4	43.8	55.1					1.20
4.5	20.2	26.2	32.7	39.4	46.4	60.9	62.0				1.25
5.0	20.7	27.1	34.0	41.2	48.7	64.4	68.9				1.30
5.5	21.1	27.8	35.0	42.6	50.6	67.4	75.8				1.30
6.0	21.4	28.4	35.9	43.9	52.3	70.1	82.7				1.35
6.5	21.7	28.8	36.5	44.9	53.8	72.5	89.7				1.40
7.0	21.9	29.2	37.2	45.8	55.0	74.6	95.4	96.6			1.45
7.5	22.0	29.5	37.7	46.6	56.1	76.4	98.2	103.5			1.45
8.0	22.1	29.7	38.1	47.2	57.0	78.0	100.7	110.4			1.50
8.5	22.2	29.9	38.5	47.8	57.8	79.5	103.0	117.4			1.55
9.0	22.3	30.1	38.7	48.2	58.5	80.7	105.0	124.3			1.60
9.5	22.4	30.2	39.0	48.6	59.0	81.8	106.8	131.2			1.60
10.0	22.4	30.3	39.2	48.9	59.5	82.8	108.4	135.8	138.1		1.65
10.5	22.4	30.4	39.3	49.2	60.0	83.7	109.9	138.0	145.0		1.65
11.0	22.5	30.4	39.5	49.5	60.4	84.5	111.2	140.0	152.0		1.70
11.5	22.5	30.5	39.6	49.7	60.7	85.1	112.4	141.9	158.9		1.75
12.0	22.5	30.5	39.7	49.8	61.0	85.7	113.4	143.5	165.8		1.75
12.5	22.5	30.6	39.7	50.0	61.2	86.3	114.4	145.0	172.7		1.80
13.0	22.5	30.6	39.8	50.1	61.4	86.7	115.3	146.4	179.6		1.80
13.5	22.5	30.6	39.9	50.2	61.6	87.2	116.0	147.7	181.6	186.6	1.85
14.0	22.5	30.6	39.9	50.3	61.7	87.5	116.7	148.8	183.4	193.5	1.90
14.5	22.5	30.6	39.9	50.4	61.9	87.8	117.3	149.8	184.9	200.4	1.90
15.0	22.5	30.7	40.0	50.4	62.0	88.1	117.9	150.8	186.4	207.3	1.95

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	0.60	0.70	0.80	0.90	1.00	1.20	1.40	1.60	1.80	2.00	(m)
1.5	12.4	15.1	17.9	20.4							0.90
2.0	15.1	18.6	22.1	25.7	27.4						0.95
2.5	17.2	21.4	25.7	30.1	34.3						1.00
3.0	18.9	23.8	28.8	33.9	39.2	41.2					1.05
3.5	20.3	25.8	31.4	37.3	43.2	48.1					1.10
4.0	21.4	27.4	33.7	40.1	46.8	55.1					1.15
4.5	22.3	28.8	35.6	42.6	49.9	62.0					1.20
5.0	23.0	29.9	37.2	44.8	52.6	66.9	68.9				1.25
5.5	23.6	30.8	38.5	46.6	55.0	72.5	75.8				1.25
6.0	24.1	31.6	39.7	48.2	57.1	75.7	82.7				1.30
6.5	24.5	32.3	40.7	49.6	59.0	78.7	89.7				1.35
7.0	24.8	32.8	41.5	50.8	60.6	81.3	96.6				1.35
7.5	25.0	33.2	42.2	51.9	62.0	83.6	103.5				1.40
8.0	25.2	33.6	42.8	52.8	63.3	85.7	109.6	110.4			1.45
8.5	25.4	33.9	43.4	53.5	64.4	87.6	112.5	117.4			1.45
9.0	25.5	34.2	43.8	54.2	65.3	89.3	115.1	124.3			1.50
9.5	25.6	34.4	44.2	54.8	66.2	90.8	117.4	131.2			1.50
10.0	25.7	34.6	44.5	55.3	66.9	92.2	119.6	138.1			1.55
10.5	25.8	34.7	44.8	55.7	67.6	93.4	121.6	145.0			1.60
11.0	25.8	34.8	45.0	56.1	68.2	94.5	123.3	152.0			1.60
11.5	25.9	34.9	45.2	56.5	68.7	95.5	125.0	156.5	158.9		1.65
12.0	25.9	35.0	45.3	56.7	69.1	96.4	126.5	158.8	165.8		1.65
12.5	25.9	35.1	45.5	57.0	69.5	97.2	127.8	160.8	172.7		1.70
13.0	25.9	35.1	45.6	57.2	69.8	97.9	129.0	162.7	179.6		1.70
13.5	26.0	35.2	45.7	57.4	70.1	98.5	130.2	164.5	186.6		1.75
14.0	26.0	35.2	45.8	57.5	70.4	99.1	131.2	166.1	193.5		1.75
14.5	26.0	35.3	45.9	57.7	70.6	99.6	132.1	167.6	200.4		1.80
15.0	26.0	35.3	45.9	57.8	70.8	100.1	133.0	168.9	207.3		1.80

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	0.60	0.70	0.80	0.90	1.00	1.20	1.40	1.60	1.80	2.00	(m)
1.5	13.0	15.7	18.5	20.4							0.90
2.0	16.0	19.5	23.1	26.8	27.4						0.95
2.5	18.5	22.8	27.2	31.7	34.3						1.00
3.0	20.5	25.6	30.7	36.0	41.2						1.00
3.5	22.2	27.9	33.6	39.8	45.9	49.1					1.05
4.0	23.7	30.0	36.5	43.2	50.0	55.1					1.10
4.5	24.9	31.7	38.8	46.2	53.7	62.0					1.15
5.0	25.8	33.2	40.9	48.8	57.0	68.9					1.15
5.5	26.7	34.4	42.6	51.2	60.0	75.8					1.20
6.0	27.4	35.5	44.2	53.3	62.6	82.1	82.7				1.25
6.5	27.9	36.4	45.5	55.1	65.0	85.7	89.7				1.25
7.0	28.4	37.2	46.7	56.7	67.1	89.0	96.6				1.30
7.5	28.8	37.9	47.7	58.2	69.0	91.9	103.5				1.30
8.0	29.1	38.5	48.6	59.4	70.8	94.7	110.4				1.35
8.5	29.4	39.0	49.4	60.6	72.3	97.2	117.4				1.40
9.0	29.6	39.4	50.1	61.5	73.7	99.4	124.3				1.40
9.5	29.8	39.8	50.7	62.4	74.9	101.5	129.9	131.2			1.45
10.0	30.0	40.1	51.2	63.2	76.0	103.4	132.7	138.1			1.45
10.5	30.1	40.3	51.6	63.9	77.0	105.1	135.3	145.0			1.50
11.0	30.2	40.6	52.0	64.5	77.9	106.7	137.8	152.0			1.50
11.5	30.3	40.7	52.4	65.1	78.6	108.1	140.0	158.9			1.55
12.0	30.4	40.9	52.7	65.5	79.4	109.4	142.1	165.8			1.55
12.5	30.4	41.0	52.9	66.0	80.0	110.6	144.0	172.7			1.60
13.0	30.5	41.2	53.2	66.3	80.6	111.7	145.8	179.6			1.60
13.5	30.5	41.3	53.4	66.7	81.1	112.7	147.4	184.6	186.6		1.65
14.0	30.6	41.4	53.5	67.0	81.5	113.6	146.9	186.9	193.5		1.65
14.5	30.6	41.4	53.7	67.2	81.9	114.4	150.3	189.0	200.4		1.70
15.0	30.6	41.5	53.8	67.4	82.3	115.2	151.6	191.0	207.3		1.70

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.11 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

450 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 0.70	0.80	0.90	1.00	1.20	1.40	1.60	1.80	2.00	2.20	TRANSITION WIDTH (m)
1.5	14.2	16.8	19.5	22.2	24.0						1.10
2.0	17.0	20.5	24.0	27.5	32.2						1.15
2.5	19.3	23.5	27.7	32.0	40.4						1.20
3.0	21.1	25.9	30.8	35.8	46.1	48.5					1.25
3.5	22.6	27.9	33.4	39.0	50.7	56.7					1.35
4.0	23.7	29.5	35.5	41.8	54.7	64.9					1.40
4.5	24.6	30.8	37.3	44.1	58.2	73.0	73.0				1.45
5.0	25.3	31.8	38.8	46.0	61.3	77.3	81.2				1.45
5.5	25.8	32.7	40.0	47.7	64.0	81.1	89.4				1.50
6.0	26.3	33.4	41.0	49.1	66.3	84.5	97.5				1.55
6.5	26.6	34.0	41.9	50.3	68.3	87.5	105.7				1.60
7.0	26.9	34.4	42.6	51.3	70.1	90.2	111.4	113.9			1.65
7.5	27.1	34.8	43.2	52.2	71.6	92.6	114.8	122.0			1.70
8.0	27.3	35.1	43.7	52.9	72.9	94.7	117.8	130.2			1.75
8.5	27.4	35.4	44.1	53.5	74.1	96.6	120.6	138.3			1.75
9.0	27.5	35.6	44.4	54.0	75.1	98.3	123.1	146.5			1.80
9.5	27.6	35.7	44.7	54.5	76.0	99.8	125.3	152.2	154.7		1.85
10.0	27.7	35.9	45.0	54.9	76.8	101.1	127.3	155.1	162.8		1.90
10.5	27.7	36.0	45.2	55.2	77.5	102.3	129.1	157.7	171.0		1.90
11.0	27.8	36.1	45.3	55.5	78.1	103.3	130.6	160.0	179.2		1.95
11.5	27.8	36.1	45.5	55.7	78.6	104.2	132.2	162.2	187.3		2.00
12.0	27.8	36.2	45.6	55.9	79.0	105.1	133.6	164.1	195.5		2.00
12.5	27.8	36.3	45.7	56.0	79.4	105.8	134.6	165.9	198.9	203.7	2.05
13.0	27.9	36.3	45.8	56.2	79.7	106.4	135.9	167.6	201.2	211.8	2.10
13.5	27.9	36.3	45.8	56.3	80.0	107.0	136.6	169.0	203.3	220.0	2.10
14.0	27.9	36.3	45.9	56.4	80.3	107.5	137.7	170.4	205.3	228.2	2.15
14.5	27.9	36.4	45.9	56.5	80.5	108.0	138.5	171.6	207.1	236.3	2.20
15.0	27.9	36.4	46.0	56.6	80.7	108.4	139.2	172.8	208.7	244.5	2.20

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 0.70	0.80	0.90	1.00	1.20	1.40	1.60	1.80	2.00	2.20	TRANSITION WIDTH (m)
1.5	14.6	17.3	20.0	22.7	24.0						1.05
2.0	17.7	21.2	24.7	28.3	32.2						1.15
2.5	20.2	24.4	28.7	33.1	40.4						1.20
3.0	22.2	27.1	32.1	37.2	47.6	48.5					1.25
3.5	23.9	29.3	35.0	40.7	52.6	56.7					1.30
4.0	25.2	31.2	37.4	43.8	57.0	64.9					1.35
4.5	26.2	32.7	39.4	46.4	60.9	73.0					1.40
5.0	27.1	34.0	41.2	48.7	64.4	80.8	81.2				1.45
5.5	27.8	35.0	42.6	50.6	67.4	85.0	89.4				1.45
6.0	28.4	35.9	43.9	52.3	70.1	88.9	97.5				1.50
6.5	28.8	36.6	44.9	53.8	72.5	92.3	105.7				1.55
7.0	29.2	37.2	45.8	55.0	74.6	95.4	113.9				1.60
7.5	29.5	37.7	46.6	56.1	76.4	98.2	121.1	122.0			1.65
8.0	29.7	38.1	47.2	57.0	78.0	100.7	124.6	130.2			1.65
8.5	29.9	38.5	47.8	57.8	79.5	103.0	127.8	138.3			1.70
9.0	30.1	38.7	48.2	58.5	80.7	105.0	130.8	146.5			1.75
9.5	30.2	39.0	48.6	59.0	81.8	106.8	133.4	154.7			1.80
10.0	30.3	39.2	48.9	59.5	82.8	108.4	135.8	162.8			1.80
10.5	30.4	39.3	49.2	60.0	83.7	109.9	138.0	167.8	171.0		1.85
11.0	30.4	39.5	49.5	60.4	84.5	111.2	140.0	170.6	179.2		1.90
11.5	30.5	39.6	49.7	60.7	85.1	112.4	141.9	173.2	187.3		1.90
12.0	30.5	39.7	49.8	61.0	85.7	113.4	143.5	175.6	195.5		1.95
12.5	30.6	39.7	50.0	61.2	86.3	114.4	145.0	177.8	203.7		2.00
13.0	30.6	39.8	50.1	61.4	86.7	115.3	146.4	179.6	211.8		2.00
13.5	30.6	39.9	50.2	61.6	87.2	116.0	147.7	181.6	217.6	220.0	2.05
14.0	30.6	39.9	50.3	61.7	87.5	116.7	148.8	183.4	220.0	228.2	2.05
14.5	30.6	39.9	50.4	61.9	87.8	117.3	149.8	184.9	222.2	236.3	2.10
15.0	30.7	40.0	50.4	62.0	88.1	117.9	150.8	186.4	224.2	244.5	2.15

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 0.70	0.80	0.90	1.00	1.20	1.40	1.60	1.80	2.00	2.20	TRANSITION WIDTH (m)
1.5	15.1	17.9	20.6	23.4	24.0						1.05
2.0	18.6	22.1	25.7	29.3	32.2						1.10
2.5	21.4	25.7	30.1	34.6	40.4						1.15
3.0	23.8	28.8	33.9	39.2	48.5						1.20
3.5	25.8	31.4	37.3	43.2	55.3	56.7					1.25
4.0	27.4	33.7	40.1	46.8	60.4	64.9					1.30
4.5	28.8	35.6	42.6	49.9	64.8	73.0					1.35
5.0	29.9	37.2	44.8	52.6	68.9	81.2					1.35
5.5	30.8	38.5	46.6	55.0	72.5	89.4					1.40
6.0	31.6	39.7	48.2	57.1	75.7	95.2	97.5				1.45
6.5	32.3	40.7	49.6	59.0	78.7	99.3	105.7				1.50
7.0	32.8	41.5	50.8	60.6	81.3	103.1	113.9				1.50
7.5	33.2	42.2	51.9	62.0	83.6	106.5	122.0				1.55
8.0	33.6	42.8	52.8	63.3	85.7	109.6	130.2				1.60
8.5	33.9	43.4	53.5	64.4	87.6	112.5	138.3				1.60
9.0	34.2	43.8	54.2	65.3	89.3	115.1	142.2	146.5			1.65
9.5	34.4	44.2	54.8	66.2	90.8	117.4	145.6	154.7			1.70
10.0	34.6	44.5	55.3	66.9	92.2	119.6	148.7	162.8			1.70
10.5	34.7	44.8	55.7	67.5	93.4	121.6	151.5	171.0			1.75
11.0	34.8	45.0	56.1	68.2	94.5	123.3	154.1	179.2			1.80
11.5	34.9	45.2	56.5	68.7	95.5	125.0	156.5	187.3			1.80
12.0	35.0	45.3	56.7	69.1	96.4	126.5	158.8	192.9	195.5		1.85
12.5	35.1	45.5	57.0	69.5	97.2	127.8	160.8	195.8	203.7		1.85
13.0	35.1	45.6	57.2	69.6	97.9	129.0	162.7	198.4	211.8		1.90
13.5	35.2	45.7	57.4	70.1	98.5	130.2	164.5	200.9	220.0		1.95
14.0	35.2	45.8	57.5	70.4	99.1	131.2	166.1	203.3	228.2		1.95
14.5	35.3	45.9	57.7	70.6	99.6	132.1	167.6	205.4	236.3		2.00
15.0	35.3	45.9	57.8	70.8	100.1	133.0	168.9	207.4	244.5		2.00

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 0.70	0.80	0.90	1.00	1.20	1.40	1.60	1.80	2.00	2.20	TRANSITION WIDTH (m)
1.5	15.7	18.5	21.2	24.0	24.0						1.05
2.0	19.5	23.1	26.8	30.4	32.2						1.05
2.5	22.8	27.2	31.7	36.2	40.4						1.10
3.0	25.6	30.7	36.0	41.3	48.5						1.15
3.5	27.9	33.8	39.8	45.9	56.7						1.20
4.0	30.0	36.5	43.2	50.0	64.0	64.9					1.25
4.5	31.7	38.8	46.2	53.7	69.1	73.0					1.25
5.0	33.2	40.9	48.8	57.0	73.9	81.2					1.30
5.5	34.4	42.6	51.2	60.0	78.2	89.4					1.35
6.0	35.5	44.2	53.3	62.6	82.1	97.5					1.40
6.5	36.4	45.5	55.1	65.0	85.7	105.7					1.40
7.0	37.2	46.7	56.7	67.1	89.0	111.7	113.9				1.45
7.5	37.9	47.7	58.2	69.0	91.9	116.0	122.0				1.45
8.0	38.5	48.6	59.4	70.8	94.7	119.8	130.2				1.50
8.5	39.0	49.4	60.6	72.3	97.2	123.4	138.3				1.55
9.0	39.4	50.1	61.5	73.7	99.4	126.8	146.5				1.55
9.5	39.8	50.7	62.4	74.9	101.5	129.9	154.7				1.60
10.0	40.1	51.2	63.2	76.0	103.4	132.7	162.8				1.60
10.5	40.3	51.6	63.9	77.0	105.1	135.3	167.1	171.0			1.65
11.0	40.6	52.0	64.5	77.9	106.7	137.8	170.6	179.2			1.70
11.5	40.7	52.4	65.1	78.6	108.1	140.0	173.8	187.3			1.70
12.0	40.9	52.7	65.5	79.4	109.4	142.1	176.8	195.5			1.75
12.5	41.0	52.9	66.0	80.0	110.6	144.0	179.5	203.7			1.75
13.0	41.2	53.2	66.3	80.6	111.7	145.8	182.1	211.8			1.80
13.5	41.3	53.4	66.7	81.1	112.7	147.4	184.6	220.0			1.80
14.0	41.4	53.5	67.0	81.5	113.6	148.9	186.9	226.9	228.2		1.85
14.5	41.4	53.7	67.2	81.9	114.4	150.3	189.0	229.8	236.3		1.85
15.0	41.5	53.8	67.4	82.3	115.2	151.6	191.0	232.6	244.5		1.90

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.12 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

525 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	0.80	0.90	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	
1.5	16.8	19.5	22.2	27.6							1.20
2.0	20.5	24.0	27.5	34.7	37.0						1.30
2.5	23.5	27.7	32.0	40.8	46.4						1.35
3.0	25.9	30.8	35.8	46.1	55.8						1.40
3.5	27.9	33.4	39.0	50.7	62.7	65.3					1.45
4.0	29.5	35.5	41.8	54.7	68.2	74.7					1.50
4.5	30.8	37.3	44.1	58.2	73.0	84.1					1.55
5.0	31.8	38.8	46.0	61.3	77.3	93.5					1.60
5.5	32.7	40.0	47.7	64.0	81.1	98.9	102.9				1.65
6.0	33.4	41.0	49.1	66.3	84.5	103.5	112.3				1.70
6.5	34.0	41.9	50.3	68.3	87.5	107.7	121.7				1.75
7.0	34.4	42.6	51.3	70.1	90.2	111.4	131.1				1.80
7.5	34.8	43.2	52.2	71.6	92.6	114.8	137.9	140.5			1.85
8.0	35.1	43.7	52.9	72.9	94.7	117.8	142.0	149.9			1.90
8.5	35.4	44.1	53.5	74.1	96.6	120.6	145.7	159.3			1.95
9.0	35.6	44.4	54.0	75.1	98.3	123.1	149.1	168.7			1.95
9.5	35.7	44.7	54.5	76.0	99.8	125.3	152.2	178.1			2.00
10.0	35.9	45.0	54.9	76.8	101.1	127.3	155.1	184.1	187.5		2.05
10.5	36.0	45.2	55.2	77.5	102.3	129.1	157.7	187.6	196.9		2.10
11.0	36.1	45.3	55.5	78.1	103.3	130.8	160.0	190.8	206.4		2.10
11.5	36.1	45.5	55.7	78.6	104.2	132.2	162.2	193.7	215.8		2.15
12.0	36.2	45.6	55.9	79.0	105.1	133.6	164.1	196.4	225.2		2.20
12.5	36.3	45.7	56.0	79.4	105.8	134.8	165.9	198.9	233.4	234.6	2.25
13.0	36.3	45.8	56.2	79.7	106.4	135.9	167.6	201.2	236.5	244.0	2.25
13.5	36.3	45.8	56.3	80.0	107.0	136.8	169.0	203.3	239.3	253.4	2.30
14.0	36.3	45.9	56.4	80.3	107.5	137.7	170.4	205.3	242.0	262.8	2.35
14.5	36.4	45.9	56.5	80.5	108.0	138.5	171.6	207.1	244.4	272.2	2.35
15.0	36.4	46.0	56.6	80.7	108.4	139.2	172.8	208.7	246.7	281.6	2.40

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	0.80	0.90	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	
1.5	17.3	20.0	22.7	27.6							1.20
2.0	21.2	24.7	28.3	35.5	37.0						1.25
2.5	24.4	28.7	33.1	41.9	46.4						1.35
3.0	27.1	32.1	37.2	47.6	55.8						1.40
3.5	29.3	35.0	40.7	52.6	64.8	65.3					1.45
4.0	31.2	37.4	43.8	57.0	70.7	74.7					1.50
4.5	32.7	39.4	46.4	60.9	76.0	84.1					1.55
5.0	34.0	41.2	48.7	64.4	80.8	93.5					1.60
5.5	35.0	42.6	50.8	67.4	85.0	102.9					1.60
6.0	35.9	43.9	52.3	70.1	88.9	108.3	112.3				1.65
6.5	36.6	44.9	53.8	72.5	92.0	113.0	121.7				1.70
7.0	37.2	45.8	55.0	74.6	95.4	117.2	131.1				1.75
7.5	37.7	46.6	56.1	76.4	98.2	121.1	140.5				1.80
8.0	38.1	47.2	57.0	78.0	100.7	124.6	149.5	149.9			1.85
8.5	38.5	47.8	57.8	79.5	103.0	127.8	153.8	159.3			1.85
9.0	38.7	48.2	58.5	80.7	105.0	130.8	157.7	168.7			1.90
9.5	39.0	48.6	59.0	81.8	106.8	133.4	161.4	178.1			1.95
10.0	39.2	48.9	59.5	82.8	108.4	135.8	164.7	187.5			2.00
10.5	39.3	49.2	60.0	83.7	109.9	138.0	167.8	196.9			2.00
11.0	39.5	49.5	60.4	84.5	111.2	140.0	170.6	202.5	206.4		2.05
11.5	39.6	49.7	60.7	85.1	112.4	141.9	173.2	206.0	215.8		2.10
12.0	39.7	49.8	61.0	85.7	113.4	143.5	175.6	209.2	225.2		2.10
12.5	39.7	50.0	61.2	86.3	114.4	145.0	177.8	212.2	234.6		2.15
13.0	39.8	50.1	61.4	86.7	115.3	146.4	179.8	215.0	244.0		2.20
13.5	39.9	50.2	61.6	87.2	116.0	147.7	181.6	217.6	253.4		2.20
14.0	39.9	50.3	61.7	87.5	116.7	148.8	183.4	220.0	258.4	262.8	2.25
14.5	39.9	50.4	61.9	87.8	117.3	149.8	184.9	222.2	261.3	272.2	2.30
15.0	40.0	50.4	62.0	88.1	117.9	150.8	186.4	224.2	264.1	281.6	2.30

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	0.80	0.90	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	
1.5	17.9	20.6	23.4	27.6							1.20
2.0	22.1	25.7	29.3	36.6	37.0						1.25
2.5	25.7	30.1	34.6	43.5	46.4						1.30
3.0	28.8	33.9	39.2	49.8	55.8						1.35
3.5	31.4	37.3	43.2	55.3	65.3						1.40
4.0	33.7	40.1	46.8	60.4	74.3	74.7					1.45
4.5	35.6	42.6	49.9	64.8	80.3	84.1					1.45
5.0	37.2	44.8	52.6	68.9	85.7	93.5					1.50
5.5	38.5	46.6	55.0	72.5	90.7	102.9					1.55
6.0	39.7	48.2	57.1	75.7	95.2	112.3					1.60
6.5	40.7	49.6	59.0	78.7	99.3	120.7	121.7				1.65
7.0	41.5	50.8	60.6	81.3	103.1	125.8	131.1				1.65
7.5	42.2	51.9	62.0	83.6	106.5	130.4	140.5				1.70
8.0	42.8	52.8	63.3	85.7	109.6	134.7	149.9				1.75
8.5	43.4	53.5	64.4	87.6	112.5	138.6	159.3				1.80
9.0	43.8	54.2	65.3	89.3	115.1	142.2	168.7				1.80
9.5	44.2	54.8	66.2	90.8	117.4	145.6	174.9	178.1			1.85
10.0	44.5	55.3	66.9	92.2	119.6	148.7	179.0	187.5			1.90
10.5	44.8	55.7	67.8	93.4	121.6	151.5	182.9	196.9			1.90
11.0	45.0	56.1	68.2	94.5	123.3	154.1	186.4	206.4			1.95
11.5	45.2	56.5	68.7	95.5	125.0	156.5	189.8	215.8			2.00
12.0	45.3	56.7	69.1	96.4	126.5	158.8	192.9	225.2			2.00
12.5	45.5	57.0	69.5	97.2	127.8	160.8	195.8	232.3	234.6		2.05
13.0	45.6	57.2	69.8	97.9	129.0	162.7	198.4	235.9	244.0		2.05
13.5	45.7	57.4	70.1	98.5	130.2	164.5	200.9	239.2	253.4		2.10
14.0	45.8	57.5	70.4	99.1	131.2	166.1	203.3	242.4	262.8		2.15
14.5	45.9	57.7	70.6	99.6	132.1	167.6	205.4	245.3	272.2		2.15
15.0	45.9	57.8	70.8	100.1	133.0	168.9	207.4	248.1	281.6		2.20

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	0.80	0.90	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	
1.5	18.5	21.2	24.0	27.6							1.15
2.0	23.1	26.8	30.4	37.0							1.20
2.5	27.2	31.7	36.2	45.2	46.4						1.25
3.0	30.7	36.0	41.3	52.1	55.8						1.30
3.5	33.8	39.8	45.9	58.3	65.3						1.35
4.0	36.5	43.2	50.0	64.0	74.7						1.40
4.5	38.8	46.2	53.7	69.1	84.1						1.40
5.0	40.9	48.8	57.0	73.9	91.1	93.5					1.45
5.5	42.6	51.2	60.0	78.2	96.9	102.9					1.50
6.0	44.2	53.3	62.6	82.1	102.3	112.3					1.50
6.5	45.5	55.1	65.0	85.7	107.2	121.7					1.55
7.0	46.7	56.7	67.1	89.0	111.7	131.1					1.60
7.5	47.7	58.2	69.0	91.9	116.0	140.5					1.60
8.0	48.6	59.4	70.8	94.7	119.8	145.9	149.9				1.65
8.5	49.4	60.6	72.3	97.2	123.4	150.8	159.3				1.70
9.0	50.1	61.5	73.7	99.4	126.8	155.3	168.7				1.70
9.5	50.7	62.4	74.9	101.5	129.9	159.5	178.1				1.75
10.0	51.2	63.2	76.0	103.4	132.7	163.5	187.5				1.80
10.5	51.6	63.9	77.0	105.1	135.3	167.1	196.9				1.80
11.0	52.0	64.5	77.9	106.7	137.8	170.6	204.7	206.4			1.85
11.5	52.4	65.1	78.6	108.1	140.0	173.8	209.0	215.8			1.85
12.0	52.7	65.5	79.4	109.4	142.1	176.6	213.0	225.2			1.90
12.5	52.9	66.0	80.0	110.6	144.0	179.5	216.8	234.6			1.90
13.0	53.2	66.3	80.6	111.7	145.8	182.1	220.3	244.0			1.95
13.5	53.4	66.7	81.1	112.7	147.4	184.6	223.7	253.4			1.95
14.0	53.5	67.0	81.5	113.6	148.9	186.9	226.9	262.8			2.00
14.5	53.7	67.2	81.9	114.4	150.3	189.0	229.8	272.2			2.00
15.0	53.8	67.4	82.3	115.2	151.6	191.0	232.6	276.2	281.6		2.05

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.13 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

600 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	0.90	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	(m)
1.5	19.5	22.2	27.7	31.2							1.35
2.0	24.0	27.5	34.7	41.8							1.40
2.5	27.7	32.0	40.8	49.7	52.5						1.50
3.0	30.8	35.8	46.1	56.6	63.1						1.55
3.5	33.4	39.0	50.7	62.7	73.8						1.60
4.0	35.5	41.8	54.7	68.2	81.9	84.4					1.65
4.5	37.3	44.1	58.2	73.0	88.2	95.1					1.70
5.0	38.8	46.0	61.3	77.3	93.8	105.7					1.75
5.5	40.0	47.7	64.0	81.1	98.9	116.4					1.80
6.0	41.0	49.1	66.3	84.5	103.5	123.1	127.0				1.85
6.5	41.9	50.3	68.3	87.5	107.7	128.5	137.7				1.90
7.0	42.6	51.3	70.1	90.2	111.4	133.4	148.3				1.95
7.5	43.2	52.2	71.6	92.6	114.8	137.9	159.0				2.00
8.0	43.7	52.9	72.9	94.7	117.8	142.0	167.0	169.5			2.05
8.5	44.1	53.5	74.1	96.6	120.6	145.7	171.8	180.3			2.10
9.0	44.4	54.0	75.1	98.3	123.1	149.1	176.3	190.9			2.15
9.5	44.7	54.5	76.0	99.8	125.3	152.2	180.4	201.6			2.15
10.0	45.0	54.9	76.8	101.1	127.3	155.1	184.1	212.2			2.20
10.5	45.2	55.2	77.5	102.3	129.1	157.7	187.6	218.7	222.9		2.25
11.0	45.3	55.5	78.1	103.3	130.8	160.0	190.8	222.8	233.5		2.30
11.5	45.5	55.7	78.6	104.2	132.2	162.2	193.7	226.6	244.2		2.35
12.0	45.6	55.9	79.0	105.1	133.6	164.1	196.4	230.2	254.8		2.35
12.5	45.7	56.0	79.4	105.8	134.8	165.9	198.9	233.4	265.5		2.40
13.0	45.8	56.2	79.7	106.4	135.9	167.5	201.2	236.5	273.2	276.1	2.45
13.5	45.8	56.3	80.0	107.0	136.8	169.0	203.3	239.3	276.9	286.8	2.50
14.0	45.9	56.4	80.3	107.5	137.7	170.4	205.3	242.0	280.3	297.4	2.50
14.5	45.9	56.5	80.5	108.0	138.5	171.6	207.1	244.4	283.5	308.1	2.55
15.0	46.0	56.6	80.7	108.4	139.2	172.6	208.7	246.7	286.4	318.7	2.60

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	0.80	0.90	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	(m)
1.5	17.3	20.0	22.7	27.6							1.20
2.0	21.2	24.7	28.3	35.5	37.0						1.25
2.5	24.4	28.7	33.1	41.9	46.4						1.35
3.0	27.1	32.1	37.2	47.6	55.8						1.40
3.5	29.3	35.0	40.7	52.6	64.8	65.3					1.45
4.0	31.2	37.4	43.8	57.0	70.7	74.7					1.50
4.5	32.7	39.4	46.4	60.9	76.0	84.1					1.55
5.0	34.0	41.2	48.7	64.4	80.8	93.5					1.60
5.5	35.0	42.6	50.8	67.4	85.0	102.9					1.60
6.0	35.9	43.9	52.3	70.1	88.9	108.3	112.3				1.65
6.5	36.6	44.9	53.8	72.5	92.0	113.0	121.7				1.70
7.0	37.2	45.8	55.0	74.6	95.4	117.2	131.1				1.75
7.5	37.7	46.6	56.1	76.4	98.2	121.1	140.5				1.80
8.0	38.1	47.2	57.0	78.0	100.7	124.6	149.5	149.9			1.85
8.5	38.5	47.8	57.8	79.5	103.0	127.8	153.8	159.3			1.85
9.0	38.7	48.2	58.5	80.7	105.0	130.8	157.7	168.7			1.90
9.5	39.0	48.6	59.0	81.8	106.8	133.4	161.4	178.1			1.95
10.0	39.2	48.9	59.5	82.8	108.4	135.6	164.7	187.5			2.00
10.5	39.3	49.2	60.0	83.7	109.9	138.0	167.8	195.9			2.00
11.0	39.5	49.5	60.4	84.5	111.2	140.0	170.6	202.5	206.4		2.05
11.5	39.6	49.7	60.7	85.1	112.4	141.9	173.2	206.0	215.8		2.10
12.0	39.7	49.8	61.0	85.7	113.4	143.5	175.6	209.2	225.2		2.10
12.5	39.7	50.0	61.2	86.3	114.4	145.0	177.8	212.2	234.6		2.15
13.0	39.8	50.1	61.4	86.7	115.3	146.4	179.8	215.0	244.0		2.20
13.5	39.9	50.2	61.6	87.2	116.0	147.7	181.6	217.6	253.4		2.20
14.0	39.9	50.3	61.7	87.5	116.7	148.8	183.4	220.0	258.4	262.8	2.25
14.5	39.9	50.4	61.9	87.8	117.3	149.8	184.9	222.2	261.3	272.2	2.30
15.0	40.0	50.4	62.0	88.1	117.9	150.8	186.4	224.2	264.1	281.6	2.30

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	0.80	0.90	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	(m)
1.5	17.9	20.6	23.4	27.6							1.20
2.0	22.1	25.7	29.3	36.6	37.0						1.25
2.5	25.7	30.1	34.6	43.5	46.4						1.30
3.0	28.8	33.9	39.2	49.8	55.8						1.35
3.5	31.4	37.3	43.2	55.3	65.3						1.40
4.0	33.7	40.1	46.8	60.4	74.3	74.7					1.45
4.5	35.6	42.6	49.9	64.8	80.3	84.1					1.45
5.0	37.2	44.8	52.6	68.9	85.7	93.5					1.50
5.5	38.5	46.6	55.0	72.5	90.7	102.9					1.55
6.0	39.7	48.2	57.1	75.7	95.2	112.3					1.60
6.5	40.7	49.6	59.0	78.7	99.3	120.7	121.7				1.65
7.0	41.5	50.8	60.6	81.3	103.1	125.8	131.1				1.65
7.5	42.2	51.9	62.0	83.6	106.5	130.4	140.5				1.70
8.0	42.8	52.8	63.3	85.7	109.6	134.7	149.9				1.75
8.5	43.4	53.5	64.4	87.6	112.5	138.6	159.3				1.80
9.0	43.8	54.2	65.3	89.3	115.1	142.2	168.7				1.80
9.5	44.2	54.8	66.2	90.8	117.4	145.6	174.9	178.1			1.85
10.0	44.5	55.3	66.9	92.2	119.6	148.7	179.0	187.5			1.90
10.5	44.8	55.7	67.8	93.4	121.6	151.5	182.9	196.9			1.90
11.0	45.0	56.1	68.2	94.5	123.3	154.1	186.4	206.4			1.95
11.5	45.2	56.5	68.7	95.5	125.0	156.5	189.8	215.8			2.00
12.0	45.3	56.7	69.1	96.4	126.5	158.8	192.9	225.2			2.00
12.5	45.5	57.0	69.5	97.2	127.8	160.8	195.8	232.3	234.6		2.05
13.0	45.6	57.2	69.8	97.9	129.0	162.7	198.4	235.9	244.0		2.05
13.5	45.7	57.4	70.1	98.5	130.2	164.5	200.9	239.2	253.4		2.10
14.0	45.8	57.5	70.4	99.1	131.2	166.1	203.3	242.4	262.8		2.15
14.5	45.9	57.7	70.6	99.6	132.1	167.6	205.4	245.3	272.2		2.15
15.0	45.9	57.8	70.8	100.1	133.0	168.9	207.4	248.1	281.6		2.20

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	0.80	0.90	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	(m)
1.5	18.5	21.2	24.0	27.6							1.15
2.0	23.1	26.8	30.4	37.0							1.20
2.5	27.2	31.7	36.2	45.2	46.4						1.25
3.0	30.7	36.0	41.3	52.1	55.8						1.30
3.5	33.8	39.8	45.9	58.3	65.3						1.35
4.0	36.5	43.2	50.0	64.0	74.7						1.40
4.5	38.8	46.2	53.7	69.1	84.1						1.40
5.0	40.9	48.8	57.0	73.9	91.1	93.5					1.45
5.5	42.6	51.2	60.0	78.2	96.9	102.9					1.50
6.0	44.2	53.3	62.6	82.1	102.3	112.3					1.50
6.5	45.5	55.1	65.0	85.7	107.2	121.7					1.55
7.0	46.7	56.7	67.1	89.0	111.7	131.1					1.60
7.5	47.7	58.2	69.0	91.9	116.0	140.5					1.60
8.0	48.6	59.4	70.8	94.7	119.8	145.9	149.9				1.65
8.5	49.4	60.6	72.3	97.2	123.4	150.8	159.3				1.70
9.0	50.1	61.5	73.7	99.4	126.8	155.3	168.7				1.70
9.5	50.7	62.4	74.9	101.5	129.9	159.5	178.1				1.75
10.0	51.2	63.2	76.0	103.4	132.7	163.5	187.5				1.80
10.5	51.6	63.9	77.0	105.1	135.3	167.1	196.9				1.80
11.0	52.0	64.5	77.9	106.7	137.8	170.6	204.7	206.4			1.85
11.5	52.4	65.1	78.6	108.1	140.0	173.8	209.0	215.8			1.85
12.0	52.7	65.5	79.4	109.4	142.1	176.8	213.0	225.2			1.90
12.5	52.9	66.0	80.0	110.6	144.0	179.5	216.8	234.6			1.90
13.0	53.2	66.3	80.6	111.7	145.8	182.1	220.3	244.0			1.95
13.5	53.4	66.7	81.1	112.7	147.4	184.6	223.7	253.4			1.95
14.0	53.5	67.0	81.5	113.6	148.9	186.9	226.9	262.8			2.00
14.5	53.7	67.2	81.9	114.4	150.3	189.0	229.8	272.2			2.00
15.0	53.8	67.4	82.3	115.2	151.6	191.0	232.6	276.2	281.6		2.05

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.14 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

675 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	(m)
1.5	22.2	27.7	33.3	33.9							1.45
2.0	27.5	34.7	42.0	46.6							1.55
2.5	32.0	40.8	49.7	58.5							1.60
3.0	35.8	46.1	56.6	67.3	70.4						1.70
3.5	39.0	50.7	62.7	75.0	82.3						1.75
4.0	41.8	54.7	68.2	81.9	94.2						1.80
4.5	44.1	58.2	73.0	88.2	103.7	106.1					1.85
5.0	46.0	61.3	77.3	93.8	110.8	118.0					1.90
5.5	47.7	64.0	81.1	98.9	117.2	129.9					1.95
6.0	49.1	66.3	84.5	103.5	123.1	141.8					2.00
6.5	50.3	68.3	87.5	107.7	128.5	149.9	153.6				2.05
7.0	51.3	70.1	90.2	111.4	133.4	156.1	165.5				2.10
7.5	52.2	71.6	92.6	114.8	137.9	161.8	177.4				2.15
8.0	52.9	72.9	94.7	117.8	142.0	167.0	189.3				2.20
8.5	53.5	74.1	96.6	120.6	145.7	171.8	198.7	201.2			2.25
9.0	54.0	75.1	98.3	123.1	149.1	176.3	204.3	213.1			2.30
9.5	54.5	76.0	99.8	125.3	152.2	180.4	209.4	225.0			2.35
10.0	54.9	76.8	101.1	127.3	155.1	184.1	214.2	236.9			2.35
10.5	55.2	77.5	102.3	129.1	157.7	187.6	218.7	248.8			2.40
11.0	55.5	78.1	103.3	130.8	160.0	190.8	222.8	255.8	260.7		2.45
11.5	55.7	78.6	104.2	132.2	162.2	193.7	226.6	260.6	272.6		2.50
12.0	55.9	79.0	105.1	133.6	164.1	196.4	230.2	265.1	284.4		2.55
12.5	56.0	79.4	105.8	134.8	165.9	198.9	233.4	269.3	296.3		2.55
13.0	56.2	79.7	106.4	135.9	167.6	201.2	236.5	273.2	308.2		2.60
13.5	56.3	80.0	107.0	136.8	169.0	203.3	239.3	276.9	315.7	320.1	2.65
14.0	56.4	80.3	107.5	137.7	170.4	205.3	242.0	280.3	320.0	332.0	2.70
14.5	56.5	80.5	108.0	138.5	171.6	207.1	244.4	283.5	324.0	343.9	2.70
15.0	56.6	80.7	108.4	139.2	172.8	208.7	246.7	286.4	327.7	355.8	2.75

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	(m)
1.5	22.7	28.2	33.8	33.9							1.45
2.0	28.3	35.5	42.8	46.6							1.55
2.5	33.1	41.9	50.9	58.5							1.60
3.0	37.2	47.8	58.2	69.0	70.4						1.65
3.5	40.7	52.8	64.8	77.2	82.3						1.70
4.0	43.8	57.0	70.7	84.6	94.2						1.75
4.5	46.4	60.9	76.0	91.4	106.1						1.80
5.0	48.7	64.4	80.8	97.6	114.8	118.0					1.85
5.5	50.6	67.4	85.0	103.2	121.9	129.9					1.90
6.0	52.3	70.1	88.9	108.3	128.3	141.8					1.95
6.5	53.8	72.5	92.3	113.0	134.3	153.6					2.00
7.0	55.0	74.6	95.4	117.2	139.8	162.9	165.5				2.05
7.5	56.1	76.4	98.2	121.1	144.9	169.3	177.4				2.10
8.0	57.0	78.0	100.7	124.6	149.5	175.2	189.3				2.15
8.5	57.8	79.5	103.0	127.8	153.8	180.6	201.2				2.20
9.0	58.5	80.7	105.0	130.8	157.7	185.7	213.1				2.20
9.5	59.0	81.8	106.8	133.4	161.4	190.4	220.3	225.0			2.25
10.0	59.5	82.8	108.4	135.8	164.7	194.7	225.7	236.9			2.30
10.5	60.0	83.7	109.9	138.0	167.6	198.6	230.9	248.8			2.35
11.0	60.4	84.5	111.2	140.0	170.6	202.5	235.6	260.7			2.35
11.5	60.7	85.1	112.4	141.9	173.2	206.0	240.1	272.6			2.40
12.0	61.0	85.7	113.4	143.5	175.6	209.2	244.3	280.4	284.4		2.45
12.5	61.2	86.3	114.4	145.0	177.8	212.2	248.1	285.3	296.3		2.50
13.0	61.4	86.7	115.3	146.4	179.8	215.0	251.8	289.8	308.2		2.50
13.5	61.6	87.2	116.0	147.7	181.6	217.6	255.2	294.2	320.1		2.55
14.0	61.7	87.5	116.7	148.8	183.4	220.0	258.4	298.2	332.0		2.60
14.5	61.9	87.8	117.3	149.8	184.9	222.2	261.3	302.0	343.9		2.60
15.0	62.0	88.1	117.9	150.8	186.4	224.2	264.1	305.6	348.6	355.8	2.85

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	(m)
1.5	23.4	28.9	33.9								1.40
2.0	29.3	36.6	44.0	46.6							1.50
2.5	34.6	43.5	52.6	58.5							1.55
3.0	39.2	49.8	60.5	70.4							1.60
3.5	43.2	55.3	67.7	80.3	82.3						1.65
4.0	46.8	60.4	74.3	88.5	94.2						1.70
4.5	49.9	64.8	80.3	96.0	106.1						1.75
5.0	52.6	68.9	85.7	103.0	118.0						1.80
5.5	55.0	72.5	90.7	109.4	128.4	129.9					1.85
6.0	57.1	75.7	95.2	115.3	135.8	141.8					1.90
6.5	59.0	78.7	99.3	120.7	142.7	153.6					1.90
7.0	60.6	81.3	103.1	125.8	149.0	165.5					1.95
7.5	62.0	83.6	106.5	130.4	155.0	177.4					2.00
8.0	63.3	85.7	109.6	134.7	160.5	187.0	189.3				2.05
8.5	64.4	87.6	112.5	138.6	165.6	193.4	201.2				2.10
9.0	65.3	89.3	115.1	142.2	170.4	199.5	213.1				2.10
9.5	66.2	90.8	117.4	145.6	174.9	205.1	225.0				2.15
10.0	66.9	92.2	119.6	148.7	179.0	210.4	236.9				2.20
10.5	67.6	93.4	121.6	151.5	182.9	215.4	248.8				2.20
11.0	68.2	94.5	123.3	154.1	186.4	220.0	254.6	260.7			2.25
11.5	68.7	95.5	125.0	156.5	189.8	224.4	260.1	272.6			2.30
12.0	69.1	96.4	126.5	158.8	192.9	228.5	265.2	284.4			2.35
12.5	69.5	97.2	127.8	160.8	195.8	232.3	270.1	296.3			2.35
13.0	69.8	97.9	129.0	162.7	198.4	235.9	274.7	308.2			2.40
13.5	70.1	98.5	130.2	164.5	200.9	239.2	279.0	320.0	320.1		2.45
14.0	70.4	99.1	131.2	166.1	203.3	242.4	283.1	325.1	332.0		2.45
14.5	70.6	99.6	132.1	167.6	205.4	245.3	286.9	329.9	343.9		2.50
15.0	70.8	100.1	133.0	168.9	207.4	248.1	290.5	334.5	355.8		2.50

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	(m)
1.5	24.0	29.6	33.9								1.40
2.0	30.4	37.8	45.2	46.6							1.45
2.5	36.2	45.2	54.4	58.5							1.50
3.0	41.3	52.1	63.0	70.4							1.55
3.5	45.9	58.3	70.9	82.3							1.60
4.0	50.0	64.0	78.2	92.5	94.2						1.65
4.5	53.7	69.1	84.9	100.9	106.1						1.70
5.0	57.0	73.9	91.1	108.6	118.0						1.75
5.5	60.0	78.2	96.9	116.1	129.9						1.75
6.0	62.6	82.1	102.3	122.9	141.8						1.80
6.5	65.0	85.7	107.2	129.3	151.8	153.6					1.85
7.0	67.1	89.0	111.7	135.2	159.2	165.5					1.90
7.5	69.0	91.9	116.0	140.8	166.2	177.4					1.90
8.0	70.6	94.7	119.8	145.9	172.7	189.3					1.95
8.5	72.3	97.2	123.4	150.8	178.9	201.2					2.00
9.0	73.7	99.4	126.8	155.3	184.7	213.1					2.00
9.5	74.9	101.5	129.9	159.5	190.2	221.6	225.0				2.05
10.0	76.0	103.4	132.7	163.5	195.3	228.0	236.9				2.10
10.5	77.0	105.1	135.3	167.1	200.1	234.1	248.8				2.10
11.0	77.9	106.7	137.8	170.6	204.7	239.9	260.7				2.15
11.5	78.6	108.1	140.0	173.8	209.0	246.3	272.6				2.15
12.0	79.4	109.4	142.1	176.8	213.0	250.5	284.4				2.20
12.5	80.0	110.6	144.0	179.5	216.8	255.4	295.1	296.3			2.25
13.0	80.6	111.7	145.8	182.1	220.3	260.0	300.9	308.2			2.25
13.5	81.1	112.7	147.4	184.6	223.7	264.4	306.4	320.1			2.30
14.0	81.5	113.6	148.9	186.9	226.9	268.5	311.6	332.0			2.30
14.5	81.9	114.4	150.3	189.0	229.8	272.5	316.6	343.9			2.35
15.0	82.3	115.2	151.6	191.0	232.6	276.2	321.3	355.8			2.35

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.15 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

750 mm

A SAND AND GRAVEL $K\mu'$ = 0.165 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.70	3.00	(m)
1.5	22.2	27.7	33.3	36.1							1.55
2.0	27.5	34.7	42.0	49.3	51.4						1.70
2.5	32.0	40.8	49.7	58.8	64.5						1.75
3.0	35.8	46.1	56.6	67.3	77.7						1.80
3.5	39.0	50.7	62.7	75.0	87.4	90.8					1.90
4.0	41.8	54.7	68.2	81.9	95.9	103.9					1.95
4.5	44.1	58.2	73.0	88.2	103.7	117.1					2.00
5.0	46.0	61.3	77.3	93.8	110.8	128.0	130.2				2.05
5.5	47.7	64.0	81.1	98.9	117.2	135.9	143.3				2.10
6.0	49.1	66.3	84.5	103.5	123.1	143.2	156.5				2.15
6.5	50.3	68.3	87.5	107.7	128.5	149.9	169.6				2.20
7.0	51.3	70.1	90.2	111.4	133.4	156.1	179.2	182.7			2.25
7.5	52.2	71.6	92.6	114.8	137.9	161.8	186.2	195.9			2.30
8.0	52.9	72.9	94.7	117.8	142.0	167.0	192.7	209.0			2.35
8.5	53.5	74.1	96.6	120.6	145.7	171.8	198.7	222.1			2.40
9.0	54.0	75.1	98.3	123.1	149.1	176.3	204.3	232.9	235.3		2.45
9.5	54.5	76.0	99.8	125.3	152.2	180.4	209.4	239.3	248.4		2.50
10.0	54.9	76.8	101.1	127.3	155.1	184.1	214.2	245.2	261.5		2.55
10.5	55.2	77.5	102.3	129.1	157.7	187.6	218.7	250.7	274.7		2.55
11.0	55.5	78.1	103.3	130.8	160.0	190.8	222.8	255.8	287.8		2.60
11.5	55.7	78.6	104.2	132.2	162.2	193.7	226.6	260.6	300.9		2.65
12.0	55.9	79.0	105.1	133.6	164.1	196.4	230.2	265.1	314.1		2.70
12.5	56.0	79.4	105.8	134.8	165.9	198.9	233.4	269.3	325.2	327.2	2.75
13.0	56.2	79.7	106.4	135.9	167.6	201.2	236.5	273.2	330.5	340.3	2.80
13.5	56.3	80.0	107.0	136.8	169.0	203.3	239.3	276.9	335.5	353.5	2.80
14.0	56.4	80.3	107.5	137.7	170.4	205.3	242.0	280.3	340.3	366.6	2.85
14.5	56.5	80.5	108.0	138.5	171.6	207.1	244.4	283.5	344.7	379.7	2.90
15.0	56.6	80.7	108.4	139.2	172.8	206.7	246.7	286.4	348.9	392.9	2.95

B SATURATED TOP SOIL $K\mu'$ = 0.15 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.70	3.00	(m)
1.5	22.7	28.2	33.8	36.1							1.50
2.0	28.3	35.5	42.8	50.2	51.4						1.65
2.5	33.1	41.9	50.9	60.0	64.5						1.70
3.0	37.2	47.6	58.2	69.0	77.7						1.80
3.5	40.7	52.6	64.8	77.2	89.7	90.8					1.85
4.0	43.8	57.0	70.7	84.6	98.8	103.9					1.90
4.5	46.4	60.9	76.0	91.4	107.1	117.1					1.95
5.0	48.7	64.4	80.8	97.6	114.8	130.2					2.00
5.5	50.6	67.4	85.0	103.2	121.9	140.8	143.3				2.05
6.0	52.3	70.1	88.9	108.3	128.3	148.8	156.5				2.10
6.5	53.8	72.5	92.3	113.0	134.3	156.1	169.6				2.15
7.0	55.0	74.6	95.4	117.2	139.8	162.9	182.7				2.20
7.5	56.1	76.4	98.2	121.1	144.9	169.3	194.2	195.9			2.25
8.0	57.0	78.0	100.7	124.6	149.5	175.2	201.4	209.0			2.30
8.5	57.8	79.5	103.0	127.8	153.8	180.6	208.1	222.1			2.35
9.0	58.5	80.7	105.0	130.8	157.7	185.7	214.4	235.3			2.35
9.5	59.0	81.8	106.8	133.4	161.4	190.4	220.3	248.4			2.40
10.0	59.5	82.8	108.4	135.8	164.7	194.7	225.7	257.5	261.5		2.45
10.5	60.0	83.7	109.9	138.0	167.8	198.8	230.9	263.8	274.7		2.50
11.0	60.4	84.5	111.2	140.0	170.6	202.5	235.6	269.7	287.8		2.55
11.5	60.7	85.1	112.4	141.9	173.2	206.0	240.1	275.2	300.9		2.55
12.0	61.0	85.7	113.4	143.5	175.6	209.2	244.3	280.4	314.1		2.60
12.5	61.2	86.3	114.4	145.0	177.8	212.2	248.1	285.3	327.2		2.65
13.0	61.4	86.7	115.3	146.4	179.8	215.0	251.8	289.9	340.3		2.70
13.5	61.6	87.2	116.0	147.7	181.6	217.6	255.2	294.2	353.5		2.70
14.0	61.7	87.5	116.7	148.8	183.4	220.0	258.4	298.2	360.4	366.6	2.75
14.5	61.9	87.8	117.3	149.8	184.9	222.2	261.3	302.0	365.6	379.7	2.80
15.0	62.0	88.1	117.9	150.8	186.4	224.2	264.1	305.6	370.6	392.9	2.85

C ORDINARY CLAY $K\mu'$ = 0.13 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.20	3.40	3.60	(m)
1.5	40.0	45.5									1.80
2.0	51.4	58.8	65.7								2.00
2.5	61.8	71.0	80.3	88.3							2.20
3.0	71.4	82.4	93.4	104.5	106.4						2.25
3.5	80.3	93.0	105.7	118.6	124.5						2.30
4.0	88.5	102.8	117.3	131.8	142.6						2.35
4.5	96.0	112.0	128.1	144.3	160.7	160.7					2.45
5.0	103.0	120.5	138.2	156.1	174.2	178.8					2.50
5.5	109.4	128.4	147.7	167.3	187.0	196.9					2.55
6.0	115.3	135.8	156.6	177.8	199.1	215.0					2.55
6.5	120.7	142.7	165.0	187.6	210.6	233.2					2.60
7.0	125.8	149.0	172.8	196.9	221.4	246.1	251.3				2.65
7.5	130.4	155.0	180.1	205.7	231.7	257.9	269.4				2.70
8.0	134.7	160.5	187.0	214.0	241.4	269.2	287.5				2.75
8.5	138.6	165.6	193.4	221.8	250.7	279.9	305.6				2.80
9.0	142.2	170.4	199.5	229.2	259.4	290.1	321.1	323.7			2.85
9.5	145.6	174.9	205.1	236.1	267.7	299.8	332.3	341.8			2.90
10.0	148.7	179.0	210.4	242.6	275.5	309.0	342.9	359.9			2.90
10.5	151.5	182.9	215.4	248.8	283.0	317.8	353.1	378.0			2.95
11.0	154.1	186.4	220.0	254.6	290.0	326.1	362.8	396.1			3.00
11.5	156.5	189.8	224.4	260.1	296.7	334.0	372.0	414.2			3.05
12.0	158.8	192.9	228.5	265.2	303.0	341.6	380.9	432.3			3.10
12.5	160.8	195.8	232.3	270.1	309.0	348.8	389.3	450.4			3.10
13.0	162.7	198.4	235.9	274.7	314.6	355.6	397.4	468.5			3.15
13.5	164.5	200.9	239.2	279.0	320.0	362.1	405.1	486.6			3.20
14.0	166.1	203.3	242.4	283.1	325.1	368.3	412.4	503.0	504.7		3.25
14.5	167.6	205.4	245.3	286.9	329.9	374.1	419.4	512.5	522.8		3.25
15.0	168.9	207.4	248.1	290.5	334.5	379.7	426.1	521.6	540.9		3.30

D SATURATED CLAY $K\mu'$ = 0.11 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.70	3.00	(m)
1.5	24.0	29.6	35.2	36.1							1.45
2.0	30.4	37.8	45.2	51.4							1.60
2.5	36.2	45.2	54.4	63.6	64.5						1.65
3.0	41.3	52.1	63.0	73.9	77.7						1.70
3.5	45.9	58.3	70.9	83.6	90.8						1.75
4.0	50.0	64.0	78.2	92.5	103.9						1.80
4.5	53.7	69.1	84.9	100.9	117.1						1.80
5.0	57.0	73.9	91.1	108.8	126.6	130.2					1.85
5.5	60.0	78.2	96.9	116.1	135.5	143.3					1.90
6.0	62.6	82.1	102.3	122.9	143.9	156.5					1.95
6.5	65.0	85.7	107.2	129.3	151.8	169.6					2.00
7.0	67.1	89.0	111.7	135.2	159.2	182.7					2.00
7.5	69.0	91.9	116.0	140.8	166.2	192.0	195.9				2.05
8.0	70.8	94.7	119.8	145.9	172.7	200.0	209.0				2.10
8.5	72.3	97.2	123.4	150.8	178.9	207.6	222.1				2.10
9.0	73.7	99.4	126.8	155.3	184.7	214.8	235.3				2.15
9.5	74.9	101.5	129.9	159.5	190.2	221.6	248.4				2.20
10.0	76.0	103.4	132.7	163.5	195.3	228.0	261.4	261.5			2.25
10.5	77.0	105.1	135.3	167.1	200.1	234.1	268.9	274.7			2.25
11.0	77.9	106.7	137.8	170.6	204.7	239.9	275.9	287.8			2.30
11.5	78.6	108.1	140.0	173.8	209.0	245.3	282.6	300.9			2.30
12.0	79.4	109.4	142.1	176.8	213.0	250.5	289.0	314.1			2.35
12.5	80.0	110.6	144.0	179.5	216.8	255.4	295.1	327.2			2.40
13.0	80.6	111.7	145.8	182.1	220.3	260.0	300.9	340.3			2.40
13.5	81.1	112.7	147.4	184.6	223.7	264.4	306.4	349.4	353.5		2.45
14.0	81.5	113.6	148.9	186.9	226.9	268.5	311.6	355.8	366.6		2.45
14.5	81.9	114.4	150.3	189.0	229.8	272.5	316.6	361.9	379.7		2.50
15.0	82.3	115.2	151.6	191.0	232.6	276.2	321.3	367.8	392.9		2.55

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.16 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

825 mm

A SAND AND GRAVEL $K\mu'$ = 0.165 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.10	(m)
1.5	27.7	33.3	**38.4**								1.60
2.0	34.7	42.0	49.3	**56.1**							1.80
2.5	40.8	49.7	58.8	67.9	**70.5**						1.90
3.0	46.1	56.6	67.3	78.1	**84.9**						1.95
3.5	50.7	62.7	75.0	87.4	**99.3**						2.00
4.0	54.7	68.2	81.9	95.9	110.1	**113.6**					2.05
4.5	58.2	73.0	88.2	103.7	119.4	**128.0**					2.15
5.0	61.3	77.3	93.8	110.8	128.0	**142.4**					2.20
5.5	64.0	81.1	98.9	117.2	135.9	154.9	**156.8**				2.25
6.0	66.3	84.5	103.5	123.1	143.2	163.6	**171.1**				2.30
6.5	68.3	87.5	107.7	128.5	149.9	171.7	**185.5**				2.35
7.0	70.1	90.2	111.4	133.4	156.1	179.2	**199.9**				2.40
7.5	71.6	92.6	114.8	137.9	161.8	186.2	211.1	**214.3**			2.45
8.0	72.9	94.7	117.8	142.0	167.0	192.7	218.9	**228.6**			2.50
8.5	74.1	96.6	120.6	145.7	171.8	198.7	226.2	**243.0**			2.55
9.0	75.1	98.3	123.1	149.1	176.3	204.3	232.9	**257.4**			2.60
9.5	76.0	99.8	125.3	152.2	180.4	209.4	239.3	269.8	**271.8**		2.65
10.0	76.8	101.1	127.3	155.1	184.1	214.2	245.2	276.9	**286.1**		2.70
10.5	77.5	102.3	129.1	157.7	187.6	218.7	250.7	283.5	**300.5**		2.75
11.0	78.1	103.3	130.8	160.0	190.8	222.8	255.8	289.8	**314.9**		2.75
11.5	78.6	104.2	132.2	162.2	193.7	226.6	260.6	295.6	**329.3**		2.80
12.0	79.0	105.1	133.6	164.1	196.4	230.2	265.1	301.1	338.1	**343.6**	2.85
12.5	79.4	105.8	134.8	165.9	198.9	233.4	269.3	306.3	344.3	**358.0**	2.90
13.0	79.7	106.4	135.9	167.6	201.2	236.5	273.2	311.2	350.1	**372.4**	2.95
13.5	80.0	107.0	136.8	169.0	203.3	239.3	276.9	315.7	355.7	**386.8**	3.00
14.0	80.3	107.5	137.7	170.4	205.3	242.0	280.3	320.0	360.9	**401.2**	3.00
14.5	80.5	108.0	138.5	171.6	207.1	244.4	283.5	324.0	365.8	**415.5**	3.05
15.0	80.7	108.4	139.2	172.8	208.7	246.7	286.4	327.7	370.4	**429.9**	3.10

B SATURATED TOP SOIL $K\mu'$ = 0.15 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.10	(m)
1.5	28.2	33.6	**38.4**								1.60
2.0	35.5	42.8	50.2	**56.1**							1.80
2.5	41.9	50.9	60.0	69.2	**70.5**						1.85
3.0	47.6	58.2	69.0	79.9	**84.9**						1.90
3.5	52.6	64.8	77.2	89.7	**99.3**						2.00
4.0	57.0	70.7	84.6	98.8	113.1	**113.6**					2.05
4.5	60.9	76.0	91.4	107.1	123.0	**128.0**					2.10
5.0	64.4	80.8	97.6	114.8	132.3	**142.4**					2.15
5.5	67.4	85.0	103.2	121.9	140.8	**156.8**					2.20
6.0	70.1	88.9	108.3	128.3	148.8	169.5	**171.1**				2.25
6.5	72.5	92.3	113.0	134.3	156.1	178.3	**185.5**				2.30
7.0	74.6	95.4	117.2	139.8	162.9	186.5	**199.9**				2.35
7.5	76.4	98.2	121.1	144.9	169.3	194.2	**214.3**				2.40
8.0	78.0	100.7	124.6	149.5	175.2	201.4	228.2	**228.6**			2.45
8.5	79.5	103.0	127.8	153.8	180.6	208.1	236.2	**243.0**			2.45
9.0	80.7	105.0	130.8	157.7	185.7	214.4	243.8	**257.4**			2.50
9.5	81.8	106.8	133.4	161.4	190.4	220.3	250.9	**271.8**			2.55
10.0	82.8	108.4	135.8	164.7	194.7	225.7	257.5	**286.1**			2.60
10.5	83.7	109.9	138.0	167.8	198.8	230.9	263.8	297.5	**300.5**		2.65
11.0	84.5	111.2	140.0	170.6	202.5	235.6	269.7	304.6	**314.9**		2.70
11.5	85.1	112.4	141.9	173.2	206.0	240.1	275.2	311.2	**329.3**		2.70
12.0	85.7	113.4	143.5	175.6	209.2	244.3	280.4	317.5	**343.6**		2.75
12.5	86.3	114.4	145.0	177.8	212.2	248.1	285.3	323.5	**358.0**		2.80
13.0	86.7	115.3	146.4	179.8	215.0	251.8	289.9	329.1	369.3	**372.4**	2.85
13.5	87.2	116.0	147.7	181.6	217.6	255.2	294.2	334.4	375.6	**386.8**	2.90
14.0	87.5	116.7	148.8	183.4	220.0	258.4	298.2	339.4	381.7	**401.2**	2.90
14.5	87.8	117.3	149.8	184.9	222.2	261.3	302.0	344.1	387.4	**415.5**	2.95
15.0	88.1	117.9	150.8	186.4	224.2	264.1	305.6	348.6	392.8	**429.9**	3.00

C ORDINARY CLAY $K\mu'$ = 0.13 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.10	(m)
1.5	28.9	34.5	**38.4**								1.55
2.0	36.6	44.0	51.4	**56.1**							1.75
2.5	43.5	52.6	61.8	**70.5**							1.80
3.0	49.8	60.5	71.4	82.4	**84.9**						1.85
3.5	55.3	67.7	80.3	93.0	**99.3**						1.90
4.0	60.4	74.3	88.5	102.8	**113.6**						1.95
4.5	64.8	80.3	96.0	112.0	**128.0**						2.00
5.0	68.9	85.7	103.0	120.5	138.2	**142.4**					2.05
5.5	72.5	90.7	109.4	128.4	147.7	**156.8**					2.10
6.0	75.7	95.2	115.3	135.8	156.6	**171.1**					2.15
6.5	78.7	99.3	120.7	142.7	165.0	**185.5**					2.20
7.0	81.3	103.1	125.8	149.0	172.8	196.9	**199.9**				2.25
7.5	83.6	106.5	130.4	155.0	180.1	205.7	**214.3**				2.30
8.0	85.7	109.6	134.7	160.5	187.0	214.0	**228.6**				2.35
8.5	87.6	112.5	138.6	165.6	193.4	221.8	**243.0**				2.35
9.0	89.3	115.1	142.2	170.4	199.5	229.2	**257.4**				2.40
9.5	90.8	117.4	145.6	174.9	205.1	236.1	267.7	**271.8**			2.45
10.0	92.2	119.6	148.7	179.0	210.4	242.6	275.5	**286.1**			2.50
10.5	93.4	121.6	151.5	182.9	215.4	248.8	283.0	**300.5**			2.55
11.0	94.5	123.3	154.1	186.4	220.0	254.6	290.0	**314.9**			2.55
11.5	95.5	125.0	156.5	189.8	224.4	260.1	296.7	**329.3**			2.60
12.0	96.4	126.5	158.8	192.9	228.5	265.2	303.0	341.6	**343.6**		2.65
12.5	97.2	127.8	160.8	195.8	232.3	270.1	309.0	348.8	**358.0**		2.65
13.0	97.9	129.0	162.7	198.4	235.9	274.7	314.6	355.6	**372.4**		2.70
13.5	98.5	130.2	164.5	200.9	239.2	279.0	320.0	362.1	**386.8**		2.75
14.0	99.1	131.2	166.1	203.3	242.4	283.1	325.1	368.3	**401.2**		2.75
14.5	99.6	132.1	167.6	205.4	245.3	286.9	329.9	374.1	**415.5**		2.80
15.0	100.1	133.0	168.9	207.4	248.1	290.5	334.5	379.7	426.1	**429.9**	2.85

D SATURATED CLAY $K\mu'$ = 0.11 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.10	(m)
1.5	29.6	35.2	**38.4**								1.55
2.0	37.8	45.2	52.6	**56.1**							1.70
2.5	45.2	54.4	63.6	**70.5**							1.75
3.0	52.1	63.0	73.9	**84.9**							1.80
3.5	58.3	70.9	83.6	96.4	**99.3**						1.85
4.0	64.0	78.2	92.5	107.1	**113.6**						1.90
4.5	69.1	84.9	100.9	117.1	**128.0**						1.95
5.0	73.9	91.1	108.8	126.6	**142.4**						2.00
5.5	78.2	96.9	116.1	135.5	155.2	**156.8**					2.05
6.0	82.1	102.3	122.9	143.9	165.1	**171.1**					2.10
6.5	85.7	107.2	129.3	151.8	174.6	**185.5**					2.10
7.0	89.0	111.7	135.2	159.2	183.6	**199.9**					2.15
7.5	91.9	116.0	140.8	166.2	192.0	**214.3**					2.20
8.0	94.7	119.8	145.9	172.7	200.0	227.8	**228.6**				2.25
8.5	97.2	123.4	150.8	178.9	207.6	236.8	**243.0**				2.25
9.0	99.4	126.8	155.3	184.7	214.8	245.4	**257.4**				2.30
9.5	101.5	129.9	159.5	190.2	221.6	253.6	**271.8**				2.35
10.0	103.4	132.7	163.5	195.3	228.0	261.4	**286.1**				2.35
10.5	105.1	135.3	167.1	200.1	234.1	268.9	**300.5**				2.40
11.0	106.7	137.8	170.6	204.7	239.9	275.9	312.6	**314.9**			2.45
11.5	108.1	140.0	173.8	209.0	245.3	282.6	320.7	**329.3**			2.45
12.0	109.4	142.1	176.8	213.0	250.5	289.0	328.4	**343.6**			2.50
12.5	110.6	144.0	179.5	216.8	255.4	295.1	335.7	**358.0**			2.55
13.0	111.7	145.8	182.1	220.3	260.0	300.9	342.7	**372.4**			2.55
13.5	112.7	147.4	184.6	223.7	264.4	306.4	349.4	**386.8**			2.60
14.0	113.6	148.9	186.9	226.9	268.5	311.6	355.8	401.0	**401.2**		2.65
14.5	114.4	150.3	189.0	229.8	272.5	316.6	361.9	408.3	**415.5**		2.65
15.0	115.2	151.6	191.0	232.6	276.2	321.3	367.8	415.3	**429.9**		2.70

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\, p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.17 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

900 mm

A SAND AND GRAVEL Kμ' = 0.165 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.30	
1.5	33.3	38.8	40.7								1.70
2.0	42.0	49.3	56.7	59.6							1.90
2.5	49.7	58.8	67.9	76.5							2.00
3.0	56.6	67.3	78.1	89.0	92.1						2.10
3.5	62.7	75.0	87.4	100.0	107.7						2.15
4.0	68.2	81.9	95.9	110.1	123.3						2.20
4.5	73.0	88.2	103.7	119.4	135.3	138.9					2.25
5.0	77.3	93.8	110.8	128.0	145.5	154.6					2.35
5.5	81.1	98.9	117.2	135.9	154.9	170.2					2.40
6.0	84.5	103.5	123.1	143.2	163.6	184.3	185.8				2.45
6.5	87.5	107.7	128.5	149.9	171.7	193.9	201.4				2.50
7.0	90.2	111.4	133.4	156.1	179.2	202.8	217.0				2.55
7.5	92.6	114.8	137.9	161.8	186.2	211.1	232.6				2.60
8.0	94.7	117.8	142.0	167.0	192.7	218.9	245.6	248.3			2.65
8.5	96.6	120.6	145.7	171.8	198.7	226.2	254.2	263.9			2.70
9.0	98.3	123.1	149.1	176.3	204.3	232.9	262.2	279.5			2.75
9.5	99.8	125.3	152.2	180.4	209.4	239.3	269.8	295.1			2.80
10.0	101.1	127.3	155.1	184.1	214.2	245.2	276.9	309.2	310.7		2.85
10.5	102.3	129.1	157.7	187.6	218.7	250.7	283.5	317.1	326.4		2.90
11.0	103.3	130.8	160.0	190.8	222.8	255.8	289.8	324.5	342.0		2.90
11.5	104.2	132.2	162.2	193.7	226.6	260.6	295.6	331.5	357.6		2.95
12.0	105.1	133.6	164.1	196.4	230.2	265.1	301.1	338.1	373.2		3.00
12.5	105.8	134.8	165.9	198.9	233.4	269.3	306.3	344.3	383.1	388.8	3.05
13.0	106.4	135.9	167.6	201.2	236.5	273.2	311.2	350.1	390.0	404.5	3.10
13.5	107.0	136.8	169.0	203.3	239.3	276.9	315.7	355.7	396.8	420.1	3.15
14.0	107.5	137.7	170.4	205.3	242.0	280.3	320.0	360.9	402.8	435.7	3.20
14.5	108.0	138.5	171.6	207.1	244.4	283.5	324.0	365.8	408.7	451.3	3.20
15.0	108.4	139.2	172.8	208.7	246.7	286.4	327.7	370.4	414.3	466.9	3.25

B SATURATED TOP SOIL Kμ' = 0.15 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.30	
1.5	33.8	39.3	40.7								1.70
2.0	42.6	50.2	57.6	59.6							1.90
2.5	50.9	60.0	69.2	76.5							2.00
3.0	58.2	69.0	79.9	90.8	92.1						2.05
3.5	64.8	77.2	89.7	102.4	107.7						2.10
4.0	70.7	84.6	98.8	113.1	123.3						2.15
4.5	76.0	91.4	107.1	123.0	138.9						2.20
5.0	80.8	97.6	114.8	132.3	149.9	154.6					2.30
5.5	85.0	103.2	121.9	140.8	160.0	170.2					2.35
6.0	88.9	108.3	128.3	148.6	169.5	185.8					2.40
6.5	92.3	113.0	134.3	156.1	178.3	200.8	201.4				2.45
7.0	95.4	117.2	139.8	162.9	186.5	210.5	217.0				2.50
7.5	98.2	121.1	144.9	169.3	194.2	219.6	232.6				2.55
8.0	100.7	124.6	149.5	175.2	201.4	228.2	248.3				2.55
8.5	103.0	127.8	153.8	180.6	208.1	236.2	263.9				2.60
9.0	105.0	130.8	157.7	185.7	214.4	243.8	273.7	279.5			2.65
9.5	106.8	133.4	161.4	190.4	220.3	250.9	282.1	295.1			2.70
10.0	108.4	135.8	164.7	194.7	225.7	257.5	290.0	310.7			2.75
10.5	109.9	138.0	167.8	198.8	230.9	263.8	297.5	326.4			2.80
11.0	111.2	140.0	170.6	202.5	235.6	269.7	304.6	340.1	342.0		2.85
11.5	112.4	141.9	173.2	206.0	240.1	275.2	311.2	348.0	357.6		2.90
12.0	113.4	143.5	175.6	209.2	244.3	280.4	317.5	355.5	373.2		2.90
12.5	114.4	145.0	177.8	212.2	248.1	285.3	323.5	362.6	388.8		2.95
13.0	115.3	146.4	179.8	215.0	251.8	289.9	329.1	369.3	404.5		3.00
13.5	116.0	147.7	181.6	217.6	255.2	294.2	334.4	375.6	417.8	420.1	3.05
14.0	116.7	148.8	183.4	220.0	258.4	298.2	339.4	381.7	424.9	435.7	3.05
14.5	117.3	149.8	184.9	222.2	261.3	302.0	344.1	387.4	431.7	451.3	3.10
15.0	117.9	150.8	186.4	224.2	264.1	305.6	348.6	392.8	438.2	466.9	3.15

C ORDINARY CLAY Kμ' = 0.13 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.30	
1.5	34.5	40.0	40.7								1.65
2.0	44.0	51.4	58.8	59.6							1.85
2.5	52.6	61.8	71.0	76.5							1.95
3.0	60.5	71.4	82.4	92.1							2.00
3.5	67.7	80.3	93.0	105.7	107.7						2.05
4.0	74.3	88.5	102.8	117.3	123.3						2.10
4.5	80.3	96.0	112.0	128.1	138.9						2.15
5.0	85.7	103.0	120.5	138.2	154.6						2.20
5.5	90.7	109.4	128.4	147.7	167.3	170.2					2.25
6.0	95.2	115.3	135.8	156.6	177.8	185.8					2.30
6.5	99.3	120.7	142.7	165.0	187.6	201.4					2.35
7.0	103.1	125.8	149.0	172.8	196.9	217.0					2.40
7.5	106.5	130.4	155.0	180.1	205.7	231.7	232.6				2.45
8.0	109.6	134.7	160.5	187.0	214.0	241.4	248.3				2.45
8.5	112.5	138.6	165.6	193.4	221.8	250.7	263.9				2.50
9.0	115.1	142.2	170.4	199.5	229.2	259.4	279.5				2.55
9.5	117.4	145.6	174.9	205.1	236.1	267.7	295.1				2.60
10.0	119.6	148.7	179.0	210.4	242.6	275.5	309.0	310.7			2.65
10.5	121.6	151.5	182.9	215.4	248.8	283.0	317.8	326.4			2.65
11.0	123.3	154.1	186.4	220.0	254.6	290.0	326.1	342.0			2.70
11.5	125.0	156.5	189.8	224.4	260.1	296.7	334.0	357.6			2.75
12.0	126.5	158.8	192.9	228.5	265.2	303.0	341.6	373.2			2.80
12.5	127.8	160.8	195.8	232.3	270.1	309.0	348.8	388.8			2.80
13.0	129.0	162.7	198.4	235.9	274.7	314.6	355.6	397.4	404.5		2.85
13.5	130.2	164.5	200.9	239.2	279.0	320.0	362.1	405.1	420.1		2.90
14.0	131.2	166.1	203.3	242.4	283.1	325.1	368.3	412.4	435.7		2.95
14.5	132.1	167.6	205.4	245.3	286.9	329.9	374.1	419.4	451.3		2.95
15.0	133.0	168.9	207.4	248.1	290.5	334.5	379.7	426.1	466.9		3.00

D SATURATED CLAY Kμ' = 0.11 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.30	
1.5	35.2	40.7									1.60
2.0	45.2	52.6	59.6								1.80
2.5	54.4	63.6	72.9	76.5							1.90
3.0	63.0	73.9	85.0	92.1							1.95
3.5	70.9	83.8	96.4	107.7							2.00
4.0	78.2	92.5	107.1	121.7	123.3						2.05
4.5	84.9	100.9	117.1	133.5	138.9						2.10
5.0	91.1	108.8	126.6	144.6	154.6						2.15
5.5	96.9	116.1	135.5	155.2	170.2						2.20
6.0	102.3	122.9	143.9	165.1	185.8						2.20
6.5	107.2	129.3	151.8	174.6	197.7	201.4					2.25
7.0	111.7	135.2	159.2	183.6	208.2	217.0					2.30
7.5	116.0	140.8	166.2	192.0	218.2	232.6					2.35
8.0	119.8	145.9	172.7	200.0	227.8	248.3					2.35
8.5	123.4	150.8	178.9	207.6	236.8	263.9					2.40
9.0	126.8	155.3	184.7	214.8	245.4	276.5	279.5				2.45
9.5	129.9	159.5	190.2	221.6	253.6	286.2	295.1				2.50
10.0	132.7	163.5	195.3	228.0	261.4	295.4	310.7				2.50
10.5	135.3	167.1	200.1	234.1	268.9	304.2	326.4				2.55
11.0	137.8	170.6	204.7	239.9	275.9	312.6	342.0				2.60
11.5	140.0	173.8	209.0	245.3	282.6	320.7	357.6				2.60
12.0	142.1	176.8	213.0	250.5	289.0	328.4	368.4	373.2			2.65
12.5	144.0	179.5	216.8	255.4	295.1	335.7	377.1	388.8			2.70
13.0	145.8	182.1	220.3	260.0	300.9	342.7	385.4	404.5			2.70
13.5	147.4	184.6	223.7	264.4	306.4	349.4	393.3	420.1			2.75
14.0	148.9	186.9	226.9	268.5	311.6	355.8	401.0	435.7			2.80
14.5	150.3	189.0	229.8	272.5	316.6	361.9	408.3	451.3			2.80
15.0	151.6	191.0	232.6	276.2	321.3	367.8	415.3	463.8	466.9		2.85

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon Kμ′ = 0.19, $r_{sd}\,p$ = 0.5 in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.18 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

975 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.50	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.10	3.40	(m)
1.5	36.0	38.8	43.1								1.80
2.0	45.6	49.3	56.7	62.6							2.00
2.5	54.2	58.8	67.9	77.0	82.4						2.15
3.0	61.9	67.3	78.1	89.0	99.3						2.20
3.5	68.8	75.0	87.4	100.0	112.6	116.1					2.30
4.0	75.0	81.9	95.9	110.1	124.4	133.0					2.35
4.5	80.6	88.2	103.7	119.4	135.3	149.8					2.40
5.0	85.5	93.8	110.8	128.0	145.5	163.1	166.7				2.45
5.5	90.0	98.9	117.2	135.9	154.9	174.1	183.6				2.50
6.0	93.9	103.5	123.1	143.2	163.6	184.3	200.4				2.60
6.5	97.5	107.7	128.5	149.9	171.7	193.9	216.3	217.3			2.65
7.0	100.7	111.4	133.4	156.1	179.2	202.8	226.7	234.2			2.70
7.5	103.6	114.8	137.9	161.8	186.2	211.1	236.5	251.0			2.75
8.0	106.1	117.8	142.0	167.0	192.7	218.9	245.6	267.9			2.80
8.5	108.4	120.6	145.7	171.8	198.7	226.2	254.2	282.6	284.7		2.85
9.0	110.5	123.1	149.1	176.3	204.3	232.9	262.2	292.0	301.6		2.90
9.5	112.3	125.3	152.2	180.4	209.4	239.3	269.8	300.9	318.5		2.95
10.0	114.0	127.3	155.1	184.1	214.2	245.2	276.9	309.2	335.3		3.00
10.5	115.5	129.1	157.7	187.6	218.7	250.7	283.5	317.1	352.2		3.05
11.0	116.8	130.8	160.0	190.8	222.8	255.8	289.8	324.5	369.0		3.10
11.5	118.0	132.2	162.2	193.7	226.6	260.6	295.6	331.5	385.9		3.10
12.0	119.0	133.6	164.1	196.4	230.2	265.1	301.1	338.1	394.9	402.8	3.15
12.5	120.0	134.8	165.9	198.9	233.4	269.3	306.3	344.3	402.8	419.6	3.20
13.0	120.8	135.9	167.6	201.2	236.5	273.2	311.2	350.1	410.3	436.5	3.25
13.5	121.6	136.8	169.0	203.3	239.3	276.9	315.7	355.7	417.4	453.3	3.30
14.0	122.3	137.7	170.4	205.3	242.0	280.3	320.0	360.9	424.1	470.2	3.35
14.5	122.9	138.5	171.6	207.1	244.4	283.5	324.0	365.8	430.5	487.1	3.40
15.0	123.5	139.2	172.8	208.7	246.7	286.4	327.7	370.4	436.6	503.9	3.40

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.50	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.10	3.40	(m)
1.5	36.5	39.3	43.1								1.75
2.0	46.5	50.2	57.6	62.6							1.95
2.5	55.5	60.0	69.2	78.4	82.4						2.10
3.0	63.6	69.0	79.9	90.8	99.3						2.20
3.5	71.0	77.2	89.7	102.4	115.1	116.1					2.25
4.0	77.6	84.6	98.8	113.1	127.5	133.0					2.30
4.5	83.7	91.4	107.1	123.0	139.1	149.8					2.35
5.0	89.1	97.6	114.8	132.3	149.9	166.7					2.40
5.5	94.1	103.2	121.9	140.8	160.0	179.5	183.6				2.45
6.0	98.5	108.3	128.3	148.8	169.5	190.5	200.4				2.50
6.5	102.6	113.0	134.3	156.1	178.3	200.8	217.3				2.55
7.0	106.2	117.2	139.8	162.9	186.6	210.5	234.2				2.60
7.5	109.5	121.1	144.9	169.3	194.2	219.8	245.3	251.0			2.65
8.0	112.5	124.6	149.5	175.2	201.4	228.2	255.3	267.9			2.70
8.5	115.2	127.8	153.8	180.6	208.1	236.2	264.8	284.7			2.75
9.0	117.7	130.8	157.7	185.7	214.4	243.8	273.7	301.6			2.80
9.5	119.9	133.4	161.4	190.4	220.3	250.9	282.1	313.8	318.5		2.85
10.0	121.9	135.8	164.7	194.7	225.7	257.5	290.0	323.0	335.3		2.90
10.5	123.7	138.0	167.8	198.8	230.9	263.8	297.5	331.8	352.2		2.95
11.0	125.4	140.0	170.6	202.5	235.6	269.7	304.6	340.1	369.0		3.00
11.5	126.9	141.9	173.2	206.0	240.1	275.2	311.2	348.0	385.9		3.05
12.0	128.2	143.5	175.6	209.2	244.3	280.4	317.5	355.5	402.8		3.05
12.5	129.4	145.0	177.8	212.2	248.1	285.3	323.5	362.6	419.6		3.10
13.0	130.5	146.4	179.8	215.0	251.8	289.9	329.1	369.3	431.1	436.5	3.15
13.5	131.5	147.7	181.6	217.6	255.2	294.2	334.4	375.8	439.2	453.3	3.20
14.0	132.4	148.8	183.4	220.0	258.4	298.2	339.4	381.7	446.9	470.2	3.25
14.5	133.2	149.8	184.9	222.2	261.3	302.0	344.1	387.4	454.2	487.1	3.25
15.0	134.0	150.8	186.4	224.2	264.1	305.6	348.6	392.8	461.2	503.9	3.30

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.50	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.10	3.40	(m)
1.5	37.2	40.0	43.1								1.75
2.0	47.7	51.4	58.8	62.6							1.95
2.5	57.2	61.8	71.0	80.3	82.4						2.05
3.0	66.0	71.4	82.4	93.4	99.3						2.15
3.5	74.0	80.3	93.0	105.7	116.1						2.20
4.0	81.4	88.5	102.8	117.3	131.8	133.0					2.25
4.5	88.1	96.0	112.0	128.1	144.3	149.8					2.30
5.0	94.3	103.0	120.5	138.2	156.1	166.7					2.35
5.5	100.0	109.4	128.4	147.7	167.3	183.6					2.40
6.0	105.2	115.3	135.8	156.6	177.8	199.1	200.4				2.45
6.5	110.0	120.7	142.7	165.0	187.6	210.5	217.3				2.50
7.0	114.3	125.8	149.0	172.8	196.9	221.4	234.2				2.55
7.5	118.4	130.4	155.0	180.1	205.7	231.7	251.0				2.55
8.0	122.0	134.7	160.5	187.0	214.0	241.4	267.9				2.60
8.5	125.4	138.6	165.6	193.4	221.8	250.7	279.9	284.7			2.65
9.0	128.5	142.2	170.4	199.5	229.2	259.4	290.1	301.6			2.70
9.5	131.3	145.6	174.9	205.1	236.1	267.7	299.8	318.5			2.75
10.0	133.9	148.7	179.0	210.4	242.6	275.5	309.0	335.3			2.80
10.5	136.3	151.5	182.9	215.4	248.6	283.0	317.8	352.2			2.80
11.0	138.5	154.1	186.4	220.0	254.6	290.0	326.1	362.8	369.0		2.85
11.5	140.5	156.5	189.8	224.4	260.1	296.7	334.0	372.0	385.9		2.90
12.0	142.4	158.8	192.9	228.5	265.2	303.0	341.6	380.9	402.8		2.95
12.5	144.1	160.8	195.8	232.3	270.1	309.0	348.8	389.3	419.6		2.95
13.0	145.6	162.7	198.4	235.9	274.7	314.6	355.6	397.4	436.5		3.00
13.5	147.0	164.5	200.9	239.2	279.0	320.0	362.1	405.1	453.3		3.05
14.0	148.3	166.1	203.3	242.4	283.1	325.1	368.3	412.4	470.2		3.10
14.5	149.5	167.5	205.4	245.3	286.9	329.9	374.1	419.4	487.1		3.10
15.0	150.6	168.9	207.4	248.1	290.5	334.5	379.7	426.1	497.4	503.9	3.15

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.50	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.10	3.40	(m)
1.5	38.0	40.8	43.1								1.70
2.0	48.9	52.6	60.0	62.6							1.90
2.5	59.0	63.6	72.9	82.2	82.4						2.05
3.0	68.4	73.9	85.0	96.1	99.3						2.10
3.5	77.2	83.6	96.4	109.2	116.1						2.15
4.0	85.3	92.5	107.1	121.7	133.0						2.20
4.5	92.9	100.9	117.1	133.5	149.8						2.20
5.0	99.9	108.8	126.6	144.6	162.7	166.7					2.25
5.5	106.5	116.1	135.5	155.2	175.0	183.6					2.30
6.0	112.5	122.9	143.9	165.1	186.6	200.4					2.35
6.5	118.2	129.3	151.8	174.6	197.7	217.3					2.40
7.0	123.4	135.2	159.2	183.6	208.2	233.1	234.2				2.45
7.5	128.3	140.8	166.2	192.0	218.2	244.7	251.0				2.45
8.0	132.8	145.9	172.7	200.0	227.8	255.8	267.9				2.50
8.5	137.0	150.8	178.9	207.6	236.8	266.4	284.7				2.55
9.0	140.9	155.3	184.7	214.8	245.4	276.5	301.6				2.60
9.5	144.5	159.5	190.2	221.6	253.6	286.2	318.5				2.60
10.0	147.9	163.5	195.3	228.0	261.4	295.4	329.8	335.3			2.65
10.5	151.1	167.1	200.1	234.1	268.9	304.2	340.1	352.2			2.70
11.0	154.0	170.6	204.7	239.9	275.9	312.6	349.9	369.0			2.75
11.5	156.7	173.8	209.0	245.3	282.6	320.7	359.4	385.9			2.75
12.0	159.2	176.8	213.0	250.5	289.0	328.4	368.4	402.8			2.80
12.5	161.5	179.5	216.8	255.4	295.1	335.7	377.1	419.1	419.6		2.85
13.0	163.7	182.1	220.3	260.0	300.9	342.7	385.4	428.7	436.5		2.85
13.5	165.7	184.6	223.7	264.4	306.4	349.4	393.3	438.0	453.3		2.90
14.0	167.6	186.9	226.9	268.5	311.6	355.8	401.0	447.0	470.2		2.95
14.5	169.3	189.0	229.6	272.5	316.6	361.9	408.3	455.5	487.1		2.95
15.0	171.0	191.0	232.6	276.2	321.3	367.8	415.3	463.8	503.9		3.00

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.19 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

1050 mm

A SAND AND GRAVEL Kμ' = 0.165 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.20	3.40	3.60	TRANSITION WIDTH (m)
1.5	38.8	44.4	45.5								1.85
2.0	49.3	56.7	64.1	65.7							2.05
2.5	58.8	67.9	77.0	86.2	88.3						2.25
3.0	67.3	78.1	89.0	99.9	106.4						2.35
3.5	75.0	87.4	100.0	112.8	124.5						2.40
4.0	81.9	95.9	110.1	124.4	138.8	142.6					2.50
4.5	88.2	103.7	119.4	135.3	151.4	160.7					2.55
5.0	93.8	110.8	128.0	145.5	163.1	178.8					2.60
5.5	98.9	117.2	135.9	154.9	174.1	193.5	196.9				2.65
6.0	103.5	123.1	143.2	163.6	184.3	205.3	215.0				2.70
6.5	107.7	128.5	149.9	171.7	193.9	216.3	233.2				2.75
7.0	111.4	133.4	156.1	179.2	202.8	226.7	250.9	251.3			2.85
7.5	114.8	137.9	161.8	186.2	211.1	236.5	262.1	269.4			2.90
8.0	117.8	142.0	167.0	192.7	218.9	245.6	272.7	287.5			2.95
8.5	120.6	145.7	171.8	198.7	226.2	254.2	282.6	305.6			3.00
9.0	123.1	149.1	176.3	204.3	232.9	262.2	292.0	323.7			3.05
9.5	125.3	152.2	180.4	209.4	239.3	269.8	300.9	341.8			3.10
10.0	127.3	155.1	184.1	214.2	245.2	276.9	309.2	359.9			3.15
10.5	129.1	157.7	187.6	218.7	250.7	283.5	317.1	378.0			3.20
11.0	130.8	160.0	190.8	222.8	255.8	289.8	324.5	395.7	396.1		3.25
11.5	132.2	162.2	193.7	226.6	260.6	295.6	331.5	405.2	414.2		3.25
12.0	133.6	164.1	196.4	230.2	265.1	301.1	338.1	414.1	432.3		3.30
12.5	134.8	165.9	198.9	233.4	269.3	306.3	344.3	422.6	450.4		3.35
13.0	135.9	167.6	201.2	236.5	273.2	311.2	350.1	430.7	468.5		3.40
13.5	136.8	169.0	203.3	239.3	276.9	315.7	355.7	438.4	480.9	486.6	3.45
14.0	137.7	170.4	205.3	242.0	280.3	320.0	360.9	445.7	489.3	504.7	3.50
14.5	138.5	171.6	207.1	244.4	283.5	324.0	365.8	452.6	497.4	522.8	3.55
15.0	139.2	172.8	208.7	246.7	286.4	327.7	370.4	459.2	505.0	540.9	3.60

B SATURATED TOP SOIL Kμ' = 0.15 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.20	3.40	3.60	TRANSITION WIDTH (m)
1.5	39.3	44.9	45.5								1.85
2.0	50.2	57.6	65.0	65.7							2.05
2.5	60.0	69.2	78.4	87.6	88.3						2.25
3.0	69.0	79.9	90.8	101.8	106.4						2.30
3.5	77.2	89.7	102.4	115.1	124.5						2.35
4.0	84.6	98.8	113.1	127.5	142.0	142.6					2.45
4.5	91.4	107.1	123.0	139.1	155.3	160.7					2.50
5.0	97.6	114.8	132.3	149.9	167.8	178.8					2.55
5.5	103.2	121.9	140.8	160.0	179.5	196.9					2.60
6.0	108.3	128.3	148.8	169.5	190.5	211.6	215.0				2.65
6.5	113.0	134.3	156.1	178.3	200.8	223.5	233.2				2.70
7.0	117.2	139.8	162.9	186.5	210.5	234.7	251.3				2.75
7.5	121.1	144.9	169.3	194.2	219.6	245.3	269.4				2.80
8.0	124.6	149.5	175.2	201.4	228.2	255.3	282.8	287.5			2.85
8.5	127.8	153.8	180.6	208.1	236.2	264.8	293.7	305.6			2.90
9.0	130.8	157.7	185.7	214.4	243.8	273.7	304.0	323.7			2.95
9.5	133.4	161.4	190.4	220.3	250.9	282.1	313.8	341.8			3.00
10.0	135.8	164.7	194.7	225.7	257.5	290.0	323.0	359.9			3.05
10.5	138.0	167.8	198.8	230.9	263.8	297.5	331.8	378.0			3.10
11.0	140.0	170.6	202.5	235.6	269.7	304.6	340.1	396.1			3.15
11.5	141.9	173.2	206.0	240.1	275.2	311.2	348.0	414.2			3.20
12.0	143.5	175.6	209.2	244.3	280.4	317.5	355.5	432.3			3.20
12.5	145.0	177.8	212.2	248.1	285.3	323.5	362.6	442.9	450.4		3.25
13.0	146.4	179.8	215.0	251.8	289.9	329.1	369.3	452.0	468.5		3.30
13.5	147.7	181.6	217.6	255.2	294.2	334.4	375.6	460.7	486.6		3.35
14.0	148.8	183.4	220.0	258.4	298.2	339.4	381.7	469.0	504.7		3.40
14.5	149.8	184.9	222.2	261.3	302.0	344.1	387.4	476.9	522.8		3.40
15.0	150.8	186.4	224.2	264.1	305.6	348.6	392.8	484.4	531.6	540.9	3.45

C ORDINARY CLAY Kμ' = 0.13 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.20	3.40	3.60	TRANSITION WIDTH (m)
1.5	40.0	45.5									1.80
2.0	51.4	58.8	65.7								2.00
2.5	61.8	71.0	80.3	88.3							2.20
3.0	71.4	82.4	93.4	104.5	106.4						2.25
3.5	80.3	93.0	105.7	118.6	124.5						2.30
4.0	88.5	102.8	117.3	131.8	142.6						2.35
4.5	96.0	112.0	128.1	144.3	160.7	160.7					2.45
5.0	103.0	120.5	138.2	156.1	174.2	178.8					2.50
5.5	109.4	128.4	147.7	167.3	187.0	196.9					2.55
6.0	115.3	136.8	156.6	177.8	199.1	215.0					2.55
6.5	120.7	142.7	165.0	187.6	210.5	233.2					2.60
7.0	125.8	149.0	172.8	196.9	221.4	246.1	251.3				2.65
7.5	130.4	155.0	180.1	205.7	231.7	257.9	269.4				2.70
8.0	134.7	160.5	187.0	214.0	241.4	269.2	287.5				2.75
8.5	138.6	165.6	193.4	221.8	250.7	279.9	305.6				2.80
9.0	142.2	170.4	199.5	229.2	259.4	290.1	321.1	323.7			2.85
9.5	145.6	174.9	205.1	236.1	267.7	299.8	332.3	341.8			2.90
10.0	148.7	179.0	210.4	242.6	275.5	309.0	342.9	359.9			2.90
10.5	151.5	182.9	215.4	248.8	283.0	317.8	353.1	378.0			2.95
11.0	154.1	186.4	220.0	254.6	290.0	326.1	362.8	396.1			3.00
11.5	156.5	189.8	224.4	260.1	296.7	334.0	372.0	414.2			3.05
12.0	158.8	192.9	228.5	265.2	303.0	341.6	380.9	432.3			3.10
12.5	160.8	195.8	232.3	270.1	309.0	348.8	389.3	450.4			3.10
13.0	162.7	198.4	235.9	274.7	314.6	355.6	397.4	468.5			3.15
13.5	164.5	200.9	239.2	279.0	320.0	362.1	405.1	486.6			3.20
14.0	166.1	203.3	242.4	283.1	325.1	368.3	412.4	503.0	504.7		3.25
14.5	167.6	205.4	245.3	286.9	329.9	374.1	419.4	512.5	522.8		3.25
15.0	168.9	207.4	248.1	290.5	334.5	379.7	426.1	521.6	540.9		3.30

D SATURATED CLAY Kμ' = 0.11 DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.20	3.40	3.60	TRANSITION WIDTH (m)
1.5	40.8	45.5									1.80
2.0	52.6	60.0	65.7								2.00
2.5	63.6	72.9	82.2	88.3							2.15
3.0	73.9	85.0	96.1	106.4							2.20
3.5	83.6	96.4	109.2	122.1	124.5						2.25
4.0	92.5	107.1	121.7	136.4	142.6						2.30
4.5	100.9	117.1	133.5	149.9	160.7						2.35
5.0	108.8	126.6	144.6	162.7	178.8						2.40
5.5	116.1	135.5	155.2	175.0	194.9	196.9					2.45
6.0	122.9	143.9	165.1	186.6	208.2	215.0					2.50
6.5	129.3	151.8	174.6	197.7	221.0	233.2					2.55
7.0	135.2	159.2	183.6	208.2	233.1	251.3					2.55
7.5	140.8	166.2	192.0	218.2	244.7	269.4					2.60
8.0	145.9	172.7	200.0	227.8	255.8	284.1	287.5				2.65
8.5	150.8	178.9	207.6	236.8	266.4	296.3	305.6				2.70
9.0	155.3	184.7	214.8	245.4	276.6	307.9	323.7				2.70
9.5	159.5	190.2	221.6	253.6	286.2	319.1	341.8				2.75
10.0	163.5	195.3	228.0	261.4	295.4	329.8	359.9				2.80
10.5	167.1	200.1	234.1	268.9	304.2	340.1	376.4	378.0			2.85
11.0	170.6	204.7	239.9	275.9	312.6	349.9	387.7	396.1			2.85
11.5	173.8	209.0	245.3	282.6	320.7	359.4	398.5	414.2			2.90
12.0	176.8	213.0	250.5	289.0	328.4	368.4	409.0	432.3			2.95
12.5	179.5	216.8	255.4	295.1	335.7	377.1	419.1	450.4			2.95
13.0	182.1	220.3	260.0	300.9	342.7	385.4	428.7	468.5			3.00
13.5	184.6	223.7	264.4	306.4	349.4	393.3	438.0	486.6			3.05
14.0	186.9	226.9	268.5	311.6	355.8	401.0	447.0	504.7			3.05
14.5	189.0	229.8	272.5	316.6	361.9	408.3	455.5	522.8			3.10
15.0	191.0	232.6	276.2	321.3	367.8	415.3	463.8	540.9			3.15

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd} p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.20 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

1200 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.30	3.60	3.90	(m)
1.5	44.4	50.0	**50.3**								2.05
2.0	56.7	64.1	71.5	**71.8**							2.25
2.5	67.9	77.0	86.2	95.5	**96.4**						2.45
3.0	78.1	89.0	99.9	110.9	**120.7**						2.60
3.5	87.4	100.0	112.6	125.3	138.1	**141.3**					2.65
4.0	95.9	110.1	124.4	138.8	153.3	**161.9**					2.75
4.5	103.7	119.4	135.3	151.4	167.6	**182.5**					2.80
5.0	110.8	128.0	145.6	163.1	181.0	198.9	**203.0**				2.85
5.5	117.2	135.9	154.9	174.1	193.5	213.1	**223.6**				2.95
6.0	123.1	143.2	163.6	184.3	205.3	226.4	**244.2**				3.00
6.5	128.5	149.9	171.7	193.9	216.3	239.0	261.9	**264.8**			3.05
7.0	133.4	156.1	179.2	202.8	226.7	250.9	275.3	**285.4**			3.10
7.5	137.9	161.8	186.2	211.1	236.5	262.1	288.0	**306.0**			3.15
8.0	142.0	167.0	192.7	218.9	245.6	272.7	300.1	**326.6**			3.20
8.5	145.7	171.8	198.7	226.2	254.2	282.6	311.4	**347.2**			3.25
9.0	149.1	176.3	204.3	232.9	262.2	292.0	322.2	**367.8**			3.30
9.5	152.2	180.4	209.4	239.3	269.8	300.9	332.4	380.5	**388.3**		3.35
10.0	155.1	184.1	214.2	245.2	276.9	309.2	342.1	392.2	**408.9**		3.40
10.5	157.7	187.6	218.7	250.7	283.5	317.1	351.2	403.3	**429.5**		3.45
11.0	160.0	190.8	222.8	255.8	289.8	324.5	359.8	413.9	**450.1**		3.50
11.5	162.2	193.7	226.6	260.6	295.6	331.5	368.0	424.0	**470.7**		3.55
12.0	164.1	196.4	230.2	265.1	301.1	338.1	375.8	433.5	**491.3**		3.60
12.5	165.9	198.9	233.4	269.3	306.3	344.3	383.1	442.7	503.6	**511.9**	3.65
13.0	167.6	201.2	236.5	273.2	311.2	350.1	390.0	451.3	514.1	**532.5**	3.70
13.5	169.0	203.3	239.3	276.9	315.7	356.7	396.6	459.6	524.1	**553.0**	3.75
14.0	170.4	205.3	242.0	280.3	320.0	360.9	402.8	467.4	533.7	**573.6**	3.80
14.5	171.6	207.1	244.4	283.5	324.0	365.8	406.7	474.9	542.9	**594.2**	3.85
15.0	172.8	208.7	246.7	286.4	327.7	370.4	414.3	482.0	551.6	**614.8**	3.90

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.30	3.60	3.90	(m)
1.5	44.9	**50.3**									2.00
2.0	57.6	65.0	**71.8**								2.20
2.5	69.2	78.4	87.6	**96.4**							2.40
3.0	79.9	90.8	101.8	112.9	**120.7**						2.55
3.5	89.7	102.4	115.1	127.9	140.8	**141.3**					2.65
4.0	98.6	113.1	127.5	142.0	156.6	**161.9**					2.70
4.5	107.1	123.0	139.1	155.3	171.6	**182.5**					2.75
5.0	114.8	132.3	149.9	167.8	185.7	**203.0**					2.80
5.5	121.9	140.8	160.0	179.5	199.0	218.8	**223.6**				2.85
6.0	128.3	148.8	169.5	190.5	211.6	233.0	**244.2**				2.95
6.5	134.3	156.1	178.3	200.8	223.5	246.5	**264.8**				3.00
7.0	139.8	162.9	186.5	210.5	234.7	259.2	283.9	**285.4**			3.05
7.5	144.9	169.3	194.2	219.6	245.3	271.3	297.6	**306.0**			3.10
8.0	149.5	175.2	201.4	228.2	255.3	282.8	310.6	**326.6**			3.15
8.5	153.8	180.6	208.1	236.2	264.8	293.7	322.9	**347.2**			3.20
9.0	157.7	185.7	214.4	243.8	273.7	304.0	334.7	**367.8**			3.25
9.5	161.4	190.4	220.3	250.9	282.1	313.8	345.9	**388.3**			3.30
10.0	164.7	194.7	225.7	257.5	290.0	323.0	356.5	407.5	**408.9**		3.35
10.5	167.8	198.8	230.9	263.8	297.5	331.8	366.6	419.7	**429.5**		3.40
11.0	170.6	202.5	235.6	269.7	304.6	340.1	376.3	431.4	**450.1**		3.45
11.5	173.2	206.0	240.1	275.2	311.2	348.0	385.4	442.5	**470.7**		3.45
12.0	175.6	209.2	244.3	280.4	317.5	355.5	394.1	453.2	**491.3**		3.50
12.5	177.8	212.2	248.1	285.3	323.5	362.6	402.4	463.4	**511.9**		3.55
13.0	179.8	215.0	251.8	289.9	329.1	369.3	410.3	473.1	**532.5**		3.60
13.5	181.6	217.6	255.2	294.2	334.4	375.6	417.8	482.4	548.5	**553.0**	3.65
14.0	183.4	220.0	258.4	298.2	339.4	381.7	424.9	491.3	559.3	**573.6**	3.70
14.5	184.9	222.2	261.3	302.0	344.1	387.4	431.7	499.8	569.6	**594.2**	3.75
15.0	186.4	224.2	264.1	305.6	348.6	392.8	438.2	507.9	579.5	**614.8**	3.75

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.30	3.60	3.90	(m)
1.5	45.6	**50.3**									2.00
2.0	58.8	66.2	**71.8**								2.20
2.5	71.0	80.3	89.5	**96.4**							2.35
3.0	82.4	93.4	104.5	115.6	**120.7**						2.50
3.5	93.0	105.7	118.6	131.4	**141.3**						2.60
4.0	102.8	117.3	131.8	146.5	161.1	**161.9**					2.65
4.5	112.0	128.1	144.3	160.7	177.1	**182.5**					2.70
5.0	120.5	138.2	156.1	174.2	192.3	**203.0**					2.75
5.5	128.4	147.7	167.3	187.0	206.8	**223.6**					2.80
6.0	135.8	156.6	177.8	199.1	220.5	242.2	**244.2**				2.85
6.5	142.7	165.0	187.6	210.5	233.6	256.9	**264.8**				2.90
7.0	149.0	172.8	196.9	221.4	246.1	270.9	**285.4**				2.95
7.5	155.0	180.1	205.7	231.7	257.9	284.4	**306.0**				3.00
8.0	160.5	187.0	214.0	241.4	269.2	297.2	325.4	**326.6**			3.05
8.5	165.6	193.4	221.8	250.7	279.9	309.4	339.2	**347.2**			3.10
9.0	170.4	199.5	229.2	259.4	290.1	321.1	352.6	**367.8**			3.10
9.5	174.9	205.1	236.1	267.7	299.8	332.3	365.1	**388.3**			3.15
10.0	179.0	210.4	242.6	275.5	309.0	342.9	377.2	**408.9**			3.20
10.5	182.9	215.4	248.8	283.0	317.8	353.1	388.8	**429.5**			3.25
11.0	186.4	220.0	254.6	290.0	326.1	362.8	399.9	**450.1**			3.30
11.5	189.8	224.4	260.1	296.7	334.0	372.0	410.6	469.2	**470.7**		3.35
12.0	192.9	228.5	265.2	303.0	341.6	380.9	420.8	481.6	**491.3**		3.35
12.5	195.8	232.3	270.1	309.0	348.8	389.3	430.5	493.3	**511.9**		3.40
13.0	198.4	235.9	274.7	314.6	355.6	397.4	439.8	504.7	**532.5**		3.45
13.5	200.9	239.2	279.0	320.0	362.1	405.1	448.8	515.6	**553.0**		3.50
14.0	203.3	242.4	283.1	325.1	368.3	412.4	457.4	526.1	**573.6**		3.55
14.5	205.4	245.3	286.9	329.9	374.1	419.4	465.6	536.2	**594.2**		3.55
15.0	207.4	248.1	290.5	334.5	379.7	426.1	473.4	545.9	**614.8**		3.60

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.30	3.60	3.90	(m)
1.5	46.4	**50.3**									1.95
2.0	60.0	67.5	**71.8**								2.15
2.5	72.9	82.2	91.5	**96.4**							2.35
3.0	85.0	96.1	107.2	118.3	**120.7**						2.45
3.5	96.4	109.2	122.1	135.1	**141.3**						2.50
4.0	107.1	121.7	136.4	151.1	**161.9**						2.55
4.5	117.1	133.5	149.9	166.4	**182.5**						2.60
5.0	126.6	144.6	162.7	181.0	199.3	**203.0**					2.65
5.5	135.5	155.2	175.0	194.9	215.0	**223.6**					2.70
6.0	143.9	165.1	186.6	208.2	230.0	**244.2**					2.75
6.5	151.8	174.6	197.7	221.0	244.4	**264.8**					2.80
7.0	159.2	183.6	208.2	233.1	258.2	283.4	**285.4**				2.85
7.5	166.2	192.0	218.2	244.7	271.4	298.3	**306.0**				2.90
8.0	172.7	200.0	227.8	255.8	284.1	312.6	**326.6**				2.90
8.5	178.9	207.6	236.8	266.4	296.3	326.4	**347.2**				2.95
9.0	184.7	214.8	245.4	276.5	307.9	339.6	**367.8**				3.00
9.5	190.2	221.6	253.6	286.2	319.1	352.4	385.9	**388.3**			3.05
10.0	195.3	228.0	261.4	295.4	329.8	364.6	399.7	**408.9**			3.10
10.5	200.1	234.1	268.9	304.2	340.1	376.4	413.0	**429.5**			3.10
11.0	204.7	239.9	275.9	312.6	349.9	387.7	425.8	**450.1**			3.15
11.5	209.0	245.3	282.6	320.7	359.4	398.5	438.2	**470.7**			3.20
12.0	213.0	250.5	289.0	328.4	368.4	409.0	450.1	**491.3**			3.20
12.5	216.8	255.4	295.1	335.7	377.1	419.1	461.6	**511.9**			3.25
13.0	220.3	260.0	300.9	342.7	385.4	428.7	472.6	**532.5**			3.30
13.5	223.7	264.4	306.4	349.4	393.3	438.0	483.3	552.2	**553.0**		3.35
14.0	226.9	268.5	311.6	355.8	401.0	447.0	493.6	564.7	**573.6**		3.35
14.5	229.8	272.5	316.6	361.9	408.3	455.5	503.5	576.6	**594.2**		3.40
15.0	232.6	276.2	321.3	367.8	415.3	463.8	513.1	588.3	**614.8**		3.45

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.21 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

1350 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 2.00	2.20	2.40	2.60	2.80	3.00	3.20	3.50	3.80	4.20	TRANSITION WIDTH (m)
1.5	50.0	55.1									2.20
2.0	64.1	71.5	78.1								2.40
2.5	77.0	86.2	95.5	104.0							2.60
3.0	89.0	99.9	110.9	122.0	133.0						2.80
3.5	100.0	112.6	125.3	138.1	151.0	158.0					2.95
4.0	110.1	124.4	138.8	153.3	167.9	181.0					3.00
4.5	119.4	135.3	151.4	167.6	183.8	200.2	204.1				3.05
5.0	128.0	145.5	163.1	181.0	198.9	216.9	227.2				3.15
5.5	135.9	154.9	174.1	193.5	213.1	232.7	250.2				3.20
6.0	143.2	163.6	184.3	205.3	226.4	247.7	269.2	273.3			3.25
6.5	149.9	171.7	193.9	216.3	239.0	261.9	284.9	296.4			3.30
7.0	156.1	179.2	202.8	226.7	250.9	275.3	299.9	319.5			3.40
7.5	161.8	186.2	211.1	236.5	262.1	288.0	314.2	342.5			3.45
8.0	167.0	192.7	218.9	245.6	272.7	300.1	327.7	365.6			3.50
8.5	171.8	196.7	226.2	254.2	282.6	311.4	340.6	384.7	388.7		3.55
9.0	176.3	204.3	232.9	262.2	292.0	322.2	352.8	399.2	411.8		3.60
9.5	180.4	209.4	239.3	269.8	300.9	332.4	364.4	412.9	434.8		3.65
10.0	184.1	214.2	245.2	276.9	309.2	342.1	375.4	426.0	457.9		3.70
10.5	187.6	218.7	250.7	283.5	317.1	351.2	385.8	438.6	481.0		3.75
11.0	190.8	222.8	255.8	289.8	324.5	359.8	395.7	450.5	504.0		3.80
11.5	193.7	226.6	260.6	295.5	331.5	368.0	405.2	461.9	519.6	527.1	3.85
12.0	196.4	230.2	265.1	301.1	338.1	375.6	414.1	472.8	532.5	550.2	3.90
12.5	198.9	233.4	269.3	306.3	344.3	383.1	422.6	483.1	544.8	573.3	3.95
13.0	201.2	236.5	273.2	311.2	350.1	390.0	430.7	493.0	556.6	596.3	4.00
13.5	203.3	239.3	276.9	315.7	355.7	396.6	438.4	502.5	567.9	619.4	4.05
14.0	205.3	242.0	280.3	320.0	360.9	402.6	445.7	511.5	578.7	642.5	4.10
14.5	207.1	244.4	283.5	324.0	365.8	408.7	452.6	520.0	589.1	665.6	4.15
15.0	208.7	246.7	286.4	327.7	370.4	414.3	459.2	528.2	599.0	688.6	4.20

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 2.00	2.20	2.40	2.60	2.80	3.00	3.20	3.50	3.80	4.20	TRANSITION WIDTH (m)
1.5	50.5	55.1									2.20
2.0	65.0	72.4	78.1								2.40
2.5	78.4	87.6	96.9	104.0							2.60
3.0	90.8	101.9	112.9	124.0	133.0						2.80
3.5	102.4	115.1	127.9	140.8	153.6	158.0					2.90
4.0	113.1	127.5	142.0	156.6	171.3	181.0					2.95
4.5	123.0	139.1	155.3	171.6	187.9	204.1					3.00
5.0	132.3	149.9	167.8	185.7	203.8	221.9	227.2				3.10
5.5	140.8	160.0	179.5	199.0	218.8	238.6	250.2				3.15
6.0	148.8	169.5	190.5	211.6	233.0	254.5	273.3				3.20
6.5	156.1	178.3	200.8	223.5	246.5	269.6	292.6	296.4			3.25
7.0	162.9	186.5	210.5	234.7	259.2	283.9	308.8	319.5			3.30
7.5	169.3	194.2	219.6	245.3	271.3	297.6	324.0	342.5			3.35
8.0	175.2	201.4	228.2	255.3	282.8	310.6	338.6	365.6			3.40
8.5	180.6	208.1	236.2	264.8	293.7	322.9	352.5	388.7			3.45
9.0	185.7	214.4	243.8	273.7	304.0	334.7	365.7	411.8			3.50
9.5	190.4	220.3	250.9	282.1	313.8	345.9	378.4	427.6	434.8		3.55
10.0	194.7	225.7	257.5	290.0	323.0	356.5	390.4	441.9	457.9		3.60
10.5	198.8	230.9	263.8	297.5	331.8	366.6	401.9	455.6	481.0		3.65
11.0	202.5	235.6	269.7	304.6	340.1	376.3	412.9	466.7	504.0		3.70
11.5	206.0	240.1	275.2	311.2	348.0	385.4	423.4	481.2	527.1		3.75
12.0	209.2	244.3	280.4	317.5	355.5	394.1	433.4	493.2	550.2		3.80
12.5	212.2	248.1	285.3	323.5	362.6	402.4	442.9	504.7	567.6	573.3	3.85
13.0	215.0	251.8	289.9	329.1	369.3	410.3	452.0	515.8	580.7	596.3	3.90
13.5	217.6	255.2	294.2	334.4	375.6	417.8	460.7	526.3	593.2	619.4	3.95
14.0	220.0	258.4	298.2	339.4	381.7	424.9	469.0	536.4	605.3	642.5	4.00
14.5	222.2	261.3	302.0	344.1	387.4	431.7	476.9	546.1	616.9	665.6	4.05
15.0	224.2	264.1	305.6	348.6	392.6	438.2	484.4	555.4	628.0	688.6	4.05

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 2.00	2.20	2.40	2.60	2.80	3.00	3.20	3.50	3.80	4.20	TRANSITION WIDTH (m)
1.5	51.2	55.1									2.15
2.0	66.2	73.7	78.1								2.35
2.5	80.3	89.5	98.8	104.0							2.55
3.0	93.4	104.5	115.6	126.7	133.0						2.75
3.5	105.7	116.6	131.4	144.3	157.3	158.0					2.85
4.0	117.3	131.8	146.5	161.1	175.9	181.0					2.90
4.5	128.1	144.3	160.7	177.1	193.6	204.1					2.95
5.0	138.2	156.1	174.2	192.3	210.6	227.2					3.00
5.5	147.7	167.3	187.0	206.8	226.7	246.7	250.2				3.05
6.0	156.6	177.8	199.1	220.5	242.2	263.9	273.3				3.10
6.5	165.0	187.6	210.5	233.6	256.9	280.3	296.4				3.15
7.0	172.8	196.9	221.4	246.1	270.9	296.0	319.5				3.20
7.5	180.1	205.7	231.7	257.9	284.4	311.0	337.9	342.5			3.25
8.0	187.0	214.0	241.4	269.2	297.2	325.4	353.9	365.6			3.30
8.5	193.4	221.8	250.7	279.9	309.4	339.2	369.3	388.7			3.35
9.0	199.5	229.2	259.4	290.1	321.1	352.6	384.1	411.8			3.40
9.5	205.1	236.1	267.7	299.8	332.3	365.1	398.2	434.8			3.45
10.0	210.4	242.6	275.5	309.0	342.9	377.2	411.9	457.9			3.50
10.5	215.4	248.8	283.0	317.8	353.1	388.8	424.9	479.7	481.0		3.55
11.0	220.0	254.6	290.0	326.1	362.8	399.9	437.5	494.5	504.0		3.55
11.5	224.4	260.1	296.7	334.0	372.0	410.6	449.6	508.8	527.1		3.60
12.0	228.5	265.2	303.0	341.6	380.9	420.8	461.1	522.5	550.2		3.65
12.5	232.3	270.1	309.0	348.8	389.3	430.5	472.3	535.8	573.3		3.70
13.0	235.9	274.7	314.6	355.6	397.4	439.8	482.9	548.5	596.3		3.75
13.5	239.2	279.0	320.0	362.1	405.1	448.8	493.2	560.8	619.4		3.80
14.0	242.4	283.1	325.1	368.3	412.4	457.4	503.0	572.7	642.5		3.80
14.5	245.3	286.9	329.9	374.1	419.4	465.6	512.5	584.1	657.0	665.6	3.85
15.0	248.1	290.5	334.5	379.7	426.1	473.4	521.6	585.1	670.0	688.6	3.90

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 2.00	2.20	2.40	2.60	2.80	3.00	3.20	3.50	3.80	4.20	TRANSITION WIDTH (m)
1.5	52.0	55.1									2.15
2.0	67.5	75.0	78.1								2.30
2.5	82.2	91.5	100.8	104.0							2.50
3.0	96.1	107.2	118.3	129.5	133.0						2.70
3.5	109.2	122.1	135.1	148.1	158.0						2.80
4.0	121.7	136.4	151.1	165.9	180.7	181.0					2.85
4.5	133.5	149.9	166.4	182.9	199.5	204.1					2.90
5.0	144.6	162.7	181.0	199.3	217.7	227.2					2.95
5.5	155.2	175.0	194.9	215.0	235.1	250.2					3.00
6.0	165.1	186.6	208.2	230.0	251.8	273.3					3.00
6.5	174.6	197.7	221.0	244.4	267.9	291.6	296.4				3.05
7.0	183.6	208.2	233.1	258.2	283.4	308.8	319.5				3.10
7.5	192.0	218.2	244.7	271.4	298.3	325.4	342.5				3.15
8.0	200.0	227.8	255.8	284.1	312.6	341.3	365.6				3.20
8.5	207.6	236.6	266.4	296.3	326.4	356.7	367.3	388.7			3.25
9.0	214.8	245.4	276.5	307.9	339.6	371.6	403.7	411.8			3.25
9.5	221.6	253.6	286.2	319.1	352.4	385.9	419.7	434.8			3.30
10.0	228.0	261.4	295.4	329.8	364.6	399.7	435.0	457.9			3.35
10.5	234.1	268.9	304.2	340.1	376.4	413.0	449.9	481.0			3.40
11.0	239.9	275.9	312.6	349.9	387.7	425.6	464.3	504.0			3.45
11.5	245.3	282.6	320.7	359.4	398.5	436.2	476.2	527.1			3.45
12.0	250.5	289.0	328.4	368.4	409.0	450.1	491.6	550.2			3.50
12.5	255.4	295.1	335.7	377.1	419.1	461.6	504.5	569.7	573.3		3.55
13.0	260.0	300.9	342.7	385.4	428.7	472.6	517.1	584.4	596.3		3.60
13.5	264.4	306.4	349.4	393.3	438.0	483.3	529.2	598.8	619.4		3.60
14.0	268.5	311.6	355.8	401.0	447.0	493.6	540.8	612.6	642.5		3.65
14.5	272.5	316.6	361.9	408.3	455.5	503.5	552.1	626.1	665.6		3.70
15.0	276.2	321.3	367.8	415.3	463.8	513.1	563.0	639.1	688.6		3.70

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.22 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

1500 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	2.20	2.40	2.60	2.80	3.00	3.20	3.50	3.80	4.10	4.50	
1.5	55.6	60.0									2.40
2.0	71.5	78.9	84.5								2.60
2.5	86.2	95.5	104.7	111.7							2.80
3.0	99.9	110.9	122.0	133.0	141.9						3.00
3.5	112.6	125.3	138.1	151.0	163.8	174.5					3.20
4.0	124.4	138.8	153.3	167.9	182.5	197.2	200.1				3.25
4.5	135.3	151.4	167.6	183.8	200.2	216.6	225.7				3.35
5.0	145.5	163.1	181.0	198.9	216.9	235.0	251.2				3.40
5.5	154.9	174.1	193.5	213.1	232.7	252.5	276.8				3.45
6.0	163.6	184.3	205.3	226.4	247.7	269.2	301.5	302.3			3.55
6.5	171.7	193.9	216.3	239.0	261.9	284.9	319.8	327.9			3.60
7.0	179.2	202.8	226.7	250.9	275.3	299.9	337.2	353.4			3.65
7.5	186.2	211.1	236.5	262.1	288.0	314.2	353.8	379.0			3.70
8.0	192.7	218.9	245.6	272.7	300.1	327.7	369.6	404.6			3.75
8.5	198.7	226.2	254.2	282.6	311.4	340.6	384.7	429.4	430.1		3.85
9.0	204.3	232.9	262.2	292.0	322.2	352.8	399.2	446.1	455.7		3.90
9.5	209.4	239.3	269.8	300.9	332.4	364.4	412.9	462.1	481.2		3.95
10.0	214.2	245.2	276.9	309.2	342.1	375.4	426.0	477.5	506.8		4.00
10.5	218.7	250.7	283.5	317.1	351.2	385.8	438.6	492.1	532.3		4.05
11.0	222.8	255.8	289.8	324.5	359.8	395.7	450.5	506.2	557.9		4.10
11.5	226.6	260.6	295.6	331.5	368.0	405.2	461.9	519.6	578.1	583.5	4.15
12.0	230.2	265.1	301.1	338.1	375.8	414.1	472.8	532.5	593.1	609.0	4.20
12.5	233.4	269.3	306.3	344.3	383.1	422.8	483.1	544.8	607.5	634.6	4.25
13.0	236.5	273.2	311.2	350.1	390.0	430.7	493.0	556.6	621.3	660.1	4.30
13.5	239.3	276.9	315.7	355.7	396.6	438.4	502.5	567.9	634.6	685.7	4.35
14.0	242.0	280.3	320.0	360.9	402.8	445.7	511.5	578.7	647.3	711.2	4.40
14.5	244.4	283.5	324.0	365.8	408.7	452.6	520.0	589.1	659.6	736.8	4.45
15.0	246.7	286.4	327.7	370.4	414.3	459.2	528.2	599.0	671.3	762.4	4.50

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	2.20	2.40	2.60	2.80	3.00	3.20	3.50	3.80	4.10	4.50	
1.5	56.1	60.0									2.35
2.0	72.4	79.8	84.5								2.55
2.5	87.6	96.9	106.2	111.7							2.75
3.0	101.8	112.9	124.0	135.1	141.9						2.95
3.5	115.1	127.9	140.8	153.8	166.6	174.5					3.15
4.0	127.5	142.0	156.6	171.3	185.9	200.1					3.20
4.5	139.1	155.3	171.6	187.9	204.4	220.9	225.7				3.30
5.0	149.9	167.8	185.7	203.8	221.9	240.1	251.2				3.35
5.5	160.0	179.5	199.0	218.8	238.6	258.5	276.8				3.40
6.0	169.5	190.5	211.6	233.0	254.5	276.1	302.3				3.45
6.5	178.3	200.8	223.5	246.5	269.6	292.8	327.9				3.50
7.0	186.5	210.5	234.7	259.2	283.9	308.8	346.4	353.4			3.60
7.5	194.2	219.6	245.3	271.3	297.6	324.0	364.0	379.0			3.65
8.0	201.4	228.2	255.3	282.8	310.6	338.6	381.0	404.6			3.70
8.5	208.1	236.2	264.8	293.7	322.9	352.5	397.2	430.1			3.75
9.0	214.4	243.8	273.7	304.0	334.7	365.7	412.7	455.7			3.80
9.5	220.3	250.9	282.1	313.8	345.9	378.4	427.6	477.5	481.2		3.85
10.0	225.7	257.5	290.0	323.0	356.5	390.4	441.9	494.0	506.8		3.90
10.5	230.9	263.8	297.5	331.8	366.6	401.9	455.6	509.9	532.3		3.95
11.0	235.6	269.7	304.6	340.1	376.3	412.9	468.7	525.2	557.9		4.00
11.5	240.1	275.2	311.2	348.0	385.4	423.4	481.2	539.9	583.5		4.05
12.0	244.3	280.4	317.5	355.5	394.1	433.4	493.2	554.0	609.0		4.10
12.5	248.1	285.3	323.5	362.6	402.4	442.9	504.7	567.6	631.4	634.6	4.15
13.0	251.8	289.9	329.1	369.3	410.3	452.0	515.8	580.7	646.5	660.1	4.20
13.5	255.2	294.2	334.4	375.6	417.8	460.7	526.3	593.2	661.1	685.7	4.25
14.0	258.4	298.2	339.4	381.7	424.9	469.0	536.4	605.3	675.2	711.2	4.30
14.5	261.3	302.0	344.1	387.4	431.7	476.9	546.1	616.9	688.8	736.8	4.30
15.0	264.1	305.6	348.6	392.8	438.2	484.4	555.4	628.0	701.9	762.4	4.35

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	2.20	2.40	2.60	2.80	3.00	3.20	3.50	3.80	4.10	4.50	
1.5	56.9	60.0									2.35
2.0	73.7	81.1	84.5								2.50
2.5	89.5	98.8	108.1	111.7							2.70
3.0	104.5	115.6	126.7	137.8	141.9						2.90
3.5	118.6	131.4	144.3	157.3	170.3	174.5					3.10
4.0	131.8	146.5	161.1	175.9	190.6	200.1					3.15
4.5	144.3	160.7	177.1	193.6	210.2	225.7					3.20
5.0	156.1	174.2	192.3	210.6	228.8	247.2	251.2				3.25
5.5	167.3	187.0	206.8	226.7	246.7	266.8	276.8				3.30
6.0	177.8	199.1	220.5	242.2	263.9	285.7	302.3				3.40
6.5	187.6	210.5	233.6	256.9	280.3	303.8	327.9				3.45
7.0	196.9	221.4	246.1	270.9	296.0	321.2	353.4				3.50
7.5	205.7	231.7	257.9	284.4	311.0	337.9	378.4	379.0			3.55
8.0	214.0	241.4	269.2	297.2	325.4	353.9	396.9	404.6			3.60
8.5	221.8	250.7	279.9	309.4	339.2	369.3	414.7	430.1			3.65
9.0	229.2	259.4	290.1	321.1	352.5	384.1	431.9	455.7			3.65
9.5	236.1	267.7	299.8	332.3	365.1	398.2	448.4	481.2			3.70
10.0	242.6	275.5	309.0	342.9	377.2	411.9	464.4	506.8			3.75
10.5	248.8	283.0	317.8	353.1	388.8	424.9	479.7	532.3			3.80
11.0	254.6	290.0	326.1	362.8	399.9	437.5	494.5	552.2	557.9		3.85
11.5	260.1	296.7	334.0	372.0	410.6	449.6	508.8	568.6	583.5		3.90
12.0	265.2	303.0	341.6	380.9	420.8	461.1	522.5	584.7	609.0		3.95
12.5	270.1	309.0	348.8	389.3	430.5	472.3	535.8	600.2	634.6		4.00
13.0	274.7	314.6	355.6	397.4	439.8	482.9	548.5	615.1	660.1		4.05
13.5	279.0	320.0	362.1	405.1	448.8	493.2	560.8	629.6	685.7		4.05
14.0	283.1	325.1	368.3	412.4	457.4	503.0	572.7	643.5	711.2		4.10
14.5	286.9	329.9	374.1	419.4	465.6	512.5	584.1	657.0	730.9	736.8	4.15
15.0	290.5	334.5	379.7	426.1	473.4	521.6	595.1	670.0	746.0	762.4	4.20

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	2.20	2.40	2.60	2.80	3.00	3.20	3.50	3.80	4.10	4.50	
1.5	57.6	60.0									2.30
2.0	75.0	82.5	84.5								2.50
2.5	91.5	100.8	110.1	111.7							2.65
3.0	107.2	118.3	129.5	140.7	141.9						2.85
3.5	122.1	135.1	148.1	161.1	174.1	174.5					3.05
4.0	136.4	151.1	165.9	180.7	195.5	200.1					3.10
4.5	149.9	166.4	182.9	199.5	216.2	225.7					3.15
5.0	162.7	181.0	199.3	217.7	236.1	251.2					3.20
5.5	175.0	194.9	215.0	235.1	255.3	275.5	276.8				3.25
6.0	186.6	208.2	230.0	251.8	273.8	295.8	302.3				3.30
6.5	197.7	221.0	244.4	267.9	291.6	315.3	327.9				3.35
7.0	208.2	233.1	258.2	283.4	308.8	334.3	353.4				3.40
7.5	218.2	244.7	271.4	298.3	325.4	352.5	379.0				3.40
8.0	227.8	255.8	284.1	312.6	341.3	370.2	404.6				3.45
8.5	236.8	266.4	296.3	326.4	356.7	387.3	430.1				3.50
9.0	245.4	276.5	307.9	339.8	371.6	403.7	452.3	455.7			3.55
9.5	253.6	286.2	319.1	352.4	385.9	419.7	470.7	481.2			3.60
10.0	261.4	295.4	329.8	364.6	399.7	435.0	488.5	506.8			3.65
10.5	268.9	304.2	340.1	376.4	413.0	449.9	505.8	532.3			3.65
11.0	275.9	312.6	349.9	387.7	425.8	464.3	522.5	557.9			3.70
11.5	282.6	320.7	359.4	398.5	438.2	478.2	538.7	583.5			3.75
12.0	289.0	328.4	368.4	409.0	450.1	491.8	554.5	609.0			3.80
12.5	295.1	335.7	377.1	419.1	461.6	504.5	569.7	634.6			3.80
13.0	300.9	342.7	385.4	428.7	472.6	517.1	584.4	652.6	660.1		3.85
13.5	306.4	349.4	393.3	438.0	483.3	529.2	598.8	669.2	685.7		3.90
14.0	311.6	355.8	401.0	447.0	493.6	540.8	612.6	685.3	711.2		3.95
14.5	316.8	361.9	408.3	455.6	503.5	552.1	626.1	701.0	736.8		3.95
15.0	321.3	367.8	415.3	463.8	513.1	563.0	639.1	716.2	762.4		4.00

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.23 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

1650 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	2.50	2.70	2.90	3.10	3.30	3.50	3.80	4.10	4.40	4.80	(m)
1.5	64.0	64.9									2.55
2.0	82.6	90.1	90.9								2.75
2.5	100.1	109.3	118.6	119.5							2.95
3.0	116.4	127.5	138.6	149.7	151.0						3.15
3.5	131.7	144.5	157.4	170.3	183.2	185.6					3.35
4.0	146.1	160.6	175.2	189.8	204.5	219.1					3.50
4.5	159.5	175.7	192.0	208.4	224.8	241.3	247.1				3.60
5.0	172.0	189.9	207.9	226.0	244.1	262.3	275.2				3.65
5.5	183.8	203.3	222.9	242.6	262.5	282.4	303.2				3.75
6.0	194.8	215.8	237.1	258.4	279.9	301.5	331.3				3.80
6.5	205.1	227.7	250.4	273.4	296.5	319.8	354.8	359.3			3.85
7.0	214.7	238.8	263.1	287.6	312.3	337.2	374.7	387.3			3.95
7.5	223.8	249.2	275.0	301.1	327.3	353.8	393.8	415.4			4.00
8.0	232.2	259.1	286.3	313.9	341.6	369.6	412.0	443.4			4.05
8.5	240.1	268.4	297.0	326.0	355.2	384.7	429.4	471.5			4.10
9.0	247.5	277.1	307.1	337.4	368.2	399.2	446.1	493.6	499.5		4.15
9.5	254.5	285.3	316.6	348.3	380.5	412.9	462.1	511.9	527.6		4.20
10.0	260.9	293.0	325.6	358.7	392.2	426.0	477.5	529.4	555.6		4.25
10.5	267.0	300.2	334.1	368.4	403.3	438.6	492.1	546.3	583.6		4.35
11.0	272.7	307.0	342.1	377.7	413.9	450.5	506.2	562.6	611.7		4.40
11.5	278.0	313.5	349.7	386.5	424.0	461.9	519.6	578.1	637.4	639.7	4.45
12.0	283.0	319.5	356.8	394.9	433.5	472.6	532.5	593.1	654.5	667.8	4.50
12.5	287.7	325.2	363.6	402.8	442.7	483.1	544.8	607.5	671.0	695.8	4.55
13.0	292.0	330.5	370.0	410.3	451.3	493.0	556.6	621.3	686.9	723.8	4.60
13.5	296.1	335.5	376.0	417.4	459.6	502.5	567.9	634.6	702.2	751.9	4.65
14.0	300.0	340.3	381.7	424.1	467.4	511.5	578.7	647.3	717.0	779.9	4.70
14.5	303.5	344.7	387.1	430.5	474.9	520.0	589.1	659.6	731.2	808.0	4.75
15.0	306.9	346.9	392.2	436.6	482.0	528.2	599.0	671.3	744.9	836.0	4.80

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	2.50	2.70	2.90	3.10	3.30	3.50	3.80	4.10	4.40	4.80	(m)
1.5	64.5	64.9									2.55
2.0	83.6	90.9									2.70
2.5	101.5	110.8	119.5								2.90
3.0	118.4	129.5	140.6	151.0							3.10
3.5	134.3	147.2	160.1	173.0	185.6						3.30
4.0	149.3	163.9	178.6	193.3	208.0	219.1					3.45
4.5	163.4	179.8	196.2	212.6	229.1	245.7	247.1				3.55
5.0	176.7	194.7	212.8	231.0	249.3	267.6	275.2				3.60
5.5	189.2	208.9	228.7	248.6	268.5	288.6	303.2				3.65
6.0	201.0	222.3	243.7	265.3	286.9	308.7	231.3				3.75
6.5	212.1	235.0	258.0	281.2	304.5	327.9	359.3				3.80
7.0	222.6	247.0	271.6	296.3	321.3	346.4	384.2	387.3			3.85
7.5	232.4	258.3	284.4	310.8	337.3	364.0	404.3	415.4			3.90
8.0	241.7	269.0	296.7	324.6	352.7	381.0	423.7	443.4			3.95
8.5	250.4	279.2	308.3	337.7	367.3	397.2	442.3	471.5			4.00
9.0	258.7	288.8	319.3	350.2	381.3	412.7	460.2	499.5			4.05
9.5	266.4	297.9	329.8	362.1	394.7	427.6	477.5	527.6			4.10
10.0	273.7	306.5	339.7	373.4	407.5	441.9	494.0	546.6	555.6		4.20
10.5	280.6	314.6	349.2	384.2	419.7	455.6	509.9	564.8	583.6		4.25
11.0	287.0	322.3	358.1	394.5	431.4	468.7	525.2	582.4	611.7		4.30
11.5	293.1	329.5	366.6	404.3	442.5	481.2	539.9	599.3	639.7		4.35
12.0	298.9	336.4	374.7	413.7	453.2	493.2	554.0	616.6	667.8		4.40
12.5	304.3	342.9	382.4	422.6	463.4	504.7	567.6	631.4	695.8		4.40
13.0	309.4	349.1	389.7	431.1	473.1	515.8	580.7	646.5	713.2	723.8	4.45
13.5	314.2	354.9	396.6	439.2	482.4	526.3	593.2	661.1	730.0	751.9	4.50
14.0	318.7	360.4	403.2	446.9	491.3	536.4	605.3	675.2	746.2	779.9	4.55
14.5	322.9	365.6	409.4	454.2	499.8	546.1	616.9	688.8	761.8	808.0	4.60
15.0	326.9	370.6	415.4	461.2	507.9	555.4	628.0	701.9	776.9	836.0	4.65

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	2.50	2.70	2.90	3.10	3.30	3.50	3.80	4.10	4.40	4.80	(m)
1.5	64.9										2.50
2.0	84.9	90.9									2.70
2.5	103.5	112.8	119.5								2.85
3.0	121.1	132.3	143.4	151.0							3.05
3.5	137.9	150.8	163.8	176.8	185.6						3.25
4.0	153.8	168.5	183.3	198.0	212.9	219.1					3.40
4.5	168.9	185.4	201.9	218.4	235.1	247.1					3.45
5.0	183.2	201.4	219.7	238.0	256.4	274.8	275.2				3.55
5.5	196.9	216.7	236.7	256.8	276.9	297.1	303.2				3.60
6.0	209.8	231.3	253.0	274.8	296.6	318.6	331.3				3.65
6.5	222.1	245.2	268.6	292.0	315.6	339.2	359.3				3.70
7.0	233.7	258.5	283.5	308.6	333.8	359.2	387.3				3.75
7.5	244.8	271.1	297.7	324.4	351.3	378.4	415.4				3.80
8.0	255.3	283.1	311.3	339.6	368.2	396.9	440.1	443.4			3.85
8.5	265.2	294.6	324.3	354.2	384.4	414.7	460.4	471.5			3.90
9.0	274.7	305.5	336.7	368.2	399.9	431.9	480.1	499.5			3.95
9.5	283.7	316.0	348.6	381.6	414.9	448.4	499.0	527.6			4.00
10.0	292.2	325.9	360.0	394.5	429.3	464.4	517.4	555.6			4.05
10.5	300.3	335.3	370.9	406.8	443.1	479.7	535.1	583.6			4.10
11.0	308.0	344.4	381.3	418.7	456.4	494.5	552.2	610.4	611.7		4.15
11.5	315.3	353.0	391.2	430.0	469.2	508.8	568.8	629.3	639.7		4.20
12.0	322.2	361.1	400.7	440.9	481.5	522.5	584.7	647.6	667.8		4.20
12.5	328.8	368.9	409.8	451.3	493.3	535.8	600.2	665.3	695.8		4.25
13.0	335.0	376.4	418.5	461.3	504.7	548.5	615.1	682.5	723.8		4.30
13.5	340.9	383.5	426.8	470.9	515.6	560.8	629.6	699.1	751.9		4.35
14.0	346.5	390.2	434.8	480.1	526.1	572.7	643.5	715.2	779.9		4.40
14.5	351.9	396.7	442.4	488.9	536.2	584.1	657.0	730.9	805.6	808.0	4.45
15.0	357.0	402.8	449.6	497.4	545.9	595.1	670.0	746.0	822.9	836.0	4.50

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	2.50	2.70	2.90	3.10	3.30	3.50	3.80	4.10	4.40	4.80	(m)
1.5	64.9										2.50
2.0	86.2	90.9									2.65
2.5	105.5	114.8	119.5								2.85
3.0	123.9	135.1	146.3	151.0							3.00
3.5	141.6	154.6	167.6	180.6	185.6						3.20
4.0	158.5	173.3	188.1	203.0	217.8	219.1					3.35
4.5	174.6	191.2	207.8	224.5	241.2	247.1					3.40
5.0	190.1	208.5	226.9	245.3	263.8	275.2					3.45
5.5	204.9	225.0	245.2	265.4	285.7	303.2					3.50
6.0	219.1	240.9	262.8	284.8	306.8	328.9	331.3				3.55
6.5	232.7	256.1	279.8	303.5	327.3	351.1	359.3				3.60
7.0	245.6	270.8	296.1	321.5	347.0	372.6	387.3				3.65
7.5	258.0	284.9	311.8	338.9	366.2	393.5	415.4				3.70
8.0	269.9	298.3	327.0	355.7	384.7	413.7	443.4				3.75
8.5	281.3	311.3	341.5	372.0	402.6	433.3	471.5				3.75
9.0	292.2	323.8	355.6	387.6	419.9	452.3	499.5				3.80
9.5	302.6	335.7	369.1	402.8	436.6	470.7	522.0	527.6			3.85
10.0	312.6	347.2	382.1	417.3	452.8	488.5	542.3	555.6			3.90
10.5	322.1	358.2	394.6	431.4	468.5	505.8	562.1	583.6			3.95
11.0	331.2	368.7	406.7	445.0	483.6	522.5	581.2	611.7			4.00
11.5	340.0	378.9	418.3	458.1	498.3	538.7	599.9	639.7			4.00
12.0	348.3	388.6	429.5	470.8	512.5	554.5	618.0	667.8			4.05
12.5	356.3	398.0	440.3	483.0	526.2	569.7	635.5	695.8			4.10
13.0	364.0	407.0	450.6	494.8	539.4	584.4	652.6	721.4	723.8		4.15
13.5	371.3	415.6	460.6	506.2	552.2	598.8	669.2	740.3	751.9		4.15
14.0	378.3	423.9	470.2	517.2	564.7	612.6	685.3	758.8	779.9		4.20
14.5	385.0	431.8	479.4	527.8	576.6	626.1	701.0	776.7	808.0		4.25
15.0	391.4	439.5	488.4	538.0	588.3	639.1	716.2	794.2	836.0		4.30

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.24 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

1800 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 2.80	3.00	3.20	3.40	3.60	3.90	4.20	4.50	4.80	5.10	TRANSITION WIDTH (m)
1.5	69.8										2.75
2.0	93.8	97.4									2.90
2.5	114.0	123.3	127.5								3.10
3.0	133.0	144.1	155.2	160.3							3.30
3.5	151.0	163.8	176.7	189.7	196.2						3.50
4.0	167.9	182.5	197.2	211.9	226.6	235.2					3.75
4.5	183.8	200.2	216.6	233.1	249.6	268.5					3.85
5.0	198.9	216.9	235.0	253.2	271.5	298.9	299.0				3.95
5.5	213.1	232.7	252.5	272.4	292.4	322.4	329.6				4.00
6.0	226.4	247.7	269.2	290.7	312.3	345.0	360.1				4.05
6.5	239.0	261.9	284.9	308.1	331.4	366.6	390.6				4.15
7.0	250.9	275.3	299.9	324.7	349.7	387.3	421.2				4.20
7.5	262.1	288.0	314.2	340.5	367.1	407.1	447.5	451.7			4.25
8.0	272.7	300.1	327.7	355.6	383.7	426.2	469.0	482.2			4.30
8.5	282.6	311.4	340.6	370.0	399.6	444.4	489.6	512.7			4.40
9.0	292.0	322.2	352.8	383.6	414.8	461.9	509.5	543.3			4.45
9.5	300.9	332.4	364.4	396.7	429.3	478.7	528.5	573.8			4.50
10.0	309.2	342.1	375.4	409.1	443.1	494.7	546.9	599.5	604.3		4.55
10.5	317.1	351.2	385.8	420.9	456.3	510.1	564.5	619.5	634.8		4.60
11.0	324.5	359.8	395.7	432.1	469.0	524.9	581.5	638.7	665.4		4.65
11.5	331.5	368.0	405.2	442.8	481.0	539.0	597.8	657.3	695.9		4.70
12.0	338.1	375.8	414.1	453.1	492.6	552.6	613.5	675.1	726.4		4.75
12.5	344.3	383.1	422.6	462.8	503.6	565.6	628.6	692.4	756.8	757.0	4.85
13.0	350.1	390.0	430.7	472.1	514.1	578.1	643.1	709.0	775.6	787.5	4.90
13.5	355.7	396.6	438.4	480.9	524.1	590.0	657.0	725.0	793.7	818.0	4.95
14.0	360.9	402.8	445.7	489.3	533.7	601.5	670.4	740.4	811.3	848.5	5.00
14.5	365.8	408.7	452.6	497.4	542.9	612.5	683.3	755.3	828.2	879.1	5.05
15.0	370.4	414.3	459.2	505.0	551.6	623.0	695.7	769.6	844.6	909.6	5.10

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 2.80	3.00	3.20	3.40	3.60	3.90	4.20	4.50	4.80	5.10	TRANSITION WIDTH (m)
1.5	69.8										2.70
2.0	94.8	97.4									2.90
2.5	115.4	124.8	127.5								3.10
3.0	135.1	146.2	157.3	160.3							3.30
3.5	153.6	166.6	179.5	192.5	196.2						3.50
4.0	171.3	185.9	200.7	215.4	230.2	235.2					3.70
4.5	187.9	204.4	220.9	237.4	254.0	268.5					3.80
5.0	203.8	221.9	240.1	258.4	276.8	299.0					3.85
5.5	218.8	238.6	258.5	278.5	298.6	328.8	329.6				3.95
6.0	233.0	254.5	276.1	297.8	319.6	352.4	360.1				4.00
6.5	246.5	269.6	292.8	316.2	339.7	375.0	390.6				4.05
7.0	259.2	283.9	308.8	333.8	358.9	396.9	421.2				4.10
7.5	271.3	297.6	324.0	350.7	377.4	417.8	451.7				4.15
8.0	282.8	310.6	338.6	366.8	395.2	438.0	481.2	482.2			4.25
8.5	293.7	322.9	352.6	382.2	412.2	457.5	503.1	512.7			4.30
9.0	304.0	334.7	365.7	397.0	428.5	476.2	524.2	543.3			4.35
9.5	313.8	345.9	378.4	411.1	444.2	494.2	544.6	573.8			4.40
10.0	323.0	356.5	390.4	424.7	459.2	511.5	564.3	604.3			4.45
10.5	331.8	366.6	401.9	437.6	473.6	528.2	583.3	634.8			4.50
11.0	340.1	376.3	412.9	450.0	487.4	544.2	601.6	659.5	665.4		4.55
11.5	348.0	385.4	423.4	461.8	500.7	559.6	619.3	679.5	695.9		4.60
12.0	355.5	394.1	433.4	473.1	513.4	574.5	636.3	698.8	726.4		4.65
12.5	362.6	402.4	442.9	484.0	525.6	588.6	652.8	717.5	757.0		4.70
13.0	369.3	410.3	452.0	494.4	537.3	602.5	668.7	735.6	787.5		4.75
13.5	375.6	417.8	460.7	504.3	548.5	615.7	684.0	753.1	818.0		4.80
14.0	381.7	424.9	469.0	513.6	559.3	626.5	698.8	770.0	842.0	848.5	4.85
14.5	387.4	431.7	476.9	522.9	569.6	640.7	713.0	786.3	860.5	879.1	4.90
15.0	392.8	438.2	484.4	531.6	579.5	652.5	726.8	802.2	878.4	909.6	4.95

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 2.80	3.00	3.20	3.40	3.60	3.90	4.20	4.60	4.80	5.10	TRANSITION WIDTH (m)
1.5	69.8										2.70
2.0	96.1	97.4									2.85
2.5	117.4	126.8	127.5								3.05
3.0	137.8	149.0	160.2	160.3							3.25
3.5	157.3	170.3	183.3	196.2							3.40
4.0	175.9	190.6	205.4	220.3	235.1	235.2					3.65
4.5	193.6	210.2	226.7	243.4	260.0	268.5					3.75
5.0	210.6	228.8	247.2	265.6	284.0	299.0					3.80
5.5	226.7	246.7	266.8	287.0	307.2	329.6					3.85
6.0	242.2	263.9	285.7	307.6	329.5	360.1					3.90
6.5	256.9	280.3	303.8	327.4	351.1	386.8	390.6				3.95
7.0	270.9	296.0	321.2	346.5	371.9	410.1	421.2				4.00
7.5	284.4	311.0	337.9	364.8	391.9	432.7	451.7				4.05
8.0	297.2	325.4	353.9	382.5	411.3	454.6	482.2				4.10
8.5	309.4	339.2	369.3	399.5	429.9	475.8	512.7				4.15
9.0	321.1	352.5	384.1	415.9	447.9	496.2	543.3				4.20
9.5	332.3	365.1	398.2	431.6	465.2	516.0	567.1	573.8			4.25
10.0	342.9	377.2	411.9	446.8	482.0	535.1	588.7	604.3			4.30
10.5	353.1	388.8	424.9	461.4	498.1	553.7	609.6	634.8			4.35
11.0	362.8	399.9	437.5	475.4	513.7	571.6	629.9	665.4			4.40
11.5	372.0	410.6	449.6	489.0	528.7	588.9	649.6	695.9			4.45
12.0	380.9	420.8	461.1	502.0	543.2	605.6	668.7	726.4			4.50
12.5	389.3	430.5	472.3	514.5	557.2	621.8	687.2	753.1	757.0		4.55
13.0	397.4	439.8	482.9	526.6	570.6	637.5	705.1	773.3	787.5		4.60
13.5	405.1	448.8	493.2	538.2	583.6	652.7	722.5	793.0	818.0		4.65
14.0	412.4	457.4	503.0	549.3	596.2	667.3	739.3	812.1	848.5		4.65
14.5	419.4	465.6	512.5	560.1	608.3	681.5	755.7	830.7	879.1		4.70
15.0	426.1	473.4	521.6	570.4	619.9	695.2	771.5	848.7	909.6		4.75

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 2.80	3.00	3.20	3.40	3.60	3.90	4.20	4.50	4.80	5.10	TRANSITION WIDTH (m)
1.5	69.8										2.65
2.0	97.4										2.80
2.5	119.5	127.5									3.00
3.0	140.7	151.9	160.3								3.20
3.5	161.1	174.1	187.1	196.2							3.35
4.0	180.7	195.5	210.4	225.3	235.2						3.55
4.5	199.5	216.2	232.8	249.5	266.3	268.5					3.65
5.0	217.7	236.1	254.5	273.1	291.6	299.0					3.70
5.5	235.1	255.3	275.5	295.8	316.1	329.6					3.75
6.0	251.8	273.8	295.8	317.8	340.0	360.1					3.80
6.5	267.9	291.6	315.3	339.2	363.1	390.6					3.85
7.0	283.4	308.8	334.3	359.8	385.5	421.2					3.90
7.5	298.3	325.4	352.5	379.8	407.2	448.4	451.7				3.95
8.0	312.6	341.3	370.2	399.2	428.3	472.1	482.2				4.00
8.5	326.4	356.7	387.3	417.9	448.7	495.1	512.7				4.05
9.0	339.6	371.6	403.7	436.1	468.5	517.5	543.3				4.10
9.5	352.4	385.9	419.7	453.6	487.8	539.2	573.8				4.15
10.0	364.6	399.7	435.0	470.6	506.4	560.4	604.3				4.15
10.5	376.4	413.0	449.9	487.1	524.5	580.9	634.8				4.20
11.0	387.7	425.8	464.3	503.0	542.0	600.9	660.2	665.4			4.25
11.5	398.5	438.2	476.2	518.5	559.1	620.4	682.1	695.9			4.30
12.0	409.0	450.1	491.6	533.4	575.6	639.3	703.4	726.4			4.35
12.5	419.1	461.6	504.5	547.9	591.6	657.6	724.2	757.0			4.35
13.0	428.7	472.6	517.1	561.9	607.1	675.5	744.5	787.5			4.40
13.5	438.0	483.3	529.2	575.4	622.1	692.8	764.2	818.0			4.45
14.0	447.0	493.6	540.8	588.6	636.8	709.7	783.4	848.5			4.50
14.5	455.5	503.5	552.1	601.3	650.9	726.1	802.1	878.7	879.1		4.55
15.0	463.8	513.1	563.0	613.6	664.7	742.1	820.3	899.3	909.6		4.55

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.25 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

1950 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	2.90	3.10	3.30	3.50	3.80	4.10	4.40	4.80	5.10	5.40	
1.5	74.7										2.90
2.0	97.5	103.8									3.10
2.5	116.6	127.9	135.5								3.30
3.0	138.6	149.7	160.6	169.7							3.50
3.5	157.4	170.3	183.2	196.2	206.9						3.70
4.0	175.2	189.8	204.5	219.3	241.4	247.1					3.90
4.5	192.0	208.4	224.8	241.3	266.1	289.8					4.10
5.0	207.9	226.0	244.1	262.3	289.8	317.3	322.8				4.20
5.5	222.9	242.6	262.5	282.4	312.4	342.5	355.9				4.25
6.0	237.1	258.4	279.9	301.5	334.1	366.8	388.9				4.35
6.5	250.4	273.4	296.5	319.6	354.6	390.1	421.9				4.40
7.0	263.1	287.6	312.3	337.2	374.7	412.5	450.5	454.9			4.45
7.5	275.0	301.1	327.3	353.8	393.6	434.0	474.5	487.9			4.50
8.0	286.3	313.9	341.6	369.6	412.0	454.7	497.6	520.9			4.60
8.5	297.0	326.0	355.2	384.7	429.4	474.5	519.9	553.9			4.65
9.0	307.1	337.4	368.2	399.2	446.1	493.6	541.4	586.9			4.70
9.5	316.6	348.3	380.5	412.9	462.1	511.9	562.0	619.9			4.75
10.0	325.6	358.7	392.2	426.0	477.5	529.4	581.9	652.6	653.0		4.85
10.5	334.1	368.4	403.3	438.6	492.1	545.3	601.1	674.9	686.0		4.90
11.0	342.1	377.7	413.9	450.5	506.2	562.6	619.6	696.4	719.0		4.95
11.5	349.7	386.5	424.0	461.9	519.6	578.1	637.4	717.2	752.0		5.00
12.0	356.8	394.9	433.5	472.8	532.5	593.1	654.5	737.4	785.0		5.05
12.5	363.6	402.8	442.7	483.1	544.8	607.5	671.0	756.8	818.0		5.10
13.0	370.0	410.3	451.3	493.0	556.6	621.3	686.9	775.6	842.9	851.0	5.15
13.5	376.0	417.4	459.6	502.5	567.9	634.6	702.2	793.7	863.2	884.0	5.20
14.0	381.7	424.1	467.4	511.5	578.7	647.3	717.0	811.3	882.9	917.1	5.25
14.5	387.1	430.5	474.9	520.0	589.1	659.6	731.2	828.2	901.9	950.1	5.30
15.0	392.2	436.6	482.0	528.2	599.0	671.3	744.9	844.6	920.4	983.1	5.35

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	2.90	3.10	3.30	3.50	3.80	4.10	4.40	4.80	5.10	5.40	
1.5	74.7										2.90
2.0	98.5	103.8									3.05
2.5	120.1	129.4	135.5								3.25
3.0	140.6	151.7	162.9	169.7							3.45
3.5	160.1	173.0	186.0	199.0	206.9						3.65
4.0	178.6	193.3	208.0	222.8	245.0	247.1					3.85
4.5	196.2	212.6	229.1	245.7	270.6	289.8					4.05
5.0	212.8	231.0	249.3	267.6	295.1	322.6	322.8				4.15
5.5	228.7	248.6	268.5	288.6	318.7	349.0	355.9				4.20
6.0	243.7	265.3	286.9	308.7	341.4	374.3	388.9				4.25
6.5	258.0	281.2	304.5	327.9	363.2	398.7	421.9				4.30
7.0	271.6	296.3	321.3	346.4	384.2	422.2	454.9				4.40
7.5	284.4	310.8	337.3	364.0	404.3	444.9	485.7	487.9			4.45
8.0	296.7	324.6	352.7	381.0	423.7	466.8	510.1	520.9			4.50
8.5	308.3	337.7	367.3	397.2	442.3	487.8	533.6	553.9			4.55
9.0	319.3	350.2	381.3	412.7	460.2	508.2	556.4	596.9			4.60
9.5	329.8	362.1	394.7	427.6	477.5	527.8	578.4	619.9			4.65
10.0	339.7	373.4	407.5	441.9	494.0	546.6	599.7	653.0			4.70
10.5	349.2	384.2	419.7	455.6	509.9	564.8	620.3	686.0			4.80
11.0	358.1	394.5	431.4	468.7	525.2	582.4	640.1	717.8	719.0		4.85
11.5	366.6	404.3	442.5	481.2	539.9	599.3	659.3	740.2	752.0		4.90
12.0	374.7	413.7	453.2	493.2	554.0	615.6	677.9	761.8	785.0		4.95
12.5	382.4	422.6	463.4	504.7	567.6	631.4	695.9	782.8	818.0		5.00
13.0	389.7	431.1	473.1	515.8	580.7	646.5	713.2	803.1	851.0		5.05
13.5	396.6	439.2	482.4	526.3	593.2	661.1	730.0	822.9	884.0		5.10
14.0	403.2	446.9	491.3	536.4	605.3	675.2	746.2	842.0	914.6	917.1	5.15
14.5	409.4	454.2	499.8	546.1	616.9	688.8	761.8	860.5	935.3	950.1	5.20
15.0	415.4	461.2	507.9	555.4	628.0	701.9	776.9	878.4	955.5	983.1	5.25

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	2.90	3.10	3.30	3.50	3.80	4.10	4.40	4.80	5.10	5.40	
1.5	74.7										2.85
2.0	99.8	103.8									3.05
2.5	122.1	131.4	135.5								3.20
3.0	143.4	154.6	165.8	169.7							3.40
3.5	163.8	176.8	189.8	202.8	206.9						3.60
4.0	183.3	198.0	212.9	227.7	247.1						3.80
4.5	201.9	218.4	235.1	251.7	276.7	289.8					4.00
5.0	219.7	238.0	256.4	274.8	302.5	322.8					4.05
5.5	236.7	256.8	276.9	297.1	327.5	355.9					4.10
6.0	253.0	274.8	296.6	318.6	351.6	384.7	388.9				4.15
6.5	268.6	292.0	315.6	339.2	374.8	410.6	421.9				4.20
7.0	283.5	308.6	333.8	359.2	397.4	435.7	454.9				4.25
7.5	297.7	324.4	351.3	378.4	419.1	460.1	487.9				4.35
8.0	311.3	339.6	368.2	396.9	440.1	483.6	520.9				4.40
8.5	324.3	354.2	384.4	414.7	460.4	506.5	552.7	553.9			4.45
9.0	336.7	368.2	399.9	431.9	480.1	528.6	577.4	586.9			4.50
9.5	348.6	381.6	414.9	448.4	499.0	550.0	601.3	619.9			4.55
10.0	360.0	394.5	429.3	464.4	517.4	570.8	624.6	653.0			4.60
10.5	370.9	406.8	443.1	479.7	535.1	590.9	647.2	686.0			4.65
11.0	381.3	418.7	456.4	494.5	552.2	610.4	669.1	719.0			4.70
11.5	391.2	430.0	469.2	508.8	568.8	629.3	690.4	752.0			4.75
12.0	400.7	440.9	481.5	522.6	584.7	647.6	711.0	785.0			4.75
12.5	409.8	451.3	493.3	535.6	600.2	665.3	731.1	818.0			4.80
13.0	418.5	461.3	504.7	548.5	615.1	682.5	750.5	842.1	851.0		4.85
13.5	426.8	470.9	515.6	560.8	629.6	699.1	769.4	864.1	884.0		4.90
14.0	434.8	480.1	526.1	572.7	643.5	715.2	787.8	885.6	917.1		4.95
14.5	442.4	488.9	536.2	584.1	657.0	730.9	805.6	906.4	950.1		5.00
15.0	449.6	497.4	545.9	595.1	670.0	746.0	822.9	926.7	983.1		5.05

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	2.90	3.10	3.30	3.50	3.80	4.10	4.40	4.80	5.10	5.40	
1.5	74.7										2.85
2.0	101.2	103.8									3.00
2.5	124.2	133.5	135.5								3.15
3.0	146.3	157.5	168.7	169.7							3.35
3.5	167.6	180.6	193.7	206.7	206.9						3.55
4.0	188.1	203.0	217.8	232.7	247.1						3.70
4.5	207.8	224.5	241.2	257.9	283.0	289.8					3.90
5.0	226.9	245.3	263.8	282.3	310.1	322.8					3.95
5.5	245.2	265.4	285.7	306.0	336.5	355.9					4.00
6.0	262.8	284.8	306.8	328.9	362.1	388.9					4.05
6.5	279.8	303.5	327.3	351.1	387.0	421.9					4.10
7.0	296.1	321.5	347.0	372.6	411.2	449.8	454.9				4.15
7.5	311.8	338.9	366.2	393.5	434.6	475.9	487.9				4.20
8.0	327.0	355.7	384.7	413.7	457.4	501.4	520.9				4.25
8.5	341.5	372.0	402.6	433.3	479.6	526.1	553.9				4.30
9.0	355.6	387.6	419.9	452.3	501.1	550.2	586.9				4.35
9.5	369.1	402.8	436.6	470.7	522.0	573.7	619.9				4.40
10.0	382.1	417.3	452.8	488.5	542.3	596.5	651.0	653.0			4.45
10.5	394.6	431.4	468.5	505.8	562.1	618.8	675.7	686.0			4.50
11.0	406.7	445.0	483.6	522.5	581.2	640.4	699.9	719.0			4.50
11.5	418.3	458.1	498.3	538.7	599.9	661.5	723.5	752.0			4.55
12.0	429.5	470.8	512.5	554.5	618.0	682.0	746.4	785.0			4.60
12.5	440.3	483.0	526.2	569.7	635.5	702.0	768.9	818.0			4.65
13.0	450.6	494.8	539.4	584.4	652.6	721.4	790.7	851.0			4.70
13.5	460.6	506.2	552.2	598.8	669.2	740.3	812.1	884.0			4.70
14.0	470.2	517.2	564.7	612.6	685.3	758.8	832.8	917.1			4.75
14.5	479.4	527.8	576.6	626.1	701.0	776.7	853.1	950.1			4.80
15.0	488.4	538.0	588.3	639.1	716.2	794.2	872.9	978.9	983.1		4.85

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.26 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

2100 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	3.20	3.40	3.60	3.90	4.20	4.50	4.80	5.10	5.40	5.70	
1.5	80										3.10
2.0	109	110									3.25
2.5	133	142	143								3.45
3.0	155	166	178	179							3.65
3.5	177	190	203	218							3.85
4.0	197	212	227	249	259						4.05
4.5	217	233	250	274	299	304					4.30
5.0	235	253	271	299	326	347					4.45
5.5	253	272	292	322	353	382					4.50
6.0	269	291	312	345	378	411	418				4.60
6.5	285	308	331	367	402	437	453				4.65
7.0	300	325	350	387	425	463	489				4.70
7.5	314	341	367	407	447	488	524				4.80
8.0	328	356	384	426	469	512	555	560			4.85
8.5	341	370	400	444	490	535	581	595			4.90
9.0	353	384	415	462	509	557	606	631			5.00
9.5	364	397	429	479	529	579	629	666			5.05
10.0	375	409	443	495	547	600	653	702			5.10
10.5	386	421	456	510	565	619	675	731	737		5.15
11.0	396	432	469	525	582	639	696	755	773		5.20
11.5	405	443	481	539	598	657	717	778	808		5.25
12.0	414	453	493	553	614	675	737	800	844		5.35
12.5	423	463	504	566	629	692	757	822	879		5.40
13.0	431	472	514	578	643	709	776	843	911	914	5.45
13.5	438	481	524	590	657	725	794	863	933	950	5.50
14.0	446	489	534	601	670	740	811	883	955	985	5.55
14.5	453	497	543	612	683	755	828	902	976	1021	5.60
15.0	459	505	552	623	696	770	845	920	997	1056	5.65

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	3.20	3.40	3.60	3.90	4.20	4.50	4.80	5.10	5.40	5.70	
1.5	80										3.05
2.0	110	110									3.25
2.5	134	143	143								3.45
3.0	157	168	179								3.60
3.5	180	192	205	218							3.80
4.0	201	215	230	252	259						4.00
4.5	221	237	254	279	304	304					4.25
5.0	240	258	277	304	332	347					4.40
5.5	259	279	299	329	359	382					4.45
6.0	276	298	320	352	385	419					4.50
6.5	293	316	340	375	411	446	453				4.60
7.0	309	334	359	397	435	473	489				4.65
7.5	324	351	377	418	458	499	524				4.70
8.0	339	367	395	438	481	525	560				4.75
8.5	352	382	412	457	503	549	595				4.80
9.0	366	397	429	476	524	573	621	631			4.90
9.5	378	411	444	494	545	595	646	666			4.95
10.0	390	425	459	511	564	617	671	702			5.00
10.5	402	438	474	528	583	639	695	737			5.05
11.0	413	450	487	544	602	659	716	773			5.10
11.5	423	462	501	560	619	679	740	801	808		5.15
12.0	433	473	513	574	636	699	762	825	844		5.20
12.5	443	484	526	589	653	717	783	849	879		5.25
13.0	452	494	537	603	669	736	803	871	914		5.30
13.5	461	504	548	616	684	753	823	893	950		5.35
14.0	469	514	559	628	699	770	842	915	985		5.40
14.5	477	523	570	641	713	786	860	935	1011	1021	5.45
15.0	484	532	579	653	727	802	878	955	1033	1056	5.50

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	3.20	3.40	3.60	3.90	4.20	4.50	4.80	5.10	5.40	5.70	
1.5	80										3.05
2.0	110										3.20
2.5	136	143									3.40
3.0	160	171	179								3.55
3.5	183	196	209	218							3.75
4.0	205	220	235	257	259						3.95
4.5	227	243	260	285	304						4.15
5.0	247	266	284	312	340	347					4.30
5.5	267	287	307	338	368	382					4.35
6.0	286	308	330	363	396	418					4.40
6.5	304	327	351	387	423	453					4.50
7.0	321	346	372	410	449	487	489				4.55
7.5	338	365	392	433	474	515	524				4.60
8.0	354	383	411	455	498	542	560				4.65
8.5	369	400	430	476	522	568	595				4.70
9.0	384	416	448	496	545	594	631				4.75
9.5	398	432	465	516	567	619	666				4.80
10.0	412	447	482	535	589	643	697	702			4.85
10.5	425	461	498	554	610	666	723	737			4.90
11.0	438	475	514	572	630	689	748	773			4.95
11.5	450	489	529	589	650	711	772	808			5.00
12.0	461	502	543	606	669	732	796	844			5.05
12.5	472	515	557	622	687	753	819	879			5.10
13.0	483	527	571	637	705	779	842	911	914		5.15
13.5	493	538	584	653	722	793	864	936	950		5.20
14.0	503	549	596	667	739	812	886	960	985		5.25
14.5	512	560	608	681	756	831	906	983	1021		5.25
15.0	522	570	620	695	772	849	927	1005	1056		5.30

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH (m)
	3.20	3.40	3.60	3.90	4.20	4.50	4.80	5.10	5.40	5.70	
1.5	80										3.00
2.0	110										3.15
2.5	138	143									3.35
3.0	163	174	179								3.50
3.5	187	200	213	218							3.70
4.0	210	225	240	259							3.90
4.5	233	250	266	291	304						4.05
5.0	255	273	292	319	347						4.20
5.5	276	296	316	347	377	382					4.25
6.0	296	318	340	373	407	418					4.30
6.5	315	339	363	399	435	453					4.40
7.0	334	360	385	424	463	489					4.40
7.5	353	380	407	448	490	524					4.45
8.0	370	399	428	472	516	560					4.50
8.5	387	418	449	495	542	588	595				4.55
9.0	404	436	469	517	567	616	631				4.60
9.5	420	454	488	539	591	643	666				4.65
10.0	435	471	506	560	615	669	702				4.70
10.5	450	487	524	581	638	695	737				4.75
11.0	464	503	542	601	660	720	773				4.80
11.5	478	518	559	620	682	744	807	808			4.85
12.0	492	533	576	639	703	768	833	844			4.85
12.5	505	548	592	658	724	791	859	879			4.90
13.0	517	562	607	675	744	814	884	914			4.95
13.5	529	575	622	693	764	836	908	950			5.00
14.0	541	589	637	710	783	858	932	985			5.05
14.5	552	601	651	726	802	879	956	1021			5.10
15.0	563	614	665	742	820	899	979	1056			5.10

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon* $K\mu' = 0.19$, $r_{sd}p = 0.5$ *in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.27 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

2250 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 3.40	3.60	3.90	4.20	4.50	4.80	5.10	5.40	5.70	6.00	TRANSITION WIDTH (m)
1.5	85										3.25
2.0	116	117									3.45
2.5	142	151	152								3.65
3.0	166	178	189								3.85
3.5	190	203	222	229							4.05
4.0	212	227	249	271	271						4.25
4.5	233	250	274	299	317						4.45
5.0	253	271	299	326	354	367					4.65
5.5	272	292	322	353	383	408					4.75
6.0	291	312	345	378	411	444	446				4.85
6.5	308	331	367	402	437	473	484				4.90
7.0	325	350	387	425	463	501	522				5.00
7.5	341	367	407	447	488	529	560				5.05
8.0	356	384	426	469	512	555	598				5.10
8.5	370	400	444	490	535	581	627	636			5.20
9.0	384	415	462	509	557	606	654	674			5.25
9.5	397	429	479	529	579	629	680	712			5.30
10.0	409	443	495	547	600	653	706	750			5.35
10.5	421	456	510	565	619	675	731	787	788		5.45
11.0	432	469	525	582	639	696	755	813	826		5.50
11.5	443	481	539	598	657	717	778	839	864		5.55
12.0	453	493	553	614	675	737	800	863	902		5.60
12.5	463	504	566	629	692	757	822	887	940		5.65
13.0	472	514	578	643	709	776	843	911	978		5.70
13.5	481	524	590	657	725	794	863	933	1004	1016	5.80
14.0	489	534	601	670	740	811	883	955	1028	1054	5.85
14.5	497	543	612	683	755	828	902	976	1051	1092	5.90
15.0	505	552	623	696	770	845	920	997	1074	1130	5.95

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 3.40	3.60	3.90	4.20	4.50	4.80	5.10	5.40	5.70	6.00	TRANSITION WIDTH (m)
1.5	85										3.25
2.0	117										3.40
2.5	143	152									3.60
3.0	168	180	189								3.80
3.5	192	205	225	229							4.00
4.0	215	230	252	271							4.20
4.5	237	254	279	304	317						4.40
5.0	258	277	304	332	360	367					4.60
5.5	279	299	329	359	390	408					4.70
6.0	298	320	352	385	418	446					4.80
6.5	316	340	375	411	448	482	484				4.85
7.0	334	359	397	435	473	512	522				4.90
7.5	351	377	418	458	499	540	560				4.95
8.0	367	395	438	481	525	568	598				5.05
8.5	382	412	457	503	549	595	636				5.10
9.0	397	429	476	524	573	621	670	674			5.15
9.5	411	444	494	545	595	646	698	712			5.20
10.0	425	459	511	564	617	671	725	750			5.25
10.5	438	474	528	583	639	695	751	788			5.30
11.0	450	487	544	602	659	718	777	826			5.40
11.5	462	501	560	619	679	740	801	863	864		5.45
12.0	473	513	574	636	699	762	825	889	902		5.50
12.5	484	526	589	653	717	783	849	915	940		5.55
13.0	494	537	603	669	736	803	871	940	978		5.60
13.5	504	548	616	684	753	823	893	964	1016		5.65
14.0	514	559	628	699	770	842	915	988	1054		5.70
14.5	523	570	641	713	786	860	935	1011	1087	1092	5.75
15.0	532	579	653	727	802	878	955	1033	1112	1130	5.80

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 3.40	3.60	3.90	4.20	4.50	4.80	5.10	5.40	5.70	6.00	TRANSITION WIDTH (m)
1.5	85										3.20
2.0	117										3.40
2.5	145	152									3.55
3.0	171	183	189								3.75
3.5	196	209	229								3.90
4.0	220	235	257	271							4.10
4.5	243	260	285	310	317						4.30
5.0	266	284	312	340	367						4.50
5.5	287	307	338	368	399	408					4.60
6.0	308	330	363	396	429	446					4.70
6.5	327	351	387	423	458	484					4.75
7.0	346	372	410	449	487	522					4.80
7.5	365	392	433	474	515	556	560				4.85
8.0	383	411	455	498	542	586	598				4.90
8.5	400	430	476	522	568	615	636				4.95
9.0	416	448	496	545	594	643	674				5.00
9.5	432	465	516	567	619	670	712				5.05
10.0	447	482	535	589	643	697	750				5.10
10.5	461	498	554	610	666	723	780	788			5.15
11.0	475	514	572	630	689	748	807	826			5.20
11.5	489	529	589	650	711	772	834	864			5.25
12.0	502	543	606	669	732	796	861	902			5.30
12.5	515	557	622	687	753	819	886	940			5.35
13.0	527	571	637	705	773	842	911	978			5.40
13.5	538	584	653	722	793	864	936	1008	1016		5.45
14.0	549	596	667	739	812	886	960	1034	1054		5.50
14.5	560	608	681	756	831	906	983	1060	1092		5.55
15.0	570	620	695	772	849	927	1005	1084	1130		5.60

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m) 3.40	3.60	3.90	4.20	4.50	4.80	5.10	5.40	5.70	6.00	TRANSITION WIDTH (m)
1.5	85										3.20
2.0	117										3.35
2.5	148	152									3.50
3.0	174	186	189								3.70
3.5	200	213	229								3.85
4.0	225	240	263	271							4.05
4.5	250	266	291	317	317						4.25
5.0	273	292	319	347	367						4.45
5.5	296	316	347	377	408	408					4.55
6.0	318	340	373	407	440	446					4.60
6.5	339	363	399	435	471	484					4.65
7.0	360	385	424	463	502	522					4.70
7.5	380	407	448	490	531	560					4.75
8.0	399	428	472	516	560	598					4.80
8.5	418	449	495	542	588	635	636				4.85
9.0	436	469	517	567	616	665	674				4.90
9.5	454	488	539	591	643	695	712				4.90
10.0	471	506	560	615	669	724	750				4.95
10.5	487	524	581	638	695	752	788				5.00
11.0	503	542	601	660	720	780	826				5.05
11.5	516	559	620	682	744	807	864				5.10
12.0	533	576	639	703	768	833	898	902			5.15
12.5	548	592	658	724	791	859	926	940			5.20
13.0	562	607	675	744	814	884	954	978			5.25
13.5	575	622	693	764	836	908	981	1016			5.25
14.0	589	637	710	783	858	932	1008	1054			5.30
14.5	601	651	726	802	879	956	1034	1092			5.35
15.0	614	665	742	820	899	979	1059	1130			5.40

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd} p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.28 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

2400 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	3.60	3.80	4.10	4.40	4.70	5.00	5.30	5.60	5.90	6.20	(m)
1.5	89										3.45
2.0	123										3.60
2.5	151	160									3.80
3.0	178	189	198								4.00
3.5	203	216	235	240							4.20
4.0	227	241	264	284							4.40
4.5	250	266	291	316	331						4.60
5.0	271	290	317	345	373	381					4.80
5.5	292	312	343	373	403	434	434				5.05
6.0	312	334	367	400	433	466	475				5.10
6.5	331	355	390	426	461	497	515				5.20
7.0	350	375	413	450	489	527	556				5.25
7.5	367	394	434	475	515	556	596				5.30
8.0	384	412	455	498	541	584	628	637			5.40
8.5	400	429	475	520	566	612	658	677			5.45
9.0	415	446	494	541	589	638	687	717			5.50
9.5	429	462	512	562	613	663	715	758			5.60
10.0	443	477	529	582	635	688	742	796	798		5.65
10.5	456	492	546	601	656	712	768	824	839		5.70
11.0	469	506	563	620	677	735	794	852	879		5.75
11.5	481	520	578	637	697	758	818	879	920		5.80
12.0	493	532	593	655	717	779	842	906	960		5.90
12.5	504	545	607	671	735	800	865	931	997	1001	5.95
13.0	514	557	621	687	753	820	888	956	1025	1041	6.00
13.5	524	568	635	702	771	840	910	980	1051	1082	6.05
14.0	534	579	647	717	788	859	931	1004	1077	1122	6.10
14.5	543	589	660	731	804	877	951	1026	1102	1163	6.15
15.0	552	599	671	745	819	895	971	1048	1126	1203	6.20

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	3.60	3.80	4.10	4.40	4.70	5.00	5.30	5.60	5.90	6.20	(m)
1.5	89										3.40
2.0	123										3.60
2.5	153	160									3.75
3.0	180	191	198								3.95
3.5	205	218	238	240							4.15
4.0	230	245	267	284							4.35
4.5	254	271	296	321	331						4.55
5.0	277	295	323	350	378	381					4.75
5.5	299	319	349	379	410	434					4.95
6.0	320	341	374	407	440	474	475				5.05
6.5	340	363	399	434	470	506	515				5.10
7.0	359	384	422	460	499	537	556				5.15
7.5	377	404	445	486	527	568	596				5.25
8.0	395	424	467	510	554	597	637				5.30
8.5	412	442	488	534	580	626	672	677			5.35
9.0	429	460	508	556	605	654	703	717			5.40
9.5	444	477	528	578	629	681	732	758			5.45
10.0	459	494	547	600	653	707	761	798			5.55
10.5	474	510	565	620	676	732	789	839			5.60
11.0	487	525	582	640	698	757	816	875	879		5.65
11.5	501	540	599	659	720	781	842	904	920		5.70
12.0	513	554	616	678	741	804	868	932	960		5.75
12.5	526	568	631	696	761	827	893	959	1001		5.80
13.0	537	581	647	713	781	848	917	986	1041		5.85
13.5	548	593	661	730	800	870	940	1012	1082		5.90
14.0	559	605	675	746	818	890	963	1037	1111	1122	5.95
14.5	570	617	689	762	836	910	986	1061	1138	1163	6.00
15.0	579	628	702	777	853	930	1007	1085	1164	1203	6.05

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	3.60	3.80	4.10	4.40	4.70	5.00	5.30	5.60	5.90	6.20	(m)
1.5	89										3.40
2.0	123										3.55
2.5	155	160									3.75
3.0	183	194	198								3.90
3.5	209	222	240								4.10
4.0	235	250	272	284							4.30
4.5	260	277	302	327	331						4.45
5.0	284	303	330	358	381						4.65
5.5	307	327	358	388	419	434					4.85
6.0	330	352	385	418	451	475					4.95
6.5	351	375	411	446	482	515					5.00
7.0	372	397	436	474	513	552	556				5.05
7.5	392	419	460	501	542	584	596				5.10
8.0	411	440	484	527	571	615	637				5.15
8.5	430	460	506	553	599	646	677				5.25
9.0	448	480	529	577	626	676	717				5.30
9.5	465	499	550	601	653	705	757	758			5.35
10.0	482	517	571	625	679	733	788	798			5.40
10.5	498	535	591	647	704	761	818	839			5.45
11.0	514	552	610	669	728	787	847	879			5.50
11.5	529	569	629	690	752	814	876	920			5.55
12.0	543	585	648	711	775	839	904	960			5.60
12.5	557	600	665	731	797	864	931	998	1001		5.65
13.0	571	615	682	751	819	888	958	1028	1041		5.70
13.5	584	630	699	769	840	912	984	1056	1082		5.75
14.0	596	643	715	788	861	935	1009	1084	1122		5.80
14.5	608	657	731	806	881	957	1034	1111	1163		5.80
15.0	620	670	746	823	901	979	1058	1137	1203		5.85

D SATURATED CLAY $K\mu' = 0.11$ DENSITY 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	3.60	3.80	4.10	4.40	4.70	5.00	5.30	5.60	5.90	6.20	(m)
1.5	89										3.35
2.0	123										3.50
2.5	157	160									3.70
3.0	186	197	198								3.85
3.5	213	226	240								4.05
4.0	240	255	277	284							4.20
4.5	266	283	308	331							4.40
5.0	292	310	338	366	381						4.60
5.5	316	337	367	398	428	434					4.80
6.0	340	362	395	429	462	475					4.85
6.5	363	387	423	459	495	515					4.90
7.0	385	411	450	489	527	556					4.95
7.5	407	435	476	517	559	596					5.00
8.0	428	457	501	545	590	634	637				5.05
8.5	449	480	526	573	620	667	677				5.10
9.0	469	501	550	600	649	699	717				5.15
9.5	488	522	574	626	678	730	758				5.20
10.0	506	542	597	651	706	760	798				5.25
10.5	524	562	619	676	733	790	839				5.30
11.0	542	581	640	700	760	820	879				5.30
11.5	559	600	661	723	786	848	911	920			5.35
12.0	576	618	682	746	811	876	942	960			5.40
12.5	592	636	702	769	836	904	972	1001			5.45
13.0	607	653	721	791	860	931	1001	1041			5.50
13.5	622	669	740	812	884	957	1030	1082			5.55
14.0	637	685	759	833	907	983	1058	1122			5.60
14.5	651	701	777	853	930	1008	1086	1163			5.60
15.0	665	716	794	873	952	1032	1113	1193	1203		5.65

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.29 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

2550 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	3.80	4.00	4.20	4.50	4.80	5.10	5.40	5.70	6.10	6.50	(m)
1.5	94										3.60
2.0	130										3.80
2.5	161	168									4.00
3.0	189	200	208								4.15
3.5	216	229	242	251							4.35
4.0	241	256	271	293	296						4.55
4.5	266	283	299	324	345						4.75
5.0	290	308	326	354	382	396					5.00
5.5	312	332	353	383	413	444	451				5.20
6.0	334	356	378	411	444	477	503				5.35
6.5	355	378	402	437	473	509	545	546			5.45
7.0	375	400	425	463	501	540	578	589			5.50
7.5	394	421	447	488	529	570	611	632			5.60
8.0	412	440	469	512	555	599	642	675			5.65
8.5	429	459	490	535	581	627	673	718			5.70
9.0	446	478	509	557	606	654	703	752	761		5.80
9.5	462	495	529	579	629	680	732	783	804		5.85
10.0	477	512	547	600	653	706	760	814	847		5.90
10.5	492	528	565	619	675	731	787	843	890		5.95
11.0	506	544	582	639	696	755	813	872	933		6.05
11.5	520	559	598	657	717	778	839	900	976		6.10
12.0	532	573	614	675	737	800	863	927	1012	1018	6.15
12.5	545	587	629	692	757	822	887	953	1042	1061	6.20
13.0	557	600	643	709	776	843	911	979	1071	1104	6.25
13.5	568	612	657	725	794	863	933	1004	1099	1147	6.35
14.0	579	624	670	740	811	883	955	1028	1126	1190	6.40
14.5	589	636	683	755	828	902	976	1051	1152	1233	6.45
15.0	599	647	696	770	845	920	997	1074	1178	1276	6.50

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	3.80	4.00	4.20	4.50	4.80	5.10	5.40	5.70	6.10	6.50	(m)
1.5	94										3.60
2.0	130										3.75
2.5	162	168									3.95
3.0	191	202	208								4.15
3.5	218	231	245	251							4.30
4.0	245	260	275	296							4.50
4.5	271	287	304	329	345						4.70
5.0	295	314	332	360	388	396					4.90
5.5	319	339	359	390	420	461	451				5.15
6.0	341	363	385	418	452	485	503				5.30
6.5	363	387	411	446	482	518	546				5.35
7.0	384	410	435	473	512	550	589	589			5.45
7.5	404	431	458	499	540	581	623	632			5.50
8.0	424	452	481	525	568	612	656	675			5.55
8.5	442	473	503	549	595	641	688	718			5.60
9.0	460	492	524	573	621	670	719	761			5.70
9.5	477	511	545	595	646	698	749	801	804		5.75
10.0	494	529	564	617	671	725	779	833	847		5.80
10.5	510	546	583	639	695	751	808	864	890		5.85
11.0	525	563	602	659	718	777	836	895	933		5.90
11.5	540	579	619	679	740	801	863	925	976		5.95
12.0	554	595	636	699	762	825	889	953	1018		6.05
12.5	568	610	653	717	783	849	915	981	1061		6.10
13.0	581	624	669	736	803	871	940	1009	1101	1104	6.15
13.5	593	638	684	753	823	893	964	1036	1131	1147	6.20
14.0	605	652	699	770	842	915	986	1062	1161	1190	6.25
14.5	617	665	713	786	860	935	1011	1087	1189	1233	6.30
15.0	628	677	727	802	878	955	1033	1112	1217	1276	6.35

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	3.80	4.00	4.20	4.50	4.80	5.10	5.40	5.70	6.10	6.50	(m)
1.5	94										3.55
2.0	130										3.75
2.5	164	168									3.90
3.0	194	205	208								4.10
3.5	222	235	248	251							4.25
4.0	250	265	280	296							4.45
4.5	277	293	310	335	345						4.65
5.0	303	321	340	367	395	396					4.85
5.5	327	348	368	399	429	451					5.05
6.0	352	374	396	429	462	496	503				5.20
6.5	375	399	423	458	494	530	546				5.25
7.0	397	423	449	487	526	564	589				5.30
7.5	419	446	474	515	556	598	632				5.35
8.0	440	469	498	542	586	630	674	675			5.45
8.5	460	491	522	568	615	661	708	718			5.50
9.0	480	512	545	594	643	692	741	761			5.55
9.5	499	533	567	619	670	722	774	804			5.60
10.0	517	553	589	643	697	751	806	847			5.65
10.5	535	572	610	666	723	780	837	890			5.70
11.0	552	591	630	689	748	807	867	927	933		5.75
11.5	569	609	650	711	772	834	896	959	976		5.80
12.0	585	627	669	732	796	861	925	990	1018		5.85
12.5	600	644	687	753	819	886	953	1021	1061		5.90
13.0	615	660	705	773	842	911	981	1051	1104		5.95
13.5	630	676	722	793	864	936	1008	1080	1147		6.00
14.0	643	691	739	812	886	960	1034	1109	1190		6.05
14.5	657	706	756	831	906	983	1060	1137	1233		6.10
15.0	670	721	772	849	927	1005	1084	1164	1271	1276	6.15

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	3.80	4.00	4.20	4.50	4.80	5.10	5.40	5.70	6.10	6.50	(m)
1.5	94										3.55
2.0	130										3.70
2.5	166	168									3.85
3.0	197	208	208								4.05
3.5	226	239	251								4.20
4.0	255	270	285	296							4.40
4.5	283	300	317	342	345						4.55
5.0	310	329	347	375	396						4.75
5.5	337	357	377	408	439	451					4.95
6.0	362	384	407	440	473	503					5.10
6.5	387	411	435	471	507	543	546				5.15
7.0	411	437	463	502	540	579	589				5.20
7.5	435	462	490	531	573	614	632				5.25
8.0	457	487	516	560	604	649	675				5.30
8.5	480	511	542	588	635	682	718				5.35
9.0	501	534	567	616	665	715	761				5.40
9.5	522	556	591	643	695	747	800	804			5.45
10.0	542	578	615	669	724	779	834	847			5.50
10.5	562	600	638	695	752	810	867	890			5.55
11.0	581	621	660	720	780	840	900	933			5.60
11.5	600	641	682	744	807	869	932	976			5.65
12.0	618	661	703	768	833	898	964	1018			5.70
12.5	636	680	724	791	859	926	994	1061			5.70
13.0	653	698	744	814	884	954	1025	1095	1104		5.75
13.5	669	717	764	836	908	981	1054	1128	1147		5.80
14.0	685	734	783	858	932	1008	1083	1159	1190		5.85
14.5	701	751	802	879	956	1034	1112	1190	1233		5.90
15.0	716	768	820	899	979	1059	1139	1220	1276		5.95

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon* $K\mu' = 0.19$, $r_{sd}\, p = 0.5$ *in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.30 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

2700 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	4.00	4.20	4.50	4.80	5.10	5.40	5.70	6.00	6.40	6.80	(m)
1.5	99										3.80
2.0	136										3.95
2.5	170	176									4.15
3.0	200	211	216								4.35
3.5	229	242	261	262							4.55
4.0	256	271	293	309							4.75
4.5	283	299	324	349	359						4.95
5.0	308	326	354	382	410	411					5.15
5.5	332	353	383	413	444	467					5.35
6.0	356	378	411	444	477	510	527				5.60
6.5	378	402	437	473	509	545	577				5.70
7.0	400	425	463	501	540	578	617	622			5.75
7.5	421	447	488	529	570	611	652	668			5.85
8.0	440	469	512	555	599	642	686	713			5.90
8.5	459	490	535	581	627	673	719	759			6.00
9.0	478	509	557	606	654	703	752	801	804		6.05
9.5	495	529	579	629	680	732	783	835	849		6.10
10.0	512	547	600	653	706	760	814	868	895		6.20
10.5	528	565	619	675	731	787	843	900	940		6.25
11.0	544	582	639	696	755	813	872	931	986		6.30
11.5	559	598	657	717	778	839	900	961	1031		6.35
12.0	573	614	675	737	800	863	927	991	1077	1077	6.45
12.5	587	629	692	757	822	887	953	1020	1109	1122	6.50
13.0	600	643	709	776	843	911	979	1048	1140	1168	6.55
13.5	612	657	725	794	863	933	1004	1075	1170	1213	6.60
14.0	624	670	740	811	883	955	1028	1101	1200	1258	6.65
14.5	636	683	755	828	902	976	1051	1127	1229	1304	6.70
15.0	647	696	770	845	920	997	1074	1152	1257	1349	6.80

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	4.00	4.20	4.50	4.80	5.10	5.40	5.70	6.00	6.40	6.80	(m)
1.5	99										3.75
2.0	136										3.95
2.5	171	176									4.10
3.0	202	213	216								4.30
3.5	231	245	262								4.50
4.0	260	275	297	309							4.70
4.5	287	304	329	354	359						4.90
5.0	314	332	360	388	411						5.10
5.5	339	359	390	420	451	467					5.30
6.0	363	385	418	452	485	518	527				5.50
6.5	387	411	446	482	518	554	577				5.60
7.0	410	435	473	512	550	589	622				5.70
7.5	431	458	499	540	581	623	664	668			5.75
8.0	452	481	525	568	612	656	700	713			5.80
8.5	473	503	549	595	641	688	734	759			5.90
9.0	492	524	573	621	670	719	768	804			5.95
9.5	511	545	595	646	698	749	801	849			6.00
10.0	529	564	617	671	725	779	833	888	895		6.05
10.5	546	583	639	695	751	808	864	921	940		6.10
11.0	563	602	659	718	777	836	895	954	986		6.20
11.5	579	619	679	740	801	863	925	987	1031		6.25
12.0	595	636	699	762	825	889	953	1018	1077		6.30
12.5	610	653	717	783	849	915	981	1048	1122		6.35
13.0	624	669	736	803	871	940	1009	1078	1168		6.40
13.5	638	684	753	823	893	964	1036	1107	1204	1213	6.45
14.0	652	699	770	842	915	988	1062	1136	1235	1258	6.50
14.5	665	713	786	860	935	1011	1087	1163	1266	1304	6.55
15.0	677	727	802	878	955	1033	1112	1190	1296	1349	6.60

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	4.00	4.20	4.50	4.80	5.10	5.40	5.70	6.00	6.40	6.80	(m)
1.5	99										3.75
2.0	136										3.90
2.5	174	176									4.10
3.0	205	216	218								4.25
3.5	235	248	262								4.45
4.0	265	280	302	309							4.60
4.5	293	310	335	359							4.80
5.0	321	340	367	395	411						5.00
5.5	348	368	399	429	460	467					5.20
6.0	374	396	429	462	496	527					5.40
6.5	399	423	458	494	530	567	577				5.50
7.0	423	449	487	526	564	603	622				5.55
7.5	446	474	515	556	598	639	668				5.65
8.0	469	498	542	586	630	674	713				5.70
8.5	491	522	568	615	661	708	755	759			5.75
9.0	512	545	594	643	692	741	791	804			5.80
9.5	533	567	619	670	722	774	826	849			5.85
10.0	553	589	643	697	751	806	860	895			5.90
10.5	572	610	666	723	780	837	894	940			5.95
11.0	591	630	689	748	807	867	927	986			6.00
11.5	609	650	711	772	834	896	959	1022	1031		6.05
12.0	627	669	732	796	861	925	990	1055	1077		6.10
12.5	644	687	753	819	886	953	1021	1089	1122		6.15
13.0	660	705	773	842	911	981	1051	1121	1168		6.20
13.5	676	722	793	864	936	1008	1080	1153	1213		6.25
14.0	691	739	812	886	960	1034	1109	1184	1258		6.30
14.5	706	756	831	906	983	1060	1137	1214	1304		6.35
15.0	721	772	849	927	1005	1084	1164	1244	1349		6.40

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	4.00	4.20	4.50	4.80	5.10	5.40	5.70	6.00	6.40	6.80	(m)
1.5	99										3.70
2.0	136										3.85
2.5	176	176									4.05
3.0	208	218									4.20
3.5	239	253	262								4.35
4.0	270	285	307	309							4.55
4.5	300	317	342	359							4.75
5.0	329	347	375	403	411						4.90
5.5	357	377	408	439	467						5.10
6.0	384	407	440	473	507	527					5.30
6.5	411	435	471	507	543	577					5.40
7.0	437	463	502	540	579	618	622				5.45
7.5	462	490	531	573	614	656	668				5.50
8.0	487	516	560	604	649	693	713				5.55
8.5	511	542	588	635	682	729	759				5.60
9.0	534	567	616	665	715	765	804				5.65
9.5	556	591	643	695	747	800	849				5.70
10.0	578	616	669	724	779	834	889	895			5.75
10.5	600	638	695	752	810	867	925	940			5.80
11.0	621	660	720	780	840	900	960	986			5.85
11.5	641	682	744	807	869	932	995	1031			5.90
12.0	661	703	768	833	898	964	1029	1077			5.95
12.5	680	724	791	859	926	994	1063	1122			6.00
13.0	698	744	814	884	954	1025	1095	1166	1168		6.05
13.5	717	764	836	908	981	1054	1128	1201	1213		6.05
14.0	734	783	858	932	1008	1083	1159	1235	1258		6.10
14.5	751	802	879	956	1034	1112	1190	1269	1304		6.15
15.0	768	820	899	979	1059	1139	1220	1301	1349		6.20

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.31 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

3000 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	4.50	4.80	5.10	5.40	5.70	6.00	6.30	6.60	7.00	7.40	(m)
1.5	109										4.15
2.0	150										4.30
2.5	192										4.50
3.0	226	237									4.70
3.5	261	281	284								4.90
4.0	293	316	334								5.10
4.5	324	349	374	387							5.30
5.0	354	382	410	437	442						5.50
5.5	383	413	444	474	501						5.70
6.0	411	444	477	510	543	562					5.90
6.5	437	473	509	545	580	616	627				6.10
7.0	463	501	540	578	617	655	689				6.30
7.5	488	529	570	611	652	693	735	739			6.35
8.0	512	555	599	642	686	730	774	790			6.45
8.5	535	581	627	673	719	766	812	840			6.50
9.0	557	606	654	703	752	801	850	890			6.55
9.5	579	629	680	732	783	835	886	938	941		6.65
10.0	600	653	706	760	814	868	922	976	991		6.70
10.5	619	675	731	787	843	900	957	1014	1042		6.75
11.0	639	696	755	813	872	931	990	1050	1092		6.85
11.5	657	717	778	839	900	961	1023	1085	1142		6.90
12.0	675	737	800	863	927	991	1055	1120	1193		6.95
12.5	692	757	822	887	953	1020	1086	1153	1243	1243	7.05
13.0	709	776	843	911	979	1048	1117	1186	1279	1294	7.10
13.5	725	794	863	933	1004	1075	1146	1218	1314	1344	7.15
14.0	740	811	883	955	1028	1101	1175	1249	1349	1394	7.20
14.5	755	828	902	976	1051	1127	1203	1280	1382	1445	7.25
15.0	770	845	920	997	1074	1152	1231	1309	1415	1495	7.35

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	4.50	4.80	5.10	5.40	5.70	6.00	6.30	6.60	7.00	7.40	(m)
1.5	109										4.10
2.0	150										4.30
2.5	192										4.45
3.0	230	237									4.65
3.5	264	284	284								4.85
4.0	297	319	334								5.05
4.5	329	354	379	387							5.20
5.0	360	388	415	442							5.40
5.5	390	420	451	481	501						5.60
6.0	418	452	485	518	551	562					5.80
6.5	446	482	518	554	590	626	627				6.05
7.0	473	512	550	589	627	666	689				6.20
7.5	499	540	581	623	664	705	739				6.25
8.0	525	568	612	656	700	744	788	790			6.35
8.5	549	595	641	688	734	781	826	840			6.40
9.0	573	621	670	719	768	818	867	890			6.45
9.5	595	646	698	749	801	853	905	941			6.55
10.0	617	671	725	779	833	886	942	991			6.60
10.5	639	695	751	808	864	921	979	1036	1042		6.65
11.0	659	718	777	836	895	954	1014	1074	1092		6.70
11.5	679	740	801	863	925	987	1049	1111	1142		6.75
12.0	699	762	825	889	953	1018	1083	1148	1193		6.85
12.5	717	783	849	915	981	1046	1116	1183	1243		6.90
13.0	736	803	871	940	1009	1078	1148	1218	1294		6.95
13.5	753	823	893	964	1036	1107	1179	1252	1344		7.00
14.0	770	842	915	988	1062	1136	1210	1285	1385	1394	7.05
14.5	786	860	935	1011	1087	1163	1240	1318	1421	1445	7.10
15.0	802	878	955	1033	1112	1190	1270	1349	1456	1495	7.15

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	4.50	4.80	5.10	5.40	5.70	6.00	6.30	6.60	7.00	7.40	(m)
1.5	109										4.10
2.0	150										4.25
2.5	192										4.40
3.0	233	237									4.60
3.5	268	284									4.80
4.0	302	325	334								4.95
4.5	335	360	386	387							5.15
5.0	367	395	423	442							5.35
5.5	399	429	460	491	501						5.55
6.0	429	462	496	529	562						5.70
6.5	458	494	530	567	603	627					5.95
7.0	487	526	564	603	642	681	689				6.10
7.5	515	556	598	639	681	722	739				6.15
8.0	542	586	630	674	718	763	790				6.20
8.5	568	615	661	708	755	802	840				6.25
9.0	594	643	692	741	791	841	890				6.30
9.5	619	670	722	774	826	878	931	941			6.40
10.0	643	697	751	806	860	915	970	991			6.45
10.5	666	723	780	837	894	952	1009	1042			6.50
11.0	689	748	807	867	927	987	1047	1092			6.55
11.5	711	772	834	896	959	1022	1084	1142			6.60
12.0	732	796	861	925	990	1055	1121	1187	1193		6.65
12.5	753	819	886	953	1021	1089	1157	1225	1243		6.70
13.0	773	842	911	981	1051	1121	1192	1262	1294		6.75
13.5	793	864	936	1008	1080	1153	1226	1299	1344		6.80
14.0	812	886	960	1034	1109	1184	1259	1335	1394		6.85
14.5	831	906	983	1060	1137	1214	1292	1371	1445		6.90
15.0	849	927	1005	1084	1164	1244	1325	1405	1495		6.95

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	4.50	4.80	5.10	5.40	5.70	6.00	6.30	6.60	7.00	7.40	(m)
1.5	109										4.05
2.0	150										4.20
2.5	192										4.40
3.0	236	237									4.55
3.5	272	284									4.70
4.0	307	330	334								4.90
4.5	342	367	387								5.05
5.0	375	403	431	442							5.25
5.5	408	439	469	500	501						5.45
6.0	440	473	507	540	562						5.60
6.5	471	507	543	580	616	627					5.80
7.0	502	540	579	618	657	689					5.95
7.5	531	573	614	656	698	739					6.00
8.0	560	604	649	693	738	782	790				6.05
8.5	588	635	682	729	777	824	840				6.15
9.0	616	665	715	765	815	865	890				6.20
9.5	643	695	747	800	852	905	941				6.25
10.0	669	724	779	834	889	944	991				6.30
10.5	695	752	810	867	925	983	1041	1042			6.35
11.0	720	780	840	900	960	1021	1082	1092			6.40
11.5	744	807	869	932	995	1058	1122	1142			6.40
12.0	768	833	898	964	1029	1095	1161	1193			6.45
12.5	791	859	926	994	1063	1131	1200	1243			6.50
13.0	814	884	954	1025	1095	1166	1238	1294			6.55
13.5	836	908	981	1054	1128	1201	1275	1344			6.60
14.0	858	932	1008	1083	1159	1235	1312	1388	1394		6.65
14.5	879	956	1034	1112	1190	1269	1348	1427	1445		6.70
15.0	899	979	1059	1139	1220	1301	1383	1465	1495		6.75

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.32 - BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION (kN/m)

3600 mm

A SAND AND GRAVEL $K\mu' = 0.165$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	5.40	5.70	6.00	6.30	6.60	6.90	7.20	7.60	8.00	8.40	(m)
1.5	129										4.85
2.0	176										5.00
2.5	225										5.20
3.0	270										5.40
3.5	320	330									5.60
4.0	360	383	386								5.75
4.5	399	425	444								5.95
5.0	437	465	493	505							6.15
5.5	474	505	535	566	569						6.35
6.0	510	543	576	610	636						6.55
6.5	545	580	616	652	689	706					6.75
7.0	578	617	655	694	733	772	779				7.00
7.5	611	652	693	735	776	816	855				7.20
8.0	642	686	730	774	818	862	907	934			7.40
8.5	673	719	766	812	859	906	953	1002			7.55
9.0	703	752	801	850	899	949	998	1062			7.60
9.5	732	783	835	886	938	990	1043	1112	1122		7.70
10.0	760	814	868	922	976	1031	1086	1159	1183		7.75
10.5	787	843	900	957	1014	1071	1128	1205	1243		7.80
11.0	813	872	931	990	1050	1110	1169	1250	1303		7.90
11.5	839	900	961	1023	1085	1147	1210	1293	1364		7.95
12.0	863	927	991	1055	1120	1184	1249	1336	1424	1424	8.05
12.5	887	953	1020	1086	1153	1221	1288	1378	1469	1484	8.10
13.0	911	979	1048	1117	1186	1256	1326	1419	1513	1545	8.15
13.5	933	1004	1075	1146	1218	1290	1363	1460	1557	1605	8.20
14.0	955	1028	1101	1175	1249	1324	1399	1499	1600	1665	8.30
14.5	976	1051	1127	1203	1280	1357	1434	1537	1641	1726	8.35
15.0	997	1074	1152	1231	1309	1389	1468	1575	1682	1786	8.40

B SATURATED TOP SOIL $K\mu' = 0.15$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	5.40	5.70	6.00	6.30	6.60	6.90	7.20	7.60	8.00	8.40	(m)
1.5	129										4.80
2.0	176										5.00
2.5	225										5.15
3.0	276										5.35
3.5	323	330									5.55
4.0	364	386									5.70
4.5	404	429	444								5.90
5.0	443	471	499	505							6.10
5.5	481	512	542	569							6.30
6.0	518	551	585	618	636						6.50
6.5	554	590	626	662	698	706					6.70
7.0	589	627	666	705	744	779					6.90
7.5	623	664	705	747	789	830	855				7.10
8.0	656	700	744	788	832	877	921	934			7.30
8.5	688	734	781	828	875	922	969	1002			7.45
9.0	719	768	818	867	917	966	1016	1062			7.50
9.5	749	801	853	905	957	1010	1062	1122			7.55
10.0	779	833	888	942	997	1052	1107	1181	1183		7.65
10.5	808	864	921	979	1036	1094	1151	1228	1243		7.70
11.0	836	895	954	1014	1074	1134	1194	1275	1303		7.75
11.5	863	925	987	1049	1111	1174	1237	1321	1364		7.85
12.0	889	953	1018	1083	1148	1213	1278	1366	1424		7.90
12.5	915	981	1048	1116	1183	1251	1319	1410	1484		7.95
13.0	940	1009	1078	1148	1218	1288	1359	1453	1545		8.00
13.5	964	1036	1107	1179	1252	1325	1398	1495	1593	1605	8.05
14.0	988	1062	1136	1210	1285	1360	1436	1537	1638	1665	8.15
14.5	1011	1087	1163	1240	1318	1395	1473	1577	1682	1726	8.20
15.0	1033	1112	1190	1270	1349	1429	1510	1617	1725	1786	8.25

C ORDINARY CLAY $K\mu' = 0.13$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	5.40	5.70	6.00	6.30	6.60	6.90	7.20	7.60	8.00	8.40	(m)
1.5	129										4.80
2.0	176										4.95
2.5	225										5.10
3.0	276										5.30
3.5	327	330									5.45
4.0	369	386									5.65
4.5	411	436	444								5.80
5.0	451	479	505								6.00
5.5	491	521	552	569							6.20
6.0	529	562	596	629	636						6.40
6.5	567	603	639	675	706						6.60
7.0	603	642	681	720	759	779					6.75
7.5	639	681	722	764	806	846	855				7.00
8.0	674	718	763	807	851	896	934				7.20
8.5	708	755	802	849	896	943	991	1002			7.30
9.0	741	791	841	890	940	990	1040	1062			7.35
9.5	774	826	878	931	983	1036	1089	1122			7.40
10.0	806	860	915	970	1026	1081	1136	1183			7.50
10.5	837	894	952	1009	1067	1125	1183	1243			7.55
11.0	867	927	987	1047	1108	1168	1229	1303			7.60
11.5	896	959	1022	1084	1147	1211	1274	1358	1364		7.65
12.0	925	990	1055	1121	1187	1252	1318	1406	1424		7.70
12.5	953	1021	1089	1157	1225	1293	1362	1453	1484		7.75
13.0	981	1051	1121	1192	1262	1333	1404	1499	1545		7.80
13.5	1008	1080	1153	1226	1299	1373	1446	1545	1605		7.85
14.0	1034	1109	1184	1259	1335	1411	1487	1589	1665		7.90
14.5	1060	1137	1214	1292	1371	1449	1528	1633	1726		7.95
15.0	1084	1164	1244	1325	1405	1486	1568	1676	1786	1786	8.05

D SATURATED CLAY $K\mu' = 0.11$ DENSITY = 1900 kg/m³

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, (m)	TRENCH WIDTH AT TOP OF PIPE (m)										TRANSITION WIDTH
	5.40	5.70	6.00	6.30	6.60	6.90	7.20	7.60	8.00	8.40	(m)
1.5	129										4.75
2.0	176										4.90
2.5	225										5.10
3.0	276										5.25
3.5	330										5.40
4.0	375	386									5.55
4.5	417	443	444								5.75
5.0	459	487	505								5.90
5.5	500	531	562	569							6.10
6.0	540	574	608	636							6.30
6.5	580	616	652	689	706						6.45
7.0	618	657	696	736	775	779					6.65
7.5	656	698	740	781	823	855					6.85
8.0	693	738	782	827	871	916	934				7.05
8.5	729	777	824	871	918	966	1002				7.15
9.0	765	815	865	915	965	1015	1062				7.20
9.5	800	852	905	958	1010	1063	1116	1122			7.25
10.0	834	889	944	1000	1055	1111	1166	1183			7.30
10.5	867	925	983	1041	1099	1158	1216	1243			7.35
11.0	900	960	1021	1082	1143	1204	1265	1303			7.40
11.5	932	995	1058	1122	1165	1249	1313	1364			7.45
12.0	964	1029	1095	1161	1227	1293	1360	1424			7.50
12.5	994	1063	1131	1200	1268	1337	1406	1484			7.55
13.0	1025	1095	1166	1236	1309	1381	1462	1545			7.60
13.5	1054	1128	1201	1275	1349	1423	1497	1597	1605		7.65
14.0	1083	1159	1235	1312	1388	1465	1542	1645	1665		7.70
14.5	1112	1190	1269	1348	1427	1506	1586	1692	1726		7.75
15.0	1139	1220	1301	1383	1465	1547	1629	1739	1786		7.80

Notes:

1. *For Densities other than shown, loads are determined by multiplying values in table by ratio of actual density shown*
2. *Transition loads(White -on -black values) and widths are based upon $K\mu' = 0.19$, $r_{sd}\,p = 0.5$ in the embankment equation*
3. *Interpolate for intermediate heights of backfill and/or trench widths.*

Table 4.33 - DESIGN VALUES OF SETTLEMENT RATIO

Installation and Foundation Condition	Settlement Ratio r_{sd} Usual Range	Settlement Ratio r_{sd} Design Value
Positive Projecting	0.0 to +1.0	
Rock or Unyielding Soil	+1.0	+1.0
*Ordinary Soil	+0.5 to +0.8	+0.7
Yielding Soil	0.0 to +0.5	+0.3
Zero Projecting		0.0
Negative Projecting	−1.0 to 0.0	
$p' = 0.5$		−0.1
$p' = 1.0$		−0.3
$p' = 1.5$		−0.5
$p' = 2.0$		−1.0

* *The value of the settlement ratio depends on the degree of compaction of the fill material adjacent to the sides of the pipe. With good construction methods resulting in proper compaction of bedding and sidefill materials, a settlement ratio design value of + 0.5 is recommended.*

Table 4.34 - DESIGN VALUES OF COEFFICIENT OF COHESION

Type of Soil	Values of c (P_a)
Clay	
Soft	1900
Medium	12000
Hard	48000
Sand	
Loose Dry	0
Silty	4800
Dense	14400
Top Soil	
Saturated	4800

Table 4.35 - HIGHWAY LOADS ON CIRCULAR PIPE (Kilonewtons per Linear Metre)

Designated Diameter (mm)	Height of Fill H Above Top of Pipe in Metres														Designated Diameter (mm)
	Bc (m)	0.15	0.30	0.45	0.60	0.75	0.90	1.05	1.20	1.50	1.80	2.10	2.40	2.70	
300	0.405	55.2	30.3	21.4	15.8	11.1	8.0	6.6	5.5	4.2	3.4	2.8	2.3	1.9	300
375	0.495	61.9	34.4	25.4	18.7	13.1	9.6	7.9	6.6	5.1	4.1	3.4	2.8	2.3	375
450	0.585	60.0	38.1	28.7	21.3	15.0	10.9	9.0	7.6	5.8	4.7	3.8	3.2	2.8	450
525	0.670	57.2	41.1	32.0	23.6	16.8	12.3	10.1	8.5	6.6	5.3	4.4	3.6	3.1	525
600	0.760	59.8	43.9	35.0	26.0	18.5	13.6	11.1	9.3	7.3	5.8	4.8	4.1	3.5	600
675	0.850	56.6	42.9	37.8	28.2	20.1	14.7	12.1	10.2	8.2	6.4	5.3	4.4	3.8	675
750	0.940	52.8	41.3	40.4	30.2	21.6	15.8	13.0	10.9	8.6	7.0	5.7	4.8	4.1	750
825	1.025	49.5	42.7	43.0	32.1	23.1	16.9	14.0	11.8	9.2	7.4	6.1	5.3	4.4	825
900	1.120	46.5	41.0	42.7	34.0	24.4	17.9	14.9	12.5	9.8	8.0	6.6	5.5	4.8	900
975	1.205	43.9	39.0	41.6	35.6	25.7	18.8	15.6	13.3	10.4	8.5	7.0	6.0	5.1	975
1050	1.295	41.7	37.2	40.4	37.4	26.8	19.8	16.5	13.9	10.9	8.9	7.4	6.3	5.4	1050
1200	1.475	37.8	34.0	38.2	36.2	29.0	21.4	17.9	15.2	12.0	9.8	8.2	6.9	6.0	1200
1350	1.650	34.4	31.4	36.3	34.4	29.9	23.1	19.3	16.3	13.0	10.7	8.9	7.6	6.4	1350
1500	1.828	31.7	29.0	35.7	32.8	28.6	24.5	20.4	17.4	13.9	11.4	9.5	8.2	7.0	1500
1650	2.005	29.3	27.0	36.8	31.5	27.4	23.9	21.6	18.4	14.7	12.1	10.2	8.6	7.4	1650
1800	2.185	27.3	25.2	37.6	32.0	26.4	22.9	22.0	19.4	15.5	12.8	10.8	9.2	7.9	1800
1950	2.365	25.5	23.8	38.4	32.7	25.8	22.2	21.3	20.3	16.2	13.4	11.4	9.6	8.3	1950
2100	2.540	24.1	22.5	39.8	33.4	26.4	21.3	20.6	19.8	16.9	14.0	11.8	10.1	8.8	2100
2250	2.720	22.6	21.3	36.9	34.0	27.0	21.4	19.8	19.1	17.7	14.6	12.4	10.5	9.2	2250
2400	2.895	21.4	20.1	35.2	33.4	27.4	21.9	19.4	18.5	18.2	15.2	12.8	10.9	9.5	2400
2550	3.075	20.3	19.3	33.6	32.0	27.9	22.3	19.7	18.1	18.8	15.6	13.3	11.4	9.9	2550
2700	3.250	19.3	18.4	32.1	30.5	26.7	22.8	20.1	17.9	19.4	16.2	13.7	11.8	10.2	2700
3000	3.555	17.7	16.8	29.5	28.2	24.8	21.6	20.7	18.7	20.4	17.1	14.4	12.5	10.9	3000
3600	4.275	14.9	14.3	25.4	24.4	21.6	19.0	18.2	17.7	21.4	18.7	15.9	13.7	12.1	3600

DATA: 1. Unsurfaced Roadway.
2. Loads – AASHTO HS20, two 7250 kg dual-tired wheels, 1.2 m on centres, or alternate loading, for 5450 kg dual tired-wheels, 1.2 m on centres with impact included.

NOTES: 1. Interpolate for intermediate pipe sizes and/or fill heights.
2. Critical loads: a. For H = 0.15 m and 0.30 m, a single 7250 kg dual-tired wheel. b. For H = 0.45 m through 1.20 m, two 7250 kg dual-tired wheels, 1.2m on centres.
c. For H > 1.20 m alternate loading.
3. Truck live loads for H = 3.00 m or more are insignificant

Table 4.36 -HIGHWAY LOADS ON HORIZONTAL PIPE (Kilonewtons per Linear Metre)

Designated Diameter (mm)	Height of Fill H Above Top of Pipe in Metres														Designated Diameter (mm)
	Bc (m)	0.15	0.30	0.45	0.60	0.75	0.90	1.05	1.20	1.50	1.80	2.10	2.40	2.70	
300	0.405	55.2	30.3	21.4	15.8	11.1	8.0	6.6	5.5	4.2	3.4	2.8	2.3	1.9	300
375	0.495	61.9	34.4	25.4	18.7	13.1	9.6	7.9	6.6	5.1	4.1	3.4	2.8	2.3	375
450	0.585	60.0	38.1	28.7	21.3	15.0	10.9	9.0	7.6	5.8	4.7	3.8	3.2	2.8	450
525	0.670	57.2	41.1	32.0	23.6	16.8	12.3	10.1	8.5	6.6	5.3	4.4	3.6	3.1	525
600	0.760	59.8	43.9	35.0	26.0	18.5	13.6	11.1	9.3	7.3	5.8	4.8	4.1	3.5	600
675	0.850	56.6	42.9	37.8	28.2	20.1	14.7	12.1	10.2	8.2	6.4	5.3	4.4	3.8	675
750	0.940	52.8	41.3	40.4	30.2	21.6	15.8	13.0	10.9	8.6	7.0	5.7	4.8	4.1	750
825	1.025	49.5	42.7	43.0	32.1	23.1	16.9	14.0	11.8	9.2	7.4	6.1	5.3	4.4	825
900	1.120	46.5	41.0	42.7	34.0	24.4	17.9	14.9	12.5	9.8	8.0	6.6	5.5	4.8	900
975	1.205	43.9	39.0	41.6	35.6	25.7	18.8	15.6	13.3	10.4	8.5	7.0	6.0	5.1	975
1050	1.295	41.7	37.2	40.4	37.4	26.8	19.8	16.5	13.9	10.9	8.9	7.4	6.3	5.4	1050
1200	1.475	37.8	34.0	38.2	36.2	29.0	21.4	17.9	15.2	12.0	9.8	8.2	6.9	6.0	1200
1350	1.650	34.4	31.4	36.3	34.4	29.9	23.1	19.3	16.3	13.0	10.7	8.9	7.6	6.4	1350
1500	1.828	31.7	29.0	35.7	32.8	28.6	24.5	20.4	17.4	13.9	11.4	9.5	8.2	7.0	1500
1650	2.005	29.3	27.0	36.8	31.5	27.4	23.9	21.6	18.4	14.7	12.1	10.2	8.6	7.4	1650
1800	2.185	27.3	25.2	37.6	32.0	26.4	22.9	22.0	19.4	15.5	12.8	10.8	9.2	7.9	1800
1950	2.365	25.5	23.8	38.4	32.7	25.8	22.2	21.3	20.3	16.2	13.4	11.4	9.6	8.3	1950
2100	2.540	24.1	22.5	39.8	33.4	26.4	21.3	20.6	19.8	16.9	14.0	11.8	10.1	8.8	2100
2250	2.720	22.6	21.3	36.9	34.0	27.0	21.4	19.8	19.1	17.7	14.6	12.4	10.5	9.2	2250
2400	2.895	21.4	20.1	35.2	33.4	27.4	21.9	19.4	18.5	18.2	15.2	12.8	10.9	9.5	2400
2550	3.075	20.3	19.3	33.6	32.0	27.9	22.3	19.7	18.1	18.8	15.6	13.3	11.4	9.9	2550
2700	3.250	19.3	18.4	32.1	30.5	26.7	22.8	20.1	17.9	19.4	16.2	13.7	11.8	10.2	2700
3000	3.555	17.7	16.8	29.5	28.2	24.8	21.6	20.7	18.7	20.4	17.1	14.4	12.5	10.9	3000
3600	4.275	14.9	14.3	25.4	24.4	21.6	19.0	18.2	17.7	21.4	18.7	15.9	13.7	12.1	3600

DATA: 1. Unsurfaced Roadway.
2. Loads – AASHTO HS20, two 7250 kg dual-tired wheels, 1.2 m on centres, or alternate loading, for 5450 kg dual tired-wheels, 1.2 m on centres with impact included.

NOTES: 1. Interpolate for intermediate pipe sizes and/or fill heights.
2. Critical loads: a. For H = 0.15 m and 0.30 m, a single 7250 kg dual-tired wheel. b. For H = 0.45 m through 1.20 m, two 7250 kg dual-tired wheels, 1.2m on centres.
c. For H > 1.20 m alternate loading.
3. Truck live loads for H = 3.00 m or more are insignificant

Table 4.37 - **HIGHWAY LOADS ON VERTICAL ELLIPTICAL PIPE (Kilonewtons per Linear Metre)**

Designated Rise & Span (mm)	Designated Diameter Equiv. Cir (mm)	Height of Fill H Above Top of Pipe in Metres													Designated Rise & Span (mm)
		0.15	0.30	0.45	0.60	0.75	0.90	1.05	1.20	1.50	1.80	2.10	2.40	2.70	
1150 x 730	900	39.7	32.8	35.9	27.0	19.4	14.3	12.0	10.1	8.0	6.6	5.4	4.5	3.9	1150 x 730
1250 x 795	975	37.4	33.4	37.4	28.2	20.3	15.0	12.5	10.7	8.5	6.9	5.7	4.8	4.1	1250 x 795
1345 x 855	1050	35.3	32.1	36.9	29.3	21.2	15.6	13.1	11.1	8.8	7.1	6.0	5.1	4.4	1345 x 855
1535 x 975	1200	31.8	29.2	34.7	31.4	22.6	16.9	14.2	12.0	9.5	7.9	6.6	5.5	4.8	1535 x 975
1730 x 1095	1350	29.0	26.8	32.8	31.2	24.1	17.9	15.0	12.8	10.2	8.5	7.0	6.0	5.3	1730 x 1095
1920 x 1220	1500	26.7	24.8	31.2	29.8	25.4	19.0	15.9	13.6	10.9	9.0	7.6	6.4	5.5	1920 x 1220
2110 x 1340	1650	24.7	22.9	29.8	28.3	24.8	19.8	16.6	14.3	11.5	9.5	8.0	6.9	6.0	2110 x 1340
2305 x 1465	1800	22.9	21.4	28.2	27.0	23.8	20.7	17.4	14.9	12.0	9.9	8.5	7.1	6.3	2305 x 1465
2495 x 1585	1950	21.3	20.1	27.7	25.8	22.8	20.0	18.1	15.5	12.5	10.4	8.8	7.6	6.6	2495 x 1585
2690 x 1705	2100	20.0	19.0	28.0	24.8	21.9	19.1	18.5	16.0	13.0	10.8	9.2	7.9	6.9	2690 x 1705
2880 x 1830	2250	18.8	17.9	28.5	24.5	21.0	18.5	17.8	16.5	13.4	11.2	9.5	8.2	7.1	2880 x 1830
3070 x 1950	2400	17.8	16.9	28.7	24.8	20.3	17.8	16.9	16.6	13.9	11.5	9.9	8.5	7.4	3070 x 1950
3265 x 2075	2550	16.9	16.2	28.5	25.1	20.1	17.2	16.6	16.6	14.2	12.0	10.1	8.8	7.6	3265 x 2075
3455 x 2195	2700	16.2	15.5	27.3	25.2	20.3	16.6	16.2	15.8	14.6	12.3	10.4	9.0	7.9	3455 x 2195
3840 x 2440	3000	14.7	14.2	24.9	24.1	20.9	16.8	15.2	14.7	15.2	12.8	10.9	9.5	8.3	3840 x 2440
4610 x 2925	3600	12.4	12.0	21.4	20.7	18.4	16.2	15.8	14.2	16.3	13.9	11.8	10.4	9.0	4610 x 2925

DATA: 1. Unsurfaced Roadway.
2. Loads – AASHTO HS20, two 7250 kg dual-tired wheels, 1.2 m on centres, or alternate loading, for 5450 kg dual tired-wheels, 1.2 m on centres with impact included.

NOTES: 1. Interpolate for intermediate pipe sizes and/or fill heights.
2. Critical loads: a. For H = 0.15 m and 0.30 m, a single 7250 kg dual-tired wheel. b. For H = 0.45 m through 1.20 m, two 7250 kg dual-tired wheels, 1.2m on centres.
c. For H > 1.20 m alternate loading.
3. Truck live loads for H = 3.00 m or more are insignificant.

Table 4.38 - **RAILROAD LOADS ON CIRCULAR PIPE (Kilonewtons per Linear Metre)**

	Height of Fill H Above Top of Pipe in Metres															
SIZE	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.6	4.2	4.8	5.4	6.0	7.5	9.0
300	56.2	52.7	47.4	41.8	36.3	31.1	26.7	22.9	19.5	16.9	13.6	11.2	9.1	7.6	6.5	4.5	3.3
375	68.6	64.1	57.6	51.1	44.3	38.0	32.5	27.9	23.9	20.6	16.6	13.6	11.2	9.3	7.9	5.4	3.9
450	80.9	75.8	68.0	60.3	52.2	47.8	38.4	33.0	28.2	24.3	19.5	16.0	13.0	11.0	9.5	6.4	4.6
525	93.3	87.2	78.4	69.3	60.1	51.6	44.2	38.0	32.5	28.0	22.5	18.4	15.0	12.6	10.8	7.4	5.3
600	105.5	98.7	88.8	78.6	68.0	58.4	50.0	42.9	36.7	31.8	25.4	20.9	17.0	14.3	12.2	8.4	6.0
675	118.0	110.3	99.2	87.7	75.9	65.2	55.9	48.0	41.1	35.5	28.4	23.2	19.1	16.0	13.8	9.3	6.7
750	130.2	121.8	109.5	96.8	84.0	71.9	61.7	53.0	45.4	39.0	31.3	25.7	21.1	17.7	15.2	10.4	7.4
825	142.5	133.4	119.9	106.0	91.9	78.7	67.6	58.0	49.6	42.8	34.4	28.2	22.9	19.2	16.6	11.3	8.1
900	154.9	144.9	130.2	121.3	99.9	85.5	73.4	63.1	53.9	46.5	37.3	30.7	24.9	20.9	18.0	12.2	8.8
975	167.1	156.7	140.9	124.3	107.9	92.5	79.4	68.1	58.0	50.2	40.4	33.3	27.1	22.6	19.3	13.4	9.8
1050	179.7	167.3	150.9	133.4	115.7	99.2	85.2	73.0	62.4	53.9	43.2	35.5	29.0	24.3	20.9	14.3	10.2
1200	204.5	190.6	171.0	151.7	131.7	112.8	96.8	83.0	71.1	61.4	49.1	40.3	33.0	27.6	23.7	16.1	11.6
1350	229.3	213.8	192.1	170.4	147.5	126.4	108.5	93.0	79.6	68.8	55.2	45.2	36.9	31.0	26.7	18.0	13.0
1500	254.1	237.1	213.8	189.0	162.7	140.1	120.1	103.0	88.2	76.1	61.0	50.0	40.9	34.2	29.4	20.0	14.4
1650	277.3	260.3	234.0	206.1	179.7	153.7	131.9	113.1	96.8	83.5	66.9	55.0	44.9	37.7	32.4	22.0	15.8
1800	302.1	283.5	254.1	224.7	195.2	167.3	143.4	123.2	105.4	91.0	72.9	59.8	48.8	40.9	35.2	23.9	17.3
1950	327.0	306.8	275.8	243.3	210.7	181.3	154.9	133.1	113.9	98.4	78.9	64.8	52.8	44.3	38.1	25.9	18.6
2100	351.7	328.5	296.0	261.9	226.2	195.2	167.3	143.2	122.4	105.7	84.8	69.6	56.9	47.6	40.9	27.9	20.0
2250	376.5	351.7	316.1	280.4	243.3	207.6	178.2	153.2	131.1	113.1	90.8	74.4	60.7	51.0	43.7	29.7	21.4
2400	401.3	375.0	337.8	299.0	258.8	221.6	190.6	162.7	139.6	120.5	96.7	79.3	64.8	54.2	46.6	31.8	22.8
2550	426.1	398.2	357.9	316.1	274.3	235.6	201.4	173.5	148.1	127.8	102.6	84.1	68.8	57.6	49.6	33.8	24.2
2700	450.9	421.4	379.6	334.7	291.3	249.5	213.8	182.8	156.5	135.4	108.6	89.1	72.7	61.0	52.4	35.6	25.6
2850	467.9	438.5	393.6	348.6	302.1	258.8	221.6	190.6	162.7	140.5	112.8	92.5	75.6	63.4	54.4	37.0	26.5
3000	492.7	461.7	415.2	367.2	317.6	272.7	233.9	199.9	172.0	148.1	118.7	97.5	79.5	66.6	57.3	39.0	27.9
3600	591.9	553.1	497.4	440.0	381.2	327.0	280.4	240.2	206.1	178.2	142.4	116.8	95.4	80.0	68.6	46.8	33.5

Cooper E85 design loading consisting of four 378 kN axles space 1.5 metres c/c. Locomotive load assumed uniformly distributed over an area 2.4m x 6.0m. Weight of track structure assumed to be 2.9KN/m. Impact included. Height of fill measured from top of pipe to bottom of ties. Interpolate for intermediate pipe sizes and or fill heights.

Table 4.38 - RAILROAD LOADS ON HORIZONTAL PIPE (Kilonewtons per Linear Metre)

	Height of Fill H Above Top of Pipe in Metres																
PIPE SIZE	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.6	4.2	4.8	5.4	6.0	7.5	9.0
365 x 575	100.2	93.9	84.3	74.5	64.6	55.5	47.6	40.8	34.9	30.1	24.2	19.8	16.1	13.6	11.8	7.9	5.7
490 x 770	128.4	120.2	108.0	95.6	82.9	71.0	60.9	52.2	44.8	38.6	31.0	25.4	20.8	17.4	14.9	10.2	7.3
550 x 865	144.3	135.0	121.3	107.4	93.1	79.8	68.5	58.7	50.2	43.4	34.7	28.5	23.2	19.5	16.7	11.5	8.2
610 x 960	159.6	149.8	134.6	119.2	103.3	88.5	75.9	65.1	55.8	48.2	38.6	31.6	25.9	21.7	18.6	12.7	9.1
670 x 1055	173.5	182.7	146.6	129.5	112.3	96.4	82.6	70.8	60.6	52.4	42.0	34.3	28.2	23.6	20.3	13.8	9.9
730 x 1150	190.6	178.2	159.6	141.3	122.6	105.1	90.2	76.1	66.2	57.0	46.5	37.5	30.7	23.7	22.0	15.0	10.8
795 x 1250	206.1	192.1	173.5	153.1	132.8	113.7	97.6	83.8	71.7	61.8	49.6	40.8	33.2	29.9	23.9	16.3	11.5
855 x 1345	221.6	207.6	185.9	164.2	143.0	122.6	105.1	90.2	77.2	66.6	53.5	43.8	35.8	30.1	25.7	17.5	12.8
975 x 1535	249.5	234.0	210.7	185.9	181.1	138.1	110.5	101.6	86.9	75.1	60.3	49.4	40.3	33.8	29.0	19.8	14.1
1095 x 1730	282.0	263.4	237.1	209.2	181.3	154.9	133.6	114.5	98.1	84.6	67.9	55.6	45.4	38.1	32.7	22.3	16.0
1220 x 1920	313.0	292.8	263.4	232.4	201.4	173.5	148.4	127.4	109.1	94.1	75.5	62.0	50.5	42.5	36.4	24.8	17.8
1340 x 2110	340.9	319.2	286.6	254.1	220.0	189.0	161.1	138.8	118.8	102.6	82.3	67.6	55.2	46.2	39.7	27.0	19.4
1465 x 2305	373.4	348.6	313.0	277.3	240.2	206.1	176.6	151.7	129.8	112.0	89.9	73.8	60.3	50.5	43.4	29.4	21.1
1585 x 2495	401.3	375.0	337.8	299.0	258.8	221.6	190.6	162.7	139.6	120.5	96.7	79.3	64.8	54.2	46.6	31.8	22.8
1705 x 2690	432.3	404.4	364.1	322.3	278.9	240.2	206.1	176.6	150.8	129.8	104.3	85.5	69.9	58.6	50.4	34.2	24.5
1830 x 2880	461.7	430.7	387.4	342.4	297.5	255.7	218.5	187.5	161.1	138.5	111.1	91.1	74.4	62.4	53.6	36.4	26.2
1950 x 3070	492.7	461.7	415.2	367.2	317.6	272.7	234.0	199.9	172.0	148.1	118.7	97.4	79.5	66.6	57.3	39.0	27.9
2075 x 3265	519.1	485.0	436.9	385.8	334.7	286.6	246.4	210.7	181.3	156.5	125.0	102.6	83.8	70.2	60.3	41.1	29.4
2195 x 3455	548.5	514.4	461.7	407.5	354.8	303.7	260.3	223.1	190.6	164.2	132.3	108.6	88.6	74.4	63.8	43.4	31.1
2440 x 3840	608.9	570.2	512.9	452.4	392.0	336.2	288.2	247.9	212.3	182.8	146.7	120.4	98.2	82.4	70.8	48.2	34.6
2925 x 4610	725.1	678.7	610.5	539.2	467.9	401.3	344.0	294.4	252.6	218.5	175.1	143.3	117.0	98.1	84.3	57.3	40.9

Cooper E85 design loading consisting of four 378 kN axles space 1.5 metres c/c. Locomotive load assume uniformly distributed over an area 2.4m x 6.0m. Weight of track structure assumed to be 2.9 kN/m. Impact included. Weight of fill measured from top of pipe to bottom of ties. Interpolate for intermediate pipe sizes and/or fill heights.

Table 4.40A - BEDDING FACTOR FOR CIRCULAR PIPE POSTIVE PROJECTING EMBANKMENT INSTALLATIONS

$\frac{H}{B_c}$	TYPE 1 (CLASS B) BEDDING				
P= 0.9					
	$r_{sd}p=0$	0.1	0.3	0.5	1.0
0.5	4.19	3.82	3.81	3.81	3.81
1.0	3.34	3.00	3.00	3.00	3.00
1.5	3.13	2.83	2.71	2.71	2.71
2.0	3.03	2.77	2.67	2.61	2.61
3.0	2.94	2.72	2.62	2.56	2.50
5.0	2.88	2.67	2.58	2.52	2.46
10.0	2.83	2.64	2.55	2.50	2.44
15.0	2.81	2.63	2.54	2.49	2.43
P= 0.7					
	$r_{sd}p=0$	0.1	0.3	0.5	1.0
0.5	3.00	2.88	2.88	2.87	2.87
1.0	2.73	2.58	2.58	2.58	2.58
1.5	2.65	2.50	2.44	2.44	2.44
2.0	2.61	2.48	2.42	2.39	2.39
3.0	2.58	2.45	2.40	2.36	2.32
5.0	2.55	2.43	2.38	2.35	2.31
10.0	2.53	2.42	2.36	2.33	2.30
15.0	2.52	2.41	2.36	2.33	2.29
P= 0.5					
	$r_{sd}p=0$	0.1	0.3	0.5	1.0
0.5	2.37	2.33	2.33	2.33	2.33
1.0	2.31	2.25	2.25	2.25	2.25
1.5	2.28	2.23	2.20	2.20	2.20
2.0	2.27	2.22	2.20	2.19	2.18
3.0	2.26	2.22	2.19	2.18	2.16
5.0	2.26	2.21	2.19	2.17	2.16
10.0	2.25	2.20	2.18	2.17	2.15
15.0	2.25	2.20	2.18	2.17	2.15
P= 0.3					
	$r_{sd}p=0$	0.1	0.3	0.5	1.0
0.5	2.11	2.10	2.10	2.10	2.10
1.0	2.10	2.08	2.08	2.08	2.08
1.5	2.09	2.08	2.07	2.07	2.07
2.0	2.09	2.08	2.07	2.07	2.07
3.0	2.09	2.08	2.07	2.07	2.06
5.0	2.09	2.08	2.07	2.07	2.06
10.0	2.09	2.08	2.07	2.07	2.06
15.0	2.09	2.08	2.07	2.07	2.06
Zero Projecting					
	2.02				

Table 4.40B - BEDDING FACTOR FOR CIRCULAR PIPE POSTIVE PROJECTING EMBANKMENT INSTALLATIONS

$\frac{H}{B_c}$	TYPE 2 (CLASS C) BEDDING					CLASS D BEDDING				
					$p = 0.9$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	3.01	2.82	2.82	2.82	2.82	1.51	1.46	1.46	1.46	1.46
1.0	2.55	2.35	2.35	2.35	2.35	1.39	1.33	1.33	1.33	1.33
1.5	2.42	2.26	2.16	2.16	2.16	1.35	1.29	1.27	1.27	1.27
2.0	2.37	2.20	2.14	2.10	2.10	1.33	1.28	1.26	1.24	1.24
3.0	2.31	2.17	2.10	2.07	2.02	1.31	1.27	1.24	1.23	1.22
5.0	2.27	2.14	2.08	2.04	2.00	1.30	1.26	1.24	1.22	1.21
10.0	2.24	2.12	2.06	2.03	1.99	1.29	1.25	1.23	1.22	1.20
15.0	2.23	2.10	2.05	2.02	1.98	1.29	1.25	1.23	1.21	1.20
					$p = 0.7$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	2.35	2.27	2.27	2.27	2.27	1.33	1.30	1.30	1.30	1.30
1.0	2.18	2.08	2.08	2.08	2.08	1.27	1.24	1.24	1.24	1.24
1.5	2.13	2.03	1.99	1.99	1.99	1.25	1.22	1.20	1.20	1.20
2.0	2.10	2.01	1.97	1.95	1.95	1.24	1.21	1.20	1.19	1.19
3.0	2.08	2.00	1.96	1.94	1.91	1.24	1.21	1.19	1.18	1.17
5.0	2.06	1.98	1.95	1.93	1.90	1.23	1.20	1.19	1.18	1.17
10.0	2.05	1.98	1.94	1.92	1.89	1.22	1.20	1.18	1.18	1.17
15.0	2.04	1.97	1.94	1.91	1.89	1.22	1.20	1.18	1.18	1.17
					$p = 0.5$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	1.94	1.92	1.92	1.92	1.92	1.19	1.18	1.18	1.18	1.18
1.0	1.90	1.86	1.86	1.86	1.86	1.17	1.16	1.16	1.16	1.16
1.5	1.88	1.85	1.83	1.83	1.83	1.16	1.15	1.14	1.14	1.14
2.0	1.88	1.84	1.83	1.82	1.82	1.16	1.15	1.14	1.14	1.14
3.0	1.87	1.84	1.82	1.81	1.80	1.16	1.15	1.14	1.14	1.13
5.0	1.86	1.83	1.82	1.81	1.80	1.16	1.14	1.14	1.13	1.13
10.0	1.86	1.83	1.81	1.80	1.79	1.15	1.14	1.14	1.13	1.13
15.0	1.86	1.83	1.81	1.80	1.79	1.15	1.14	1.14	1.13	1.13
					$p = 0.3$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	1.76	1.76	1.76	1.76	1.12	1.12	1.11	1.11	1.11	1.11
1.0	1.76	1.75	1.75	1.75	1.11	1.11	1.11	1.11	1.11	1.11
1.5	1.75	1.74	1.74	1.74	1.74	1.11	1.11	1.11	1.11	1.11
2.0	1.75	1.74	1.74	1.74	1.11	1.11	1.11	1.11	1.11	1.11
3.0	1.75	1.74	1.74	1.73	1.73	1.11	1.11	1.11	1.11	1.10
5.0	1.75	1.74	1.74	1.73	1.73	1.11	1.11	1.11	1.11	1.10
10.0	1.75	1.74	1.74	1.74	1.73	1.11	1.11	1.11	1.10	1.10
15.0	1.75	1.74	1.74	1.73	1.73	1.11	1.11	1.11	1.10	1.10
					ZERO PROJECTING					
	1.70					1.10				

Table 4.41 - **BEDDING FACTOR FOR VERTIVCAL ELIPTICALPIPE POSTIVE PROJECTING EMBANKMENT INSTALLATIONS**

$\frac{H}{B_c}$	CLASS B BEDDING					CLASS C BEDDING					$\frac{H}{B_c}$
						p = 0.9					
	$r_{sd}p=0$	0.1	0.3	0.5	1.0	$r_{sd}p=0$	0.1	0.3	0.5	1.0	
0.5	—	—	—	—	—	—	—	—	—	—	0.5
1.0	—	6.57	6.57	6.57	6.57	—	4.01	4.01	4.01	4.01	1.0
1.5	—	5.45	5.03	4.70	4.70	5.78	3.57	3.38	3.23	3.23	1.5
2.0	9.20	5.00	4.15	3.88	3.88	4.87	3.36	2.96	2.82	2.82	2.0
3.0	7.08	4.44	3.89	3.54	3.26	4.20	3.10	2.82	2.64	2.48	3.0
5.0	6.00	4.15	3.61	3.37	3.13	3.79	2.96	2.68	2.54	2.40	5.0
10.0	5.36	3.78	3.46	3.27	3.03	3.52	2.82	2.59	2.48	2.34	10.0
15.0	5.18	3.86	3.52	3.21	3.00	3.45	2.81	2.57	2.45	2.32	15.0
						p = 0.7					
	$r_{sd}p=0$	0.1	0.3	0.5	1.0	$r_{sd}p=0$	0.1	0.3	0.5	1.0	
0.5	—	—	—	—	—	5.40	4.48	4.48	4.48	4.48	0.5
1.0	5.18	3.54	3.54	3.54	3.54	3.45	2.64	2.64	2.64	2.64	1.0
1.5	4.38	3.36	3.25	3.16	3.16	3.08	2.54	2.47	2.42	2.42	1.5
2.0	4.07	3.27	3.01	2.91	2.91	2.92	2.48	2.33	2.27	2.27	2.0
3.0	3.80	3.13	2.94	2.80	2.68	2.78	2.40	2.29	2.20	2.13	3.0
5.0	3.61	3.05	2.85	2.74	2.63	2.67	2.36	2.23	2.17	2.10	5.0
10.0	3.48	2.97	2.80	2.71	2.59	2.60	2.31	2.22	2.14	2.07	10.0
15.0	3.43	2.95	2.78	2.68	2.58	2.58	2.30	2.21	2.13	2.06	15.0
						p = 0.5					
	$r_{sd}p=0$	0.1	0.3	0.5	1.0	$r_{sd}p=0$	0.1	0.3	0.5	1.0	
0.5	3.10	2.94	2.94	2.94	2.94	2.38	2.29	2.29	2.29	2.29	0.5
1.0	2.77	2.48	2.48	2.48	2.48	2.18	2.00	2.00	2.00	2.00	1.0
1.5	2.67	2.46	2.43	2.40	2.40	2.12	1.98	1.97	1.95	1.95	1.5
2.0	2.63	2.44	2.37	2.34	2.34	2.10	1.97	1.93	1.91	1.91	2.0
3.0	2.59	2.41	2.36	2.31	2.27	2.07	1.96	1.92	1.89	1.86	3.0
5.0	2.55	2.40	2.33	2.30	2.26	2.04	1.95	1.90	1.88	1.85	5.0
10.0	2.53	2.38	2.32	2.29	2.25	2.03	1.94	1.90	1.87	1.84	10.0
15.0	2.52	2.38	2.31	2.28	2.24	2.02	1.93	1.90	1.87	1.84	15.0
						p = 0.3					
	$r_{sd}p=0$	0.1	0.3	0.5	1.0	$r_{sd}p=0$	0.1	0.3	0.5	1.0	
0.5	2.18	2.17	2.16	2.16	2.16	1.80	1.79	1.79	1.79	1.79	0.5
1.0	2.15	2.10	2.10	2.10	2.10	1.78	1.74	1.74	1.74	1.74	1.0
1.5	2.14	2.10	2.09	2.08	2.08	1.77	1.74	1.74	1.73	1.73	1.5
2.0	2.13	2.10	2.08	2.07	2.07	1.77	1.74	1.73	1.73	1.73	2.0
3.0	2.13	2.09	2.08	2.07	2.06	1.76	1.74	1.73	1.72	1.72	3.0
5.0	2.12	2.09	2.08	2.07	2.06	1.76	1.74	1.73	1.72	1.71	5.0
10.0	2.12	2.09	2.08	2.06	2.05	1.76	1.74	1.73	1.72	1.71	10.0
15.0	2.12	2.09	2.07	2.06	2.05	1.76	1.74	1.73	1.72	1.71	15.0
						ZERO PROJECTING					
	1.98					1.66					

Table 4.42 - **BEDDING FACTOR FOR CIRCULAR PIPE POSTIVE PROJECTING EMBANKMENT INSTALLATIONS**

$\frac{H}{B_c}$	CLASS B BEDDING					CLASS C BEDDING					$\frac{H}{B_c}$
						$p = 0.9$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	2.72	2.65	2.65	2.65	2.65	2.14	2.10	2.10	2.10	2.10	0.5
1.0	2.58	2.49	2.49	2.49	2.49	2.05	2.00	2.00	2.00	2.00	1.0
1.5	2.34	2.46	2.42	2.40	2.38	2.03	1.97	1.95	1.94	1.92	1.5
2.0	2.52	2.44	2.41	2.39	2.37	2.01	1.96	1.95	1.93	1.92	2.0
3.0	2.50	2.43	2.40	2.38	2.34	2.00	1.96	1.94	1.92	1.90	3.0
5.0	2.48	2.42	2.39	2.36	2.33	1.99	1.95	1.93	1.91	1.89	5.0
10.0	2.47	2.41	2.37	2.35	2.33	1.98	1.94	1.92	1.91	1.89	10.0
15.0	2.46	2.40	2.36	2.35	2.32	1.98	1.94	1.92	1.91	1.89	15.0
						$p = 0.7$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	2.46	2.42	2.42	2.42	2.42	1.98	1.95	1.95	1.95	1.95	0.5
1.0	2.40	2.35	2.35	2.35	2.35	1.94	1.90	1.90	1.90	1.90	1.0
1.5	2.38	2.33	2.31	2.30	2.28	1.92	1.89	1.88	1.87	1.86	1.5
2.0	2.37	2.32	2.31	2.29	2.28	1.92	1.89	1.88	1.87	1.86	2.0
3.0	2.36	2.32	2.30	2.29	2.27	1.91	1.88	1.87	1.86	1.85	3.0
5.0	2.35	2.32	2.29	2.28	2.26	1.90	1.88	1.87	1.86	1.84	5.0
10.0	2.34	2.31	2.28	2.27	2.26	1.90	1.88	1.86	1.85	1.84	10.0
15.0	2.34	2.31	2.28	2.27	2.25	1.90	1.88	1.86	1.85	1.84	15.0
						$p = 0.5$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	2.27	2.25	2.25	2.25	2.25	1.85	1.84	1.84	1.84	1.84	0.5
1.0	2.25	2.23	2.23	2.23	2.23	1.84	1.82	1.82	1.82	1.82	1.0
1.5	2.24	2.22	2.21	2.21	2.20	1.83	1.82	1.81	1.81	1.80	1.5
2.0	2.24	2.22	2.21	2.20	2.20	1.83	1.82	1.81	1.81	1.80	2.0
3.0	2.24	2.22	2.21	2.20	2.19	1.83	1.82	1.81	1.81	1.80	3.0
5.0	2.23	2.22	2.21	2.20	2.19	1.83	1.82	1.81	1.80	1.80	5.0
10.0	2.23	2.22	2.20	2.20	2.19	1.83	1.82	1.81	1.80	1.80	10.0
15.0	2.23	2.21	2.20	2.20	2.19	1.82	1.81	1.81	1.80	1.80	15.0
						$p = 0.3$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	2.16	2.16	2.16	2.16	2.16	1.78	1.78	1.78	1.78	1.78	0.5
1.0	2.16	2.15	2.15	2.15	2.15	1.78	1.77	1.77	1.77	1.77	1.0
1.5	2.16	2.15	2.15	2.15	2.15	1.78	1.77	1.77	1.77	1.77	1.5
2.0	2.16	2.15	2.15	2.15	2.15	1.78	1.77	1.77	1.77	1.77	2.0
3.0	2.16	2.15	2.15	2.15	2.14	1.78	1.77	1.77	1.77	1.77	3.0
5.0	2.16	2.15	2.15	2.15	2.14	1.78	1.77	1.77	1.77	1.77	5.0
10.0	2.16	2.15	2.15	2.15	2.14	1.78	1.77	1.77	1.77	1.77	10.0
15.0	2.16	2.15	2.15	2.15	2.14	1.78	1.77	1.77	1.77	1.77	15.0
						ZERO PROJECTING					
	2.12					1.75					

Section 5 - Performance

5.1 Durability

Durability of a pipe material is an integral component essential to pipeline performance. This aspect of pipeline design is not well understood, nor often given consideration by designers. Municipal maintenance engineers can confirm the fact that pipe material durability is frequently not accorded adequate consideration.

Durability is concerned with the service life of a material or product. A durable concrete is one that will withstand, to a satisfactory degree, the effects of service conditions to which it will be subjected, such as weathering, chemical action and wear. Applying this definition to concrete pipe requires the evaluation of three variables.

- The pipe
- The satisfactory degree of performance
- The service conditions

The purpose of this chapter is to provide some guidelines on how these variables can be evaluated. For a computer evaluation please refer to section 4.2 on PipePac.

With careful application and installation, the service life of concrete pipe is virtually unlimited. As noted in Chapter 1, the Roman Aqueducts are still usable after more than 2,800 years. Also, in Israel, there is a buried concrete pipeline that is tentatively dated as 3,000 years old. In Mohawk, New York, the site of the first known concrete pipe sewer in North America, five sections of the sewer (installed in 1842) were removed in September, 1982 for inspection and historical purposes. This 150 mm diameter precast concrete pipe was determined to be in excellent condition after 140 years. The sections remaining in service are expected to perform, as expected, well into the third millennium.

In 1994, sections of the Shoal Lake aqueduct system in Winnipeg, Manitoba, were subjected to hydraulic testing. The 18.6 km precast reinforced concrete pipe system was installed between 1917 and 1919. Since installation, the system had been operating at about half its full design capacity of 250,000,000 L/day. The city needed maximum design operation, and was concerned about increased pressures, after 75 years of use. Successful completion of tests concluded that the 75-year-old concrete pipe was as strong as originally constructed, and capable of withstanding the expected maximum internal pressure (including transient).

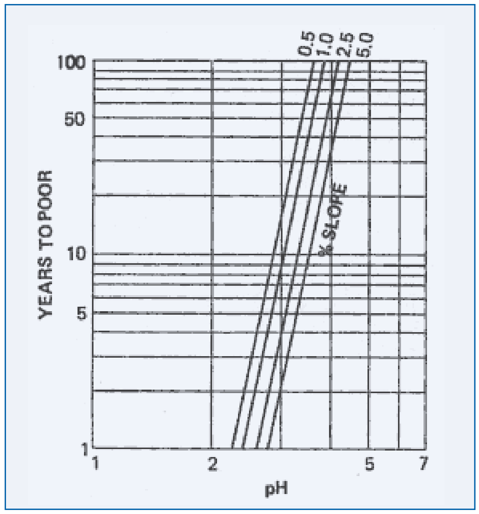
A search for precast concrete pipe durability problems indicates that very few problems exist, and consequently very few investigations have been conducted and published. In 1982, the Ohio Department of Transportation (ODOT) published a report on the results of a ten-year study of more than 1,600 culverts in all areas of the state, which included 545 precast concrete pipe installations. The ODOT report presents a rating summary by age groups for concrete pipe, corrugated steel pipe and structural steel plate pipe. The rating summary for age groups for concrete substantiates the outstanding performance of concrete pipe. Only 1.7% were rated in poor condition, with the majority of the culverts rated in the excellent and very good categories.

The environmental conditions in Ohio are relatively neutral. As with most areas of North America, the soils and water do not possess any characteristics which would contribute to premature deterioration of pipe, except for a few areas where mine acid drainage problems exist.

An equation for predicting service life was developed for precast concrete pipe. The equation relates pH and pipe slope to the number of years for the pipe to reach a poor condition.

The equation generated from the Ohio study is depicted graphically in Figure 5.1. Using the graph, we can estimate the "years to poor" of a concrete pipe culvert. For example, an installation with an average slope of 1%, and installed in an environment with a pH of 7, will take at least 1,000 years to reach a poor condition; and in an aggressive environment with a pH of 4, the concrete pipe will last 100 years, which is adequate for any sewer or major highway.

Figure 5.1 *Concrete Pipe Culvert Life*



5.2 Factors Influencing Concrete Durability

- Concrete compressive strength
- Density
- Absorption
- Cement content and type
- Aggregate characteristics
- Total alkalinity
- Concrete cover over reinforcement
- Admixtures

Minimum concrete compressive strengths of 28 MPa to 41 MPa are required by CSA and ASTM standards. The strengths relate to structural, not durability considerations, and are attained within a short period of time. The actual 28-day compressive strengths are much higher, often exceeding 65 MPa. Concrete compressive strengths are a function of available aggregates and cement, mix design, inherent characteristics of certain manufacturing processes, and curing procedures. Higher strengths usually means overall higher quality, i.e., greater abrasion resistance, lower permeability, and greater resistance to weathering and chemical attack.

Concrete density of pipe ranges from 2150 to 2650 kg/m. The higher densities are achieved by greater consolidation of the concrete, higher specific gravity aggregates, or by a combination of the two.

Absorption is an indicator of the pore structure, and is considered by some to be related to the durability of the concrete. Absorption of the cured concrete is influenced by the absorption characteristics of the aggregates, and the inherent characteristics of the manufacturing process. The processes used today have characteristically low absorption values.

CSA and ASTM standards for precast concrete pipe currently require a minimum cement content per cubic meter of concrete. This minimum is frequently exceeded by precast concrete pipe manufacturers for a variety of reasons, but mainly because of manufacturing requirements. Increased cement content leads to lower absorption, higher compressive strength and increased resistance to weathering, freeze-thaw, and certain chemical environments. It also increases the probability of shrinkage cracking, which must be balanced against potential benefits. The type of portland cement used in the manufacture of concrete pipe normally conforms to the requirements of CAN/CSA-A5-M88 as Types 10, 20 and 50. These types differ primarily in the allowable levels of tricalcium aluminate, C3A. Type 20 has a maximum of 8 percent, and Type 50 a maximum of 5 percent. C3A is the ingredient in cement which is principally involved in the disruptive expansion caused by sulfate reactions. Concrete made with lower C3A contents provides greater resistance to sulfate attack.

The preceding percentages are specified maximum values, but there is a great variation in the chemistry of individual portland cements. Since they are made from locally available materials, some Type 10 cements have less C3A than allowed by CAN/CSA-A5-M88 for Type 50. An economic factor to be considered in specifying cement type is the fact that Type 50 cement is not manufactured in all geographical areas, and, if available, may be at premium prices. Unless unusual sulfate resistance is required by the project specifications, or unless the type of cement is otherwise specified, concrete pipe is usually manufactured with Type 10 cement. Research has confirmed that blended hydraulic cement using granulated blast furnace slag can be substituted for Type 50 cement, to provide resistance to sulfate attack.

Aggregates used in concrete pipe must meet the requirements in CAN/CSA-A23.1/A23.2-M90 or ASTM C33, except for gradation. Gradation is established by the pipe manufacturer to provide compatibility with a particular manufacturing process, to achieve optimum concrete strength, and to control permeability. CAN/CSA-A23.1/A23.2-M90 or ASTM C33 provide a number of parameters covering minimum acceptable aggregate qualities. The specific hardness, or abrasion resistance of the aggregate is of particular interest in durability studies. Harder and denser aggregates produce concrete with greater abrasion resistance. Aggregates that react with cement are rarely, if ever, a problem with pipe, because aggregates are obtained from sources acceptable to the Ministry of Transportation Ontario.

Total alkalinity of concrete has a greater influence on the ability of concrete to resist acid environments than any other property. All portland cement concrete is alkaline, which means it has a pH greater than 7, and will react with acid. Total alkalinity is a measure of the total reactivity of any given mass of concrete, and is expressed as a percentage of calcium carbonate equivalent. For example, concrete with a total alkalinity of 100% will react with the same quantity of acid as would an equal mass of calcium carbonate. A given mass of concrete with a total alkalinity of 40% will react with and neutralize twice the volume of any specific acid as would the same mass of concrete with a total alkalinity of 20%. Concrete pipe made with an aggregate which is nonreactive with acid, such as granite, will have a total alkalinity of 16 to 24%,depending upon cement content. Using a calcareous aggregate, such as dolomite or limestone, can increase the total alkalinity to as much as 100%. Suitable sources of calcareous aggregates are not readily available in all geographical areas. Requiring their use could increase the cost of the pipe, and should be evaluated by a cost/benefit analysis.

Minimum concrete cover over the reinforcing steel is specified in CSA and ASTM Standards. These minimum covers represent a balance between structural efficiency and durability. Assuming both structural adequacy and proper crack control, greater durability is provided against a variety of aggressive conditions by a thicker concrete cover. A modification of cover to increase durability, however, requires re-evaluation of the structural design of the pipe, and possible use of non-standard forms, which could lead to significant increases in pipe costs.

Admixtures sometimes used by concrete pipe manufacturers include accelerators, air entraining agents, and water reducing agents. Air entrainment agents, which are normally used in wet-cast pipe, increase freeze-thaw and weathering resistance. Water reducing agents are used to provide adequate workability with drier mixes. Accelerators reduce the set time for concrete.

5.3 Principal Aggressive Factors

- Acids
- Sulphates
- Chlorides
- Freeze-thaw and weathering
- Velocity-abrasion

Acids

Interior acid attack

biochemical - H_2S

acid effluent

Hydrogen Sulphide (H2S)

Biochemical conditions resulting in hydrogen sulphide gas generation can be anticipated and controlled by design. Hydrogen sulphide gas is extremely corrosive to metals, however, not corrosive to concrete pipe. The gas is noxious, having a rotten egg odour, and is also a life threatening hazard that can kill or cause serious injury to maintenance workers. Aerobic bacteria and moisture must be present on the crown of the pipe to convert the hydrogen sulphide gas to sulphuric acid, for corrosion to occur. Control or elimination of noxious hydrogen sulphide gas, for public health and safety reasons, should preclude the possibility of this type of corrosion occuring in sanitary sewers.

Since sewers in Ontario have sufficient slope to maintain solids contained in the sewer stream in suspension, hydrogen sulphide generation is not a significant problem here. In Ontario, the average ambient temperature is low enough, during most of the year, to prevent sulphide increases. Industrial chemicals, that could facilitate sulphide production, or cause corrosion directly, are monitored and controlled at source. It is against environmental regulations to discharge waste water at elevated temperatures, to the sewer system. Further, concrete pipe can resist intermittent attacks of corrosive agents due to the manner in which it is manufactured (usually with a minimum cover of 25 mm of concrete over the reinforcement). In all regions of Canada, only sections of pipeline that retain sewage at low or no flow rates, may become susceptible to damage from sulphuric acid created from hydrogen sulphide.

When there are problems in drainage systems caused by H2S, the following factors are usually the main influences in the production of hydrogen sulphide that may lead to the formation of sulphuric acid in sewers.

Dissolved sulphide:

The sulphide concentration is the limiting factor in the release of hydrogen sulphide to the sewer walls, so that corrosion may occur. If metals are present in the sewage stream, a small amount of sulphide is immobilized to form insoluble metal salts. The amount varies from 0.1 to 0.3 mg/L.

pH:

The pH influences dissociation of the sulphide ion species in the sewer. At a pH of 6, more than 90% of the dissolved sulphide is hydrogen sulphide. At a pH of 8, less than 10% is in the form of hydrogen sulphide.

BOD and temperature:

Temperatures above 15o C may contribute to the generation of hydrogen sulphide, if all other conditions of sulphide generation are present.

Biological Oxygen Demand (BOD) is a measure of the oxygen depletion by the decomposition and mineralization of organic matter. In a sewer system, the conversion of sulphates to sulphide requires energy. The BOD determination is a measure of the energy within the system that will facilitate this conversion. The BOD usually occurs over a 5-day period, and has thus become known as the 5-day BOD.

Velocity:

Velocity affects the rate of oxygen absorption, the release of hydrogen sulphide to the atmosphere, and the build up of solids. The minimum velocity of the sewer stream should be between 0.61 m/s and 1.07 m/s to keep solids in suspension. If the velocity causes turbulent flow conditions, increased oxygen may be absorbed into the waste water, but hydrogen sulphide in waste water will also be released to the atmosphere. The released hydrogen sulphide may cause corrosion to the wall of the concrete pipe.

Junctions:

Junctions are important because the waste water from tributaries may contain high concentrations of sulphide, lower pH, high BODs, and higher temperatures. All of these factors may affect the hydrogen sulphide production in the main sewer line. Junctions may also affect the type of flow, where they enter the main. If the flow is turbulent, more oxygen may be absorbed into the waste water, or more hydrogen sulphide may be released into the atmosphere. Since the effects of corrosion outweigh the increase in oxygen absorption, the junctions should enter the main in a manner that reduces turbulence.

Force mains and siphons:

Special junctions like force mains and siphons, have a similar effect on the quality of the waste water stream, as do regular junctions. Force mains and siphons may flow at low velocities, or intermittently, allowing the increase of sulphide. Force mains usually flow full, which also facilitates the build-up of sulphides due to the anaerobic conditions in the force main. When force mains and siphons enter the main sewer, the higher concentration of sulphide may cause problems further downstream.

Ventilation:

Ventilation is not an effective measure to reduce the corrosion of concrete pipe, because it is difficult to prevent condensation on the walls of pipe, due to temperature variations. The hydrogen sulphide is oxidized in the aerobic layer on the wall of the pipe to form sulphuric acid, which may corrode the pipe as it trickles down the wall of the pipe.

If velocities of 0.61 m/s, oxygen levels of 1 mg/L and temperatures less than 15o C can be achieved, corrosion in sanitary sewers will not be a problem at any time.

Accumulation of solids could be a problem during the three warmest months of the year. During these months, the temperature is sufficiently high to have sewer water temperatures above 15o C. The elevated temperatures would also decrease the dissolved oxygen. Dissolved oxygen is inversely proportional to temperature of the water. If effective BOD levels are less than 600 mg/L, and the effective slope is 0.2%, and flow is 0.085 m3/s, sulphide concentrations will not increase sufficiently to become a problem.

Acid Effluent

Highly acidic materials are usually prohibited by municipal by-laws, because they are harmful to the sewage treatment process, and also harmful to the sewer. Continuous flow of effluent with a pH below 5.5 is considered aggressive, and below 5.0 highly aggressive. A one time only exposure will generally affect the alkaline surface paste of the pipe, exposing aggregate. Calcareous aggregate (limestone) can further add corrosion protection. Because the heavy pipe walls are much thicker than most pipe materials, concrete pipe is considered to be chemical resistant, and is recommended for industrial sanitary applications in Ontario, in the Ministry of the Environment Policy Guidelines for design of Sanitary Sewers.

Sulphates

Sodium, magnesium and calcium sulfates in soil, groundwater or effluent can be highly aggressive to portland cement concrete. The reaction with C3A in the cement, forms calcium sulphoaluminate, causing expansion and eventual disruption of the concrete.

This is typical in alkali soils where sulfate concentration has taken place because of an exposed evaporative surface. Sulfates in the soil must be in solution for this to occur.

Resistance to sulfate attack can be increased in concrete pipe by:

- Accelerated curing
- Using sulfate resistant cement
    - Type 50 for high sulfate content
    - Type 20 for moderate sulfate content
- Using a higher cement content
- Pozzolans such as flyash or slag can be blended with normal portland cement for exposures up to 240,000 ppm sulfate.

NOTE: *Resistance to sulfate attack decreases as absorption increases, regardless of cement type.*

Chlorides

De-icing chemicals used on bridge decks and highways are the most common causes of chloride corrosion of structural steel and concrete reinforcement. Problems have also occured with structures, such as piers and piling, exposed to seawater. The problem is chloride induced corrosion of the reinforcement. Portland cement concretes protect steel against corrosion through an electro-chemical phenomena that depends on the high alkalinity (pH 12.5) of concrete to passivate the steel. The chloride ion has the ability to disrupt this protective mechanism. Research has established that there is a critical chloride ion concentration at the concrete-steel interface beyond which corrosion will occur, and that oxygen must also be present to support corrosion. Although seawater has approximately 20,000 ppm of chloride, many concrete pipe installations are completely immersed in seawater and are performing satisfactorily, after many years. This is due to low oxygen diffusion through the concrete cover.

Chloride corrosion can occur in low quality concrete of high permeability and porosity, with cracking. Calcium chloride admixtures can also cause corrosion, and therefore, are not used. Service life can be extended under severe conditions with increased cover, using high quality concrete with low permeability, without cracks or voids. A very small percentage of concrete pipe is installed under conditions for which serious chloride buildup is probable.

Freeze-Thaw and Weathering

Freeze-thaw damage is caused by water penetration into concrete interstices and freezing, generating disruptive stresses. The frequency of freeze-thaw cycles governs the severity of the problem. Normally, concrete pipe is not exposed to this combined set of conditions, however, high quality concrete pipe has demonstrated an excellent performance record, when it has been exposed to this combination of conditions.

Velocity Abrasion

Velocities up to 12 m/s do not create problems for concrete pipe. A composite phenomenum is possible in which velocity abrasion is augmented by corrosion from aggressive waters. At velocities greater than12 m/s cavitation effects can occur. Bed load, the quantity of solids being moved, may influence abrasion, depending on particle size, hardness and specific gravity. This can usually be controlled by proper design, increasing concrete compressive strength and the hardness of the aggregate used to increase abrasion resistance. Internal velocity dissipators have also been used to control abrasion.

Significance of Cracking

Reinforced concrete design is based on the concept that cracking of the concrete is necessary to permit full development of the tensile strength of the reinforcing steel. Cracking of pipe to the standard 0.3 mm width crack has not been found to be deleterious. Cracks which completely penetrate the pipe wall are rare, only occuring when the pipe has reached ultimate strength. Most cracks only penetrate to the first line of reinforcement, and are vee shaped, being widest at the surface. Thus the crack width is related to the thickness of cover. Larger diameter pipe with cover greater than 25 mm may have cracks exceeding 0.3 mm in width. This should not be considered deleterious. Specifying a limitation of surface crack width of 0.3 mm, in even aggressive exposure conditions, is unnecessarily conservative. Pipe with such cracks will have the same durability performance characteristics as an uncracked pipe. Consideration, however, should be given to sealing cracks greater than 0.6 mm.

Autogenous Healing

The hairline cracks that appear at the obvert and invert of a steel reinforced concrete pipe are often confused with first damage strength. These cracks are visible evidence that the concrete pipe has deflected, placing the steel reinforcement into tension, as it was designed to do. The proper design of any reinforced concrete structural element requires the concrete to crack in order for the design to be satisfactory. These hairline cracks do not provide a source for future corrosion, and do not cause leakage, as they do not penetrate the pipe wall. The crack is vee shaped and is widest at the surface. The crack does not represent damage. It is visible evidence that the design is correct. The 0.3 mm crack criterion is conservative. This is demonstrated by more than 60 years of experience in the United States and Canada, during which there has never been a report of deleterious corrosion of reinforcement in a concrete pipe, due to the existence of cracks of 0.3 mm magnitude. One of the reasons is that the concrete pipe seals the crack with calcium carbonate crystals, through a chemical reaction called autogenous healing. Free lime (calcium hydroxide) in the concrete combines with carbon dioxide, in the presence of moisture, to form calcium carbonate crystals.

$$\mathrm{Ca\ (0H)_2 + C0_2 = Ca\ C0_3 + H_20}$$

This natural repair is impermeable and very strong. One example as evidence to illustrate the strength of a cracked pipe, concerned a 750 mm nonreinforced concrete pipe tested at Port Angeles, Washington on May 17, 1928. The pipe cracked under a three edge test load, but did not fall apart, and was laid aside. On April 8, 1931 the pipe was again placed in the same position as when the first tested in 1928, and withstood a higher load than when first tested. Both tests were made by the Engineer of Tests, Washington State Highway Department.

Section 6 - Construction and Field Testing

6.1 Introduction

The design of a concrete pipeline assumes that certain minimum conditions of installation will be met. Acceptance criteria are established to ensure that the quality of workmanship and material provided during construction meet the design requirements, and that the pipeline will perform satisfactorily. Installation and field testing are the final steps in a process that also includes research, surface and subsurface investigations, design, specification preparation, pipe manufacturing and material testing.

Installation procedures are presented in this chapter, together with some of the problems that might be encountered. These procedures include:

- Pre-construction planning
- Site preparation
- Ordering, receiving and handling
- Excavation
- Foundation and bedding preparation
- Jointing
- Backfilling
- Construction testing

6.2 Pre-construction Planning

Preconstruction planning is essential for a successful project. All plans, project specifications, soils reports, standard drawings, and special provisions must be reviewed prior to construction, and any questioned areas resolved. Addressing these potential problems can eliminate unnecessary and costly delays. A review of the plans at the project site is helpful in identifying potential problems.

All personnel associated with the project should become familiar with codes of safe practice regarding construction for federal, provincial, municipal and local agencies. Federal safety regulations for construction are published in the Canada Labour Code. In Ontario, the provincial safety regulations are published in the Occupational Health and Safety Act.

To avoid possible delays during construction, information should be obtained on several pre-construction items such as:

- Names and addresses of agencies having jurisdiction over highways, railroads, airports, utilities, drainage, etc.
- Required easements, permits, releases or any other special stipulations
- Responsibility for notifying officials of existing utilities and, if necessary, requesting appropriate agencies to locate and mark facilities affected
- Locate benchmarks, monuments and property stakes, and reference all points likely to be disturbed
- Check grade and alignment, clearing requirements, and ensure building connections, watermains, hydrants and other appurtenances are properly staked

- Coordinate work to be done, and requirements of subcontractors
- Arrange for measurement of pay quantities and procedures for change orders, extra work orders, and force account work
- Safety regulations, equipment capabilities and requirements for traffic maintenance
- Establish forms for record keeping, progress reports, diary, etc.

6.3 Site Preparation

Site preparation can significantly influence progress of the project. The amount and type of work involved in site preparation varies with the location of the project, topography, surface conditions and existing utilities. Commonly included are:

- Topsoil stripping
- Clearing and grubbing
- Pavement and sidewalk removal
- Rough grading
- Relocation of existing natural drainage
- Removal of unsuitable soil
- Access roads
- Detours
- Protection of existing structures and utilities
- Environmental considerations

6.4 Handling and Stockpiling

6.4.1 Handling

Each shipment of pipe is loaded, blocked and tied down at the plant to avoid damage during transit. However, it is the responsibility of the receiver to determine that damage has not occurred during delivery. An overall inspection of each pipe shipment should be made before unloading, and total quantities of each item checked against the delivery slip. Damaged or missing items must be recorded. Pipe sizes, up to and including 1200 mm diameter, can be unloaded by rolling the pipe sections off the truck, onto a tailgate unloader.

A common device used today for unloading small to intermediate diameter pipe, is a fork attached to a front end loader. These lift forks are easily attached to the mechanical equipment, usually the front end loader, on site. Lift forks make unloading more efficient, and enable the contractor to move pipe around the site with greater ease and speed. Since the incorporation of palletizing small diameter pipe, up to and including 250 mm in diameter, lift forks have become necessary to unload the pallets.

Pipe 975 mm and larger provided with a lift hole, commonly require a lifting device consisting of a steel thread eye bar with a wing type nut and bearing plate. For maintenance hole sections, cone sections, bases, fittings and other precast appurtenances, lifting holes and pins or lift inserts should be used.

Regardless of the method used to unload pipe, maintenance holes, or box units, precautions should be taken to avoid damage and assure unloading is accomplished in a safe manner.

6.4.2 Stockpiling

Unloading of pipe should be coordinated with the construction schedule and installation sequence, to avoid rehandling and unnecessary movement. For trench installations, where the trench is open, the pipe should be placed on the side opposite the excavated material. The pipe sections should be placed so that they will be protected from traffic and construction equipment, but close enough to the trench edge to enable minimum rehandling. If the trench is not yet open, the pipe should be strung out on the opposite side from where the excavated material will be placed. Stringing out the pipe for embankment installations depends on the specific type of installation. For culverts to be installed on a shallow bedding at approximately the same elevation as original ground, the pipe should be strung out immediately after clearing and rough grading. To avoid disruption to existing natural drainage and enable embankment construction to proceed as quickly as possible, pipe installation should follow immediately after preparation of the bedding foundation. When pipe is installed in a subtrench or negative projecting condition, the embankment should be constructed up to the required elevation, and the same procedure followed as for trench installations.

Any stockpiling of pipe should be as close as is safely possible to where the pipe will be installed. Small diameter pipe should be layered in the same manner as they were loaded on the truck. All pipe should be supported by the pipe barrel so that the ends are free of load concentrations. The bottom layer should be placed on a level base, on timbers supporting the barrel at either end. Each layer of bell and spigot pipe should be arranged so that bells are at the same end. The bells in the next layer should be at the opposite end, and projecting beyond the spigot of the section in the lower layer. Where only one layer is being stockpiled, the bell and spigot ends should alternate between adjacent pipe sections. Pipe sections generally should not be stockpiled at the job site in a greater number of layers that would result in a height of 2 m. Box units may be stockpiled in the same general manner as pipe.

All flexible gasket materials, including joint lubricating compounds, should be stored in a cool dry place in summer, and prevented from freezing in winter. Rubber gaskets and preformed or bulk mastics should be kept clean, away from oil, grease, excessive heat, and out of the direct rays of the sun.

6.5 Excavation

For sewer and culvert construction, the scope of operations involved in general excavation includes trenching, tunneling, backfilling, embankment construction, soil stabilization, and control of ground water and surface drainage. Adequate knowledge of subsurface conditions is essential for any type of excavation.

This is accomplished through soil surveys and subsequent soil classification. Soil borings are usually obtained for design purposes, and the information included on the plans, or made available to the contractor in a separate document. This soil boring information is useful in evaluating unfavourable subsoil conditions requiring special construction. If the subsoil information on the plans is not sufficiently extensive, it is normally the responsibility of the contractor to obtain additional test borings.

6.5.1 Equipment

Several types of excavating equipment are available. Selection of the most efficient piece of equipment for a specific excavation operation is important, since all excavating equipment has practical and economic limitations. Considerations include the type and amount of material to be excavated, depth and width of excavation, dimensional limitations established in the plans, pipe size, operating space and spoil placements. Basic equipment can usually be modified or adapted for use in most excavating operations.

6.5.2 Line and Grade

For sewer construction, where the pipe is installed in a trench, line and grade are usually established by one, or a combination of the following methods:

- Control points consisting of stakes and spikes set at the ground surface, and offset a certain distance from the proposed sewer centerline
- Control points established at the trench bottom, after the trench is excavated
- Trench bottom and pipe invert elevations established while excavation and pipe installation progresses
- GPS - Global Positioning System

Where control points are established at the surface and offset, lasers, transits, batter boards, tape and level, or specially designed transfer instruments, are used to transfer line and grade to the trench bottom. Regardless of the specific type of transfer apparatus used, the basic steps are:

- Stakes and spikes, as control points, are driven flush with the ground surface at 7.5 to 15m intervals for straight alignment, with shorter intervals for curved alignment.
- Offset the control points 3m, or another convenient distance, on the opposite side of the trench from which excavated material will be placed.
- Determine control point elevations by means of a level, transit or other leveling device. Drive a guard stake to the control point, and mark the depth of the control point from the control point to the trench bottom or pipe invert.
- After the surface control points are set, a grade sheet is prepared listing reference points, stationing, offset distance and vertical distance from the control points to the trench bottom or pipe invert.
- Transferring the line and grade along the trench bottom is achieved by using a laser system, or a batter board system.

The laser system, the most commonly used system, uses a transit or level to set the starting point on the trench bottom. As with any surveying instrument, the initial setting is most important. Once the starting point is established, the laser can be set for direction and grade. Lasers can be used for distances up to 300 m (average runs for pipe installations are 90 to 150 m). The projected beam is intercepted along the trench bottom with a target, placed in the bell, that reflects the light.

Temperature can affect the trueness of the laser beam, therefore, it is helpful to keep the line well ventilated. The laser instrument can be mounted in a maintenance hole, set on a tripod or placed on a solid surface to project the light beam either inside, or outside the pipe. A workman with any ordinary rule, or stadia rod, can measure offsets quickly and accurately, generally within 2 mm or less.

There are two types of batter board systems. One type is incorporated for narrow trenches, the other for wide trenches.

For narrow trenches, a horizontal batter board is spanned across the trench, and adequately supported at each end. The batter board is set level at the same elevation as the stringline, and a nail driven in the upper edge, at the centre line of the pipe. In many cases the batter board is used only as a spanning member, with a short vertical board nailed to it at the pipe centerline. A stringline is pulled tight across a minimum of three batter boards, and the line transferred to the bottom by a plumb bob cord held against the stringline. Grade is transferred to the trench bottom by means of a grade rod, or other suitable vertical measuring device.

Where wide trenches are necessary, due to large pipe sizes or sloped trench walls, the batter board may not be able to span the width of excavation. In such cases, the same transfer principle is used, except that the vertical grade rod is attached to one end of the batter board, and the other end set level against the offset stringline. The length of horizontal batter board is the same as the offset distance. The length of the vertical grade rod is the same as the distance between the pipe invert and the stringline. Specially designed instruments are available which incorporate a measuring tape, extendible arm and leveling device. These instruments are based on the same principle, but eliminate the need to construct batter boards and supports.

When pipe is installed by the jacking or tunneling method of construction, an accurate control point must be established at the bottom of the jacking pit and work shaft. Close control of horizontal and vertical alignment can be obtained by laser or transit. If excavation and pipe installation extend several hundred metres from one shaft, or the horizontal alignment is curved, vertical alignment holes can be driven from the surface through which plumb lines can be dropped.

6.5.3 Excavation Limits

The most important excavation limitations are trench width and depth. As excavation progresses, trench grades should be continuously checked against the elevations established on the sewer profile. Improper trench depths can result in high or low spots in the line, which may adversely affect the hydraulic capacity of the sewer, and require correction, or additional maintenance, after the line is completed.

The backfill load transmitted to the pipe is directly dependent on the trench width at the crown of the pipe. To determine the backfill load, the designer assumes a certain trench width, then selects a pipe strength capable of withstanding this load. If the constructed trench width exceeds the width assumed in design, the pipe may be overloaded, and possibly structurally distressed. Because the backfill loads and pipe strength requirements are a function of the trench width, maximum trench widths are usually established in the plans, or standard drawings. Where maximum trench widths are not indicated in any of the construction contract documents, trench widths should be as narrow as possible, with side clearance adequate enough to ensure proper compaction of backfill material at the sides of the pipe.

When unstable soil conditions are encountered, sheathing or shoring can be used, or the banks of the trench can be sloped to the natural angle of repose of the native soil. If the trench sides are allowed to slope back, the pipe should be installed in a shallow subtrench excavated at the bottom of the wider trench. The depth of the subtrench should be at least equal to the vertical height of the pipe.

For culverts installed under embankments, it may be possible to simulate a narrow subtrench by installing the pipe in the existing stream bed. When culverts are installed in a negative projecting condition of construction, the same excavation limitations should be followed as for trench excavation. For jacked or tunneled installations, the excavation should coincide as closely as possible to the outside dimensions, and shape of the pipe. The usual procedure in jacking pipe is to equip the leading edge with a cutter, or shoe, to protect the lead pipe. As succeeding lengths of pipe are added between the lead pipe and the jacks, and the pipe is jacked forward, soil is excavated and removed through the pipe. Materials should be trimmed approximately 25 to 50 mm larger than the pipe, and excavation should not precede pipe advancement more than necessary. This procedure usually results in minimum disturbance of the earth adjacent to the pipe.

6.5.4 Spoil Placement

The placement of excavated material is an important consideration in sewer and culvert construction, and may influence the selection of excavating equipment, the need of providing sheathing and shoring, and backfill operations.

In trench installations, the excavated material is usually used for backfill, and should be placed in a manner that reduces rehandling during backfilling operations. As a general rule, for unsupported trenches, the minimum distance from the trench to the toe of the spoil bank should not be less than one half the trench depth. For supported trenches, a minimum of one metre is normally sufficient.

Stockpiling excavated material adjacent to the trench causes a surcharge load, which may cave in trench walls. The ability of the trench walls to stand vertically under this additional load, depends on the cohesion characteristics of the particular type of material being excavated. This surcharge load should be considered when evaluating the need to provide trench support. It may be necessary, where deep or wide trenches are being excavated, to haul away a portion of the excavated soil, or spread the stockpile with a bulldozer, or other equipment. If the excavated material is to be used as backfill , the stockpiled material should be visually inspected for rocks, frozen lumps, highly plastic clay, or other objectionable material. If the excavated soil differs significantly from the backfilled material set forth in the plans, it may be necessary to haul the unsuitable soil away and bring in selected backfill material.

Spoil placement for culvert installations is usually not as critical as trench installation. If the excavated material is suitable for the embankment construction, it can be immediately incorporated into the embankment adjacent to the culvert. If using imported materials, care must be taken so that the frost susceptibility is the same as the native material. Top soil, or other highly organic soils, are usually stockpiled outside the top of the embankment slope, and used for dressing the slopes after the embankment is constructed. For pipe installed by the jacking method of construction, the excavated material is loaded into carts, or deposited onto a conveyor system, and then transported through the pipe to the jacking pit. The excavated material is then lifted from the jacking pit and deposited in a waste bank, or hauled away. Since the rate of progress of a jacking or tunneling operation is usually controlled by the rate of excavation and spoil removal, preliminary investigation and advance planning for fast and efficient removal and placement of spoil, is important in preventing delays and unnecessary rehandling.

6.5.5 Sheathing and Shoring

Trench stabilization is usually accomplished through the use of sheathing and shoring. The Occupational Health and Safety Act, municipalities and other local agencies have established codes of safe practices regarding support requirements for trench excavation. The structural requirements of sheathing and shoring depend on numerous factors such as:

- depth and width of excavation
- characteristics of the soil
- water content of the soil
- weather conditions
- proximity to other structures
- vibration from construction equipment and/or traffic
- soil placement or other surcharge loads
- code requirements

Accurate evaluation of all of these factors is usually not possible, so the design and application of temporary bracing systems varies considerably. However, certain methods of stabilizing open trenches, including materials technology, have evolved and can be used as a general guide.

Shoring for trenches is accomplished by bracing one bank against the other; structural members which transfer the load between the trench sides are termed struts. Wood planks placed against the trench walls to resist earth pressure, and retain the vertical banks, are termed sheathing. The horizontal members of the bracing system, that form the framework bearing against the sheathing, are termed walers or stringers, and the vertical members of the bracing system are termed strongbacks.

Improper removal of sheathing can reduce the frictional effects, and increase the backfill load on the pipe, so sheathing should be removed in increments, as the backfill is placed. Additional compaction of the backfill material may be necessary to fill the voids behind the sheathing, as it is removed. The four most common sheathing methods are:

open sheathing

close sheathing

tight sheathing

trench shields or boxes

6.5.5.1 Open Sheathing

Open sheathing consists of a continuous frame, with vertical sheathing planks placed at intervals along the open trench. This method of sheathing is used for cohesive stable soils, where ground water is not a problem.

6.5.5.2 Close Sheathing

Close sheathing consists of a continuous frame, with vertical sheathing planks placed side by side to form a continuous retaining wall. This method of sheathing is used for noncohesive and unstable soils.

6.5.5.3 Tight Sheathing

Tight sheathing is similar to closed sheathing, except the vertical sheathing planks are interlocked. This method of sheathing is used for satured soils. Steel sheet piling is sometimes used instead of wood planking.

6.5.5.4 Trench Shields or Boxes

Trench shields, or boxes, are heavily braced boxes of steel, or wood, which can be moved along the trench bottom as excavation and pipe laying progress. Trench boxes are used to protect workers installing pipe in stable ground conditions, where the trenches are deep and not sheathed. Trench shields are also used in lieu of other methods of shoring and sheathing for shallow excavations, where the sides of the shields can extend from the trench bottom to ground surface. When trench shields are used, care should be taken, when the shield is moved ahead, so as not to pull the pipe apart.

6.6 Foundation Preparation

A stable and uniform foundation is necessary for satisfactory performance of any pipe. The foundation must have sufficient load bearing capacity to maintain the pipe in proper alignment and sustain the mass of the backfill, or fill material placed over the pipe. The trench bottom foundation should be checked for hard or soft spots, due to rocks or low load bearing soils. Where undesirable foundations exist, they should be stabilized by ballasting, or soil modification.

Ballasting requires removal of the undesirable foundation material and replacing it with select materials such as sand, gravel, crushed rock, slag, or suitable earth backfill. The depth, gradation, and size of the ballast depends on the specific material used and the amount of stabilization required, but usually the ballast should be well graded.

Soil modification involves the addition of select material to the native soil. Crushed rock, gravel, sand, slag, or other durable inert materials with a maximum size of 75 mm, is worked into the subsoil to the extent necessary to accomplish the required stabilization.

In rock, shale or other hard, unyielding soils, the excavation should be continued below grade, and the over-excavation replaced with select material to provide a cushion for the pipe. Close control of grade during excavation will reduce hand trimming of the foundation. Bell holes should be excavated to accommodate projecting joints, and to provide support along the barrel of the pipe.

6.6.1 Pipe Bedding

Once a stable and uniform foundation is provided, it is necessary to prepare a bedding in accordance with the bedding requirements set forth in the plans, specifications or standard drawings. An important function of the bedding is to level out any irregularities in the foundation, and assure uniform support along the barrel of each pipe section. The bedding is also constructed to distribute the load bearing reaction, due to the mass of the backfill or fill material, around the lower periphery of the pipe. The structural capacity of the pipe is directly related to this load distribution, and several types of bedding have been established to enable the specification of pipe strengths during the design phase of the project.

To understand the importance of the bedding to the load carrying capacity of a pipe, assume that a pipe is set on a flat unyielding foundation with little, or no, care taken to provide uniform bearing around the lower part of the pipe. This type of bedding causes a highly concentrated reaction along the barrel of the pipe.

To balance the external loads around the pipe so that the entire pipe section is subjected to uniform loading, it is necessary to distribute the bottom reaction by placing the pipe on a bedding. Bedding the pipe so that the bottom reaction is distributed over 50% of the outside horizontal span of the pipe results in a 36% increase in supporting strength; a 60% reaction distribution results in a 73% increase in supporting strength; and a 100% distribution results in approximately a 150% increase in supporting strength.

If the pipe strength specified for a particular project was based on a design assumption that at least 60% of the outside horizontal span of the pipe would be bedded, but the pipe is simply set on a flat foundation, 75% of the load carrying capacity of the pipe would be eliminated. Since the earth load would remain the same in either case, a pipe strength up to three times greater than specified could be required, because of improper bedding. The bedding actually being constructed should be continuously compared with the bedding requirements in the plans and specifications.

The following general classifications of bedding types is presented as a guideline. Bedding for concrete pipe is found in the 3EB sub-program of PipePac.

6.6.1.1 Class B Bedding - Shaped or Unshaped Granular

Foundation Shaped - For a shaped subgrade with granular foundation, the bottom of the excavation is shaped to conform to the pipe surface for at least 0.6 times the outside pipe diameter for circular pipe, 0.7 times the outside span for elliptical pipe, and the full bottom width of box sections to be bedded in fine granular fill placed in the shaped excavation. Densely compacted backfill should be placed at the sides of the pipe to a depth at least 300 mm above the top of the pipe.

Unshaped - A granular foundation without shaping is used only with circular pipe. The pipe is bedded in compacted granular material placed on the flat trench bottom. The granular bed ding has a minimum specified thickness, and should extend at least half way up the pipe at the sides. The remainder of the side fills, and a minimum depth of 300 mm over the top of the pipe, should be filled with densely compacted material.

6.6.1.2 Class C Bedding - Shaped Subgrade or Granular Foundation

Shaped Subgrade - The pipe is bedded with ordinary care in a soil foundation, shaped to fit the lower part of the pipe exterior with reasonable closeness for a width of at least 50% of the outside diameter for a circular pipe, 10% of the outside pipe rise for elliptical pipe, and full bottom width of box units. For trench installations, the sides and area over the pipe are filled with compacted backfill to a minimum depth of 150 mm above the top of the pipe. For embankment installations, the pipe should not project more than 90% of the vertical height of the pipe above the bedding.

Granular Foundation - Used only with circular pipe, the pipe is bedded in loosely compacted granular material, or densely compacted backfill placed on a flat bottom trench. The bedding material should have a minimum specified thickness, and should extend up the sides for a height of at least 0.2 times the outside diameter. For trench installations, the sidefill and area over the pipe to a minimum depth of 150 mm should be filled with compacted backfill.

6.6.1.3 Class D Bedding

Used only with circular pipe, little or no care is exercised either to shape the foundation surface to fit the lower part of the pipe exterior, or to fill all spaces under and around the pipe with granular materials. However, the gradient of the bed should be smooth and true to the established grade. This class of bedding also includes the case of pipe on rock foundations in which an earth cushion is provided under the pipe, but is so shallow that the pipe, as it settles under the influence of vertical load, approaches contact with the rock.

Box Unit Bedding

Precast reinforced concrete box units are designed for installed conditions, rather than test conditions. Standard designs are presented in OPSS 1821 and OPSS 422.

A precast box unit bedding should be constructed, as specified in the contract, to provide uniform support for the full length and width at each box unit. The surface of the bedding should be prepared by placing a minimum of 75 mm thick layer of Granular “A”, or fine aggregate.

6.6.3 Bedding Materials

Materials for bedding should be selected on the basis that intimate contact can be obtained between the bed and the pipe. Since most granular material will shift to attain this intimate contact as the pipe settles, an ideal load distribution can be realized. Granular materials should be clean, coarse sand, or well graded crushed rock.

With the development of mechanical methods for subgrade preparation, pipe installation, backfilling and compaction, excellent results have been obtained with pipe installed on a flat bottom foundation and backfilled with well-graded, job excavated soil. If this method of bedding is used, it is essential that the bedding material be uniformly compacted under the haunches of the pipe.

Where ledge rock, compacted rocky or gravel soil, or other unyielding foundation material is encountered, the pipe should be bedded in accordance with the requirements of one of the classes of bedding, but with the following additions:

For Class B, C, and box section beddings, subgrades should be excavated or over excavated, if necessary, so a uniform foundation free of protruding rocks may be provided.

6.7 Jointing

Pipe should be lowered into the trench, or set in place for embankment installations, with the same care as when the pipe was unloaded from the delivery trucks. For intermediate and larger size pipe, it is usually more practical, economical, and safer to use mechanical equipment to place the pipe. In laying the pipe, it is general practice to face the bell end of the pipe in the upstream direction. This placing helps prevent bedding material from being forced into the bell during jointing, and enables easier coupling of pipe sections.

Several types of joints and sealant materials are utilized for concrete pipe, to satisfy a wide range of performance requirements. All of the joints are designed for ease of installation. The manufacturerís recommendations regarding jointing procedures should be closely followed to assure resistance to infiltration of ground water and/or backfill material, and exfiltration of sewage or storm water.

6.7.1 Jointing Materials

The most common compression joint sealants and joint fillers used for sanitary sewers, storm sewers, and culverts are:

- rubber, attached or separate
- mastic, bulk or preformed
- cement, neat or mortar

6.7.1.1 Rubber Compound

Rubber gaskets are of four basic types:

- single offset, with one flat side, which is placed on the pipe tongue, or spigot.
- O-ring, which is recessed in a groove on the tongue, or spigot, and confined by the bell, after the joint is completed
- roll-on type, which is placed on the spigot end of the pipe, then rolled into position as the spigot is inserted into the bell
- pre-lubricated, with one flat side, which is placed on the pipe tongue, or spigot.

For all gasket types, dirt, dust, and foreign matter must be cleaned from the joint surfaces. Except for the roll-on and pre-lubricated types, the gasket and bell should be coated with a lubricant recommended by the manufacturer. The lubricant must be clean and be applied with a brush, cloth pad, sponge or glove. In some cases, a smooth round object, such as a screwdriver shaft, should be inserted under the gasket and run around the circumference two or three times, to equalize the stretch in the gasket, before jointing.

Most standard rubber gaskets are not formulated for resistance to prolonged exposure to environmental elements, such as ultraviolet rays and ozone. Excessive exposure to these will cause premature aging and degradation of the rubber.

Gaskets are required to be stored in a sheltered cool dry place at the manufacturerís location, as well as on the job site. They need to be protected from prolonged exposure to sunlight, extreme heat in the summer, and extreme cold , snow and ice in the winter. Proper care of the gaskets prior to the installation will ensure maximum ease of installation, and maximum sealing properties of the gaskets.

Gaskets are generally formulated for maximum sealing performance in a standard sewer installation carrying primarily storm water or sanitary sewage. Custom rubber formulations are available for special situations, where specific elements are being carried in the effluent.

Some common examples of where a custom formulation would be required is where resistance is needed against hydrocarbons, acids, ultraviolet rays, ozone, and extreme heat.

6.7.1.2 Mastic

Mastic sealants consist of bitumen, or butyl rubber, and inert mineral filler, which are usually cold applied. The joint surfaces are thoroughly cleaned, dried and prepared in accordance with the manufacturerís recommendations. A sufficient amount of sealant should be used to fill the annular joint space, with some squeeze out. During cold weather, better workability of the mastic sealant can be obtained if the mastic and joint surfaces are warmed.

6.7.1.3 Mortar

Mortar sealants consist of portland cement paste, or mortar made with a mixture of portland cement, sand and water. The joint surface is thoroughly cleaned and soaked with water immediately before the joint is made. A layer of paste or mortar is placed in the lower portion of the bell, or groove, end of the installed pipe and on the upper portion of the tongue, or spigot, end of the pipe section to be installed. The tongue, or spigot, is then inserted into the bell, or groove, of the installed pipe until the sealant material is squeezed out. Any annular space within the pipe joint is filled with mortar, and the excess mortar on the inside of the pipe is wiped and finished to a smooth surface.

Regardless of the specific joint sealant used, each joint should be checked to be sure all pipe sections are in a homed position. For joints sealed with rubber gaskets, it is important to follow the manufacturers installation recommendations to ensure that the gasket is properly positioned, and is under compression.

6.7.1.4 External Bands

External bands serve two functions:

- prevent fine materials from entering the joint
- prevent infiltration of groundwater

If the prevention of bedding material from entering the conveyance system is the primary objective, filter fabric, while allowing the groundwater to infiltrate, will stop the bedding backfill material from entering.

To prevent the infiltration of water, external extruded rubber gaskets are utilized. The gasket must be of sufficient width to cover the joint, and must be installed with some tension applied, according to the manufacturerís recommendations. As the joint is backfilled, pressure is applied to the gasket as it is pressed against the structure, providing a seal at the joint.

6.7.2 Jointing Procedures

Joints for pipe sizes up to 600 mm in diameter can usually be assembled by means of a bar and wood block. The axis of the pipe section to be installed should be aligned as closely as possible to the axis of the last installed pipe section, and the tongue, or spigot, end inserted slightly into the bell, or groove. A bar is then driven into the bedding and wedged against the bottom bell, or groove, end of the pipe section being installed. A wood block is placed horizontally across the end of the pipe to act as a fulcrum point, and to protect the joint end during assembly. By pushing the top of the vertical bar forward, lever action pushes the pipe into a home position. When jointing larger diameter pipe, and when granular bedding is used, mechanical pipe pullers are required. Several types of pipe pullers, or “come along” devices, have been developed, but the basic force principles are the same.

When jointing small diameter pipe, a chain or cable is wrapped around the barrel of the pipe behind the tongue, or spigot, and fastened with a grab hook, or other suitable connecting device. A lever assembly is anchored to the installed pipe, several sections back from the last installed section, and connected by means of a chain, or cable, to the grab hook on the pipe to be installed. By pulling the lever back, the tongue, or spigot, of the pipe being jointed is pulled into the bell, or groove, of the last installed pipe section. To maintain close control over the alignment of the pipe, a laying sling can be used to lift the pipe section slightly off the bedding foundation.

Large diameter pipe can be jointed by placing a “dead man” blocking inside the installed pipe, several sections back from the last installed section, which is connected by means of a chain or cable to a strong back placed across the end of the pipe section being installed. The pipe is pulled home by lever action similar to the external assembly. Mechanical details of the specific apparatus used for pipe pullers, or come along devices, may vary, but the basic lever action principle is used to develop the necessary controlled pulling force.

Note: *The excavating equipment must not be used to push pipe sections together. The force applied by such equipment can damage pipe joints.*

For pipe installed by jacking, it is necessary to provide for relatively uniform distribution of the load around the periphery of the pipe, to prevent localized stress concentrations. This is accomplished by ensuring that the pipe ends are parallel within the tolerances prescribed by CSA Standards for precast concrete pipe, by using a cushion material between the pipe sections, such as plywood, hardboard or jacking spacers, and by care on the part of the contractor to insure that the jacking force is properly distributed through the jacking frame to the pipe, and parallel with the axis of the pipe.

6.7.3 Lateral Connections

When the pipe connects to a rigid structure such as a maintenance hole, it may be sheared or cracked at the connection, as a result of differential settlement. It is essential that the bedding and foundation for the connecting pipe section be highly compacted, to minimize differential settlement. In addition, the connection should provide some degree of flexibility, to accommodate angular and lateral deflections.

Maintenance holes and pipe can be equipped with pre-fabricated junctions, or core drilled holes fitted with gaskets, which allow for up to 5o deflection in any direction.

Rubber connectors are also available which can accommodate angular deflections of up to 20o, and lateral deflections of up to 50 mm, depending on the size and type of connector being used ó local suppliers should be contacted for more detailed and specific information.

From an installation perspective, these connectors are particularly recommended for use under adverse field conditions, and offer the added advantage of allowing the contractor to seal the connection without grouting. Backfilling can proceed immediately after the connection is completed.

6.7.4 Changes in Alignment

Changes in direction of sewer lines are usually accomplished at maintenance hole structures. Alignment changes in concrete pipe sewers can also be incorporated into the line through the use of deflected straight pipe, radius pipe, or bends. Since manufacturing and installation feasibility are dependent on the particular method used to negotiate a curve, it is important to establish the method prior to excavating the trench.

Maintenance holes can be used when there is a need to change alignment, grade or size of a pipeline. Inlet and outlet pipe are installed into the wall of the maintenance hole at the required locations. Maintenance holes usually have formed concrete channels that direct the flow.

Having the maintenance hole prebenched at the factory offers advantages over benching in the field. Prebenching is done under controlled conditions, resulting in a smooth surface with a channel of constant width. When used with flexible connectors, there is no need for workers to enter the confined space created when the maintenance hole is backfilled.

For deflected straight pipe, the joint of each pipe section is opened on one side while the other side remains in the home position. The difference between home and opened joint space is generally designated as the pull. The maximum permissible pull must be limited to that opening which will provide satisfactory joint performance. This varies for different joint configurations and is best obtained from the pipe manufacturer.

When establishing alignment for radius pipe, the first section of radius pipe should begin one half of a radius pipe length beyond the beginning of curve, and the last section of radius pipe should extend one half of a radius pipe length beyond the end of curve. (Table 3.7)

When extremely sharp curves are required, deflected straight pipe or standard lengths of radius pipe, may not be suitable. In such cases, bends or elbows may be used. Bends can be made at any angle up to the maximum shown in Table 3.8.

One or more of these methods may be employed to meet the most severe alignment requirements. Since manufacturing processes and local standards vary, local concrete pipe manufacturers should be consulted to determine the availability and geometric configuration of pipe sections to be installed on curved alignment. In addition, many manufacturers have standardized joint configurations and deflections for specific radii, and economies may be realized by using standard pipe.

6.7.5 Jacking Operations

In all jacking operations, the direction and jacking distance should be carefully established prior to beginning the operation. The first step of any jacking operation is the excavation of jacking pits or shafts at each end of the proposed line. The shaft from which pipe is to be jacked should be of sufficient size to provide ample working space, for spoil removal, and room for the jacking head, jacks, jacking frame, reaction blocks and one or two sections of pipe. Provision should be made for the erection of guide rails in the bottom of the pit. For large pipe, it is desirable to set rails in a concrete slab. If drainage is to be discharged from the jacking shaft, a collection sump and drainage pump are necessary.

The number and capacity of jacks depend on the size and length of the pipe to be jacked, and the type of soil. Regardless of the number and size of the jacks, the jacks should be placed on both sides of the pipe such that the resultant jacking force is slightly below the springline of the pipe. Use of a lubricant, such as bentonite, to coat the outside of the pipe, is helpful in reducing frictional resistance and preventing the pipe from freezing when forward movement is interrupted. Because of the tendency of soil friction to increase with time, it is usually desirable to continue jacking operations, without interruption, until completed.

Correct alignment of the pipe guide frame, jacks and backstop is necessary for uniform distribution of the axial jacking force around the periphery of the pipe. By assuring that the pipe ends are parallel and the jacking force properly distributed through the jacking frame to the pipe and parallel, with the axis of the pipe, localized stress concentrations are avoided. A jacking head is often used to transfer the pressure from the jacks, or jacking frame to the pipe. In addition to protecting the end of the pipe, a jacking head helps keep the pipe in proper line by maintaining equal pressure around the circumference of the pipe. Use of a cushion material such as plywood, hardboard or rubber spacers between adjacent pipe sections provide uniform load distribution throughout the entire pipe length being jacked. When pipe with rubber gasket joint sealants is being jacked, it is essential to provide cushioning between the pipe ends to avoid the development of radial gasket pressures which may overstress the pipe sockets or grooves.

6.8 Pipe Embedment Zone

6.8.1 Bedding and Sidefill

The load carrying capacity of an installed pipe is dependent on the embedment bedding and haunch support up to the springline of the pipe. The initial bedding must be placed on a stable foundation, and the centre 1/3 of the pipe OD must be loosely compacted. Material and density criteria should form part of the bedding requirements, because of the importance of obtaining the proper degree of compaction in the haunch area. For trench installations, where space is limited, tamping or pneumatic and mechanical impact tampers are usually the most effective means of compaction. Impact tampers, which compact by static-weight and kneading action, are primarily useful for soils containing clays. Granular soils are most effectively consolidated by vibration. Compaction equipment can generate significant dynamic forces capable of damaging installed pipe. Caution should be exercised with compaction equipment so as not to allow a direct blow on the pipe. Embedment material should be compacted at near optimum moisture content. As a minimum requirement, heavy construction equipment should not be permitted to operate directly over a pipe section, until a minimum of one metre of fill material has been placed.

6.8.2 Cover and Final Backfill

Once the sidewall has been placed and properly compacted, the remainder of the backfill should be placed. Compaction of backfill material above the pipe springline is only necessary if settlement at the surface is a concern. A 300 mm layer of cover material shall be provided before using a mechanical compactor above the pipe. The backfill material should be placed in layers, and compacted, at or near optimum moisture content.

If settlement is not a concern, water flooding and/or jetting can be used to compact the backfill material.

Pipe installed by jacking or tunneling may require the void between the pipe and the excavation to be filled. Sand, grout, concrete or other suitable material should be injected into the annular sapce. This can be accomplished by installing special fittings into the wall of the pipe, or vertical holes drilled from the surface.

When single cell boxes are used in parallel for multicell installations, positive lateral bearing must be provided between the sides of adjacent units. This is accomplished with grout to fill the annular space.

6.9 Field Testing

The physical tests included in the material specifications, under which the pipe is purchased, assure that pipe delivered to the jobsite meets, or exceeds the requirements established for a particular project. The project specifications usually include acceptance test requirements to assure that reasonable quality control of workmanship and materials has been realized during the construction phase of the project. Tests applicable to all storm sewer, sanitary sewer and culvert projects are soil density, line and grade and visual inspection, often by video. For sanitary sewers, leakage limits are usually established for infiltration or exfiltration.

6.9.1 Soil Density

Several test procedures have been developed for measuring in-place soil densities, and for cohesive soils most of the methods are based on volumetric measurement.

To correlate in-place soil densities with the maximum density of a particular soil, it is first necessary to determine the optimum moisture content for maximum compaction, then use this as a guide to determine the actual compaction of the fill, or backfill. The most common methods used to determine optimum moisture content and maximum density are the standard tests for moisture-density relations, frequently termed Standard Proctor Test and Modified Proctor Test.

ASTM D698 and AASHTO T99 require placing soil in three equal layers in a mould. Each layer is compacted by 25 blows of a 2.5 kg tamper falling a distance of 300 mm. After compaction, the soil is struck off, the compacted sample weight and the moisture content determined by drying a portion of the soil sample. Successive tests are made with increased moisture contents, and the result plotted on a moisture content-density graph. The peak of the resulting curve is the optimum moisture content required to produce maximum density.

ASTM D1557 and AASHTO T180 are similar except that the soil is compacted in five layers with a 4.5 kg tamper falling from a height of 450 mm. It is important to note that the two tests are not numerically interchangeable.

6.9.2 Moisture-Density Test

To determine the density of in-place soils, a sample is carefully cut from the compacted soil, and weighed. The volume occupied by the removed sample is determined by filling the hole with dry sand of known uniform density, or other suitable material. The in-place density is computed from the measured mass and volume of the sample, and compared with the density of the soil at maximum compaction.

ASTM D2922 and AASHTO T238 are nuclear methods which provide a rapid, nondestructive technique for in-place determination of density suitable for control and acceptance testing of soils to a depth of approximately 50 to 300 mm depending on the testing geometry. In general, the density of the material is determined by placing a gamma source and a gamma detector either on, into, or adjacent to the material. The radiation intensity reading is converted to measured wet density by a suitable calibration curve. It should be noted that density determined by these methods is not necessarily the average density within the volume involved in the measurement, and that the equipment utilizes radioactive materials, which may be hazardous to the health of users, unless proper precautions are taken.

6.9.3 Line and Grade

Line and grade should be checked as the pipe is installed. Any discrepancies between the design and actual alignment, and pipe invert elevations should be corrected prior to placing the backfill, or fill over the pipe. Obtaining maintenance hole invert levels for the preparation of as-built drawings, combined with visual inspection of the sewer or culvert, provides an additional check that settlement has not occurred during back-fill or fill operations.

6.9.4 Visual/Video Inspection

Larger pipe sizes can be entered and examined, while smaller sizes must be inspected from each maintenance hole, or by means of closed circuit television cameras. Following is a checklist for an overall visual inspection of a sewer or culvert project:

- debris and obstructions
- cracks exceeding 0.3 mm wide for sanitary sewers, storm sewers and pipe culverts
- joints properly sealed
- invert smooth and free of sags or high points
- stubs properly grouted and plugged
- laterals, diversions, and connections properly made
- catchbasins and inlets properly connected
- maintenance hole frames and grates properly installed
- surface restoration, and all other items pertinent to the construction, properly completed

6.9.5 Infiltration Testing

The infiltration of excessive ground water into a sanitary sewer can overload the capacity of a sewer collection system and treatment facilities. The infiltration test, conducted in accordance with ASTM C969M, is intended to demonstrate the integrity of the installed materials and construction procedures, as related to the infiltration of ground water, and therefore, is only applicable if the water table level is at least 0.6 m above the crown of the pipe, for the entire length of the test section. Although the test is a realistic method of determining water-tightness, there are inherent difficulties in applying the test criteria because of seasonal fluctuations in the water table, and the problem of correlating high ground water level conditions with actual test conditions.

Before conducting the test, the water table should be allowed to stabilize at its normal level such that water completely surrounds the pipe during the test period. The test is usually conducted between adjacent maintenance holes with the upstream end of the sewer bulkheaded in a suitable manner to isolate the test section. All service laterals, stubs and fittings should be properly plugged, or capped at the connection to the test pipe section to prevent the entrance of ground water at these locations. A V-notch weir, or other suitable measuring device, should be installed in the inlet pipe to the downstream maintenance hole. Infiltrating water is then allowed to build up and level off behind the weir, until steady-uniform flow is obtained. When steady flow occurs over the weir, leakage is determined by direct reading from gradations on the weir, or converting the flow quantity to litres per unit length of pipe per unit of time.

An important factor in applying the test criteria is to properly correlate the variable water head over the length of sewer being tested, to the high ground water level. The downstream end of the test section will always be subjected to a greater external pressure than the upstream end. To compensate for this variable external pressure, the test pressure should be that pressure corresponding to the average head of water over the test section. Certain test sections may exceed the allowable infiltration limits established for the particular project.

The effect of soil permeability, and increased depth of groundwater on infiltration allowances, must be considered. To effect the adjustment of the infiltration allowances to reflect the effect of permeable soil, an average head of 1.8 m of groundwater over the pipe is established as the base head. With heads of more than 1.8 m, the infiltration limit is increased by the ratio of the square root of the actual average head to the square root of the base head. For example, with permeable soil and an average groundwater head of 3.7 m, the 18.5 L/mm of diameter per kilometre of pipe per day infiltration limit should be increased by the ratio of the square root of the actual average head 3.7 m, to the square root of the base head, 1.8 m, which results in an allowable infiltration limit of 26.2 L/mm of diameter per kilometre of pipe per day.

6.9.6 Exfiltration Testing

An exfiltration test may be used in lieu of the infiltration test for small diameter sewers, where individual joints cannot be tested. Although actual infiltration will normally be less than that indicated by the water exfiltration test, the test does provide a positive method of subjecting the completed sewer system to an actual pressure test. Since sanitary sewers are not designed, or expected to operate as a pressure system, care must be exercised in conducting the test and correlating the results with allowable exfiltration limits.

The test is usually conducted between adjacent maintenance holes, in accordance with ASTM C 969M. Prior to the test, all service laterals, stubs and fittings within the test section should be plugged, or capped, and adequately braced, or blocked to withstand the water pressure resulting from the test. If maintenance holes are to be included in the test, the inlet pipe to each maintenance hole should be bulkheaded, and the test section filled with water through the upstream maintenance hole. To allow air to escape from the sewer, the flow should be at a steady rate until the water level in the upstream maintenance hole is at the specified level above the crown of the pipe. If necessary, provisions should be made to bleed off entrapped air during the filling of the test section. Once the test section is filled, the water should be allowed to stand for an adequate period of time to allow water absorption into the pipe and maintenance hole. After water absorption has stabilized, the water level in the upstream maintenance hole is brought up to the proper test level that is established by measuring down from the maintenance hole cover, or other convenient datum point. After a set period of time, the water elevation should be measured from the same reference point, and the loss of water during the test period calculated, or the water can be restored to the level existing at the beginning of the test, and the amount added used to determine the leakage.

To exclude both maintenance holes from the test, it is necessary to bulkhead the outlet pipe of the upstream maintenance hole. Provision must be made in the bulkhead for filling the pipe, and expelling trapped air.

ASTM C 969M recommends the water level at the upstream maintenance hole to be a minimum of 0.6 m elevation above the crown of the pipe, or at least 0.6 m above existing groundwater, whichever is greater. Since a sewer is installed on a grade, the test section downstream will be subjected to greater pressure. When the average head on the test section is greater than 0.9 m, the allowable exfiltration limit should be adjusted in direct relationship to the ratio of the square root of the average test head to the square root of the specified base head, 0.9 m.

The measured leakage of any individual section tested may exceed the leakage allowance specified, provided the average of all sections tested does not exceed the specified leakage allowance. Conducting exfiltration tests on large pipe is usually not practical because of the considerable quantity of water required. If the pipe is large enough to be entered, each individual joint can be visually inspected and, if necessary, subjected to a water exfiltration test by means of test apparatus specially designed for this purpose. In the procedure, the joint is isolated with an expanding shield equipped with gaskets which fit tightly against the pipe walls on each side of the joint being tested. Through appropriate piping, water is introduced into the annular space isolated by the shield, and the leakage measured. The allowable leakage for individual joints is that which would occur on the basis of the allowable water leakage for one pipe section.

6.9.7 Low Pressure Air Testing

The low pressure air test that is conducted in accordance with ASTM C 924M is a test which determines the rate at which air under pressure escapes from an isolated section of sewer. The rate of air loss is intended to indicate the presence or absence of pipe damage, and whether or not joints have been properly constructed. The test is not intended to indicate water leakage limits, as no correlation has been found between air loss and water leakage. The section of pipe to be tested is plugged at each end by means of inflatable stoppers. The ends of all laterals, stubs and fittings to be included in the test should be plugged to prevent air leakage, and securely braced to prevent possible blow-out due to the internal air pressure. One of the plugs should have an inlet tap, or other provision for connecting a hose to a portable air control source. The air equipment should consist of necessary valves and pressure gauges to control the rate at which air flows into the test section, and to enable monitoring of the air pressure within the test section. Air is added to the test section until the internal air pressure is raised to a specified level, and allowed to stabilize with the temperature of the pipe walls. The test is conducted by the pressure drop method, whereby the air supply is disconnected and the time required for the pressure to drop to a certain level is determined by means of a stopwatch. This time interval is then used to compute the rate of air loss. In applying low pressure air testing to sanitary sewers intended to carry fluid under gravity conditions, several important factors should be understood and precautions followed during the test.

The air test is intended to detect defects in construction, and pipe or joint damage, and is not intended to be a measure of infiltration or exfiltration leakage under service conditions, as no correlation has been found between air loss and water leakage.

- Air test criteria are presently limited to concrete pipe 600 mm in diameter and smaller by ASTM C 924M
- Applicable test criteria should be governed by the prevailing environmental conditions
- Plugs should be securely braced to prevent the unintentional release of a plug, which can become a high velocity projectile. Plugs must not be removed until all pressure in the test section has been released
- For safety reasons, no one should be allowed into the trench, or maintenance hole, while the test is being conducted
- The testing apparatus should be equipped with a pressure relief device to prevent the possibility of loading the test section with the full compressor capacity

6.9.8 Joint Acceptance Test

For concrete pipe diameters 675 mm and larger, joint acceptance testing can be conducted in accordance with ASTM C 1103, Standard Practice for Joint Acceptance Testing of Installed Precast Concrete Pipe Sewer Lines. The test is intended to indicate the presence or absence of pipe damage, and whether or not the joints have been properly constructed. The test is not intended to determine water leakage limits, as no correlation has been found between air loss and water leakage. The joint to be tested is to be covered on the inside of the pipe by a ring with two end element sealing tubes. Air or water, at low pressure, is introduced through a connection on the ring, into the annular space between the ring and the joint, to a specified pressure. Once the pressure has stabilized, the amount of air, or water loss in a specified time lapse determines the acceptability of the joint. The test is a go/no go test. To ensure consistent results, the joint and the interior joint surface should be free of debris, and the interior surface should be wetted. The use of compressed air may be dangerous if the sewer line is not properly prepared, and proper procedures are not followed . It is imperative that all pressures be relieved completely, prior to loosening the test apparatus for removal. The lines pressuring the two element sealing tubes are to be separate from the lines that pressurize the void. All recommendations and procedures stated by the apparatus manufacturer should be followed. To reduce hazards and avoid over-pressurization, the line pressurizing the void volume should include a pressure relief device.