CCPPA

Precast
TechNotes

FOR CONCRETE PIPE AND PRECAST USE

2025

Build on our strength

Acknowledgement

The CCPPA would like to acknowledge all the industry member companies and their employees who contributed to this document. **Precast TechNotes** is a technical resource intended for the precast industry, for designers and specifiers of concrete pipe and precast structures, for owners and users of precast concrete infrastructure, and for all others who find benefit from utilizing precast concrete for a durable, safe and sustainable option in buried infrastructure.

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Revisions

The following index is a record of revisions made to the **Precast TechNotes** resource.

Item	Section	Revision Details	Revision Date
0.0	Section Title	As required	yyyy/mm/dd

CCPPA Producer Members

The Canadian Concrete Pipe and Precast Association (CCPPA) continually welcomes the involvement of industry organizations to participate as members of this Association. It's the expertise and knowledge from these member companies and their employees that empower the CCPPA with the technical resources needed for reinforced concrete pipe and precast products for buried infrastructure.

Below is the list of current Producer members of CCPPA (as of 2025) from coast to coast. Visit our website at www.ccppa.ca to view the most current list of Association members.

British Columbia

- Amrize Canada Inc.
- Heidelberg Materials
- Leko Precast
- Tri-Kon Precast Concrete Products Ltd.

Alberta

- Amrize Canada Inc.
- Heidelberg Materials
- Precon
- Proform Construction Products
- S3 Precast

Saskatchewan

- Souris Valley Industries

Manitoba

- Amrize Canada Inc.
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Ontario

- Coldstream Concrete
- DECAST Ltd.
- Ewing Fabricators
- IECS Group Inc.
- MCON
- Miller Precast
- OMNI PRECAST
- Rainbow Concrete Industries
- Rinker Materials

Quebec

- Groupe Brunet

Nova Scotia

- Shaw Precast Solutions

Introduction

The Canadian Concrete Pipe & Precast Association (CCPPA) and its Producer members are pleased to present this resource, **Precast TechNotes for Concrete Pipe & Precast Use**. The CCPPA and its Producer members have long been recognized as industry leaders for reinforced concrete pipe, precast maintenance holes, precast box culverts and other forms of buried precast structures. This technical resource is a quick and easy reference to many of the common topic areas related to design, manufacture and installation of concrete pipe and precast products.

Within the gravity sewer and drainage market, many different construction materials are available for use. **Precast TechNotes** touches on the many considerations necessary for specifying pipe materials like concrete pipe for sewer or drainage applications. **Precast TechNotes** also highlights many of the common questions and key aspects that relate to precast use for buried infrastructure.

With origins of a provincial Association (in Ontario) since 1957, towards the current national group of the CCPPA, the Association continues to be the trusted go-to resource for all information related to buried precast concrete. The CCPPA hopes this technical resource will become a useful tool for all groups associated with buried infrastructure in sewer, drainage, water, transportation and more. The CCPPA is committed to the development and evolution of concrete pipe and precast in an ever-changing marketplace. Concrete pipe's historical reliability is evidenced by the last one hundred plus years of reliable, durable and resilient infrastructure service.

The Canadian Concrete Pipe & Precast Association delivers leadership on policy and education to ensure appropriate standards and specifications for resilient underground civil infrastructure.

Build it once. Build it right. Build it to last.

Bedding Considerations for Concrete Pipe

The ease of installation can be mistaken for ease of handling. Although lightweight flexible pipes are easy to handle, it is far more installation sensitive than the heavier concrete pipe. The degree of dependence on soil-pipe interaction is a measure of installation sensitivity and hence ease of installation. The ease of installation for concrete pipe, together with powerful new design tools for design engineers, help lead to opportunities for saving time and non-renewable materials on underground infrastructure projects.

The strength of concrete pipe is determined by the Three Edge Bearing (3EB) test, establishing pipe strength under a severe point load condition. Traditional concrete pipe design known as Indirect Design method requires a bedding factor (B_f) to equate the 3EB test load to the proposed applied load in the field.

$$\boldsymbol{3EB \quad Bedding\ Factor = Applied\ Load\ in\ Field}$$

The conservative bedding factor has proven reliable for decades for a variety of installation conditions.

In contrast to the methodology for designing a concrete pipe installation, flexible pipe installation can be associated to the relationship between pipe stiffness and soil stiffness required in the soil envelope. The relatively low stiffness of flexible pipe must be compensated for by assuming that the installer can provide high soil stiffness through good installation techniques. Imported granular material is used in the installation of flexible pipe to attain the necessary soil stiffness. The granular envelope must provide uniform pressure around the circumference of the conduit to allow the tubing to maintain an approximation of the original circular cross-section. Thermoplastic pipe with a parallel plate test stiffness of 320 kPa is often used in design with a modulus of soil reaction of 7000 kPa. The soil stiffness must be nearly 22 times higher (7000/320) than the stiffness of the flexible pipe. The flexible pipe designer must be confident that realistic assumptions are used in the design and that the installer is aware of and capable of providing the assumed design parameters in what can be adverse field conditions.

New concrete bedding designs, developed by the American Concrete Pipe Association (ACPA) and subsequently adopted by the American Society of Civil Engineers (ASCE), American Society for Testing and Materials (ASTM), the American Association of State Highway and Transportation Officials (AASHTO) and the Canadian Highway Bridge Design Code (CHBDC), have changed the way that concrete pipe installations are designed. Standard Installation Direct Design (SIDD), and a new software design tool named PipePac, provide new opportunities to optimize installations for the designer wanting to utilize the reliability and installation ease of concrete pipe. PipePac is a design package that permits the use of finite element analysis, on which SIDD is based, to determine the strength of pipe required for any installation. This is in addition to the indirect design methods used for decades. The SIDD bedding design accounts for limitations not addressed in the Indirect Design method, such as:

- Loads considered to be acting only at the top of pipe.
- Axial thrust is not considered.
- Difficulty in providing a ‘shaped bedding’.
- Bedding materials and compaction levels not adequately defined.

The finite element model prescribes definitive trench configurations (see Figure 1) and measurable levels of compaction (see Table 1).

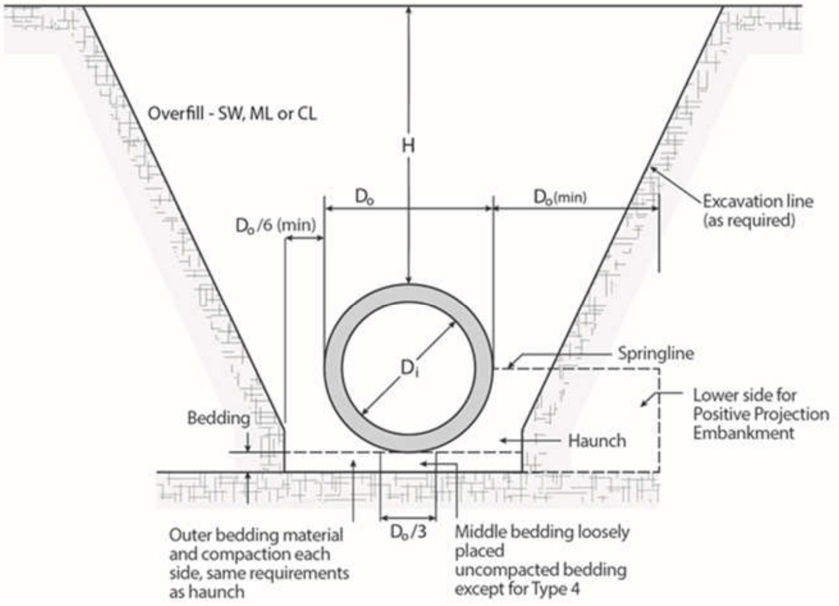


Figure 1: Standard Trench Geometry

SIDD beddings allow for a range of installation options from high quality granular bedding to the use of native materials. The bedding design is left to the designer, who can determine the most appropriate installation design for the project under consideration. This decision shall be based on a combination of issues, such as project location, ultimate use of infrastructure, site conditions, availability of materials and installation cost. The designer is given the ability to ‘design’ the project through the use of PipePac (*www.pipepac.com*).

Table 1: Standard Trench Installation Soils and Minimum Compaction Requirements

Installation Type	**Bedding Thickness**	**Haunch and Outer Bedding**	**Lower Side**
1	D_o/24 minimum, not less than 75 mm. If rock foundation, use D_o/12 minimum, not less than 150 mm.	95% SW	90% SW 95% ML, or 100% CL
2	D_o/24 minimum, not less than 75 mm. If rock foundation, use D_o/12 minimum, not less than 150 mm.	90% SW, or 95% ML	85% SW or 90% ML or 95% CL
3	D_o/24 minimum, not less than 75 mm. If rock foundation, use D_o/12 minimum, not less than 150 mm.	85% SW, 90% ML, or 95% CL	85% SW, 90% ML, or 95% CL
4	No bedding required, except if rock foundation, use D_o/12 minimum, not less than 150 mm.	No compaction required, except if CL, use 85%	No compaction required, except if CL, use 85% CL

where,
- D_o , Outer diameter of pipe
- SW, Well-graded material (sands, gravels, etc.)
- ML, Inorganic silts, fine sands, clayey silts with slight plasticity
- CL, Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, etc.

In recent years, the use of alternative granular materials is being considered in place of more traditional granular materials. Many reasons for this are attributed to cost, such as: material cost, transportation costs for importing/ exporting materials between sites, and labour costs related to handling and placement. Limitations related to environmental policies such as excess soils legislation, or restrictions related to material disposal, mandates to use more recycled content (i.e. crushed concrete or ground asphalt) mixed in granular, or alternative use byproduct materials such as high-performance bedding (HPB).

Whatever the type of bedding or backfill material considered, precautions should be taken to ensure acceptable use in pipe design, and for handling and placement specifications. The design engineer should conduct a refined analysis of the expected pipe-soil interaction while seeking the recommendations of a geotechnical engineer.

Box Culverts and Welded Wire Reinforcement

Precast reinforced concrete box units are accepted throughout North America as a standard, high quality, and economical product. Sizes can range from 1200 mm x 900 mm up to 3600 mm x 3600 mm, but are not restricted to these. The successful application of these large precast structures is due, in large measure, to the development of welded wire reinforcement (WWR). WWR sheets can be bent into shape as an economical replacement for traditional reinforcing bars or “rebar”. Use of WWR has significantly improved production efficiencies and the quality of the finished product.

Deformed WWR with its higher yield strength of 485 MPa allows for a reduction in steel area of 17% over conventional 400 MPa rebar. WWR is easily bendable into rectangular cages and is readily weldable. The closely spaced welded intersections of WWR result in superior crack control. A weld shear strength of 241 MPa contributes to the development and anchorage of WWR in concrete. This is assured by maintaining an adequate wire size differential between wires to be welded. The smaller wire cross sectional area must be a minimum 40% of the nominal area of the larger wire in order for the welded intersections to be permitted for use of anchorage and development of the WWR, as per ASTM A1064. WWR manufacturers are obliged to issue a mill compliance notification to that effect.

Wire Size Designation

Individual wire (plain and deformed) size designations are based on the cross-sectional area of a given wire. The “W” prefix denotes plain smooth wire and “D” is for deformed wire. The number following the letter gives the cross-sectional area of the wire (customary units in hundredths of an inch). For example, W4 would indicate a plain wire with a cross-sectional area of 0.04 in^2. D10 would indicate a deformed wire with an area of 0.10 in^2. When describing metric wire or WWR sheets, a prefix “M” is added denoting the steel area in metric units (mm^2). For example, MW 25.9 refers to a plain wire with an area of 25.9 mm^2.

Table 1 lists standard W & D wires and the equivalent MW and MD metric wire sizes, along with steel areas per unit length for different wire spacings. There are many smaller size and larger size wires not shown in Table 1.

Table 1: Sectional Areas for Welded Wire Reinforcement (WWR)

Wire Size	Nominal Dia.	Nominal Area	Nominal Mass	**AREA - in^2 per Linear Foot / *AREA - mm^2 per Linear Metre*** **Centre to Centre Spacing (in / *mm*)**						
	in	**in^2**	**lb/ ft**	**2 in**	**3 in**	**4 in**	**6 in**	**8 in**	**10 in**	**12 in**
	mm	*mm^2*	*kg/ m*	*51 mm*	*76 mm*	*102 mm*	*152 mm*	*203 mm*	*254 mm*	*305 mm*
D20	**0.505**	**0.200**	**0.680**	**1.200**	**0.800**	**0.600**	**0.400**	**0.300**	**0.240**	**0.200**
MD 129	*12.83*	*129*	*1.010*	*2540*	*1693*	*1270*	*847*	*635*	*508*	*423*
D18	**0.479**	**0.180**	**0.612**	**1.080**	**0.720**	**0.540**	**0.360**	**0.270**	**0.216**	**0.180**
MD 116	*12.17*	*116*	*0.911*	*2286*	*1524*	*1143*	*762*	*572*	*457*	*381*
D16	**0.451**	**0.160**	**0.544**	**0.960**	**0.640**	**0.480**	**0.320**	**0.240**	**0.192**	**0.160**
MD 103	*11.46*	*103*	*0.809*	*2032*	*1355*	*1016*	*677*	*508*	*406*	*339*
D15.5 (10M)	**0.445**	**0.155**	**0.528**	**0.930**	**0.620**	**0.465**	**0.310**	**0.233**	**0.186**	**0.155**
MD 100	*11.3*	*100*	*0.785*	*1960*	*1316*	*980*	*658*	*490*	*394*	*328*
D14	**0.422**	**0.140**	**0.476**	**0.840**	**0.560**	**0.420**	**0.280**	**0.210**	**0.168**	**0.140**
MD 90.3	*10.72*	*90*	*0.708*	*1778*	*1185*	*889*	*593*	*445*	*356*	*296*
D12	**0.391**	**0.120**	**0.408**	**0.720**	**0.480**	**0.360**	**0.240**	**0.180**	**0.144**	**0.120**
MD 77.4	*9.93*	*77*	*0.607*	*1524*	*1016*	*762*	*508*	*381*	*305*	*254*
D11	**0.374**	**0.110**	**0.374**	**0.660**	**0.440**	**0.330**	**0.220**	**0.165**	**0.132**	**0.110**
MD 71	*9.5*	*71*	*0.556*	*1397*	*931*	*699*	*466*	*349*	*279*	*233*
D10	**0.357**	**0.100**	**0.340**	**0.600**	**0.400**	**0.300**	**0.200**	**0.150**	**0.120**	**0.100**
MD 64.5	*9.07*	*65*	*0.506*	*1270*	*847*	*635*	*423*	*318*	*254*	*212*
D9	**0.339**	**0.090**	**0.306**	**0.540**	**0.360**	**0.270**	**0.180**	**0.135**	**0.108**	**0.090**
MD 58.1	*8.61*	*58*	*0.456*	*1143*	*762*	*572*	*381*	*286*	*229*	*191*
D8	**0.319**	**0.080**	**0.272**	**0.480**	**0.320**	**0.240**	**0.160**	**0.120**	**0.096**	**0.080**
MD 51.6	*8.1*	*52*	*0.405*	*1016*	*677*	*508*	*339*	*254*	*203*	*169*
D7	**0.299**	**0.070**	**0.238**	**0.420**	**0.280**	**0.210**	**0.140**	**0.105**	**0.084**	**0.070**
MD 45.2	*7.6*	*45*	*0.354*	*889*	*593*	*445*	*296*	*222*	*178*	*148*
D6	**0.276**	**0.060**	**0.204**	**0.360**	**0.240**	**0.180**	**0.120**	**0.090**	**0.072**	**0.060**
MD 38.7	*7.01*	*39*	*0.304*	*762*	*508*	*381*	*254*	*191*	*152*	*127*
D5	**0.252**	**0.050**	**0.170**	**0.300**	**0.200**	**0.150**	**0.100**	**0.075**	**0.060**	**0.050**
MD 32.3	*6.4*	*32*	*0.253*	*635*	*423*	*318*	*212*	*159*	*127*	*106*
D4	**0.226**	**0.040**	**0.136**	**0.240**	**0.160**	**0.120**	**0.080**	**0.060**	**0.048**	**0.040**
MD 25.8	*5.73*	*26*	*0.203*	*508*	*339*	*254*	*169*	*127*	*102*	*84.7*

Note: Refer to WWR manufacturer tables for additional wire sizes other than those listed above.

Steel Reinforcement

Reinforcing wire cages for square or rectangular precast are fabricated from premanufactured flat WWR sheets that are bent into ‘U-shapes’ and ‘C-shapes’. When tack welded together, these reinforcing sections form the inner and outer reinforcing cages (see Figure 1). The wire used in WWR is produced from controlled quality, low carbon (S1006 to C1012) hot rolled steel rods. These rods are cold worked through a series of dies to reduce the rod diameter to the specified wire diameter and to increase the yield strength of the steel. A deformation roll is used to produce deformed wire. Chemical composition is carefully selected to give proper welding characteristics in addition to desired mechanical properties. WWR is produced on automatic resistance welding machines that are designed for long, continuous operation. Longitudinal wires are straightened and fed continuously through the machine. Transverse wires, entering from the side or from above the welder, are individually welded to the longitudinal wires each time the longitudinal wires advance through the machine a distance equal to one transverse wire spacing.

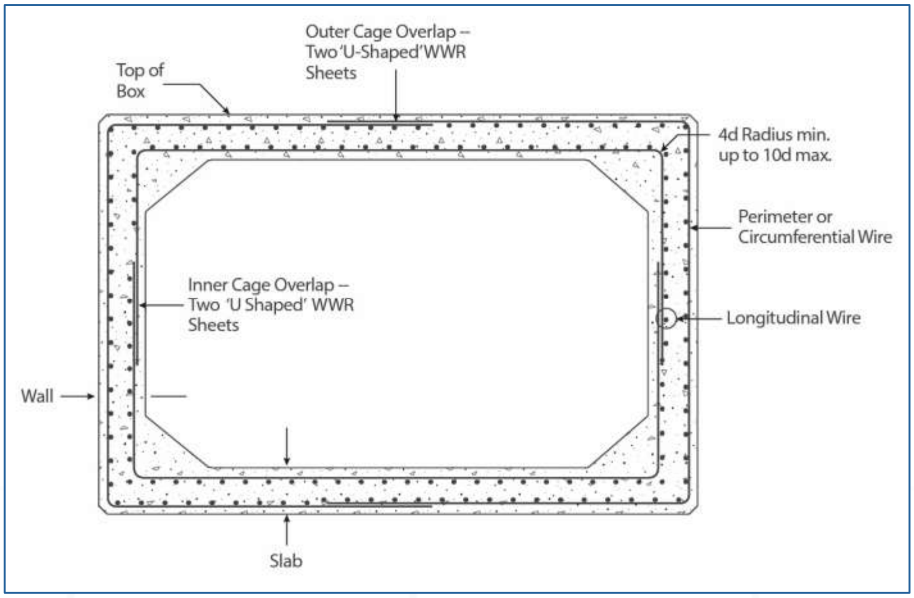


Figure 1: Reinforced Precast Concrete Box Section - Typical Arrangement of WWR

Designating Style of Welded Wire Reinforcement

Spacing and sizes of wires in WWR are identified by "style". A typical description for a WWR sheet size and style might be: 152 mm x 305 mm – MD77.4 x MW32.3 x 2337 mm +13 mm +13 mm x 7320 mm including 152 mm overhangs. This denotes a WWR sheet which is 2337 mm wide plus 13 mm overhang on each side (i.e. 2363 mm overall width) with an overall length of 7320 mm, including 152 mm overhangs on each end. Furthermore, the makeup of the WWR sheet includes:

- Spacing of longitudinal deformed wires = 152 mm
- Spacing of transverse plain smooth wires = 305 mm
- Size of longitudinal wire = 77.4 mm^2
- Size of transverse wire = 32.3 mm^2

It is important to note that the terms of “longitudinal” and “transverse” wires are related to the manufacturing process and do not refer to the relative position of the wires in a concrete structure. Figure 2 provides a graphical representation of the nomenclature used for WWR.

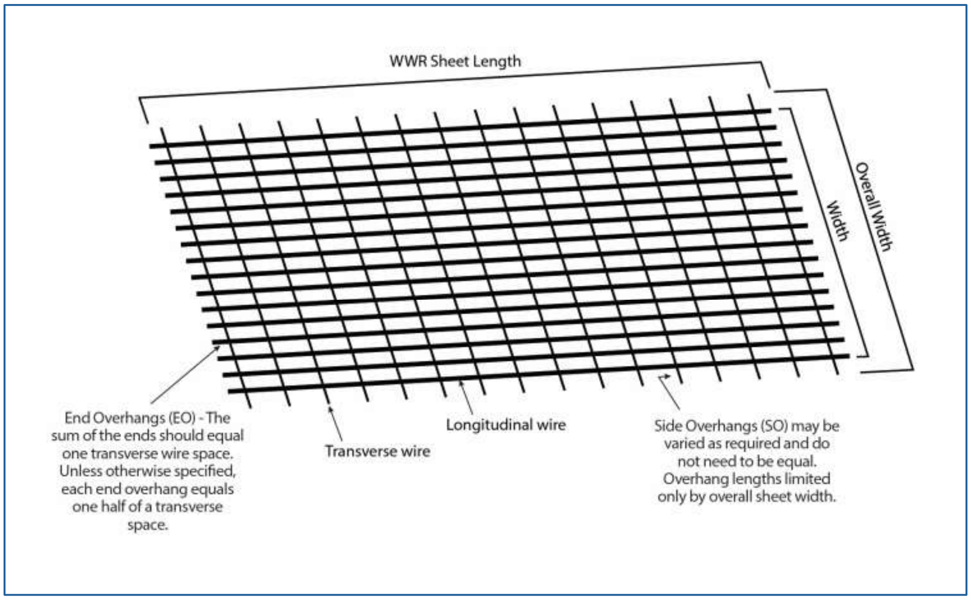


Figure 2: Nomenclature for a WWR Sheet

Specifications

Welded Wire Reinforcement and the wire for the manufacture of WWR, is produced in accordance to ASTM A1064 – *Standard Specification for Steel Wire and Welded Wire Reinforcement, Plain and Deformed for Concrete*. Table 2 lists the minimum required mechanical properties. Note, Smooth Plain and Deformed WWR have a yield strength equal to 450 MPa and 485 MPa, respectively. Higher yield strengths, improved weldability, premanufactured quality control and fabricating efficiencies are the primary advantages of WWR over rebar.

Table 2: Minimum Mechanical Properties of Welded Wire Reinforcement

Type of Wire	Minimum Tensile Strength	Minimum Yield Strength, F_y	Minimum Weld Strength
Smooth Wire Mesh	515 MPa (75 ksi)	450 MPa (65 ksi)	241 MPa (35 ksi)
Deformed Structural Wire Mesh	550 MPa (80 ksi)	485 MPa (70 ksi)	241 MPa (35 ksi)

The above properties are the minimum tension test requirements of smooth and deformed wires for WWR. Weld shear strength (in Newtons) for smooth and deformed WWR shall not be less than 241 MPa multiplied by the nominal area of the larger wire in square millimetres.

Chemical Resistance of Sanitary Sewers

Sanitary sewer systems are expensive and once installed should have a service life of 75 years or more. Sanitary sewers carry substances that can be very damaging to public health and the environment. Therefore, their structural integrity should not be compromised by the substances they are designed to carry.

Industrial chemicals that can cause corrosion directly or facilitate sulphide production are monitored and controlled at source. In addition, sewer use bylaws contain restrictions on the discharge of deleterious substances and the discharge of wastewater with elevated temperatures to the sewer system.

Concrete pipe is unique in that it has a proven record of durability, an important feature required by today's pipe specifiers. Concrete pipe's earliest use as agricultural drain tile and engineered sewer systems, thereafter, can be traced back to the early 19th century. The oldest recorded concrete pipe sanitary sewer installation was in 1842 in Mohawk, New York. There are also several installations of concrete pipelines that were installed in the late 1800's that are still in service today.

The chemical resistance of concrete pipe makes it suitable for industrial and wastewater applications. Concrete pipe benefits from its structure and its neutralizing makeup such as limestone aggregate. It is acknowledged that acids with pH below 5.5 can damage concrete. Sanitary sewer use bylaw's generally limit the discharge of substances to a range of pH 5 to pH 9, however, substances outside of this range have found their way into sewer systems. If there is a one-time situation, the surface paste of the concrete pipe can be affected but the exposed limestone aggregate will effectively limit damage. If exposure is an ongoing condition, then damage will continue to occur.

Hydrogen Sulphide Production

In sanitary sewers, the presence of hydrogen sulphide can be very prevalent under certain conditions, and lead to deleterious conditions within the sewer. Like many materials under attack, concrete pipe is one of those pipe materials susceptible to the corrosive effects of H_2S gas. Simple aspects of sewer design such as sufficient slope to maintain solids in suspension, or northern regions where the average ambient temperature is low enough during most of the year, can all to minimize hydrogen sulfide generation.

The goal of design engineers is to minimize the potential for the development of hydrogen sulfide in sewers. Concrete pipe can resist intermittent attacks of corrosive agents due to the way it is manufactured (minimum cover of 25 mm of concrete over the reinforcing steel). When there are problems in drainage systems caused by H2S, the following factors are usually the primary influences that may lead to the ultimate 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 whereby corrosion may result. 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 sulfide.

Biological Oxygen Demand (BOD) and Temperature: Temperatures above 15 ˚C may contribute to the generation of hydrogen sulphide if all other conditions of sulphide generation are present. BOD is a measure of 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 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 to 1.07 m/s to keep solids in sus pension. If the velocity causes turbulent flow conditions, increased oxygen may be absorbed into the wastewater, but hydrogen sulphide in wastewater will also be released to the atmosphere. The released hydrogen sulphide may cause corrosion to the wall of the concrete pipe.

Time. The continuous flow of sanitary sewage is the best defense in the fight against hydrogen sulphide production. Delay in the flow decreases the velocity, thus increasing the risk of production of H_2S. Designers must guard against these risks when considering the design of sanitary sewage facilities.

Junctions. Junctions are important because the wastewater from the tributaries may contain high concentrations of sulphide, lower pH, high BODs and higher temperatures. All these factors may affect the hydrogen sulphide production in the main sewer line. Junctions may also affect the type of flow wherever they enter the main. If the flow is turbulent, more oxygen may be absorbed into the wastewater, 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.

Forcemains and Siphons. Special junctions like forcemains and siphons, have a similar effect on the wastewater stream, as do regular junctions. Forcemains and siphons may flow at low velocities, or intermittently, allowing the increase of sulphide. Forcemains usually flow full, which also facilitates the build-up of sulphides due to the anaerobic conditions in the forcemain. When forcemains 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 and oxygen levels of 1 mg/L and temperatures less than 15 ˚C can be achieved, corrosion in sanitary sewers will not be problem at any time. Accumulation of solids could be a problem during the three warmest months of the year. During these months, temperature is sufficiently high to have sewer water temperatures above 15 ˚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 m^3/s, sulphide concentrations will not increase sufficiently to become a problem.

Concrete pipe is unique in that it has a record of proven durability, an important feature required by today’s pipe specifiers. Concrete pipe should not be viewed as inferior to any modern pipe materials based on observation of old mortar joint pipe. In fact, investigations of many old concrete pipe installations have demonstrated excellent durability, increased strength and superior abrasion resistance in adverse environments.

Steel Reinforcement for Concrete Pipe

Physical Properties of Reinforcement

Reinforcing areas required for concrete pipe, as deter- mined by pipe design methods like SIDD (Standard Installations Direct Design), SAMM (Spangler & Marston Method) and PipeCar vary according to design factors like depth of bury, bedding types, pipe geometry, and material properties of the concrete and steel.

Areas of steel are achieved through a grid pattern of longitudinal and circumferential wires. Longitudinal wires run the length of the pipe, while circumferential wires follow the perimeter of the pipe. For the most part, longitudinal wires maintain the position and shape of the circumferential reinforcement wires at designed spacing within the formwork. It is by varying the wire diameter and/or the wire spacing, along with concrete strength, that a pipe achieves its design strength. Reinforcing cages can be manufactured with welded wire mesh or fabricated using cage machines or mandrels.

Principles of Reinforcement

In a loaded application, the concrete pipe wall must resist the combined effects of moment and thrust known as flexural stress. The resultant of this stress is circumferential tension and compression forces within the pipe wall. Taking a closer look at how the pipe performs, it is the cross-sectional shape of the pipe that changes from its true round shape. Although the movement is unnoticeable, the vertical dimension decreases and the horizontal dimension increases. This change in shape produces tensile stresses at the invert and obvert along the inner pipe wall, and at the springline along the outer pipe wall. While this is occurring, compressive stresses are developing in areas opposite to the tensile stresses. Flexural stress is maximized in the tensile zones of the pipe (see Figure 1).

Since concrete is weak in tension, steel reinforcement must be placed in these areas to control cracking. Reinforcement in areas of compression is not required; however, methods of reinforcing and ease of placement result in it being used.

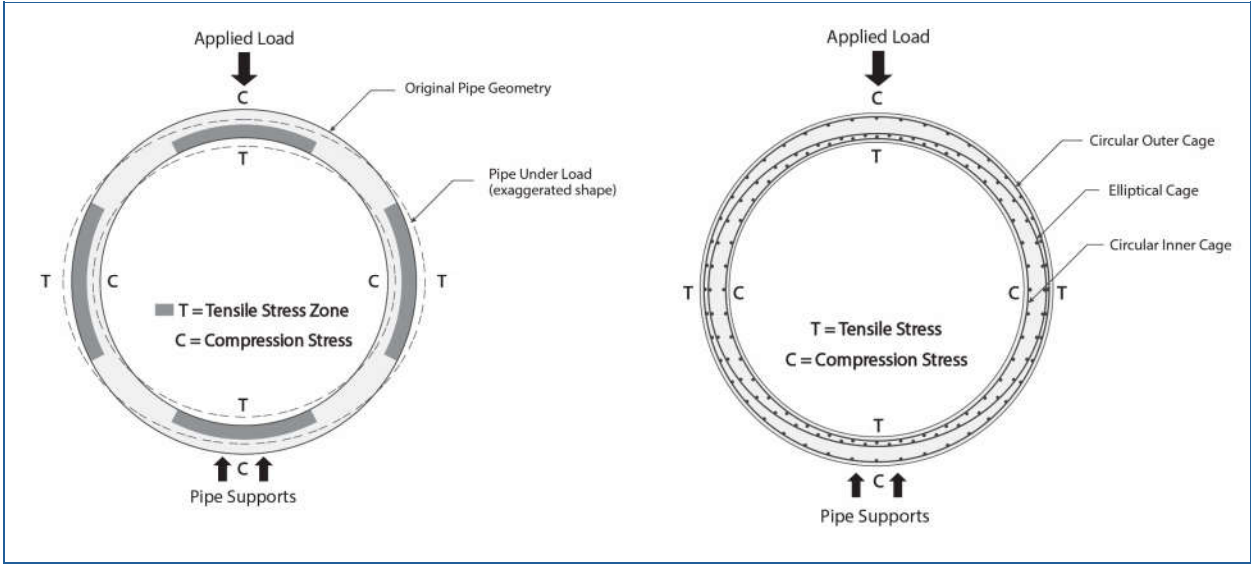


Figure 1: Flexural Stress on Loaded Concrete Pipe and Reinforcing Requirements

Shear stresses (or diagonal tension) should also be checked when considering the supporting strength of the concrete pipe. Once again, it is the tensile zones within the pipe wall where shear strength of the pipe is reduced. For a given pipe diameter with a fixed wall thickness, varying reinforcement areas (within limits) and reinforcement placement provide the additional shear strength to the pipe.

Four cage configurations are common use: single circular cage, double circular cage, single elliptical cage, and a combination of an elliptical cage and one or more circular cages. Alternatively, quadrant reinforcement can be used to provide increased steel areas in the tensile zones of the pipe. When necessary, stirrups provide the additional shear strength or radial tension strength. Figure 2 illustrates a typical reinforcement pattern for large diameter pipe combining an inner and outer cage with an elliptical cage for optimum positioning of tensile steel.

D-Load Requirements & Manufacturing Specifications

Reinforced concrete pipe is manufactured in accordance with product manufacturing Standards, CSA A257 Series or ASTM C76. The concrete pipe is tested and classified with a D-Load using the Three Edge Bearing (3EB) test method. The D-Load is the supporting strength of a pipe for an applied load expressed in Newtons per linear metre per millimetre of inside pipe diameter (N/m/mm). There are two pipe strengths determined by this method; $D_{0.3}$ is a calculated pipe strength for an applied load which will produce a crack width of 0.3 mm over a 300 mm length, while D_{ult} is a calculated ultimate pipe strength which will result in failure. The D-Load strength concept and the statistical evaluation of test results are the basis for the CSA and ASTM Standards that govern the manufacture of concrete pipe. CSA and ASTM provide minimum design tables for four and five classes of reinforced concrete pipe showing the pipe diameter, wall thickness, compressive strength of concrete and the amount of circumferential reinforcement required for

each class. The pipe strength classes in CSA are: Class 50-D, 65-D, 100-D and 140-D; the pipe strength classes in ASTM are: Class I, Class II, Class III, Class IV, and Class V.

The steel areas listed are used as a guide, however, the overriding acceptance factor is the 3EB test. For some larger pipe sizes where the standard does not list steel areas, the pipe manufacturer may employ the design methods referenced above as a guide to selecting steel areas.

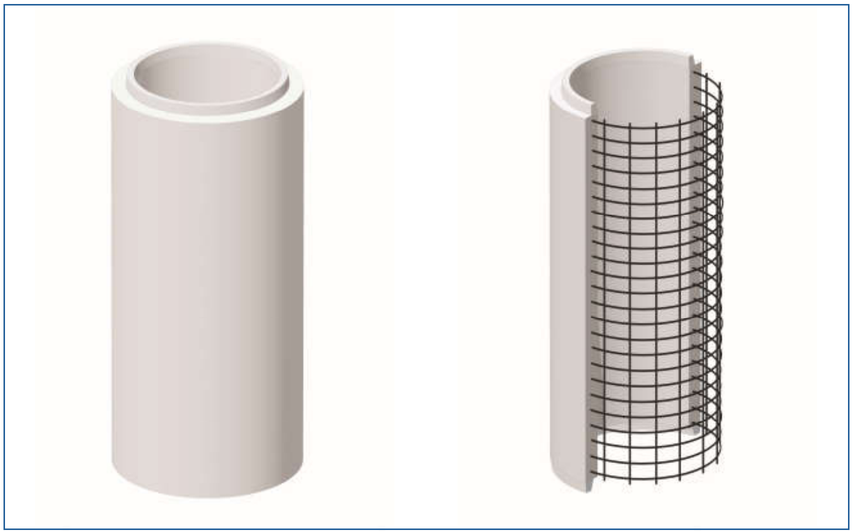


Figure 3: Single Cage Reinforcing in Concrete Pipe

0.3 mm Crack Design

Reinforced concrete pipe is designed to crack under applied load. These cracks are visible evidence that the concrete pipe has deflected due to the applied load, therefore placing the steel reinforcement into tension as it was designed to do. A reinforced concrete structural element may crack before or after the design criteria is met. The 0.3 mm crack width is a criterion used to determine the design strength of the pipe has been reached. Evidence of the 0.3 mm crack is verified by a crack gauge and should occur at or after the theoretical design load has been reached.

A 0.3 mm crack is a hairline crack and does not provide a source for future corrosion. It should not be a cause of concern for leakage or infiltration as the crack does not extend through the pipe wall. The crack is V-shaped and is widest at the concrete surface. The fact that the 0.3 mm crack criterion is conservative is demonstrated by more than 70 years of experience in the United States and Canada. There has never been a report of deleterious corrosion of the reinforcement in a concrete pipe due to the existence of cracks of the 0.3 mm magnitude.

Key Factors in the Determination of Loads on Rigid Pipe

When setting out to determine the loads on rigid pipe, and hence an appropriate pipe strength selection for a given job, designers should focus on three key areas to arrive at a safe, well-engineered and cost-effective design:

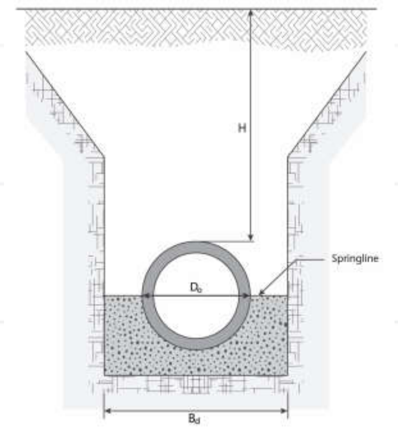
- Site soil conditions
- Installation type
- Bedding type

Site Soil Conditions

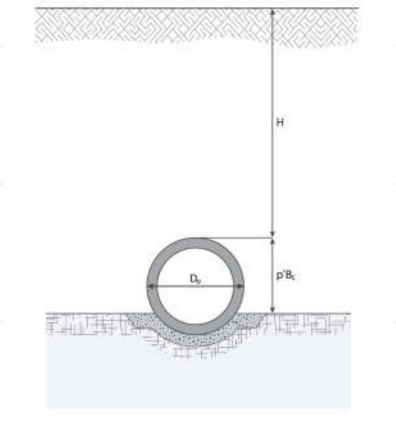
It is important that designers endeavor to use soils data relevant to their site. Failure to do so may lead to inadequate installation and bedding type selection which are the key factors for determining the pipe strength. The most important resource will be the geotechnical report, where site specific soil data and geotechnical recommendations can be found. Example soil parameters for design purposes include the in-situ soil density, coefficient of friction, and Rankine's coefficient. If using a version of fill height table for concrete pipe design, it is important that any design assumptions for the table be confirmed as applicable to the pipe design and local jurisdiction requirements.

Installation Type

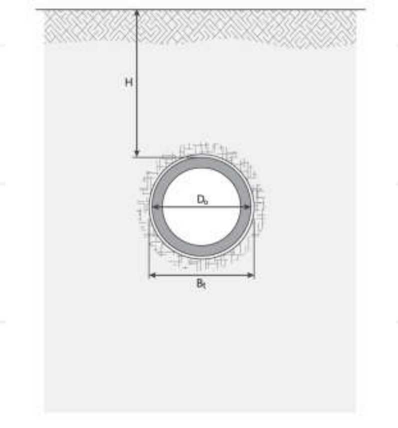
There are six installation conditions for concrete pipe. Confined Trench, Positive Projecting, and Jacked or Tunneled being the three most common conditions utilized. In some parts of Atlantic Canada where depth of bury depth for concrete pipe is high, the Negative Projecting condition is also common.



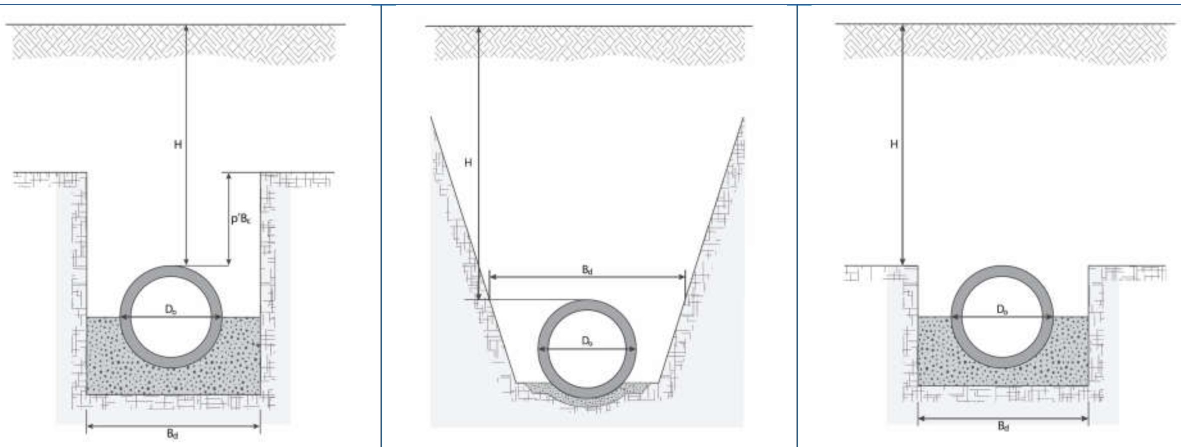
Confined Trench



Positive Projecting



Jacked or Tunneled



Negative Projecting | **Wide Trench Acting as Projecting** | **Zero Projecting**

Figure 4: Six Installation Conditions for Concrete Pipe

Note: Jacked or Tunneled also includes micro-tunneling as a method of trenchless installation.

The selection of an installation type will be determined by many factors, such as the type and condition of soils encountered on site, depth of pipe installation, as well as the existing (or natural) contour of the ground. Less challenging factors make open-cut methods more suitable for pipe installation. When pipe installations are deep, or there is the proximity of existing services or structures to the proposed sewer, trenchless installation methods may be more suited versus open-cut options. Deep installations and less stable soil classifications, as per occupations health and safety acts, may also promote a trenchless option over open-cut excavations.

For open-cut installations, the typical recommendation given is the Positive Projecting option since it provides the most conservative design for the concrete pipe. A Positive Projecting condition will influence a greater vertical load on the concrete pipe due to the width of excavation versus a narrow Trench condition that helps reduce the vertical load due to the proximity of the in-situ trench walls. Many times in typical pipe installations, the open excavation is naturally wider just due to uncontrolled site conditions and/or the installation of ancillary structures like maintenance holes or catchbasins, lateral service connections to the mainline pipe, and more.

Methods of design and their calculations for each installation type can be found in the Concrete Pipe Design Manual, as published by the concrete pipe industry.

Bedding Type

The selection of an appropriate bedding type such as the Traditional beddings or one of the four Standard Installation types, will influence the required supporting strength of the concrete pipe in different ways. Bedding types can vary between: the physical contact made with the concrete pipe (i.e. perimeter of pipe), the quality of the bedding material (i.e. granular vs sand), and/or the quality of placement (i.e. material compaction). These qualities in the bedding equate to a bedding factor value assigned to that bedding type. A lower or higher value for the bedding factor will determine whether more strength is needed in the concrete pipe.

Other factors influencing bedding type are the cost of bedding material, the availability of material type for bedding, or the installation type needed by the project site conditions. The designer can weigh the cost of upgrading the strength of pipe, against the cost of bedding material and installation labour for various bedding types. This analysis will yield the most cost-effective pipe-soil envelope design for the project site.

Design Aids

CSA S6, *Canadian Highway Bridge Design Code* also looks at concrete pipe design in Section 7 – Reinforced Concrete Buried Structures. Requirements for standard installations of circular concrete pipe in Trenches and in Embankments are provided.

The CCPPA offers a FREE software program to aid in the design and strength selection for concrete pipe. PipePac incorporates the new SIDD (Standard Installation Direct Design) method as well as the traditional SAMM (Spangler and Marston Method) to determine the loads on pipe.

Access PipePac here: *www.pipepac.com*

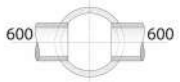
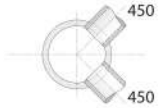
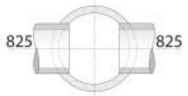
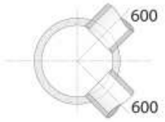
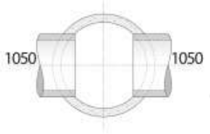
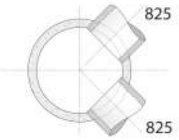
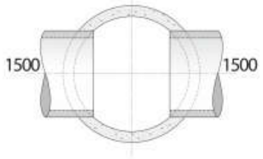
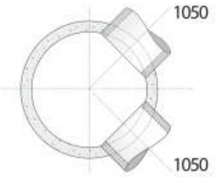
Maintenance Hole Selection Guidelines

This guideline is to assist designers in the proper sizing and selection of precast concrete maintenance holes (MH). These maintenance holes are manufactured according to the provisions of CSA A257 Series or ASTM C478.

After specifying sewer sizes, designers must consider the overall efficiency of the system by selecting the appropriate MH. Choosing the right maintenance hole assures proper hydraulic efficiency at intersections, grade changes and elevation changes. The pipe orientation (straight through, right angle, etc.) determines the diameter of the MH required for safe handling and installation.

Maintenance Hole Selection Table

Through the continued efforts of precast producers, contractors and consulting engineers, MH Selection Guidelines are available by industry. One example of this selection guideline is shown in Figure 1. This table should be used to determine the maximum concrete pipe sizes for different pipe configurations entering MHs. Designers should confirm and refer to similar guidelines provided by local agencies or jurisdictions, if applicable.

Maintenance Hole Size	Maximum Pipe Diameter Straight Through	Maximum Pipe Diameter at Angle
1200		
1500		
1800		
2400		

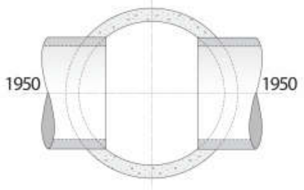
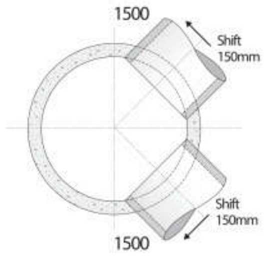
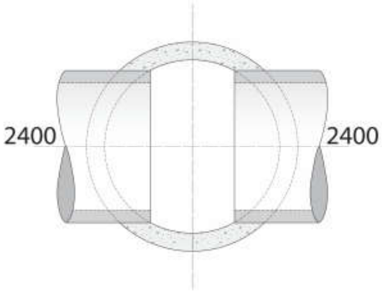
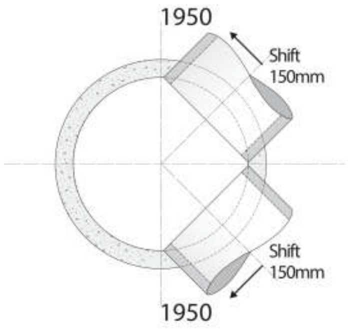
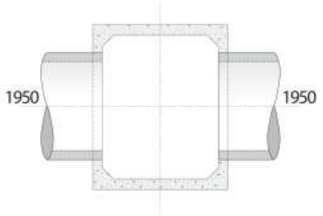
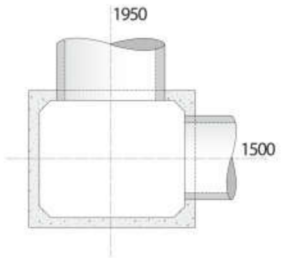
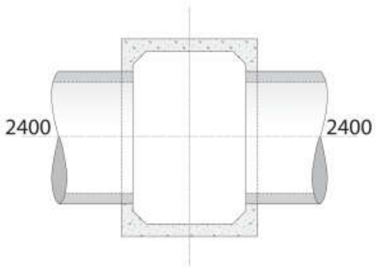
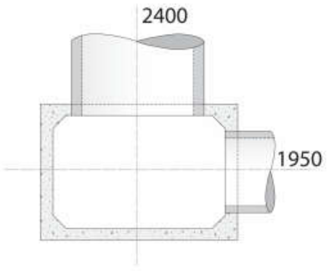
3000		
3600		
3000 x 2400		
3600 x 3000		

Figure 1: Maintenance Hole Selection Table

Other Considerations

There are several other factors to consider when determining structure sizing:

- the vertical location of pipes (see Figure 2)
- safety landings (see Figure 3)
- access for workers during the installation

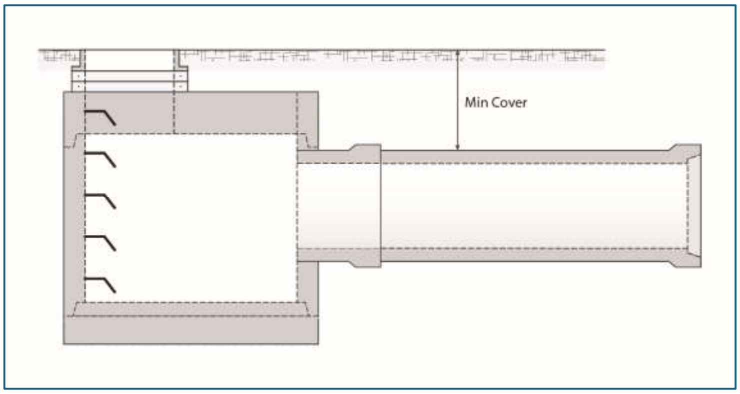


Figure 2: Shallow Bury MH with Pipe

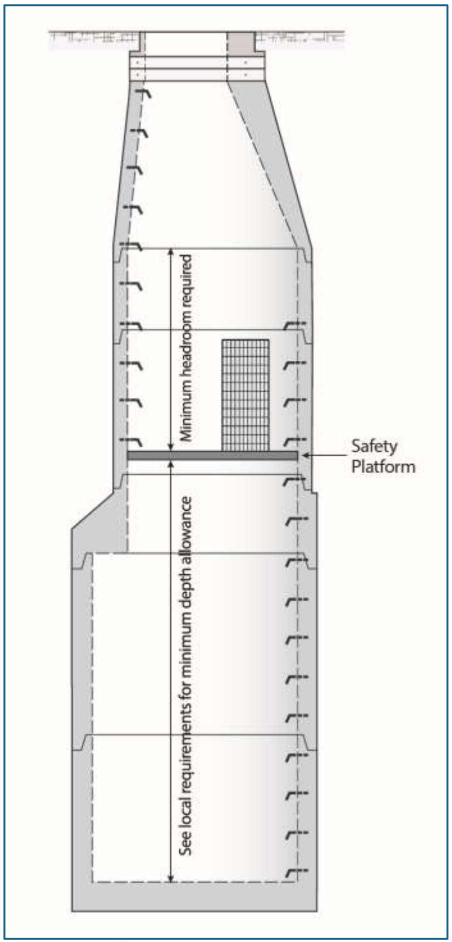


Figure 5: Deep Bury MH

Significant Advancements in Maintenance Holes

For many years, concrete MH producers in Canada have supplied prebenched MHs. Previously, benching was completed in the field. There are significant benefits of prebench that reflect similar benefits of all precast products in general:

- Exacting municipal standards in a controlled, manufacturing environment
- Product is ready to drop into place, making installation quick and easy
- Reduced labour on site and no wasted materials for site benching
- Increased worker safety since there is no need to enter a confined space
- Minimized disruption to traffic if work is within an existing ROW

Drop Structures

Drop structures are used where there may be a change in grade, pipe size, wet site conditions or to prevent water from scouring the inside of the MH. Currently, drop structures are created using an assembly of pipe junctions and fittings attached externally to the MH using steel reinforcing and all encased in concrete. Some precast producers can supply precast external drop structures. There is, however, a better way. The internal drop has been used primarily as an alternative to rehabilitating existing MHs for new connections (see Figure 1). The major difference is the upsizing of the MH structure in order to accommodate the diameter of the drop pipe. The advantages are the ease and safety of installation and the ability to inspect and clean out the drop pipe after installation. See information provided in this guide for more details on internal drop structures.

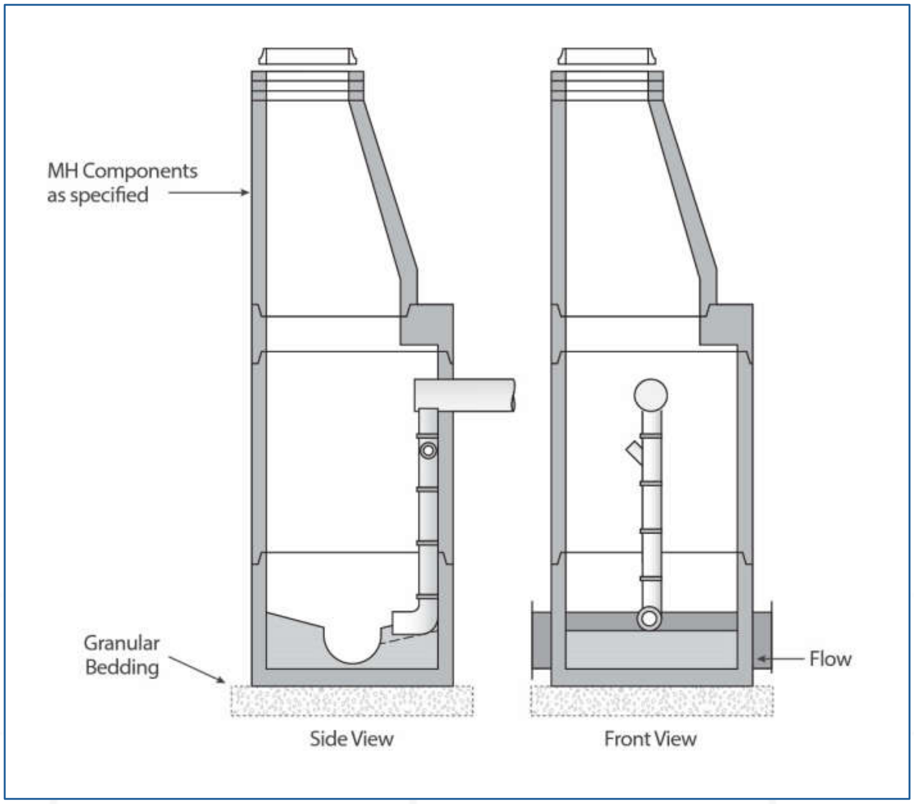


Figure 4: MH Internal Drop Structure

Maintenance Hole Tees

In large pipe runs (1200 mm dia. or greater), it is possible to gain access to the mainline through a riser section connected directly into the mainline pipe. This design option is called a maintenance hole tee (MH tee). Small incoming pipes can also be connected directly into the mainline pipe just downstream of the MH tee. This replaces a standard MH installation with a combination of tees for access and maintenance. Figure 2a and 2b illustrate, in plan view, the spacing for a lateral pipe tee and the MH tee pipe for MH riser sections. A pipe with an integral MH tee is less expensive than a maintenance hole large enough to encase the mainline pipe.

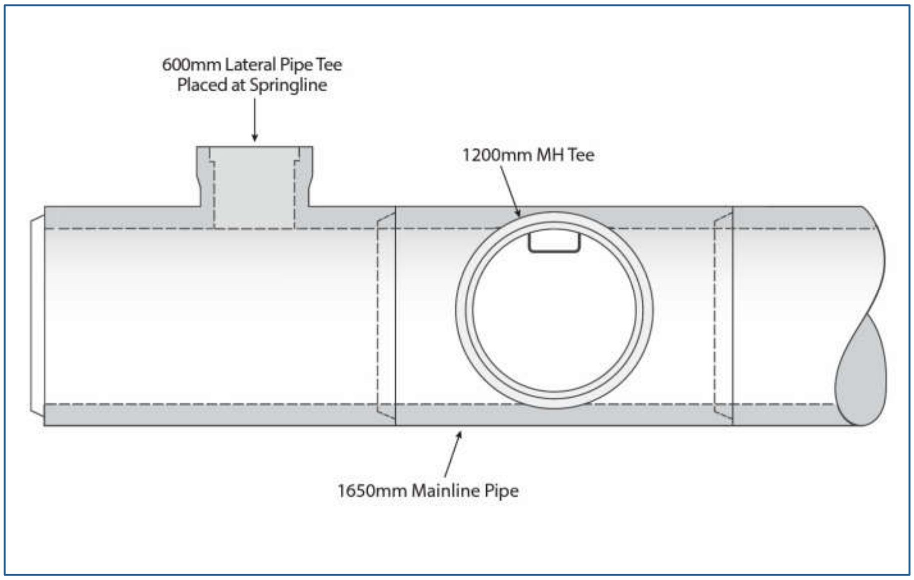


Figure 5a: MH Tee + Lateral Pipe Tee

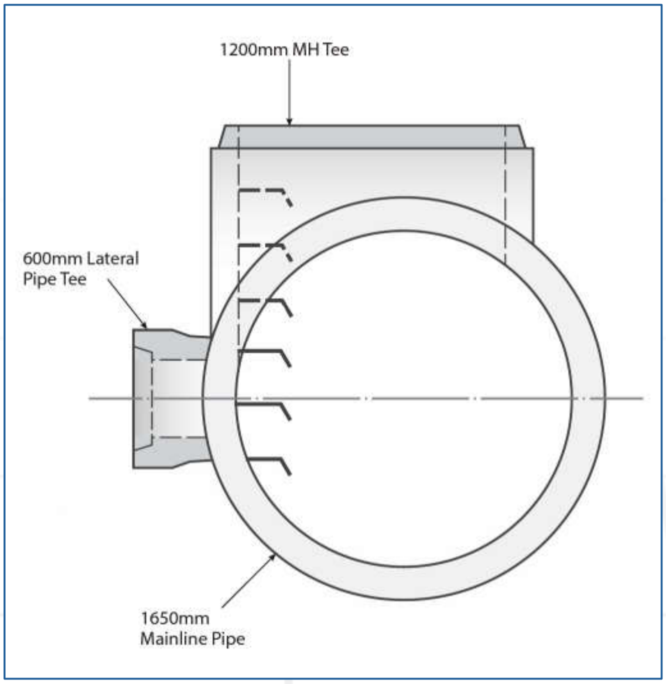


Figure 5b: Cross-section for MH Tee + Lateral Pipe Tee

Trenchless Installations with Concrete Pipe

Trenchless installation refers to a group of construction methods used to install underground utilities, such as water, sewer, gas, or telecom lines, where conventional open-cut excavation and backfill methods may not be feasible. These methods significantly reduce surface disruption in urban environments, environmentally sensitive areas, and populated metropolitan areas with existing infrastructure.

Reinforced concrete pipe is commonly used due to its inherent strength and its ability to structurally carry loads from various directions. It can withstand long-term service loads as well as the forces encountered during installation, including jacking forces.

Concrete pipe for trenchless installations first became evident in North America in 1896 when Northern Pacific Railroad utilized jacking pipe for installing drainage pipe under railway lines. In more recent years, trenchless methods have been applied to sewer construction where intermediate shafts along the line of the sewer are used as jacking stations. Reinforced concrete pipe as large as 4 metres O.D. have been successfully installed by trenchless methods.

Excavation Methods

The two most common methods of excavation used for installing concrete pipe via trenchless techniques are:

Manual Excavation (Hand Mining). Manual excavation, or hand mining, is a traditional method where workers manually dig the tunnel face using tools like shovels and picks while being protected inside a steel shield or casing. It is typically used for short runs, small-diameter tunnels, or in areas with irregular ground conditions where machines can’t be used. Though less common today due to the rise of mechanized methods, hand mining offers high precision and adaptability, making it suitable for sensitive or confined urban environments. Material is trimmed with care, and the excavation does not precede the jacking operation more than is necessary. Such procedures usually result in minimum disturbance of the natural soils adjacent to the pipe. This method is very reliant on stable native soils and therefore soil data for the proposed project is critical. Projects with loose native soils or soils affected by ground water should not consider hand mining for pipe installation.

Microtunnel Boring Machine (MTBM). Microtunneling is a remote-controlled, trenchless excavation method that combines pipe jacking with a microtunnel boring machine (MTBM) to install concrete pipes ranging typically from 900 mm to 4,000 mm in outside diameter. It uses a laser (or gyroscope) guided machine to excavate soil while slurry or screw conveyors remove the spoil, allowing for high-precision installation of underground utilities such as sewer, storm, and water lines. With no workers inside the tunnel, microtunneling is safer and well-suited for long drives in urban or environmentally sensitive areas, though it requires specialized equipment and expertise. MTBMs (and TBMs below) use a rotating cutterhead to excavate soil or rock while either supporting the tunnel face with earth pressure, slurry, or disc cutters (in rock) and install the pipe as they advance.

Tunnel Boring Machine (TBM). Tunnel boring machines are large, mechanized systems used to excavate long, and large diameter tunnels up to 18 meters or more. Hence, concrete pipe is not used in these applications based on the tunnel diameter but segmental precast liners are set in place to construct precast rings, comprising the tunnel length. TBMs are ideal for major infrastructure projects like transit tunnels, deep sewers or intakes, but require significant setup and are expensive for short drives.

With either procedure, 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.

Concrete Pipe for Trenchless Installations

Jacking Pipe. Standard jacking pipes resemble conventional reinforced concrete pipes in shape and dimensions but are engineered specifically to withstand the axial loads imposed during jacking. They are manufactured in accordance with CSA, ASCE and ASTM standards and built to tight dimensional tolerances to ensure proper alignment and load transfer during installation. These pipes often feature smooth, machined ends to minimize friction and allow even distribution of jacking forces across the pipe faces. Some designs may include a steel-reinforced collar or embedded steel rings at the pipe ends to help resist localized stress and reduce spalling or cracking during long jacking runs.

Microtunneling Pipe. Microtunneling pipe are a specialized form of jacking pipe developed for longer, high thrust installations typical of microtunneling operations. The pipe are designed to accommodate greater axial jacking forces by optimizing the load transfer area between pipe segments. Unlike conventional jacking pipes, microtunneling pipes typically include a steel bell ring at the receiving (female) end and a long spigot at the other, which may extend nearly the full wall thickness of the pipe. This configuration significantly increases the surface area over which the jacking force is applied, reducing stress concentrations and the risk of damage during extended drives. In some cases, lubrication systems (e.g. bentonite injection) are used along the pipe string to further reduce jacking resistance and friction.

These pipes are precision-manufactured and often feature integrated gaskets or joint sealing systems to ensure watertightness, which is critical for sewer and stormwater systems installed under pressure or in groundwater conditions.

Pipe Installation Setup

The first step of any trenchless operation is the excavation of pits or construction shafts, at each end of the proposed line. The shaft from which pipe is to be launched should be of sufficient size to provide ample working space for spoil removal, and room for the cutter shield or MTBM, the jacking head, jacks, jacking frame, reaction blocks and one or two sections of pipe. A guide rail frame in the bottom of the launch pit or shaft, help to establish and maintain line. In the case of large pipe, it is desirable to have such rails carefully set in a concrete slab as the weight of the large pipe may induce some settlement into native soil.

The number and capacity of the jacks used depend primarily upon the size and length of the pipe to be pushed and the type of soil. The size of excavation should coincide as closely as possible to the outside diameter of the pipe. The wall of the excavation is typically 25 to 50 mm larger than the pipe, and hydraulically operated jacks should have the capacity to ensure smooth and uniform advancement without overstressing the pipe. The shaft thrust walls provide a backstop and must be strong enough to distribute the maximum capacity of the jacks against the supporting soil behind the thrust wall.

It is important that the direction and distance of push be carefully established prior to beginning any operation. 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.

Pipe installed by trenchless methods will require the void between the pipe O.D. and the tunnel overcut to be filled. Cementitious, non-shrink grout should be flowable and pressurized for injection into the annular space. This can be accomplished by installing special fittings into the wall of the pipe for grouting hose connections.

Design Loads on Trenchless Pipe

The usual procedure in jacking concrete pipe is to equip the leading edge with a jacking head, or shield, to protect the lead pipe by distributing the jacking pressure uniformly over the entire end bearing area of 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.

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. This procedure usually results in minimum disturbance of the earth adjacent to the pipe. Use of a lubricant to coat the outside of the pipe, such as bentonite, helps to reduce the frictional resistance between the pipe and the soil. In most instances, this lubricant is pumped through special fittings installed in the wall of the pipe. It is desirable to continue jacking operations continuously all day until completed, or there is a tendency for jacked pipe to set when forward movement is interrupted for as little as a few hours. This will result in significantly increased frictional resistance to have any subsequent movement.

Axial Loads. For axial loads normally encountered, it is necessary to provide uniform distribution of the load around the periphery of the pipe to prevent localized stress concentrations. This is accomplished by assuring that the pipe ends are parallel and within the tolerances prescribed by the related CSA or ASTM product manufacturing standard. Furthermore, utilization of a cushion material such as solid core plywood or MDF in conjunction with an experienced contractor will ensure that the jacking force is properly distributed through the jacking frame and parallel to the axis of the pipe. The cross-sectional area of the concrete pipe is more than adequate to resist pressures encountered in any normal jacking operation. Yet contact surfaces at pipe joints, that transmit the axial jacking forces, must be separated by a material of equivalent or lesser stiffness that can transmit the axial jacking forces uniformly and without producing significant transverse splitting forces.

It is always a good idea to meet with the jacking contractor to ascertain the jacking forces he expects to apply to the pipe. For projects where extreme jacking pressures are anticipated, due to long jacking distances or excessive unit frictional forces, concrete compressive strength higher than standard may be required, along with greater care in avoiding bearing stress concentrations. A factor of safety on axial load capacity shall be applied based on the ultimate strength of the concrete. The effect of eccentric or concentrated loads on the pipe joints should also be evaluated.

The magnitude of the anticipated axial loads is a function of many factors including installation technique, total length of jack, pipe skin friction, and pipe diameter. The total jacking force (R_{js}) of concrete pipe is dependent on several primary factors. The rated jacking pipe force (R_{js}) (direct compression force) conforms to the following equation:

$$\boldsymbol{R_{js} = \frac{A_j \quad f'c}{F.S.}}$$

where,

A_j *Cross-sectional area of pipe at weakest point*
f'c *Compressive strength of concrete*
F.S. *Appropriate factor of safety*

Additionally, longitudinal bending due to the eccentricity of the load on the joint face should be evaluated. In general, the complete pipe remains in compression, despite minor bending due to eccentricity between the center of the joint face and the gross wall section beyond the joint. With some joint designs, the resultant force is acting considerably off the centerline of the wall, creating a net tensile stress. In such cases, this stress should be limited.

Lateral Loads. These loads can be a result of jacking force being applied to the pipe, if the jacking frame is not square to the end of the concrete jacking pipe. Another area where lateral pressure occurs is if the pipe is offline and/or grade, and the contractor adjusts the direction of the pipe to realign to the proper line and grade. This action subjects the bell and spigot ends of the pipe to extreme shear loads.

Earth and Live Loads. The calculation of the required pipe strength is determined by the soil depth, soil mass, and the live load if applicable. Two other factors need to be addressed; the dimension of the overcut on the outside of the reinforced concrete jacking pipe, and whether this area is grouted or not grouted after pipe installation. Note: Designers can use the PipePac program (*www.pipepac.com*) for load calculations based on grouted or non-grouted conditions.

Pipe Characteristics

Materials. Requirements for cement, aggregates, reinforcing steel, and other additives shall be as specified in the appropriate CSA or ASTM material standards.

Manufacture. Reinforced concrete pipe shall be manufactured according to CSA or ASTM product manufacturing standards, with attention being given to: nominal dimensions, pipe lengths, and the compressive strength of the concrete. At no time shall the compressive strength of the concrete be less than 40 MPa.

Jacking pipe shall contain two cages of circular reinforcement in the barrel of the pipe. The outer cage shall extend into the groove of the pipe, and the inner cage shall extend into the tongue of the pipe. The pipe will be manufactured with circular reinforcing cages only. At no time is elliptical steel reinforcement allowed in jacking pipe.

Should conditions warrant, the owner may request the groove end to be strengthened using an external band of hot rolled steel, (12 gauge thick, 203 mm in height). The steel band is welded to the outside reinforcing cage with the use of appropriate spacers.

Lubrication (bentonite) ports are generally installed at the time of manufacture and may, or may not, involve the use of a one-way valve. It is best to check with the jacking contractor to locate these ports where they will work best for the operation. Subaqueous lubricant should also be supplied with the pipe.

Joints in the pipe should be as symmetrical as possible; that is, the thickness of the tongue should be as close as possible to the thickness of the groove end. Gasket options for jacking pipe include ‘O’ Ring or single offset since these gasket types are not affected by small movements in the joint area expected as jacking pressure is applied and relaxed.

Permissible Variations

CSA and ASTM provide the user with minimum requirements for pipe geometry variations. ASCE Standard 27, *Standard Practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Construction*, provides further information related to dimensional variations. Specific measurements may include: internal and outside diameters; wall thickness; pipe roundness; taper; pipe length and length of opposite sites; end squareness, and more.

Users should contact the concrete pipe supplier to determine how the manufacturer ensures the dimensional limitations are met.

Hydraulic Design for Pipe and Structures

The Manning Equation

The Manning equation is an empirical equation that describes the relationship between the velocity in a conduit and the channel geometry, slope, and a friction coefficient expressed as a Manning 'n'. In its essence, the Manning equation describes the energy balance between gravity and friction in a conduit. It was developed by Irish accountant Robert Manning in the late 1800's and has become the go to choice for the hydraulic design of gravity storm and sanitary sewer systems.

The Manning Equation is,

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} \qquad \text{(metric)}$$

$$Q = \frac{1.486}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} \qquad \text{(imperial)}$$

where,

Q *design flow of the sewer, m/s (or ft/s)*
A *cross-sectional area of the flow, m^2 (or ft^2)*
R *hydraulic radius, equal to the area of flow divided by the wetted perimeter, m (or ft)*
S *slope, m/m (or ft/ft)*
n *Manning Coefficient of Roughness*

This equation can be reordered to evaluate the capacity of a given pipe of known internal diameter or if the required design flow is known, depth of flow within a given pipe can be evaluated.

Manning Coefficient of Roughness. The Manning's n value is a unitless coefficient that represents the roughness or friction factor of the conduit. Rougher conduits with higher friction have a higher value, and smoother conduits with lower friction have a lower value.

Because the Manning equation is an empirical equation, the values for Manning 'n' are derived from experiment and observation. The difference between laboratory test values of Manning's 'n' and accepted design values can be significant. Many organizations have done extensive research over the last 135 years to determine the most accurate estimates of Mannings 'n'. Most of the results were obtained utilizing clean water and straight pipe sections without maintenance holes, debris, or other obstructions. These laboratory results have been remarkably consistent over the years and have really identified that the only significant differences are not related as much to pipe material as they are to physical/structural characteristics, i.e. smooth inner wall ('n' = 0.009 – 0.015) or corrugated inner wall ('n' = 0.022 – 0.037).

This simplified but accurate approach to determining a realistic 'n' value is supported by many approval agencies. With a typical value of 'n' = 0.013 for all smooth inner wall pipes being adopted as part of published Design Criteria or standards.

- MECP Ontario 'n' = 0.013 for all smooth walled pipe – Design Criteria for Sanitary Sewers, Storm Sewers and Forcemains, May 31 2023, Section 2.2.1
- City of Edmonton 'n' = 0.013 for all smooth walled pipe – Volume 3 Drainage Design Guidelines EPCOR February 2022, Section 1.8.2
- City of Winnipeg 'n' = 0.013 – Wastewater flow estimation and servicing guidelines
- City of Regina 'n'= 0.013 – Design Standard Wastewater, May 2022, Section 2.5.8.1
- City of Vancouver 'n' = 0.013 for all smooth walled pipe – Engineering Design Manual 2019, Section 4.3.1

Design Velocities

Minimum. In sewers a minimum design flow velocity of 0.6 m/s is generally accepted as good practice to maintain "self cleaning" or a minimum scouring velocity where solids are not deposited. This lower limit can be challenging for designers to obtain in situations where a controlled outlet depth requires that pipe slopes must be minimized. Of particular concern are the upper reaches of a collection network where contributory flows are at a minimum making for even lower flow velocities. In the past it was accepted practise to simply connect a catchbasin or some other form of artificial Inflow/Infiltration to the sanitary sewer to increase volumes. This is no longer a valid engineering design solution as "bubble tight" systems are being sought for maximum efficiency and environmental reasons.

Some designers have been tempted to manage low slope/low velocity designs by looking to utilize very low Manning 'n' values proposed by some pipe manufacturers. This should be avoided, as over a century of real life data has shown time and time again that all smooth walled pipes have nearly identical 'n' values in situ (rather than in the laboratory). As can be seen by the very consistent adoption of 0.013 as the appropriate value by approval agencies across the country.

Maximum. Maximum velocity is an issue often related to topography where steep slopes must be accommodated in the design. The main design considerations are related to the maximum velocity that will cause abrasion of the pipe material, and the impact that high velocity flows can have on the receiving system or outfall structure. Additionally, high velocities can increase flow turbulence leading to off gassing that results in odour complaints and can contribute to the generation of corrosive byproducts. The downstream impact can be accommodated by a variety of methods including diameter changes and the use of inline baffles or special outfall structures.

Historically, it has been found that velocities up to 12 m/s do not create erosion problems for concrete pipe (Ref 1 & 2). Concrete pipe's excellent performance for many years carrying mine tailings in slurry have proven concrete pipe's ability to resist the severe combined conditions of high velocity and abrasive bed load (Ref 3).

Many governing agencies limit design velocities to 3.0 m/s, or some as high as 4.5 m/s for the reasons listed above. However, in exception circumstances, particularly in the case of storm sewers where odour and corrosive chemical generation are limited, velocities as high as 12.0 m/s with reinforced concrete pipe installation have been accepted. (Ref 4).

Drop Structures

Another method for addressing extreme topography, and high velocities is through the use of Drop Structures. By flatting pipe slopes and creating vertical drops between inlet and outlet inverts within a maintenance hole structure the designer can slow flow within the pipe segments and address the dissipation of excess energy at the structures. When a design results in vertical drop of more than 600 mm the use of a drop structure is often implemented to accomplish this. The dissipation of energy reduces turbulence and the resulting off-gassing, reduces erosion of the structure, promotes better hydraulics and can reduce the deposition of solids. Additionally, a drop structure provides an increased level of safety for workers should they need to enter the maintenance hole.

The basic design of a drop structure places a tee or wye along the flow path of the incoming sewer with one of it's exit legs pointing vertically downward. This vertical leg is then piped via an elbow to an elevation much nearer to that of the outlet sewer, reintroducing the flow smoothly to the structure at this lower point. The other exit leg of the tee or wye is piped to enter the structure at the higher elevation, in line with the incoming sewer pipe grade. This allows all but extremely high flows to move in a controlled fashion through the vertical drop leg. The system of piping that makes up a drop structure may be entirely external to the maintenance hole structure, or alternatively, completely within the structure.

External Drop Structure. An external drop structure has historically been constructed in one of two ways:

a. <u>Field Connection</u>. The contractor cuts and fits the various pipe and fitting segments at the time of installing the structure. Once all the fitting is completed, it is then restrained to the exterior wall of the structure using drilled-in anchors with tied reinforcing bar, and it is then encased in concrete. This process is time consuming and can result in increased risk to workers within the excavation.

b. Precast External Drop Structure. This option is offered by many manufacturers with minor variances in exact geometry of the precast drop. In this scenario, most of the setup and restraint, including concrete encasement is completed in the manufacturing facility. Precast allows the contractor to install the drop structure in one operation integral with the installation of the maintenance hole structure. Care must be taken with lifting/installing these structures as the balance is impacted by the additional off-centre material.

Internal Drop Structure. Internal drop structures have also been accepted in many areas. With the system of piping contained completely within the structure, installation is simplified as it can all be added after the structure is set in place and the external connections completed. Additionally, this allows for much easier access for future maintenance and cleaning. However, the internal piping and restraint occupies considerable space. Therefore, internal drop structures are only practical when using maintenance holes structures larger than 1500 mm in diameter and pipe sizes less than 375 mm.

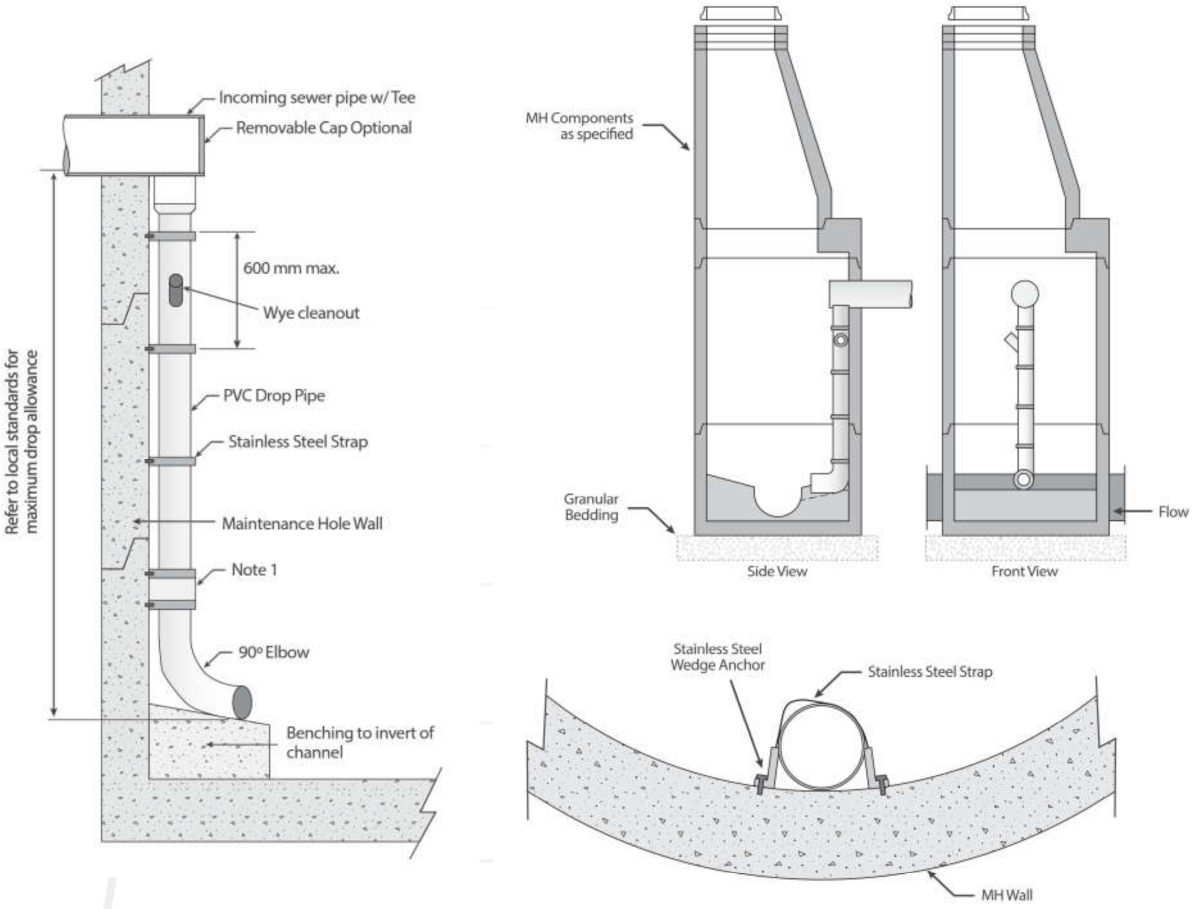


Figure 1: Internal Drop Structure

References

1. *ACPA Concrete Pipe Handbook – pages 6-10*
2. *ASCE WPCF Manual of Practice No. 9 – pages 128-129*
3. *Concrete Pipe news Vol. 6, No. 10. Oct. 1954 "Concrete Pipe Resists Abrasion"*
4. *Special Order from City of Los Angeles, City Engineer. Re: Materials for Storm Drains: Storm Drain Design – Maximum Velocities*

Gravity Sewer Pipe Specifications

For infrastructure owners or a design engineer, comfort in the knowledge of pipe specifications for all gravity sewer products may not be practical or deemed necessary. However, without this knowledge, pipe materials that arrive on a project site may in fact be unacceptable pipe products because they do not meet established CSA or ASTM product standards. Hence, a general understanding of applicable specifications becomes essential to proper design, construction and inspection.

Materials for gravity sewer pipe include: Concrete, Polyvinyl Chloride (PVC), High Density Polyethylene (HDPE) and Polypropylene (PP). Each material has their own product manufacturing standard(s). In Canada, the Canadian Standards Association (CSA) is the primary standard referenced by designers when specifying accepted gravity pipe for sewers an drainage. The CSA Standards for construction materials will outline requirements for material testing, manufacturing, product performance testing and other general requirements. Furthermore, there are also references to American Society for Testing and Materials (ASTM) specifications from which some CSA Standards for pipe were initially derived, references to the American Association of State Highway Transportation Officials (ASSHTO) and references to the American Society of Civil Engineers (ASCE). It therefore becomes easy to understand how specifiers and designers lose track of the appropriate standards or specifications Therefore, product review programs established by municipal and provincial government agencies is critical to conduct thorough product assessments, field testing and monitoring, and finally product acceptance, if deemed appropriate.

For projects where infrastructure owners permit use of alternative products for use, the specifier and design engineer should be accountable for: design, installation and field monitoring prior to final acceptance by the infrastructure owner. To simplify pipe specifications, the following breakdown will identify where to look for the appropriate standards for Concrete Pipe, PVC Pipe and HDPE Pipe.

Concrete Pipe

- CSA A257.1, *Circular Concrete Culvert, Storm Drain, Sewer Pipe and Fittings (non-reinforced)*
- CSA A257.2, *Reinforced Circular Concrete Culvert, Storm Drain, Sewer Pipe and Fittings*
- CSA A257.3, *Joints for Circular Concrete Sewer and Culvert Pipe, Manhole Sections and Fittings*
- ASTM C14, *Specification for Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe*
- ASTM C76, *Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe*

Polyvinyl Chloride Pipe

- CSA 182.2, *PVC Sewer Pipe and Fittings*
- CSA 182.4, *Profile PVC Sewer Pipe and Fittings*

High Density Polyethylene Pipe

- CSA 182.6-02, *Profile Polyethylene Sewer Pipe and Fittings for Leak Proof Sewer Application*
- CSA 182.8-02, *Profile Polyethylene Storm Sewer Drainage Pipe and Fittings*
- CSA B182.14, *Profile Steel Reinforced Polyethylene (SRPE) Storm Sewer Pipe and Fittings*
- CSA B182.15, *Profile Steel Reinforced Polyethylene (SRPE) Sewer Pipe and Fittings*

Polypropylene Pipe

- CSA B182.13, *Profile Polypropylene (PP) Sewer Pipe and Fittings For Leak-Proof Sewer Applications*

For all pipe materials discussed, the one requirement that helps ensure consistency of quality and accountable performance is a quality assurance program that is executed as an independent third party. Specifying precast concrete products from a certified plant ensures that the manufacturers are prequalified, have an ongoing quality management system in place, and proven capability to deliver high quality products for the type of project being considered.

For the concrete pipe and precast industry that means products supplied from a certified plant.

Across Canada, there are several quality assurance programs providing independent certification for both plant and for precast concrete products:

- **BNQ** – The Bureau de Normalisation du Quebec.
- **CPCQA** – The Canadian Precast Concrete Quality Assurance Certification Program.
- **CSA Group** – The Canadian Standards Association.
- **QCAST** – Quality Cast Certification Program.

BNQ	**CPCQA**	**CSA Group**	**QCAST**

Figure 1: Precast Certification Group Logos for Concrete Pipe and Precast

For all other pipe materials (PVC, HDPE, PP) similar certification programs providing third party review available to a specifier or design engineer that ensures the pipe on the project site has met the standards outlined in CSA.

When designing sewer infrastructure, ensure quality pipe materials make it to the project site. The triangular emblem is the symbol for concrete pipe certification and the CSA logos ensure flexible pipe certification. Don’t leave pipe material quality to chance but insist on certified gravity sewer pipe on the next project.

The Significance of Cracking in Concrete Pipe

Reinforced Concrete Pipe

Reinforced concrete pipe is the interaction of two historically strong and durable products, steel and concrete. The compressive strength of concrete and the tensile strength of steel combine together to resist live load and earth load forces imparted on a reinforced concrete pipe when it is installed. Figure 1 illustrates the compressive and tensile stresses that are induced on a circular pipe in an installed condition. The reader will note the steel reinforced concrete structure is required to resist the forces in critical zones. For example, at the invert and obvert of the pipe, steel resists the tensile stress from the effects of loading, while at the outside bottom and inside springline of the pipe, concrete resists the compressive stress from the effects of loading. The unique marriage of concrete and steel effectively create a structure capable of being designed to withstand virtually any loading condition.

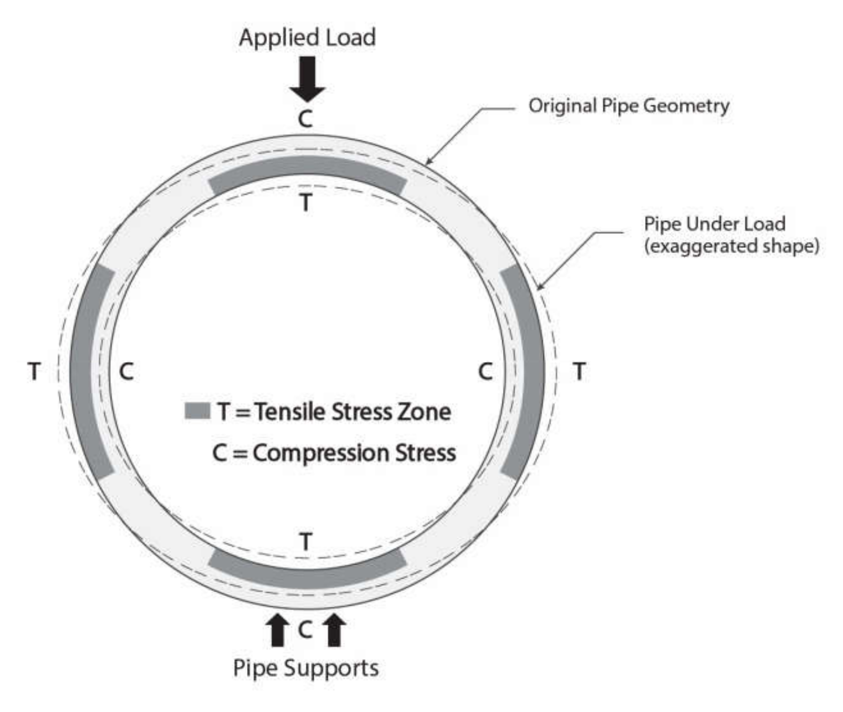


Figure 1: Stress Zones of a Concrete Pipe Under Load

Basis of Design

Design methodologies of concrete pipe used today have been in existence since the 1920’s. Work at Iowa State University by M.G. Spangler determined the impact of design loads (earth and live) on the structure. At that time, empirical work done by several researchers proposed pressure distribution fabric around the concrete pipe. From this work, design methods were introduced, which had limitations due the availability of testing apparatus. In addition, the design methodologies were not easy to use, as the age of computer computation had not arrived. A simple and reliable design method did not exist until Professor W. J. Schlick of Iowa State University developed an indirect design method to simplify the design process. Using a simple leaf gauge of 1/100th of an inch (0.3 mm), he proposed that a service (design) crack be used as a measurable and reproducible method for determining pipe strength. There is little structural significance to the 0.01” (0.3 mm) crack; it is simply a test criterion accepted by the CSA and ASTM standards for reinforced concrete pipe and is visibly the first indication the pipe load is in transfer from the concrete to the steel.

Autogenous Healing

This phenomenon occurs between opposing surfaces of narrow cracks. The mechanism of the healing is the hard white ‘crust like’ formation on the concrete pipe known as calcium carbonate. The crack healing requires the presence of moisture, which will then react with the cement powder and restart the hydration (curing) process. As autogenous healing continues, it has been witnessed that fine debris may also enter the crack and contribute to filling the void of the crack over time.

Figure 1: Autogenous Healing from Pinhole

The strength of the healed crack has been studied under laboratory conditions. It has been suggested that full healing creates a monolithic structure, so the pipe is “as good as new” and should be considered structurally sound and capable of performing in the manner originally intended.

Regardless of the mechanism, autogenous healing will occur in concrete pipe that has cracked with the presence of moisture. The question is how wide a crack can be healed, and how long does it take? The answer is not simple. Literature reports cracks as wide as 1.5 mm (Loving) healed in a period of 5 years. Edvardsen found that cracks of 0.2 mm healed completely within 7 weeks. It appears that the narrower the crack, the more rapid the healing can occur. The Ohio DOT has developed Supplemental Specification 802, Post Construction Inspection of Storm Sewers and Drainage Structures identifies the rehabilitation methods for installed pipe which has evidence of cracking. The specification requires the contractor to "Do Nothing" for cracks up to 1.8 mm in width, with the expectation that autogenous healing will create a watertight pipe over a period of a few years.

Three Edge Bearing Method

The most common method of design for reinforced concrete pipe is the Three Edge Bearing Indirect Design Method. Using this method, an estimate of loads expected to act on the reinforced concrete pipe, usually earth and live loads, are calculated. The pipe strength required to resist these loads is determined using the Three Edge Bearing (3EB) equation,

$$3EB = \frac{Applied\ Load\ in\ Field}{Bedding\ Factor}\quad Factor\ of\ Safety$$

where,

3EB *is the supporting strength of pipe required*
Applied Load *is the acting load(s) on the pipe (Dead and/or Live)*
Bedding Factor *is the ratio between the supporting strength of buried pipe to the strength of the pipe determined in the Three Edge Bearing test*
Factor of Safety *is defined in CSA as 1.5 for pipe strength ≤ Class 100-D; and, 1.25 for Class 140-D*

Figure 2: Three Edge Bearing (3EB) Testing Assembly

Reinforced concrete pipe design theory, the Three Edge Bearing equation, and estimations for the variables used in solving for the 3EB were determined in laboratory conditions over many years at Iowa State University by Marston, Spangler and Schlick and are still in use today. Based on current research and technology, this empirical process is considered to be very conservative, however, it is still in use in many jurisdictions today around the world.

Classification of Cracks

As presented above, reinforced concrete pipe is designed to permit cracking. The design crack, 0.3 mm in width over a length of not less than 300 mm is the measure used. Notwithstanding this process, cracking of reinforced concrete pipe can present a concern to infrastructure owners. Why is this?

Cracks in reinforced concrete pipe are generally discovered through video surveys or visual assessments done as a requirement of the contract. Timing of such inspection is typically prior to the assumption of an installed system by the owner.

Figure 3: 0.3mm Leaf Gauge to Check Crack Width

It is very important that owners undertake these types of inspections to elevate the accountability of all those involved in the satisfaction of the contract. There can be no denying that proper installation and inspection will have a tremendous impact on the satisfaction of the expected service life of new system. Moreover, it cannot be understated the importance for owners to understand when a crack in a concrete pipe is a problem and when it is not.

Issues which may arise in the evaluation of cracks, include:

- Width
- Length
- Orientation
- Location
- Severity

Width. As discussed earlier, the design (service) crack used in reinforced concrete pipe is the 0.3 mm (1/100th of an inch) crack over a length of at least 300 mm. This crack will generally appear at the invert, and occasionally the obvert, of the reinforced concrete pipe as the highest tensile stress or moment incurred by the pipe loads occurs at these locations. The design crack is V-shaped in nature and is widest at the surface penetrating usually no further than the first reinforcing cage in the pipe. It is very difficult to determine the magnitude or significance of a crack and the unavoidable magnification of the crack in the pipe that is inherent with video inspection technology today. As a result, it is critical that analysis of sewer video be done by an engineer. Training programs are offered on a regular basis by the National Association of Sewer Service Companies.

Hairline cracks are extremely fine cracks, narrower than design cracks yet can be visible during video inspections. Hairline cracks are often mistakenly use for design cracks, yet the hairline crack is in fact the prelude to the appearance of the design crack.

Shrinkage cracks can occur during the curing process of reinforced concrete pipe. As concrete cures, moisture disappears from the concrete matrix. Depending on the rate of curing, shrinkage cracks can occur, i.e. the more rapid the curing, the greater likelihood of shrinkage cracks. Shrinkage cracks are generally hairline type cracks appearing circumferentially on the outer surface of the pipe barrel and quite often do not penetrate through the pipe wall.

Figure 4: Autogenous Healing of Circumferential Shrinkage Crack

The width of a crack is a critical consideration when determining the impact on the durability and/or structural integrity of an installed reinforced concrete pipe. However, it is not as simple as saying the design crack is a limiting factor. The design crack can appear at as little as 50% of the ultimate (failure) load and therefore, experience and judgement must be used to determine the impact of cracking.

Length. The length of a crack is rarely an indication of poor quality of material or weak installation practices. In most if not all conditions where a crack is evident in a pipe, the width and location of the crack is more critical to understand and evaluate.

Orientation. Longitudinal cracks run lengthwise along the barrel of the pipe and can be single cracks or in some instances of severe damage can become multi-directional in appearance.

Circumferential cracks run around the barrel of the pipe and may or may not propagate the full inner circumference of the pipe barrel.

Location. Understanding how pipe performs in the installed condition is critical when evaluating the location of a crack.

Longitudinal cracks visible at the invert or obvert of the pipe are indications the pipe has excepted the load to which it was designed. Longitudinal cracking at any other location along the inside barrel of the pipe can generally be attributed to poor construction practices which may include but are not limited to improper handling or weak installation and backfilling techniques.

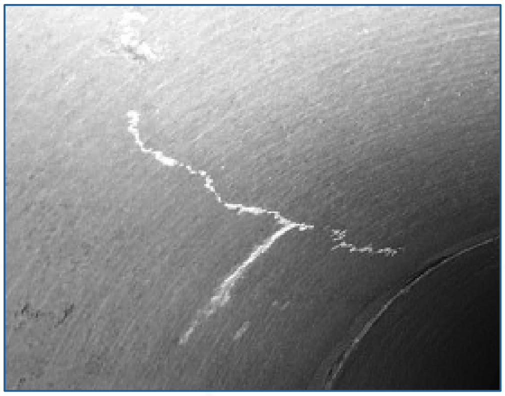


Figure 6: Autogenous Healing Along Longitudinal Crack

For example, insufficient cover over the crown of the pipe prior to the utilization of heavy compaction equipment can result in damage to the pipe.

Multi-directional longitudinal cracking, an indication the pipe has been subjected to some sort of impact load, can most certainly be attributed to the lack of care taken when installing or handling the pipe. This evidence should be considered carefully when assessing the integrity and future performance of the installed pipe.

Circumferential cracks are in no way attributed to the installation conditions to which the pipe was designed to handle. In fact, cracks propagating circumferentially on the inner surface of the pipe can be attributed in most cases to differential settlements in the pipe bedding. This condition can result from uneven placement and over compaction of the bedding material creating point loads along the barrel of the pipe. Furthermore, failure to dig ‘bell holes’ to accept a protruding pipe bell, a feature of many small to mid-range diameter pipe, can lead to the development of circumferential cracking at or just beyond the pipe joint.

Figure 7: Circumferential Crack in Joint Area of Pipe

Severity. The key to determining if structural concerns exist is the degree or severity of the damage to the pipe. Hairline and design cracks are not a result of damage to the pipe and therefore needn’t be considered for repair. Longitudinal and circumferential cracking can be an indication of damage to the pipe for which the severity should be assessed. As discussed earlier, autogenous healing is a powerful process in the repair of minor damage sustained by a concrete pipe.

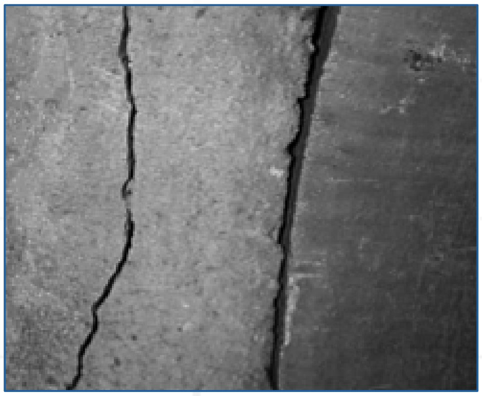


Figure 8: Crack Width Exceeding Design Crack

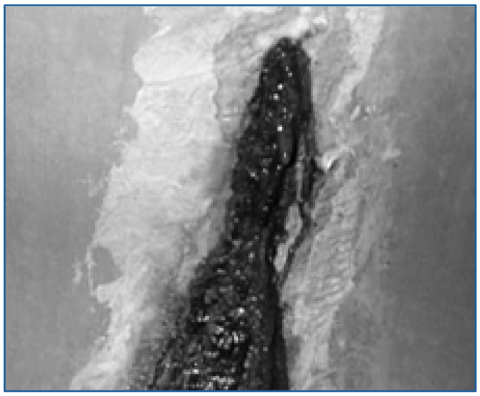


Figure 9: Dynamic Crack Not Showing Positive Autogenous Healing Effects

In most if not all cases where autogenous healing has sealed the defect, the integrity of the pipe should be considered sound. Pipe cracking or damage beyond the scope of autogenous healing must be evaluated further. Open cracks (greater than 1.8 mm in width) or cracks where concrete has been displaced should be assessed to determine structural type of repair, if necessary. Any delamination along the lower haunch area also represents signs of severe structural damage. Also of concern would be a crack or defect that is allowing water to infiltrate into the pipe system. The infiltration can be relatively clear or it can be 'rust like' in terms of its colour. The latter is an indication the steel in the pipe is being impacted by water. Regardless, both situations require assessment. ASTM C1840 provides detail guidance on inspection and acceptance of installed reinforced concrete pipe.

Basis of Acceptance

The final acceptance of reinforced concrete pipe should be subject to visual or video inspection. This is the only way to ensure the ultimate owner of the system has assurance that the pipeline will be durable and achieve its intended service life. During the evaluation process of video inspection, the owner must be aware of what the video is showing. Distortion can occur due to the presence of water or to magnification of the video. To properly evaluate the extent of the crack, actual measurements must take place. If this is not possible due to the size of the pipe, the owner should rely on professional judgement. The practitioner should look for the visible signs of structural damage. If the crack appears wide, and the pipe is displaced on either side of the crack, or the location of the crack is not conducive with the design crack, concern is justified. If no displacement is apparent, the process of autogenous healing will likely seal the crack and ensure the longevity of the reinforced concrete pipe can be achieved.

Concrete Protective Liners in Sanitary Sewer Pipe

Lined Concrete Pipe

Concrete sewer pipes and wastewater systems, though durable, face significant challenges from both chemical and environmental stresses, particularly biogenic corrosion caused by sulfuric acid (H_2SO_4). This process, also known as microbial corrosion, is a leading cause of the deterioration of concrete structures in wastewater environments. The implementation of protective measures, such as Concrete Protective Liners (CPL), is important to ensure the longevity and durability of concrete sanitary sewer pipes.

Lined Concrete Pipe is a hybrid system that combines the strength and structure of reinforced concrete pipe with the material resistance of CPL, complete with a watertight jointing system. Adding CPL enables concrete pipes to be manufactured with a continuous, corrosion resistant polymer lining for the inner pipe surface.

For a lined concrete pipe, the same concrete mix design and structural design as a standard pipe is used. The difference is that in the lined concrete pipe a CPL is placed on the interior of the pipe during casting. “After the pipe are installed, the liner edges between pipe lengths form a seam which is field welded to make the inner liner continuous across pipe joints.”

Biogenic Corrosion and the Need for Protection

One of the most severe risks to concrete sewer systems is biogenic corrosion caused by microbial activity. Wastewater environments are rich in organic matter, and the bacterial breakdown of this material produces hydrogen sulfide gas (H_2S). When H_2S comes into contact with air, it oxidizes and forms sulfuric acid, which aggressively attacks the calcium compounds of concrete above the waterline in the pipe. This results in a gradual degradation of the structural integrity of pipes, manholes and other wastewater infrastructure components.

CPL systems offer an important defense against concrete corrosion. CPL protects the underlying concrete from chemical reactions that can weaken and destabilize the infrastructure. This protection is particularly essential in systems with high concentrations of hydrogen sulfide, where the risk of rapid deterioration is significantly increased without adequate protective measures.

Different Types of CPL: Applications and Benefits in Wastewater Management

High Density Polyethylene (HDPE) and Polypropylene (PP) are two widely used thermoplastic materials for liners in concrete sewer pipes and wastewater applications. HDPE is known for its durability, flexibility, and high resistance to a broad range of chemicals, which makes it ideal for demanding environments like sewer systems. With a density of approximately 0.93 to 0.97 g/cm^3, HDPE can withstand temperatures ranging from -40°C to 60°C (-40°F to 140°F) and offers a long service life. Polypropylene (PP) is lighter, with a density of around 0.90 g/cm^3, and good for chemical resistance, particularly against acids and bases.

The decision between HDPE and PP should consider factors like environmental conditions, structural requirements, and budget constraints, ensuring the selected material aligns with the project's long-term goals. To support appropriate material selection and application, specifiers of CPL are encouraged to consult directly with liner manufacturers to confirm alignment with the most up to date materials and practices.

Anchor Stud Design of CPL

An important factor in the effectiveness of concrete protective liners is their anchor stud design. The anchor studs, integrally formed with the liner during the manufacturing process, provide strong pullout resistance and back pressure resistance. This is critical in ensuring that the liner remains firmly attached to the concrete, even under the high internal pressures often present in wastewater systems. The stud design also ensures compatibility with the concrete mixtures used during construction, preventing issues such as aggregate separation or the formation of hollow spots that could compromise the structural integrity of the pipe.

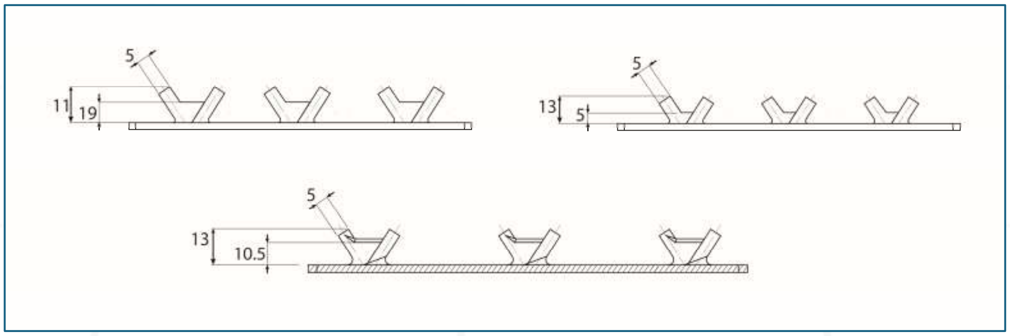


Figure 1: Different Anchor Studs Types

Types of Welds for CPL

Different types of welds can be used during the prefabrication and cap stripping of liners in sewer lines, including:

- Butt Fusion welding
- Extrusion welding
- Hot wedge welding

- Butt Fusion welding
- Hot gas string bead welding

Butt Fusion Welding. Butt fusion table welding is performed using a flat table welder that aligns and joins both sides of the liner using a heated plate. Once the hot plate reaches the specified welding temperature, it is removed, and controlled pressure is applied to the liner ends for a precise duration, depending on the type and thickness of the plastic material. This process is fully automated to ensure consistent weld quality, with strict control over time, temperature, and pressure parameters. Butt fusion table welding is widely recognized as the industry standard for manufacturing precast pipe tubes and riser sections due to its reliability and repeatability.

Extrusion Welding. Extrusion welding is typically employed during field installation or when repairs to the liner are necessary. In the field, extrusion welders, commonly referred to as welding guns, are used to apply molten plastic to the weld area. These tools feed a 4 mm or 5 mm plastic rod into a heating chamber, where it is melted and conveyed through an internal auger. The molten plastic is then extruded through the tip of the welding gun at high temperatures and applied to the weld joint. This method allows for precise, localized repairs and is ideal for non-factory conditions.

It is important to note that all sheet material, add-on cap strips and welding rod must all be of the same material to achieve a proper weld.

Hot Gas Welding. Hot gas welding is a thermoplastic welding technique used to join liners by applying a controlled stream of heated air or inert gas to the joint area. The process involves simultaneously heating the surfaces of the components to be joined, along with a compatible plastic filler rod, until the materials reach a molten state. Once softened, they are fused together under slight pressure and allowed to cool, resulting in a strong, continuous weld.

Before starting any welding operations, it is necessary to calibrate the welding equipment through shear and T-Peel tests. These tests are important for performing a qualitative assessment of the welds and ensuring they meet the required performance standards.

Two commonly used standards for conducting these tests are DVS 2226-3 and ASTM D6392. The tests are carried out on adequately cooled test specimens using a tensiometer. The testing device allows for the rapid application of load and maintains a uniform rate of deformation of 50 mm/min.

Shear Test **T-Peel Test**

Figure 2: Welded Samples in Testing

Material Preparation required to achieve quality welds

- Liner must be dry and clean.
- Weld rod should also be clean and dust free.
- Proper grinding in welding zone removes slick surface, removes any oxidation and prepares surface for welding. Take care not to grind too far outside of welding zone.
- Angle grinders with 36 to 50 grit sandpaper are recommended.
- Scraping of welding zone using a paint scraper is also acceptable if it can be done evenly and without gouges.
- For 3 mm and thicker sheets, the edge of the sheet should be beveled with the grinder.

During the welding of the liner, the weld must be checked for imperfections and visible defects. Specifically, the following features are checked:

- **Alignment of the Seam:** Ensure proper edge alignment before welding.
- **Weld Appearance:** Check for a uniform and smooth weld surface.
- **Bubble Formation:** Look for bubbles or blisters indicating inadequate fusion.
- **Cracks:** Inspect for visible cracks that could weaken the weld.
- **Incomplete Fusion:** Verify there are no areas of incomplete bonding.
- **Discoloration:** Check for signs of overheating or other issues.
- **Foreign Material Contamination:** Ensure no dust or debris on the weld surface.
- **Thickness Consistency:** Measure weld thickness to confirm it meets standards.

Moisture Control in Plastic Welding

Welding must not be performed if moisture is present on the welding rod or on the surfaces to be welded. However, this does not mean that welding cannot be conducted in environments where moisture is present. For example, large diameter plastic lined concrete pipes often require welding at the joint while installed deep underground. In such situations, condensation is commonly observed due to differences between surface air temperatures (from forced ventilation) and the cooler ambient temperatures inside the pipe.

If condensation is thoroughly removed from the weld area immediately prior to welding, the integrity of the weld will not be compromised. Furthermore, extrusion welders are equipped with a preheater that blows hot air at temperatures exceeding 400°F, which effectively helps to eliminate residual condensation on the surface.

Important: Under no circumstances should welding be carried out in standing water. If moisture is present within the weld during the welding process, it will produce a very noticeable and distinctive splatter pattern, indicating a compromised weld.

Quality Control of the Liners and Welds

Liner Hydraulic Pullout Resistance Test. The pullout resistance testing of liner is an important procedure used to evaluate the structural integrity and performance of the materials when embedded in concrete. This testing is conducted in accordance with ASTM D7853, which specifically addresses the hydraulic pullout resistance of the liner.

The test begins by ramping the pressure to an initial level of 210 kPa (30 psi). The pressure is held constant for a duration of 200 hours. The extended hold period simulates the conditions that the liner may experience in real world applications, which allows for the assessment of its ability to withstand sustained hydraulic pressure without experiencing significant deformation or failure. At the end of the 200 hour hold period, the pressure is incrementally increased by 34 kPa (5 psi) every hour. This stepwise increase continues until either a failure of the liner occurs, or a maximum pressure of 3450 kPa (500 psi) is reached.

Figure 3: Liner Hydraulic Pullout Resistance Test

In addition to the above method, there are other short-term pullout resistance tests available that can effectively indicate the performance of liners against groundwater pressure. One such method involves using a device to pull out a specific number of anchors, recording the pullout force to measure the pullout strength of the liner.

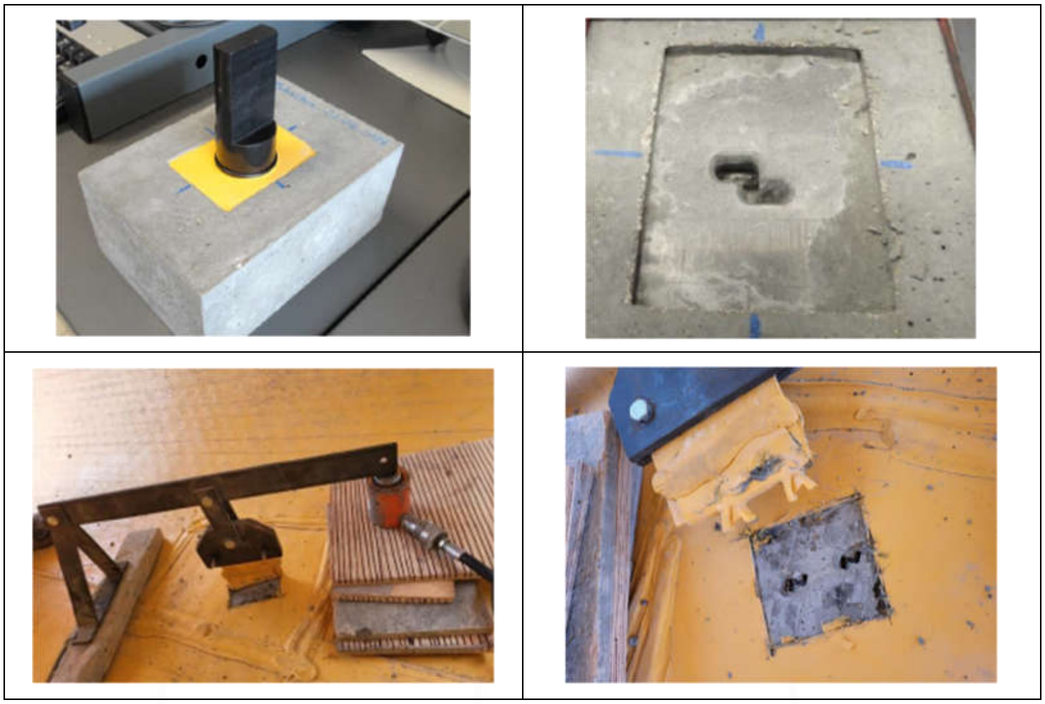


Figure 10: Short-Term Pullout Resistance Test on Liners

Liner Spark Test. Spark testing is common non-destructive testing method employed to assess the integrity of liners used in various applications, particularly in wastewater management systems. This technique is used to identify defects, such as pinholes, cracks, and other discontinuities, that may compromise the performance of liners. During the spark testing process, a high voltage electrical discharge is applied to the surface of the liner, creating a spark that can detect flaws by producing a visual or audible indication when defects are present.

When performing spark testing on liners in reinforced concrete pipes, two main standards are typically referenced: DVS Section 2225-2 and ASTM D6365. While both standards have historically been applicable to CPL, the DVS standard is more frequently adopted due to its comprehensive nature and specific guidance for plastic welding.

The DVS standard is the German guideline for plastic welding and is considered one of the most comprehensive standards for plastics welding worldwide. It specifies testing procedures and requirements, including the voltage settings that vary based on the thickness of the membrane. The DVS standard employs a voltage graph indicating that higher voltages are permissible for thicker membranes, thus ensuring the effective detection of any discontinuities in the material.

ASTM D6365 is often utilized for thinner geomembrane liners, particularly in applications such as pond or landfill liners. Although this standard has been successfully used for our CPL, its primary focus is on geomembranes and associated geosynthetics.

Figure 5: Spark Testing of Liner

Design Considerations Related to Groundwater and Backpressure

Backpressure is the primary cause of failure for thermoplastic liners. The following design considerations are important for ensuring long-term performance and structural integrity:

- Hydrostatic conditions must be carefully evaluated during design. The local groundwater table should be assessed and compared against the liner's rated backpressure capacity, as specified by the manufacturer.
- According to the German SKZ certification, the maximum allowable backpressure for thermoplastic liners is 1.75 bar, validated through a long-term test of 1,000 continuous hours under hydrostatic load.
- Pullout strength and backpressure resistance are not directly correlated. Mathematical theories between the two do not consider creep, which is the long-term deformation of plastic under load. Different plastics have different creep values. Pullout tests are immediate and short-term; backpressure tests are more representative of field conditions as they test under load for 1,000 hours.
- Liners may still be used in high head pressure environments if provisions for relieving backpressure are implemented. Examples include installing backpressure relief ports or leaving a gap at the cap strips. Best practice is to consult the manufacturer’s representative when back pressure exceeds 1.75 bar.
- Do not use pH alone as a guideline when evaluating liner compatibility. If the media is outside the neutral pH range, obtain a complete chemical breakdown of the process media, including all constituent chemicals and their concentrations. The temperature of the media can also significantly affect liner compatibility. All chemical and media data should be submitted to the manufacturer for review.

Repairs on CPL

In the presence of any defects, damage, or discontinuities observed on the liner surface, particularly during installation, the installer needs to contact the liner manufacturer for recommendations on the appropriate repair procedure. Repairs may be feasible depending on the type and extent of the defect. The manufacturer will provide guidelines on approved repair methods, including surface preparation, welding techniques, and verification requirements to ensure the repair meets performance expectations.

References

1. *DVS 2225-2, Joining of Lining Membranes Made of Polymer Materials – Site Testing*
2. *ASTM D6392, Standard Test Method for Determining the Integrity of Nonreinforced Geomembrane Seams Produced Using Thermo-Fusion Methods*
3. *DVS 22256-3, Test of fusions on PE liners - Peeling test (DVS 2226-3)*
4. *ASTM D7853, Standard Test Method for Hydraulic Pullout Resistance of a Geomembrane with Locking Extensions Embedded in Concrete*
5. *ASTM D6392, Standard Test Method for Determining the Integrity of Nonreinforced Geomembrane Seams Produced Using Thermo-Fusion Methods*
6. *Agru Design and Installation Handbook*

Buried Concrete Structures: Durability, Sustainability and Resiliency of Precast Elements According to CSA S6 (CHBDC)

The Canadian Highway Bridge Design Code (CSA S6-2025, CHBDC) mandates that structures be designed not only for ultimate and serviceability limit states, but also to meet durability, sustainability, and resiliency requirements. Section 2 of the 2025 edition, titled "Durability and Sustainability," includes expanded provisions covering both durability and resiliency. These three principles—durability, sustainability, and resiliency—are essential, interrelated pillars of modern structural design.

CHBDC stipulates that the design service life of non-replaceable components must be equal to or greater than the overall design life of the structure. In the 2025 edition, the definition of "design life" has been updated to account for climate change—it is now defined as the notional period of time on which the statistical derivation of transient loads is based, including climate considerations. Additionally, the term "design service life" is newly defined as the intended service lifespan specified during the design phase. All buried structures are considered non-replaceable and must meet this design service life requirement.

Durability

The durability of a structure is governed by the deterioration mechanisms of its materials within its surrounding environment. Designers must anticipate and mitigate these mechanisms based on the expected exposure conditions over the structure's design service life.

Underground concrete structures, such as pipes and culverts, may be exposed to:

- Freeze-thaw cycles (especially under shallow cover)
- Sulfate attack
- Alkali-aggregate reactions
- Chloride-induced or carbonation-induced corrosion
- Reinforcement corrosion
- Various chemical attacks

To counter these effects, designers must specify appropriate concrete exposure classes according to CSA A23.1. Beyond material selection, external factors contributing to material degradation—such as moisture ingress, joint movement, and crack development—must also be addressed. CHBDC provides detailed guidance on environmental and exposure considerations, including limits on key physical and chemical parameters.

Sustainability

Designing for sustainability requires the application of life cycle engineering principles, incorporating factors such as material selection, carbon footprint, and greenhouse gas (GHG) emissions. Design must comply with sustainable development criteria established by local jurisdictions.

Canada reaffirmed its commitment in December 2024 to reduce GHG emissions by 40–45% below 2005 levels by 2030. The concrete industry has been actively working toward this goal for over a decade. Key strategies include:

- Substitution of conventional Portland cement with Portland Limestone Cement (PLC), which reduces CO_2 emissions by approximately 10%
- Use of supplementary cementitious materials (SCMs) such as slag and fly ash, potentially lowering CO_2 emissions by up to 30%

Designers should collaborate with infrastructure owners to align with sustainability objectives, accounting for life cycle costs from cradle to grave.

Resiliency

To ensure resiliency, structures must minimize the risk of functional failure during catastrophic events by incorporating redundancy, robustness, and/or structural indeterminacy. Infrastructure must either maintain functionality during events such as earthquakes, flooding, or wildfires, or be restored quickly and cost effectively afterward.

In this context, buried precast elements like pipes and culverts are considered resilient if they can withstand such extreme conditions. While CHBDC 2025 acknowledges the importance of resiliency, it does not provide prescriptive design limits; instead, it defers to owner defined requirements.

Flotation Design for Vertical Structures

This technical bulletin is intended to aid designers when considering possible concerns about flotation (due to groundwater effects) for a buried concrete structure.

One of the advantages of concrete structures when used for buried infrastructure is their self-weight. Concrete is more than two times heavier than water. This provides a big advantage to resist buoyant forces acting on buried structures installed below the groundwater table. A flood plain is a good example where a high groundwater table is prevalent, and needs be considered for design purposes. Both a vertical chamber or a linear pipe create an empty volume that is subject to uplift forces by groundwater. The larger the empty volume created by a chamber or pipe, and/or the shallower that buried infrastructure is, the more likelihood flotation may be an issue in these conditions.

A buried structure installed below the groundwater table will not float if the total gravitational downward forces (i.e. structure, earth overburden) is greater than the upward buoyant force. The buoyant force is calculated using the weight of water displaced by the buried structure. A designer should always complete this design check to ensure flotation is not a concern.

$$\boldsymbol{\Sigma\ Downward\ Forces\ (W_d) > Buoyancy\ Force\ (F_b)}$$

Simple Design Procedure

The design check for buried structures should include the following considerations:

a) Groundwater table in reference to elevation of top of structure.
b) A water table below the structure may not be a concern.
c) A water table throughout or above the buried structure must be accounted for.

Calculation of downward forces includes the weight of the structure and soil overburden. Internal permanent components of the structure, or ballast within the structure that are constant can also be accounted for.

Additional downward forces can be calculated if considering frictional resistance determined by soil-structure shear forces and/or soil-soil shear forces due to a soil wedge. Not considering these forces will make the design more conservative.

Calculation of buoyant force, defined as the weight of water displaced by the volume of a buried structure submerged in water. Dimensions used are the outside diameter or outside perimeter measurements of the structure.

Determination for Factor of Safety is the resultant net force, represented as the ratio between downward and upward forces. When the net force approaches 1 or less will determine if additional measures are needed to help resist upward buoyant forces. Designers need to consider what Factor of Safety is relevant for their design.

Design Considerations

Groundwater. The design engineer should first determine if groundwater will be an issue for the buried structure. This information can be found in the geotechnical report for the project, where there is also information of the soil and site conditions provided. The maximum elevation of groundwater for a site is identified by the Seasonally High Groundwater Table (SHGWT). If not available, a reasonable assumption for the water table should be made while factoring in possible groundwater fluctuations to ensure a conservative yet cost-effective design approach is taken. Designers can also assume that the groundwater is at grade for the most conservative design.

At times, the groundwater table may exist at an elevation that only partially submerges the buried structure. In this case, the soil properties will vary for the soil with groundwater and without groundwater.

Structure Geometry. The shape of the structure, whether circular or rectangular type, does not have an influence on flotation of the buried structure. Ultimately, the total volume of a buried structure is to be calculated using its outer dimensions. Other variances in structure geometry that may need to be accounted for are transitions of size and/or shape of the structure from its lower base section to the upper top section of the structure. Based on the intended purpose of the buried structure, a designer may be able to transition to a smaller cross-section to reduce cost of the overall structure. A transition slab is used in this case.

Wall thickness and slab sections will be used to calculate the concrete mass of the structure. Typically, this is the main contributor to any downward forces resisting flotation.

The designer should account for any penetrations into the structure geometry due to connecting pipe, or any other openings that may be needed for access. These cutouts from the structure geometry will result in less concrete volume and reduce the downward forces by the structure.

To simplify the calculation and remain conservative, any resistance from the lateral pipe connections is typically neglected.

Buoyant Force (F_b)

Archimedes' Principle applies, in such, an object is subject to a buoyant force equal to the weight of the fluid displaced by its volume. Analyzing buoyancy related to underground structures requires an application of the same static equilibrium equation, assuming the structure to be stationary and either fully submerged or partially submerged in a fluid (i.e. soil + groundwater).

$$\boldsymbol{Buoyant\ Force\ (Fb) = \gamma_w \quad V_d}$$

where,

γ_w, *Density of water*
V_d, *Displaced volume of fluid*

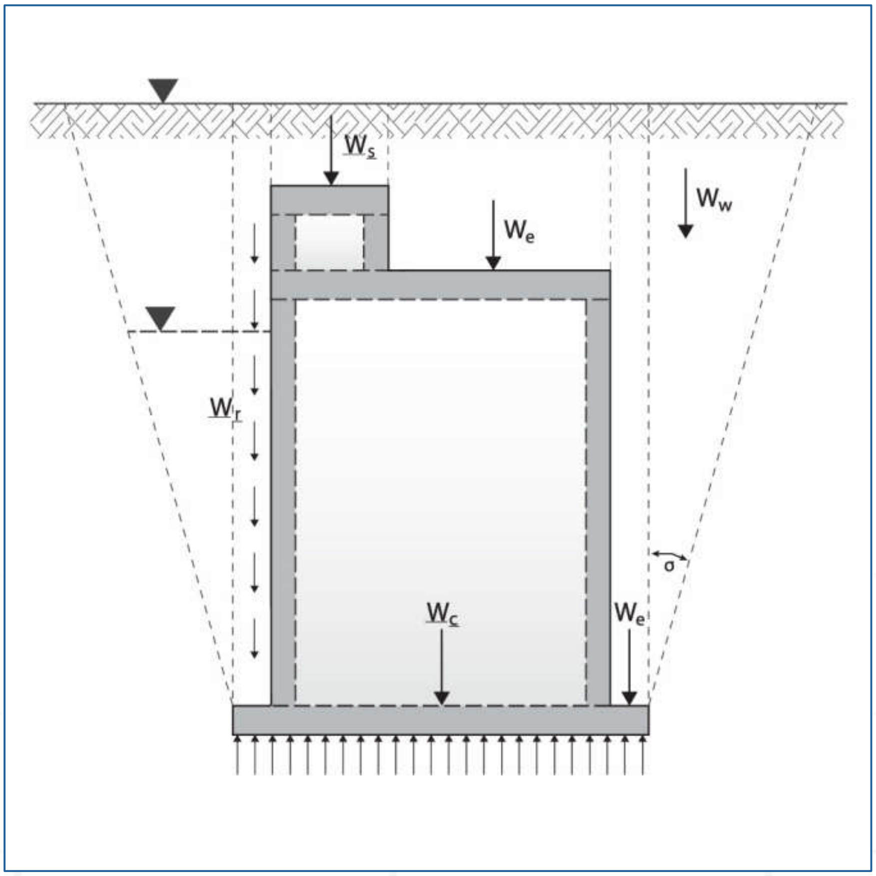


Figure 11: Sum of Downward Forces vs Buoyancy Forces

Downward Forces (W_d)

Downward forces by a buried structure are those caused by gravitational effects such as the concrete structure itself and any relevant soil loads on the buried structure. These downward forces need to be determined and summed up to ensure the total downward forces (W_d) exceed the upward buoyant force (F_b). Certainty of downward forces include: the weight of the structure's precast components, the weight of soil over the structure or above structure extensions. See Figure 1.

Shallow bury structures are most prone in high water tables due to limited downward forces by any soil overburden. In addition, a soil with low density will have little soil resistance against upward buoyant forces, while also offering limited soil load downwards on the structure.

Additional downward forces can be accounted from: the weight of equipment or appurtenances inside structure, weight of additional concrete added inside the structure, weight of cast iron frame and covers, and if accounted for the frictional forces of soil acting against the structure surface.

Weight of Concrete (W_c). Calculate the weight of concrete components for the structure, such as base slab, riser section(s), top slab or transition slab and chimney risers if applicable. Determine the volume of each solid concrete component buried and multiply by the weight of concrete (23.5 kN/m^3). Considerations affecting weight of concrete include: reinforcing steel affecting the theoretical plain concrete density; any openings or cutouts in the concrete structure that should be subtracted from the total weight.

Weight of Soil Overburden (W_s). Calculate prism weight of soil over the top of the buried structure (overburden) such as the structure's flat cap. Use the respective soil density of insitu soil or engineered soil used to backfill the structure. The vertical soil arching factor is neglected in the calculation.

Weight of Soil Capture (W_e). Calculate additional weight of soil due to any extensions or shelves created by the structure geometry. One example includes the soil load captured by a transition slab, at which location the structure diameter or perimeter is reduced in dimension. Another example of soil capture includes the soil load above an extended base slab, whereby the base diameter or perimeter extends beyond the outside dimension of the primary structure.

Soil Wedge (W_w). When calculating the soil load capture due to structure extensions, the designer can also consider a soil wedge (W_w) effect created by the soil material properties. A soil-to-soil shear plane naturally occurs at the soil's angle of internal friction. This will give shape to a soil wedge that extends up from the structure extension. This soil wedge will increase the total soil load based on the calculated volume of soil captured by the soil wedge. However, engineering judgement should be used to determine how impactful the soil wedge might be. For saturated soils, the soil wedge effect is reduced, and the assumed soil friction angle may only be 0 to 10 degrees. For conservative design purposes, the designer may elect to ignore the soil wedge effect entirely. Soil internal friction angles for different soil types are shown in the table below.

Frictional Resistance (W_r). Calculations for downward forces can include frictional resistance (i.e. surface shear) generated by the soil-structure interface. The calculated frictional resistance is based on the soil properties, the roughness of the structure's outer surface and the lateral pressure against the structure.

$$W_r = P \quad \mu_c$$

where,

$P = K_a * \gamma_{sub} * (H_s^2 / 2)$ *lateral soil pressure per liner meter around the structure*

$Ka = 0.33$ *lateral soil pressure coefficient*

$\gamma_{sub} = \gamma_s [1 -1 / (S.G.)]$ *submerged soil weight*

$\mu_c = 0.3$ *frictional coefficient between plain concrete and soil*

For conservative design purposes, some designers elect to ignore these downward forces based on unknown or variable factors related to concrete roughness, saturated soil conditions which reduce this effect, and/or the properties of in-situ soils including compaction. If there is no option to consider buoyancy countermeasures as noted below, a designer may need to consider the added downward force offered by any frictional resistance.

Factor of Safety (FS)

The Factor of Safety (FS) in design against flotation is the ratio between the sum of downward gravitational forces and the upward buoyant force. Concern for flotation exists when the factor of safety is close to or less than 1.0. A typical Factor of Safety for buoyancy is 1.5. Chosen FS values are determined by the designer and established based on conditions of design, such as the importance of the structure or good available geotechnical information. For example, where exact design information is lacking with groundwater levels or parameters for the soil properties such as soil friction, a higher FS could be used. A typical range for FS is 1.1 to 2.0. Project site limitations and/or construction costs related to buoyancy countermeasures (listed below) can limit the means to further increase the FS.

$$\mathit{Factor\ of\ Safety}\ (FS) = \frac{\Sigma\ \mathit{Downward\ Forces}\ W_d}{\mathit{Buoyant\ Force}\ (F_b)}$$

Buoyancy Countermeasures

Countermeasures can be used to overcome buoyancy concerns when the original structure design does not meet the required safety factor. All measures discussed should consider limitations of handling, shipping, and construction of the structure components, and their cost-effectiveness.

Base Slab Extension. Extending out the base beyond the outer dimension of the structure will create a lower shelf and engage additional soil load to help counteract the buoyant force. Additional downward force is gained by the weight of the soil captured above the base slab extension (soil shelf). Additional downward force is also gained by the increased concrete volume in the base slab extension. Options for an extended base include precast or cast-in-place.

Anti-Flotation Slab. The structure can be anchored to a larger mass of concrete prepared in the field. Typically, the concrete mass would be cast-in-place and include a means to anchor the structure when installed. If the concrete mass is a precast alternative, then measures should be taken to ensure proper bearing/contact between the precast mass and the precast base slab of the structure.

Increase Structure Sections. By increasing component slab thickness or wall thickness, the structure mass is increased resulting in an increased downward force of the structure. This will provide additional resistance to the buoyant force. Note, this option may also impact handling and installation considerations on site.

Increase Structure Ballast. By adding ballast to the structure, the structure mass is increased resulting in an increased downward force of the structure. This option can be achieved by adding a sump to the structure and filling this depth with concrete following installation on site. Benching inside a structure is a good example of added ballast to the structure.

Increase Structure Overburden. Another option is burying the structure deeper, if possible, by structure and/or site setup. The increased overburden will result in more soil load and hence increase the downward forces.

Anchor the Structure. Hold downs near the structure can be used to tie down the structure.

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