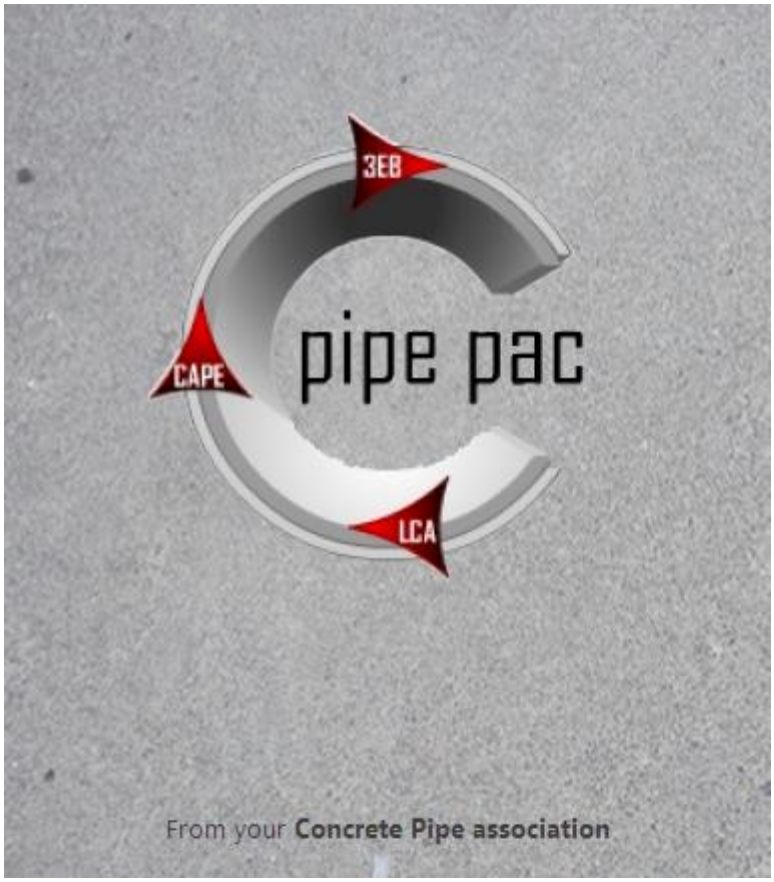


Version 4
User Manual

Table of Contents

PipePac Help Contents

To learn more about PipePac select one of the topics below:

- **System Requirements**
- **Using PipePac Help**
- **Using Form Controls**
- **Getting Started**
- **Troubleshooting**

System Requirements

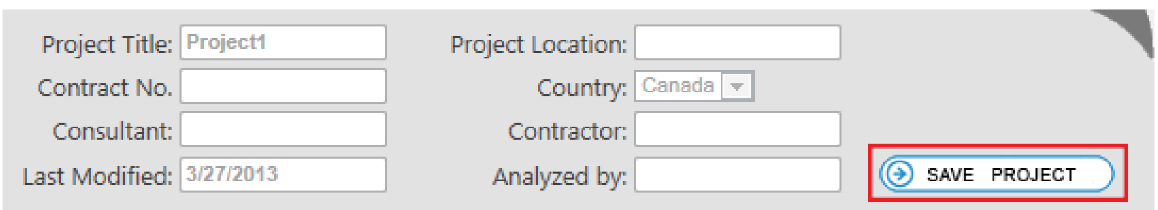
System requirements for PipePac version 4.0 Web access

To use PipePac version 4.0 you need one of the following browsers:

- Microsoft Internet Explorer 8 or later
- Apple Safari 5 or later
- Google Chrome

Other Instructions

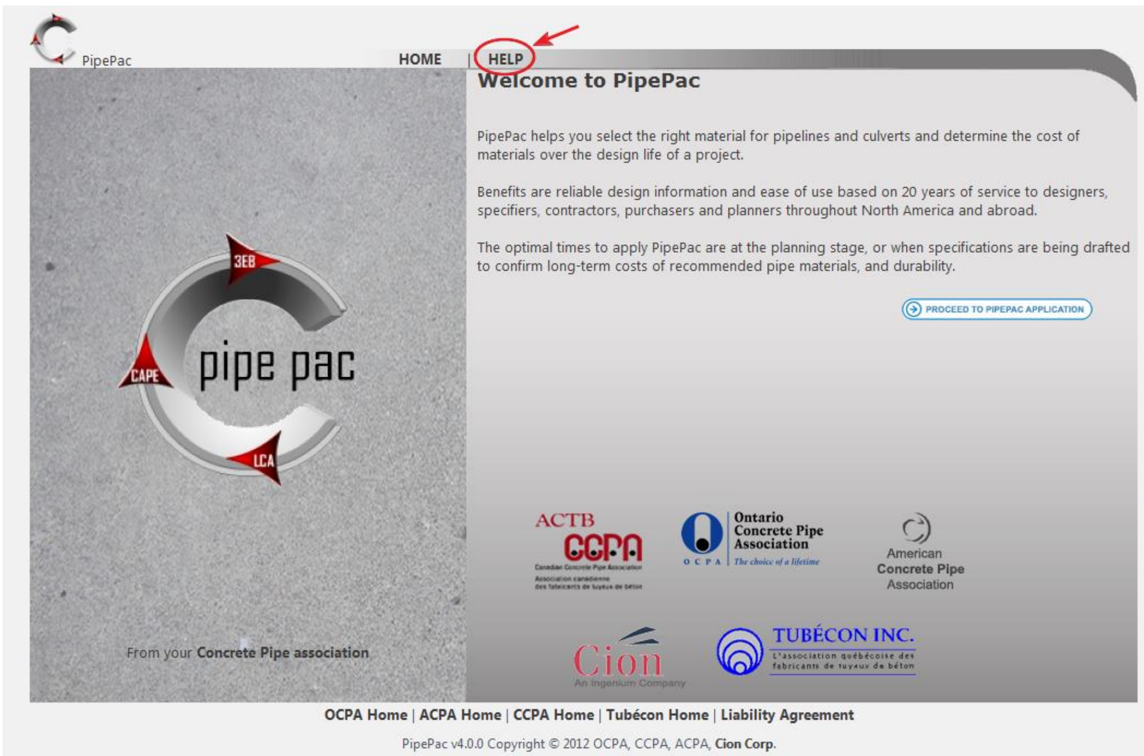
Please note that PipePac website only store your input data for the duration of the connection (active session). All your data will be discarded once the browser is closed or after the session time-out. Remember to save your data to the local storage often. To save, click on the SAVE PROJECT button and click the Save button when prompted.



PipePac - Using PipePac Help

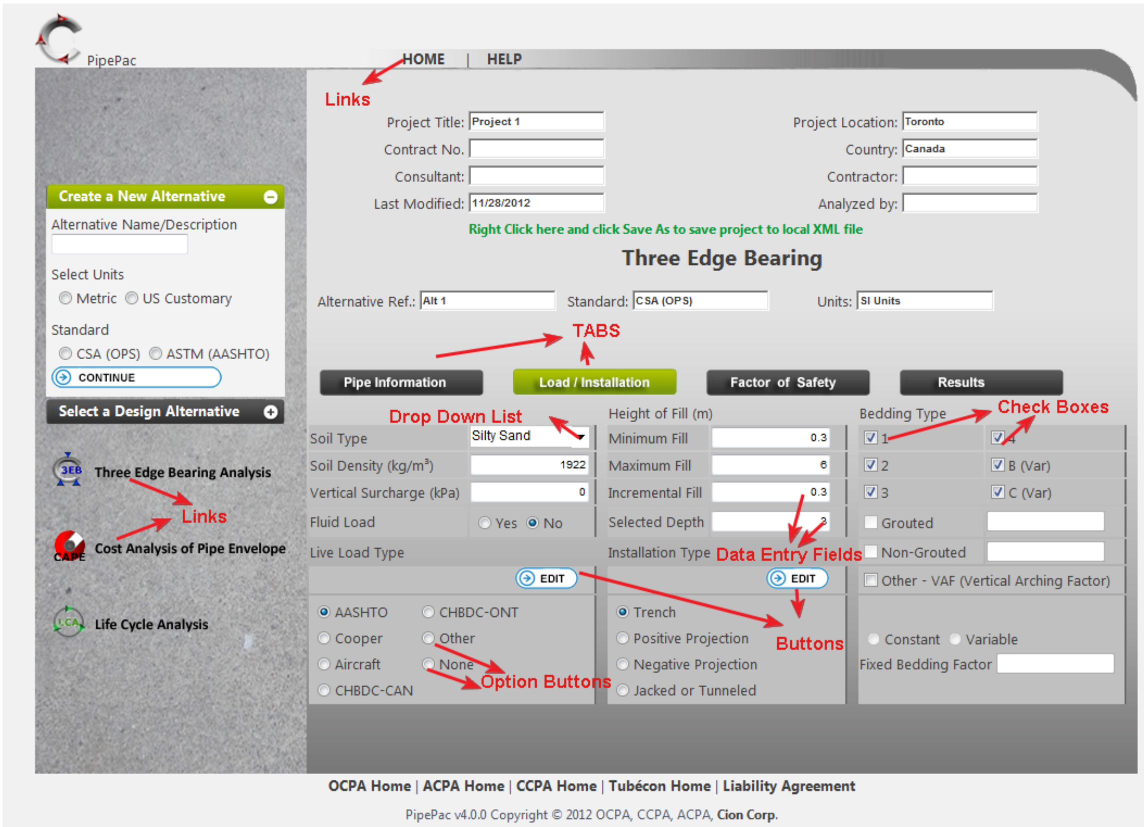
How to use PipePac Help

The PipePac Manual is in PDF format and requires a PDF viewer such as Adobe Acrobat Reader. To view, click on the **HELP** link.



PipePac - Using Form Controls

Form Controls used in PipePac



<u>Control Name</u>	<u>Description of Usage</u>
Buttons	Actions associated with command buttons are executed by clicking the button with the mouse cursor.
Tabs	Similar to buttons. The tabs are used to guide the designer step by step during each analysis.
Scroll Bars	Allow you to scroll vertically or horizontally within the current form. The scroll bars are used when viewing area is smaller than the size of the contents
Option Buttons	Usually a list of selections that only allow one selection from the list.
Check Boxes	Usually a list of selections that allow one or more selections from the list.
Drop Down Lists	Displays a list of items and allows you to select one item from the list.

PipePac - Getting Started

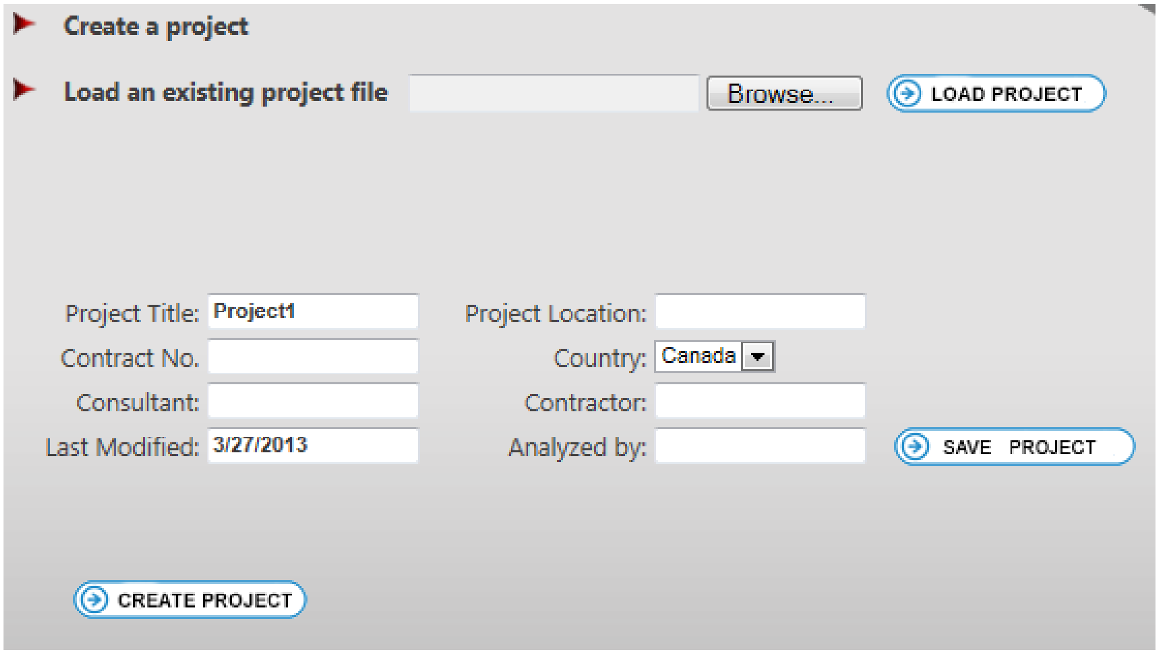
Select Project

PipePac is designed to organize your analysis data and results into a simple hierarchy of Project and its alternatives. To start using PipePac you must first create or load and existing project file. The Select Project form allows the designer to select one of the following options:

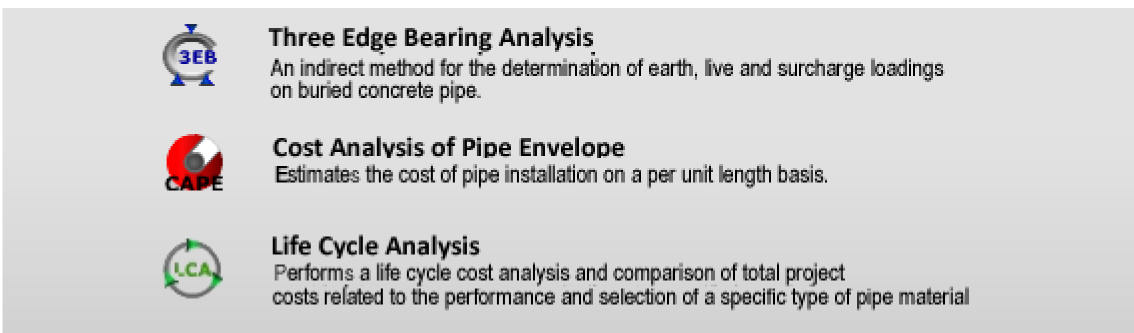
Create a project:	Select this option to create a new project.
Load an existing project file:	Load a previously saved project file from your local hard-drive or storage.

Project Details

The following project details can be specified in here: Project Title, Project Location, Contract#, Country, Consultant, Contractor and Analyzed By. The Project Title must be specified before selecting any of the design modules.



Select Design Tool



After selecting a project you must then select a specific design tool. Click on the tool icon in the text below to jump to help text specific to the tool icon selected.

3EB, an acronym for Three Edge Bearing analysis, is an indirect design method for the determination of earth, live and surcharge loadings on buried concrete pipe.

3EB is versatile because it allows the user to “customize” site conditions in which concrete pipe is to be placed. Input parameters, including pipe shape, can be easily modified in order that numerous loading and installation scenarios (trench, embankment and jacked) be modeled in a matter of seconds.

Another useful feature of 3EB analysis is that a variable bedding factor and variable arching factor may be specified by the designer for special installations. The bedding factor takes into account that the moment induced in a section of pipe after placement and backfilling, is less severe than the moment induced in a pipe section by the standard Three Edge Bearing test. In considering this information a pipe of lesser strength class may be employed in a project resulting in a cost saving to the owner.

Another time saving feature of 3EB analysis is allowing the designer to select more than one bedding type in a single analysis run.

Finally, 3EB analysis provides the designer with a clear and concise tabular output where D-Load values to produce a .3mm(.01in.) crack are listed. In the case of multiple bedding type selection, the designer can view the summary table, which compares the D-Loads at each incremental pipe depth.

Now that 3EB provides a way to calculate all bedding types and compare results, the designer has the means to safely and economically specify an appropriate strength of pipe for conditions unique to the site under investigation.

CAPE, an acronym for Cost Analysis of Pipe Envelope, is used to estimate the cost of pipe installation on a per unit length basis. As designers and project estimators are aware, pipe cost is only one portion of a project. Embedment costs can be a significant portion of project cost, which should also take into consideration handling, and disposal of excess native materials. Furthermore, additional costs can also result from environmental concerns.

An important feature of CAPE is that it performs cost analysis for six rigid pipe installations and a flexible pipe installation. If the 3EB analysis is performed prior to the CAPE analysis then the pipe classes determined in 3EB will be carried into CAPE and used to determine pipe costs for the various bedding conditions.

CAPE is fully compliant with the OPSD for both rigid and flexible pipe. Default values for the trench dimensions and cover are OPSD values. Designers have the option to override default values and enter their own requirements for trench geometry.

CAPE analysis provides the designer with a graphical and summarized comparison between rigid and flexible pipe installation alternatives.

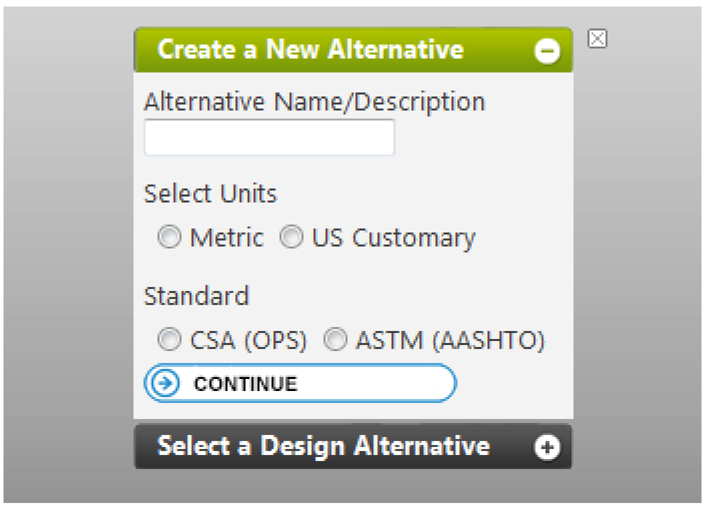
LCA, an acronym for Life Cycle Analysis, is used to perform a life cycle cost analysis and comparison of total project costs related to the performance and selection of a specific type of pipe material.

LCA provides the ability to define initial installation and future replacement costs, as well as, expected maintenance costs for the duration of the selected design life. LCA can provide an estimate of the total cost represented in Present Value, Annualized Value or Future Value for each pipe material alternative selected.

Select Design Alternative

After selecting either of the 3EB, CAPE or LCA tools you will have to create a new design alternative or select an existing alternative. The Select Design Alternative form allows the designer to select one of the following options:

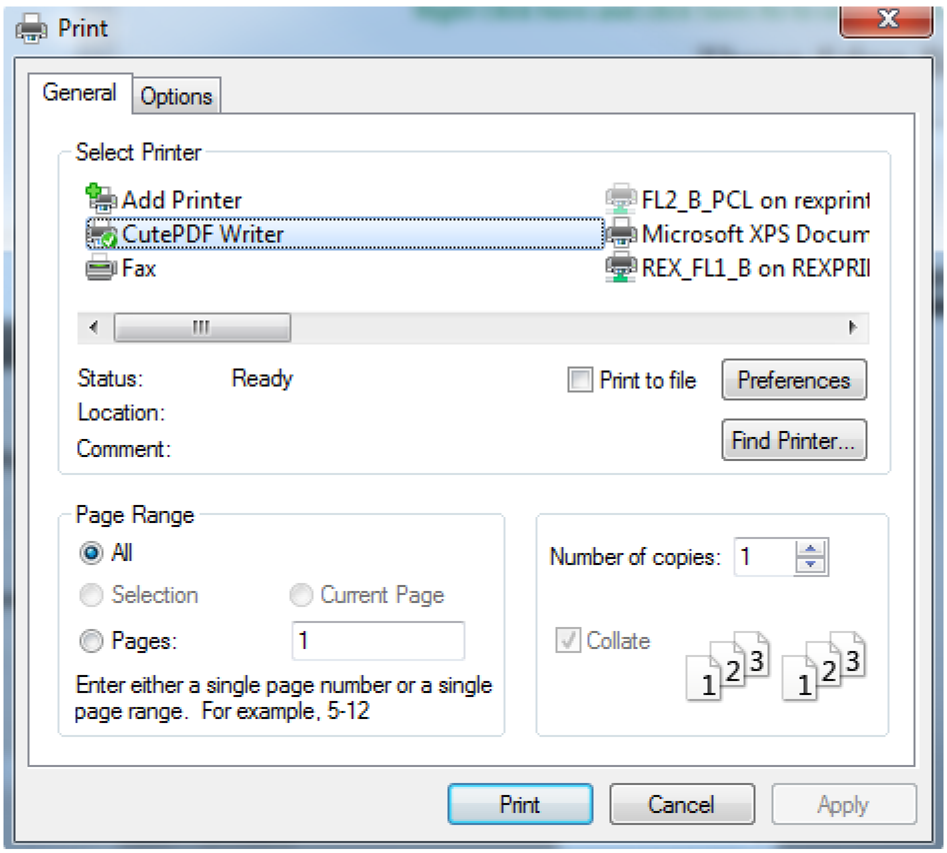
Create a New Alternative	Select this option to continue with the last design alternative.
Select a Design Alternative	Select this option to point to a specific design alternative within the current project. The designer is provided with a list of existing alternatives for the current project in the pull down list.



Troubleshooting

Problem: How to save a report in PDF format?

To do this, a PDF printer driver must be installed on your system. First preview the report in the web browser. Then use the print option available in the browser. Select your PDF printer driver in the print options and click ok to save the report in PDF format.



3EB Help Contents

- **General**
- **Load/Installation**
- **Safety**
- **Results**

3EB – Pipe Information

The Pipe Information form allows the designer to set Pipe Shape, Pipe Type, Wall Thickness, Inner Diameter, Span and Rise.

Pipe Shape: Once the designer has determined the flow requirements for a particular application, a pipe shape must be selected: Circular, Vertical Elliptical, Horizontal Elliptical or Arch. Circular pipe is used for most applications. Vertical Elliptical pipe is generally used in applications where there are trench width limitations (i.e. pipe passing between foundations) but no vertical restrictions. Horizontal elliptical pipe is generally used when there are height restrictions placed on pipe (i.e. under railways, roadways, etc.) but no width restrictions. Arch pipe is similar to horizontal elliptical pipe in that it can be placed in areas having height restrictions; however, it is easier to place than horizontal elliptical pipe owing to its flatter bottom.

Pipe Type: The designer can select pipe type according to the following table:

Diameter		ASTM C 14M-94 NON-REINFORCED	CSA-A257.1-M92 NON-REINFORCED	ASTM C 76M-94 REINFORCED	CSA-A257.2-M92 REINFORCED	SUGGESTED DEFAULTS
(mm)	(in.)					
100	4	X	X			NR
150	6	X	X			NR
200	8	X	X			NR
225	9	N/A	N/A			NR
250	10	X	X			NR
300	12	X	X	X	X	R
375	15	X	X	X	X	R
450	18	X	X	X	X	R
525	21	X	X	X	X	R
600	24	X	X	X	X	R
675	27	X	X	X	X	R
750	30	X	X	X	X	R
825	33	X	X	X	X	R
900	36	X	X	X	X	R
1050	42			X	X	R
1200	48			X	X	R
1350	54			X	X	R
1500	60			X	X	R
1650	66			X	X	R
1800	72			X	X	R
1950	78			X	X	R
2100	84			X	X	R
2250	90			X	X	R
2400	96			X	X	R
2550	102			X	X	R
2700	108			X	X	R
3000	120			X	X	R

NR-Non-Reinforced, R-Reinforced

Designers will be cautioned if they have entered information contrary to currently used standards.

Wall Thickness: Standardized wall thicknesses have been developed for each diameter of circular pipe commonly available from reinforced concrete pipe manufacturers. The wall thicknesses are designated 'A', 'B', 'C' and OTHER with 'A'-wall having the smallest thickness and 'C'-wall having the largest standard thickness within a given pipe diameter. Selecting OTHER wall thickness allows the designer to set a value for wall thickness.

Inner Diameter: A value for the inner diameter, in mm or in., of pipe being used on site must be entered if the loading on circular pipe is to be studied. In the event that horizontal or vertical elliptical pipe, or, arch pipe has been chosen for use on site, the program will require the designer to first input the span and then rise (in mm or in.) of such pipe. The designer is presented with a list of standard pipe sizes in a pull down menu.

Span: The designer is presented with a list of standard pipe span sizes in a pull down menu. Selecting a span automatically fills the rise of the pipe. This parameter is available only if the pipe shape is non-circular.

Rise: The designer is presented with a list of standard pipe rise sizes in a pull down menu. Selecting a rise automatically fills the span of the pipe. This parameter is available only if the pipe shape is non-circular.

3EB - Load/Installation

The Load/Installation form allows the designer to set the following parameters.

Soil Type: The designer is presented with list of soil type and their maximum and minimum soil densities (see soil tables for more information). Selecting a soil type automatically assigns the maximum soil density to Insitu Soil Density.

The Soil Types presented in 3EB include a number of materials in use. The following tables are provided as guidance to designers using PipePac.

The tables provide the gradations of materials identified in PipePac as percent (%) passing a particular sieve size. References are also provided as additional information.

	19 mm Clear Stone	Granular A	Granular B	Granular C
Sieve Designation				
150 mm			100	100
26.5 mm	100	100	50-100	50-100
19.0 mm	90-100	85-100		
13.2 mm		65-90		
9.5 mm	0-55	50-73		
4.75 mm	0-10	35-55	20-100	20-100
2.36 mm				
1.18 mm		15-40	10-100	10-100
0.600 mm				
0.300 mm		5-22	2-65	5-90
0.150 mm				4-30
0.075 mm		2-8	0-8	0-10

Sources:
Ontario Provincial Standard OPSS 1004: Material Specifications for Aggregates – Miscellaneous (19 mm Clear Stone)
Ontario Provincial Standard OPSS 1010: Material Specification for Aggregates – Granular A, B, M and Select Subgrade Material
Ministry of Transportation for Ontario standard MTO 1010: Material Specification for Aggregates – Granular C

	HL 3	HL 6 & HL 8
Sieve Designation		
9.5 mm	100	100
4.75 mm	90-100	85-100
2.36 mm	70-100	60-100
1.18 mm	50-90	34-90
0.600 mm	30-70	17-70
0.300 mm	15-40	9-40
0.150 mm	5-15	3-15
0.075 mm	0-5	0-7

Source:
Ontario Provincial Standard OPSS 1003: Material Specification for Aggregates – Hot Mixed, Hot Laid, Asphaltic Concrete

Default Granular Soil Type: Silty Sand

Insitu Soil Density:

Default Insitu Soil Density: 1922 kg/cu.m or 120 lb/cu.ft. The soil density will automatically change when a specific soil type is chosen, but this value can be over-ridden by the user if required.

Vertical Surcharge: The vertical surcharge loading parameter is used when construction or post construction dead loads directly over a completed section of installed pipe are anticipated. This load should not include any live or backfill loads.

Default - 0

Fluid Load: Fluid weight typically is about the same order of magnitude as pipe weight and generally represents a significant portion of the pipe design load only for large diameter pipe under relatively shallow fills (see Fluid Load for more information).

Default - No

Minimum height of fill (m/ft.): The minimum depth of fill is the smallest distance, along a line of pipe, measured between the final grade and the top of the pipe.

Default - 1ft. or .3m

Maximum height of fill (m/ft.): The maximum depth of fill is the largest distance, along a line of pipe, measured between the final grade and the top of the pipe. When determining this distance from plans, it is recommended that the designer assume a maximum depth at least 0.3m greater than that read from the plans in order to account for errors in the reproduction of drawings, or possible unforeseen problems on site with placing the pipe to the desired elevations.

Default - 20ft. or 6m

Incremental fill (m/ft.): This input value allows the designer to determine the increments between minimum and maximum depth of fill at which the loading on the pipe is to be studied.

Default - 1ft. or .3m

Selected Depth (m/ft.): The pipe classes for selected bedding type will be calculated at this height.

Live Load Types: Depending on where a given run of pipe is to be installed, an appropriate live load acting above the pipe should be considered. The following sections describe the different live loading scenarios, which can be modeled using the 3EB program:

AASHTO

The AASHTO specifications require that bridges supporting Interstate Highways shall be designed for the HL-93 Live Load. The HL-93 load consists of the worst case load from either an HS20 truck or an Interstate vehicle.

HS loadings consist of a tractor truck with semi-trailer or the corresponding lane load. The HS loadings are designated by the letters 'HS' followed by a number indicating the gross weight, in tons of the tractor truck. The live load applied to the pipe results from the heaviest single axle on the truck (32 kips for an HS 20 load = 80 percent of the gross weight of the truck). Due to increasing truck sizes, HS Truck loads may have to be increased beyond 20 tons for certain states or provinces.

The Interstate (or Military) load is applied over dual axles. The AASHTO LRFD Bridge Design Specifications applies a load of 25 kips per axle with the two axles being spaced 4 feet apart.

For required parameters, refer to AASHTO and CHBDC Live Loading Parameters

Cooper

Railroad authorities presently use AREMA loading. In determining the live load transmitted to a pipe installed under railroad tracks the weight of the locomotive driver axles plus the weight of the track structure, including ballast, is considered to be uniformly distributed over an area equal to the length occupied by the drivers multiplied by the width of the ties.

Aircraft

If pipe is to be installed underneath a runway, an Aircraft live loading should be specified. In the Aircraft Loading Parameters form, the designer can specify whether the pavement at final grade above the pipe is Rigid or flexible.

CHBDC-CAN, CHBDC-ONT

CSA S6-00 Canadian Highway Bridge Design Code offers a choice of two live loads. These are known as CL-W and CL-625-ONT. Both of the truckloads are 625kN, however, the wheel and axle spacing is slightly different. CL-W has been developed for the national road network, and CL-625-ONT has been developed for use in Ontario. Users should verify the load adopted by the provincial authority in which the design pertains to. For details on the spacing, refer to Section 3 of the Canadian Highway Bridge Design Code. For required parameters, refer to AASHTO and CHBDC Live Loading Parameters

None

The selection of this option cancels any live loading analysis performed on the pipe.

Other

If none of the above live loadings is suitable for a given analysis, the designer may wish to define a customized or 'other' loading. The remainder of the input requirements are then identical to that of the Aircraft loading.

Installation Types: The designer can select one of the following installation types: Trench, Positive Projection, Negative Projection, Jacked or Tunneled.

Trench

A Trench installation is an excavation designed in such a manner so as to have the sidewalls of the trench carry a portion of the backfill load. A Trench installation is dependent upon six elements: the diameter of the pipe being placed, the width of the trench measured at the top of the pipe, the depth at which the pipe is placed, the friction developed between the backfill material and the native trench wall material, the density of the backfill material and, the material in which the pipe is being placed.

There is a limiting width of trench measured across the top of the pipe, beyond which point the trench sidewalls no longer carry any of the backfill load directly above the pipe. This limiting width is known as the transition width. The transition width changes with depth for a given diameter of pipe. The reader is referred to the Ontario Concrete Pipe Association (OCPA) Concrete Pipe Design Manual or the American Concrete Pipe Association (ACPA) Concrete Pipe Design Manual for approximations of Transition Width values.

Once the transition width is reached for a given diameter of pipe at a certain depth, the friction and hence shear forces developed between the backfill and trench wall materials become negligible in terms of reducing the overall load the pipe must carry. At Transition Width and beyond, the excavation is no longer considered a Trench installation.

IF THE DESIGNER HAS SPECIFIED PIPE BASED ON A TRENCH INSTALLATION DESIGN, IT IS IMPERATIVE THAT CONTROLS BE MAINTAINED ON SITE SO AS TO ENSURE THAT THE TRENCH WIDTH SPECIFIED BY THE DESIGNER (MEASURED ACROSS THE TOP OF THE PIPE) IS NOT EXCEEDED. FAILURE TO DO SO MAY RESULT IN THE PLACEMENT OF PIPE OF INADEQUATE STRENGTH SHOULD THE DESIGN WIDTH BE EXCEEDED.

Positive Projection

When Transition Width for a given diameter of pipe at a given depth is reached, the installation is referred to as a Positive Projected Embankment Installation. This installation is the most conservative of the four which can be selected from the 3EB program in that the pipe carries the full load of the backfill material above it plus additional load as a result of frictional forces. Once Transition Width is exceeded, the load on the pipe does not increase.

Negative Projection

Negative Projecting Embankment Installation contains elements of both the Trench and Positive Projected Embankment installations. The bottom portion of this installation is in a native material. The portion above the sub-trench is an embankment, similar to that of the Positive Projected installation.

If the width of the sub-trench, measured across the top of the pipe is at the transition width for a given diameter of pipe at a given depth of fill, then the installation is considered to be a Positive Projected Embankment installation. If the width of the sub-trench is less than the Transition Width, then a small portion of the backfill load is taken up by the shear developed between the backfill and sub-trench wall materials.

When the top of the pipe is flush with the top of the sub-trench, the installation is referred to as a Zero Projecting Embankment.

IF THE DESIGNER HAS SPECIFIED PIPE BASED ON A NEGATIVE PROJECTING EMBANKMENT INSTALLATION DESIGN, IT IS IMPERATIVE THAT CONTROLS BE MAINTAINED ON SITE SO AS TO ENSURE THAT THE TRENCH WIDTH SPECIFIED BY THE DESIGNER (MEASURED ACROSS THE TOP OF THE PIPE) IS NOT EXCEEDED. FAILURE TO DO SO MAY RESULT IN THE PLACEMENT OF PIPE OF INADEQUATE STRENGTH SHOULD THE TRANSITION WIDTH BE EXCEEDED.

Jacked or Tunneled

Jacked: The OCPA and ACPA Concrete Pipe Design Manual indicates that this type of installation is used where surface conditions make it difficult to install the pipe by conventional open excavation and backfill methods or where it is necessary to install pipe under an existing embankment.

Reinforced concrete pipe as small as 450mm(18in.) inside diameter and as large as 3600mm(144in.) inside diameter have been installed by jacking. Since conventional jacking procedures require access by workers through the pipe to the heading, a 900mm(36in.) diameter pipe is generally the smallest practical size for most jacking operations.

Tunneled: Abbott (1992) explains that the installation of underground pipelines and sewers utilizing microtunneling or tunneling techniques is becoming more common throughout the world. Both of these terms refer to the installation of pipes or tunnels by trenchless means, either in non-man entry sizes, termed microtunneling (typically where pipe diameters are less than 900mm(36in.)), or for larger sized bores where either conventional hand or mechanized tunneling techniques are used.

The usual procedure in tunnel construction is to complete excavation of the tunnel bore first and then install the pipe. The size of the pipe installed is limitless.

Microtunneling methods, using jacking pipe and thrust jacks, are more frequently being used to install pipelines and tunnels of up to 3000mm(120in. or greater) in diameter. The equipment, for a given ground condition, is similar to that of microtunneling used for smaller pipes but the size, capacity and weight significantly increases, as do the jacking forces.

A microtunneling machine is a remotely controlled mechanical boring machine which is pushed into the soil by means of a hydraulic jacking system. The pipes to be installed are jacked behind the machine as the bore progresses.

Bedding Types: The **bedding factor**, stated simply, is the ratio of the moment induced in a section of pipe during the three-edge bearing (T.E.B.) test to the moment induced in a section of pipe when installed in the field. The bedding factor depends upon two characteristics of the installation: Width and quality of the contact between bedding and the pipe, and, the magnitude of the lateral pressure and the portion of the vertical area of the pipe over which it is effective.

The T.E.B. test is a means of verifying the structural strength of a pipe. The load per linear meter, which a pipe will support under this condition, is termed the T.E.B. strength. The T.E.B test is the most severe loading to which any pipe will be subjected. There is no lateral support for the pipe as provided under actual buried conditions. As well, the applied forces in the test are virtually point loads.

The 3EB analysis will determine the bedding factor at every increment of depth specified in the height of fill section. The bedding factor is then, in fact, a variable bedding factor as it changes with depth. If the designer wishes to simulate another bedding with a fixed bedding factor, the 'Other' option should be selected. The designer must then enter a bedding factor.

The following bedding types are available for circular pipes: 1, 2, 3, 4, B, C and Other. For non-circular pipe, the bedding types available are: 2, 3, B, C and Other .

The default bedding options for Jacked or Tunneled installation are: Grouted, Non-grouted, and Other. When Grouted is selected, this means that the designer anticipates that grout will be pumped between the pipe and soil in order to fill the void and give more consistent lateral pressure thus decreasing the chances of point loading on the pipe. The bedding factor for a grouted bedding is fixed at 3.0 by the program. When the pipe is non-grouted, the bedding factor is fixed at 1.9 by the program, simulating a class B bedding. If the Other option is chosen, it is suggested a value between 1.9 and 3.0 be selected.

AASHTO and CHBDC Loading Parameters

All of the major highway specifications in the United States and Canada require an analysis of structures beneath both a single axle load and a double axle load. The live load input screen allows the PipePac user to input the axle loads for both a single axle truck load and a double axle truck load.

While all the major specifications such as the American Association of State Highway and Transportation Officials (AASHTO) and the Canadian Highway Bridge Design Code (CHBDC) require an analysis of single and double axles, their magnitudes are different (see table below). Generally, the single axle load is higher than the individual axle loads for the double axle load condition, although the sum of the two axles is greater than the single axle load.

The input screen allows the user to specify the load values for both the single axle, and the value for the individual axle of a dual axle load. Appropriate default values are given when the "AASHTO", "CHBDC", or "CHBDC-Ont" live load option is originally chosen. However, these values can be changed by the user. Changes to the default values may be required when evaluating buried pipe for states, provinces, and municipalities where the design requirements often deviate from the national standards. Many local and private designs only require an analysis using the single axle load. In this case, the designer may simply input a value of zero for the "Load Per Axle" of the double axle load.

The impact factor (termed dynamic load allowance in some standards) is applied to the static wheel load to account for wheel load impact from moving vehicles. This dynamic response through the soil is reduced as the depth of cover over the pipe increases. In some standards, such as the AASHTO Standards, the value is allowed to dissipate to zero, while in other standards, such as CHBDC, there is a limit on the minimum impact factor. Thus, the input screen allows the user to input the impact factor at the surface, the minimum impact factor, and the depth of cover over the pipe (including pavement thickness) at which the minimum impact factor is reached. The PipePac program reduces the impact factor linearly from its maximum value at the surface, to its minimum value at the depth specified.

The PipePac program evaluates both the single axle and dual axle loads over the range of fill heights specified. The loads are applied in a direction of travel perpendicular to the axis of the pipe and in a direction of travel parallel to the axis of the pipe, and the worst case condition is used for design and printed in the output.

The default values used in PipePac are given below:

Code	Axels	Load per Axel	Space Between Axels	I.F. at the Surface	Minimum Impact Factor	Depth to Minimum I.F.
AASHTO	Single	32 kips	N/A	0.33	0.0	8 ft.
LRFD	Double	25 kips	4 ft.	0.33	0.0	8 ft.
CHBDC	Single	175kN	N/A	0.4	0.1	1.5 m
CL-625	Double	125kN	1.2 m	0.4	0.1	1.5 m
CHBDC-Ont	Single	175kN	N/A	0.4	0.1	1.5 m
CL-625 ONT	Double	140kN	1.2 m	0.4	0.1	1.5 m

Aircraft Loading Parameters

If ***Rigid pavement*** is selected, the designer is required to input the following parameters:

Number of loads **-** This parameter allows the designer to specify whether one or two live loads are active. The default setting is one live load.

Magnitude of load **-** The magnitude of the default number of loads (one) is required for this input parameter.

Magnitude of each load **-** If two loads are selected as the number of loads, then this input parameter will appear rather than the above parameter. In this case, the magnitude entered will be the magnitude of each of the two loads.

Distance between center of each load **-** This parameter appears only if the number of loads entered in the first selection is two. The designer simply enters the distance between the two active live loads.

The following parameters appear regardless of whether one or two active live loads have been selected:

Pavement thickness - This value is the thickness of the pavement upon which the live load(s) will be acting.

Modulus of elasticity of pavement **-** This value is simply Young's modulus of elasticity, with a default setting of 27579 Mpa(4,000,000 psi). *This* corresponds to a 28 day specified compressive strength of approximately 30.4 Mpa(4500 psi). The designer may specify a different modulus of elasticity by using the formula:

E = 5000 x square root (28 day compressive strength, in Mpa)

E = 57,000 x square root in psi

where E = Young's modulus of elasticity

Poisson's ratio of pavement **-** Poisson's ratio is defined as the ratio of the unit lateral strain to the longitudinal strain. The default value for this parameter is .15.

Modulus of subgrade reaction **-** The design procedure for concrete pavement outlined below was developed on the basis of AASHTO road tests. The specific assumptions and methodology used in developing this design method are given in AASHTO “Interim Guide for Design of Pavement Structure., 1972. This design method is based on the following parameters: terminal serviceability index, pt, equivalent 18-kip single-axle loads, and modulus of subgrade reaction

k (Westergaard's modulus of subgrade reaction, referred to as *gross k* in AASHTO road test reports, which represents the load, psi, on a loaded area divided by the deflection, in, of that area). The scales for k included in design charts are correlated with values obtained by plateloading tests performed. in accordance with AASHTO T222 with a 3~in diameter plate. The *k* value may be estimated on the basis of previous experience or by correlation with other tests.

***Radius of stiffness (RS) of rigid pavement* -** This value will be calculated by the program.

***Relative spacing of loads (spacing/RS)* -** This value will be calculated by the program only if the number of loads entered in the first selection is two.

If the spacing is greater than 3.2 x RS, a default spacing of 3.2RS is used since values greater than this do not exist for this range. (see ACPA Concrete Pipe Design Manual for more details)

If the ***flexible Pavement*** is selected, the designer is required to input the following parameters:

***Load magnitude* -** This is simply the magnitude of the live load the designer wishes to specify.

Load width at ground surface - This value is the width of the load 'footprint', measured in the direction parallel to the flow within the pipe.

Load length at ground surface - This value is the length of the load 'footprint', measured in the direction perpendicular to the flow within the pipe.

Live Load Distribution Factor - This is the ratio of increase in the horizontal spread of the live load with respect to increase in depth.

The load, over its designated footprint, is applied at the top of the pipe in such a manner so as to have a load distribution with dimensions:

(load width + LLDF x depth) by (load length + LLDF x depth).

NOTE: A minimum value of .305m or 1ft. must be entered for both the load width and length.

Soil Tables

Typical Standard Proctor Dry Densities and Optimum Moisture Contents

TYPE	MATERIAL	MAXIMUM STANDARD PROCTOR DRY DENSITIES (pcf)	(kg/m³)	OPTIMUM MOISTURE CONTENT(%)
Asphalt	HL6, HL8	148 - 154	2370 - 2467	-
	HL3	149 - 152	2367 - 2439	-
Base Course	Granular "A" 20mm (3/4 in)	133 - 145	2130 - 2323	5 - 8
	Crusher Run	135 - 138	2162 - 2211	5 - 8
Sub-Base	Granular "B" 50mm (2 in)	117 - 138	1874 - 2211	6 - 10
	Crusher Run	132 - 138	2114 - 2211	5 - 7
	Screenings	132 - 136	2114 - 2179	5 - 9
Subgrade Soils	Gravelly Sand	126 - 133	2018 - 2130	7 - 9
	Granular "C"	115 - 123	1842 - 1970	9 - 12
	Fine Sand	110 - 116	1762 - 1858	9 - 12
	Silty Sand	113 - 120	1810 - 1922	9 - 12
	Sandy Silt	110 - 118	1762 - 1890	9 - 12
	Silty Sand Silt	124 - 130	1986 - 2082	7 - 10
	Sandy Silt Till	120 - 128	1922 - 2050	8 - 12
	Clayey Silt Till	115 - 125	1842 - 2002	8 - 13
	Silty Clay Till	118 - 125	1890 - 2002	10 - 15
	Silty Clay	116 - 124	1858 - 1936	12 - 18
	Clayey Silt	115 - 122	1842 - 1954	10 - 15
	Silty Clay/ Weathered Shale	116 - 124	1858 - 1986	10 - 15

Information presented in this table is used when selecting soil types and densities.

Fluid Load

Fluid weight typically is about the same order of magnitude as pipe weight and generally represents a significant portion of the pipe design load only for large diameter pipe under relatively shallow fills. Fluid weight has been neglected in the traditional design procedures of the past, including the Marston Spangler design method utilizing the B and C beddings. There is no documentation of concrete pipe failures as a result of neglecting fluid load. However, some specifying agencies such as AASHTO and CHBDC, now require that the weight of the fluid inside the pipe always be considered when determining the D-load.

The fluid load option uses 9.8 kN/cu.m (62.4 lbs/cu.ft) in accordance with AASHTO. This load is added to the earth load and divided by the earth load bedding factor when determining the D-load.

When fluid load is considered in the analysis, the resulting D-load equation is:

$$D := \left(\frac{12}{S}\right) \cdot \left(\frac{W_E + W_F}{B_{fe}} + \frac{W_L}{B_{fLL}}\right)$$

Where: S = internal horizontal span of pipe, mm (in)

W_E = total earth load on pipe, kN/m (lbs/ft)

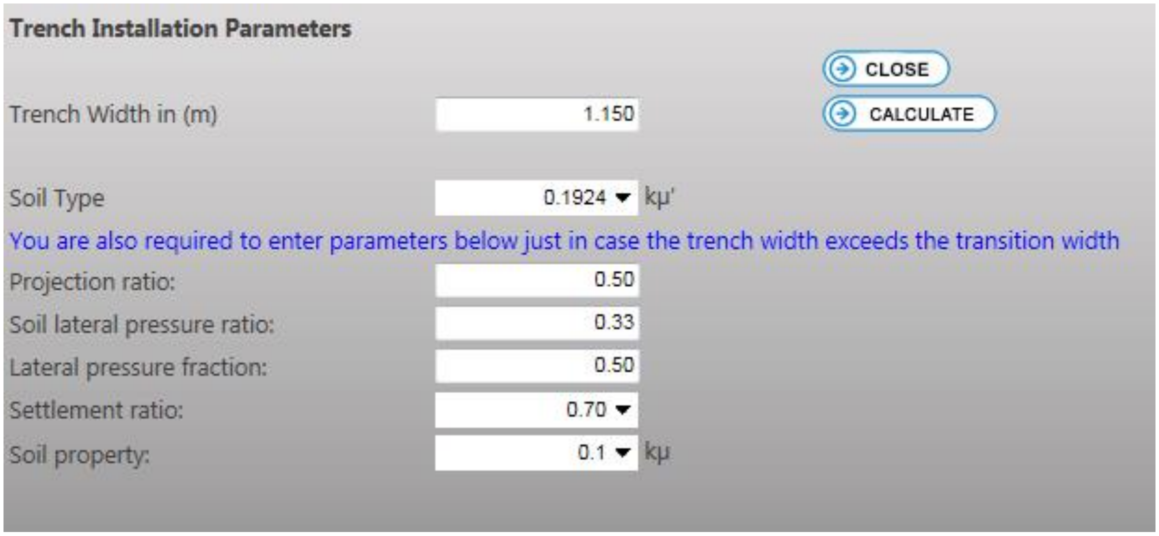
W_F = fluid load in the pipe, kN/m (lbs/ft)

W_L = total live load on pipe, kN/m (lbs/ft)

B_{fe} = earth load bedding factor

B_{fLL} = live load bedding factor

Trench



Trench Width: For bedding types B and C: The Trench Width may based on OPSD standards. The OPSD indicates a requirement for a spacing of 300mm(12in.) on both sides of a circular pipe for all diameters less than or equal to 900mm(36in.). For pipe of diameter 975mm(39in.) or greater, the OPSD standard requires a spacing of 500mm(20in.). For bedding types 1, 2, 3 and 4: The Trench Width may based on Design Data 9(DD9) standards. The DD9 indicates a requirement for a minimum spacing of 1/6 of pipe outside diameter on both sides of a circular pipe for all diameters. Click **'calculate'** button to re-calculate the trench width.

Soil Type (kμ'): The soil property (Kμ') entered in this form is a value for the native material forming the walls of the trench. The designer may input a value particular to the soil found on site if Rankine's coefficient (K) and the coefficient of friction between the backfill material and the trench walls (μ') are known. If such data are unavailable, typical values are provided in the drop down list.

Projection Ratio: The projection ratio (for Positive Projecting Embankment installations) is the horizontal projection of the profile, above the shaped bedding, after it has been placed. The projection ratio affects the relationship between the settlement of the soil column density above the pipe and the soil adjacent to the pipe. Generally, preparation of the bedding by contractors results in a projection ratio which varies between 0.7 and 0.9.

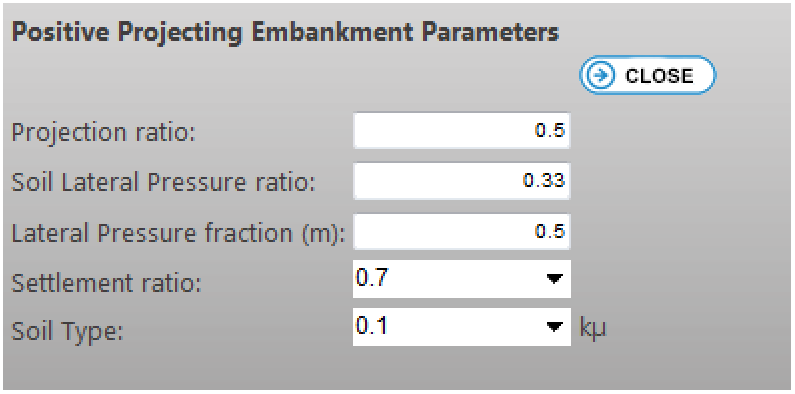
Lateral Soil Pressure Ratio: Lateral pressure ratio is another way of referring to Rankine's active earth pressure coefficient (Ka). This is a means of relating the lateral pressure of a given soil on a pipe to that caused by the vertical load above it. A lateral pressure ratio (Ka) of .33 has long been established as a conservative estimate for most situations.

Lateral Pressure Fraction: The Lateral Pressure Fraction defaults to the value entered for the projection ratio. The Lateral Pressure Fraction is an indicator of the quality of compactive effort that takes place along the exposed profile of the pipe defined by the projection ratio, for the Positive Projected Embankment installation case. If it is assumed that the contractor takes reasonable care to properly place and compact the materials along the projection ration then the default value may be accepted. If site conditions are such that achieving a good compactive effort along the projection ratio is improbable, the designer may wish to enter a number smaller than the default value.

Settlement Ratio: The settlement ratio provides an indication of the relative movement of the interior and exterior soil prisms. The differential movements of the prisms create shear forces which are aligned so as to resist movement between soil masses. Depending on how the masses move, the shear forces may add to, or slightly reduce, the load on the pipe. Typical settlement ratio values are suggested to the designer in the drop down list.

Soil Type(kμ): The soil type (Kμ) entered in this screen is a value for the backfill material only. The reason for this is because once the pipe has been installed in a trench which is beyond Transition Width, the trench walls have no effect on the load carried by the pipe. The backfill material is now considered to form the walls of the trench. The designer may input a value particular to the backfill material if Rankine's coefficient (K) and the coefficient of friction of the backfill material (μ) is known. If such data are unavailable, typical values are provided in the drop down list.

The Positive Projecting Embankment



Projection Ratio: The projection ratio (for Positive Projecting Embankment installations) is the horizontal projection of the profile, above the shaped bedding, after it has been placed. The projection ratio affects the relationship between the settlement of the soil column density above the pipe and the soil adjacent to the pipe. Generally, preparation of the bedding by contractors results in a projection ratio which varies between 0.7 and 0.9.

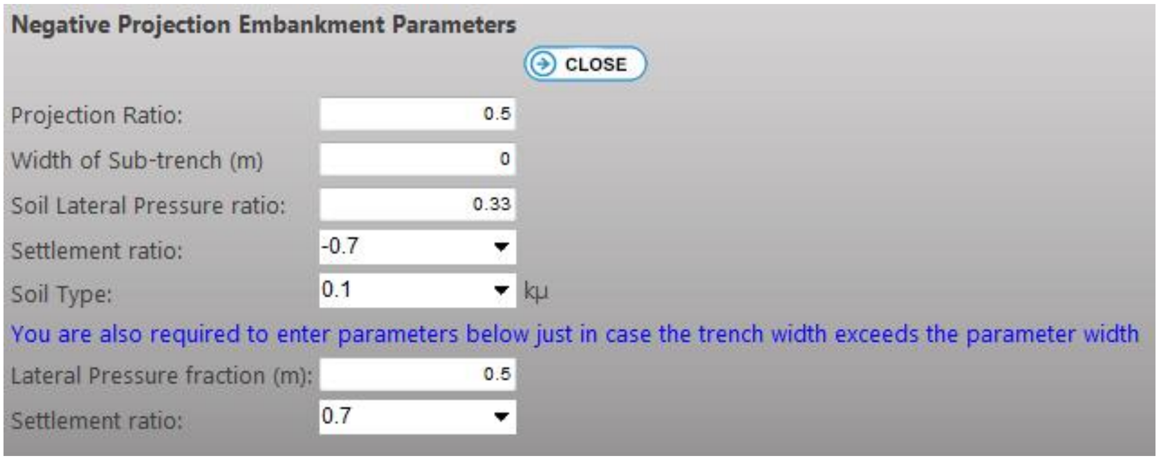
Lateral Soil Pressure Ratio: Lateral pressure ratio is another way of referring to Rankine's active earth pressure coefficient (Ka). This is a means of relating the lateral pressure of a given soil on a pipe to that caused by the vertical load above it. A lateral pressure ratio (Ka) of .33 has long been established as a conservative estimate for most situations.

Lateral Pressure Fraction: The Lateral Pressure Fraction defaults to the value entered for the projection ratio. The Lateral Pressure Fraction is an indicator of the quality of compactive effort that takes place along the exposed profile of the pipe defined by the projection ratio, for the Positive Projected Embankment installation case. If it is assumed that the contractor takes reasonable care to properly place and compact the materials along the projection ration then the default value may be accepted. If site conditions are such that achieving a good compactive effort along the projection ratio is improbable, the designer may wish to enter a number smaller than the default value.

Settlement Ratio: The settlement ratio provides an indication of the relative movement of the interior and exterior soil prisms. The differential movements of the prisms create shear forces which are aligned so as to resist movement between soil masses. Depending on how the masses move, the shear forces may add to, or slightly reduce, the load on the pipe. Typical settlement ratio values are suggested to the designer in the drop down list.

Soil Type (kμ): The soil type (Kμ) entered in this screen is a value for the backfill material only. The reason for this is because once the pipe has been installed in a trench which is beyond Transition Width, the trench walls have no effect on the load carried by the pipe. The backfill material is now considered to form the walls of the trench. The designer may input a value particular to the backfill material if Rankine's coefficient (K) and the coefficient of friction of the backfill material (μ) is known. If such data are unavailable, typical values are provided in the drop down list.

The Negative Projecting Embankment



Projection Ratio: The negative projection ratio is the distance from the top of the sub-trench to the top of the pipe. The greater the negative projection ratio, the lower the load on the pipe. The negative projection ratio is given in terms of a multiple of the width of the trench at the top of the pipe.

Width of Sub-trench: For bedding types B and C: The Trench Width may based on OPSD standards. The OPSD indicates a requirement for a spacing of 300mm(12in.) on both sides of a circular pipe for all diameters less than or equal to 900mm(36in.). For pipe of diameter 975mm(39in.) or greater, the OPSD standard requires a spacing of 500mm(20in.). For bedding types 1, 2, 3 and 4: The Trench Width may based on design data 9(DD9) standards. The DD9 indicates a requirement for a minimum spacing of 1/6 of pipe outside diameter on both sides of a circular pipe for all diameters**.**

Lateral Soil Pressure Ratio: Lateral pressure ratio is another way of referring to Rankine's active earth pressure coefficient (Ka). This is a means of relating the lateral pressure of a given soil on a pipe to that caused by the vertical load above it. A lateral pressure ratio (Ka) of .33 has long been established as a conservative estimate for most situations.

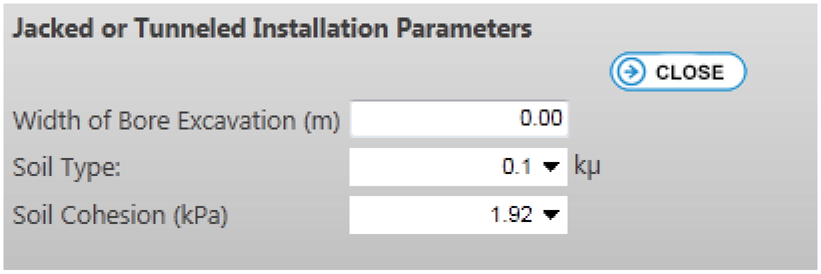
Settlement Ratio: The settlement ratio provides an indication of the relative movement of the interior and exterior soil prisms. The differential movements of the prisms create shear forces which are aligned so as to resist movement between soil masses. Depending on how the masses move, the shear forces may add to, or slightly reduce, the load on the pipe. Typical settlement ratio values are suggested to the designer in the drop down list.

Soil Type (kμ): The soil property (Kμ') entered in this screen is a value for the native material forming the walls of the trench. The designer may input a value particular to the soil found on site if Rankine's coefficient (K) and the coefficient of friction between the backfill material and the trench walls (μ') are known. If such data are unavailable, typical values are provided for the designer in the drop down list.

Lateral Pressure Fraction (m): The Lateral Pressure Fraction is set by the user. The Lateral Pressure Fraction is an indicator of the quality of compactive effort that takes place along the exposed profile of the pipe defined by the projection ratio, for the Positive Projected Embankment installation case. If it is assumed that the contractor takes reasonable care to properly place and compact the materials along the projection ratio then the default value may be accepted. If site conditions are such that achieving a good compactive effort along the projection ratio is improbable, the designer may wish to enter a number smaller than the default value.

Settlement Ratio: The settlement ratio provides an indication of the relative movement of the interior and exterior soil prisms. The differential movements of the prisms create shear forces which are aligned so as to resist movement between soil masses. Depending on how the masses move, the shear forces may add to, or slightly reduce, the load on the pipe. Typical settlement ratio values are suggested to the designer in the drop down list.

Jacked or Tunneled



Width of Bore Excavation: The value to be entered for this parameter is simply the diameter (width) of the tunnel being excavated for eventual jacking of pipe.

Soil Type (kμ): The soil property entered in this form is a value for the native material forming the walls of the bore excavation. The designer may input a value particular to the soil found on site if Rankine's coefficient (K) and the coefficient of friction of the native material (μ) is known. If such data are unavailable, typical values are provided for the designer in the drop down list.

Soil Cohesion: In general terms, a soil is considered to be cohesive if the particles adhere after wetting and subsequent drying and if significant force is then required to crumble the soil: this does not include soils whose particles adhere when wet due to surface tension. The greater the cohesion of the soil, the stronger the 'arched' or 'circular' soil structure surrounding the jacked pipe will be in supporting loads above it.

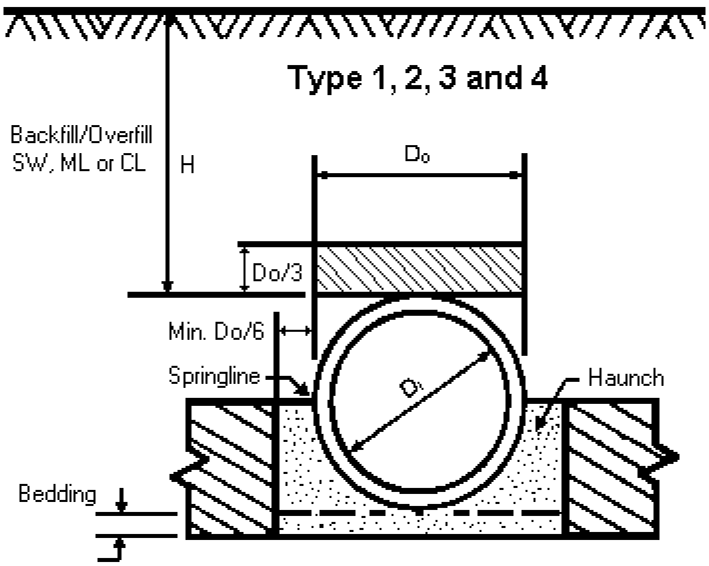
If the designer does not have cohesion values for soils from site, a list of typical values can be found in the drop down list.

3EB Bedding Types

For AASHTO Bedding Types 1, 2, 3 and 4 (CHBDC denotes these as C1, C2, C3 and C4):

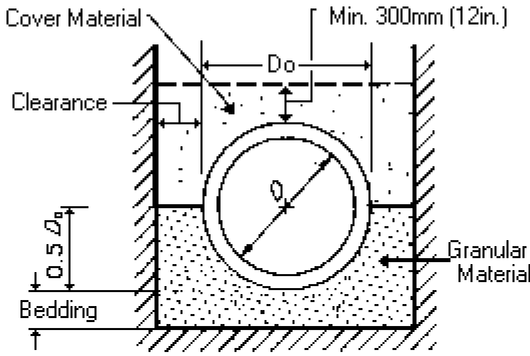
Bedding Type	Bedding Depth	Haunch
Type 1	75mm(3in.)	95% SW
Type 2	75mm(3in.)	90% SW or 95% ML
Type 3	75mm(3in.)	85% SW, 90% ML or 95% CL
Type 4	0	No compaction required, expect if CL, use 85% CL

SW-Gravelly Sandy; ML-Sandy Silt; CL-Silty Clay

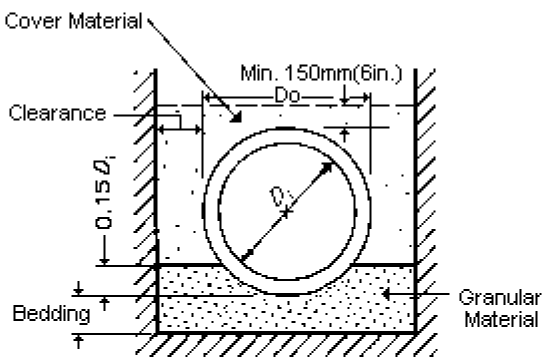


For Bedding Types B and C:

The minimum bedding depth shall be 0.15D or 150mm(6in.) whichever is greater. The OPSD indicates a requirement for a spacing of 300mm(12in.) on both sides of a circular pipe for all diameters less than or equal to 900mm(36in.). For pipe of diameter 975mm(39in.) or greater, the OPSD standard requires a spacing of 500mm(20in.).



Class B



Class C

Bedding Type Other

The "Other" option under Bedding Type allows for conditions other than those defined for the Marston/Spangler or Standard Installation Beddings. Seldom would such an occasion occur. When this option is chosen the designer must specify the bedding factor to be used. The bedding factor will remain constant for all fill heights and loading conditions. The designer has two choices under "other".

Constant VAF - This option allows the user to choose a constant Vertical Arching Factor for the positive projecting embankment condition as well as a constant bedding factor. The vertical arching factor is multiplied by the soil prism load above the pipe to determine the load on the pipe. This method of calculating soil load is synonymous with the method used for the Standard Installations, where the vertical arching factor remains constant regardless of depth. The VAF values for the Standard Installations in an embankment condition are as follows:
Type 1 - VAF = 1.35
Type 2 - VAF = 1.40
Type 3 - VAF = 1.40
Type 4 - VAF = 1.45.

Variable VAF -With this option the soil load for the positive projecting embankment condition is calculated based on the projection ratio, settlement ratio, and soil type provided under "Installation Type". This method of calculating soil load is synonymous with the method used for the Marston/Spangler beddings. Unlike the "Constant VAF" option where the vertical arching factor remains constant regardless of depth for a positive projecting embankment installaton, the vertical arching factor gradually increases with depth when using this option.

With a trench condition the program evaluates whether or not the trench is wider than transition width. If trench width exceeds transition width, then the program uses the appropriate positive projecting embankment vertical arching factor as specified above. When trench conditions prevail a reduced vertical arching factor is applied to the soil prism load as a result of the frictional forces along the trench wall, regardless of the option chosen under "other".

3EB - Safety

Pipe strengths are usually presented in terms of a 0.3mm(0.01in) crack strength or ultimate strength in the T.E.B. test for reinforced concrete pipe. The 0.3mm(0.01in) crack D-Load is the load at which a 0.3mm(0.01in) wide crack of 300mm(12in) length first appears in a pipe section under loading from the T.E.B. machine.

A comparison of imperial and metric pipe strength designations is given in the following table:

For reinforced pipes:

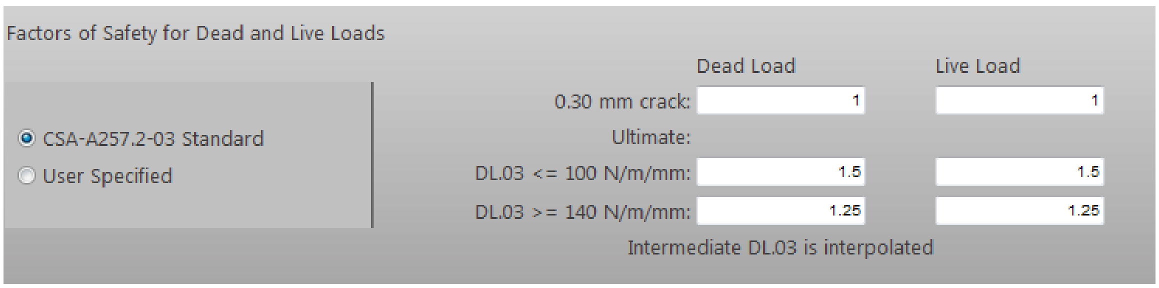
CSA			ASTM		
	METRIC N/m/mm	IMPERIAL lb/ft/ft		METRIC N/m/mm	IMPERIAL lb/ft/ft
40-D	40	830	CL-I	40	800
50-D	50	1040	CL-II	50	1000
65-D	65	1350	CL-III	65	1350
100-D	100	2090	CL-IV	100	2000
140-D	140	2920	CL-V	140	3000

For non-reinforced pipes:

Designated internal diameter,		Class 1 Min. strength TEB method,		Class 2 Min. strength TEB method,		Class 3 Min. strength TEB method,	
mm	in.	kN/m	lb/ft	kN/m	lb/ft	kN/m	lb/ft
100	4	22.0	9.5	29.0	12.9	35.0	13.0
150	6	22.0	17.0	29.0	20.0	35.0	21.0
200	8	22.0	27.0	29.0	31.0	35.0	36.0
225	9	22.5	N/A	29.0	N/A	35.0	N/A
250	10	23.5	37.0	29.0	42.0	35.0	50.0
300	12	26.5	50.0	33.0	68.0	38.0	90.0
375	15	29.0	78.0	38.0	100.0	42.0	120.0
450	18	32.0	105.0	44.0	155.0	48.0	165.0
525	21	35.0	159.0	48.0	205.0	56.0	260.0
600	24	38.0	200.0	52.5	315.0	64.0	350.0
675	27	41.0	390.0	57.5	449.0	67.0	450.0
750	30	44.0	450.0	63.0	539.0	69.5	540.0
825	33	46.0	520.0	64.0	619.0	71.0	620.0
900	36	48.0	580.0	65.5	699.0	73.0	700.0

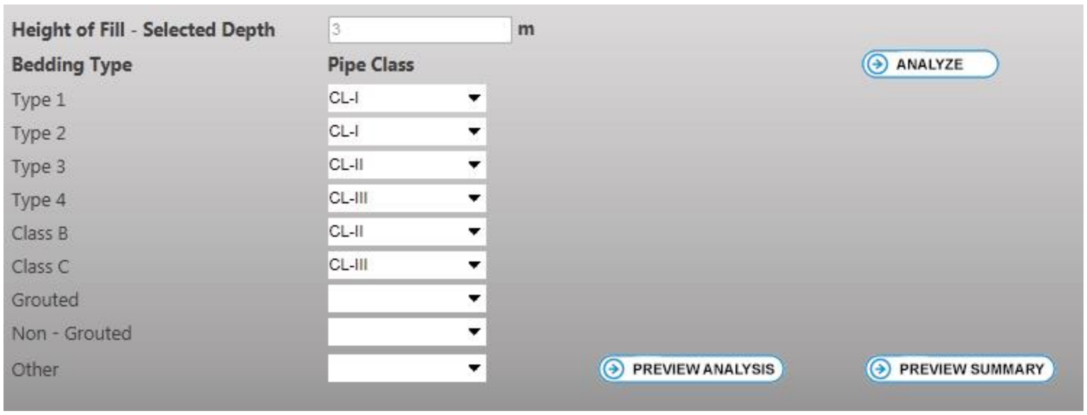
The safety factor is defined as the relationship between the ultimate strength D-load and the 0.3mm(.01in.) crack D-Load. This relationship is fixed in the CSA and ASTM standards on reinforced concrete pipe. For pipe designed for the 0.3mm(.01in.) crack for a D-load up to and including 100N/m/mm(2000lb/ft/ft) load the ultimate strength D-load is 1.5 times the D-load specified for the 0.3mm(.01in.) crack. For pipe designed for the 0.3mm(.01in) crack for a D-load 0f 140N/m/mm(3000lb/ft/ft) The ultimate load varies in linear proportion between 1.5 and 1.25 times the D-load specified for the 0.3mm(.01in.) crack.

The 3EB program displays default factors of safety as specified above. The designer is allowed to override the defaults with different safety factors.



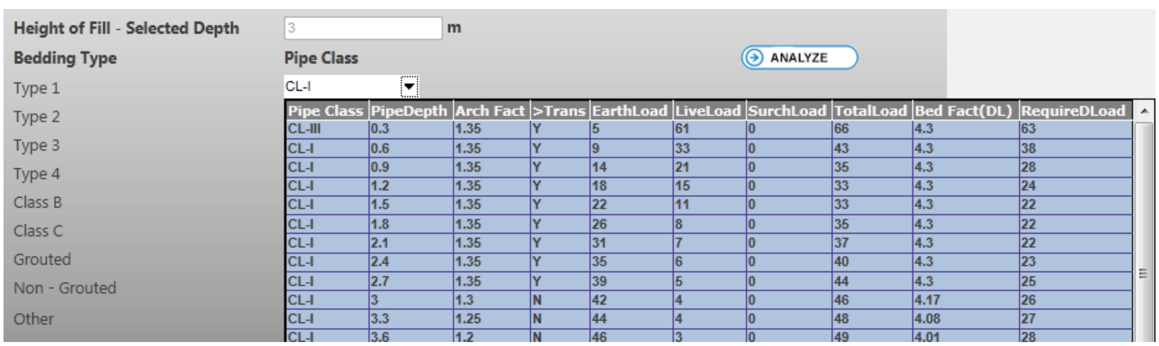
3EB - Results

The Results form allows the designer to set pipe classes for each bedding type. If you perform a CAPE analysis, these pipe classes will be used to find the pipe costs.



Pipe Class: The pipe class pull down lists are populated in the following manner:

A results table for selected bedding types.



Pipe Class	PipeDepth	Arch Fact	>Trans	EarthLoad	LiveLoad	SurchLoad	TotalLoad	Bed Fact(DL)	RequireDLoad
CL-III	0.3	1.35	Y	5	61	0	66	4.3	63
CL-I	0.6	1.35	Y	9	33	0	43	4.3	38
CL-I	0.9	1.35	Y	14	21	0	35	4.3	28
CL-I	1.2	1.35	Y	18	15	0	33	4.3	24
CL-I	1.5	1.35	Y	22	11	0	33	4.3	22
CL-I	1.8	1.35	Y	26	8	0	35	4.3	22
CL-I	2.1	1.35	Y	31	7	0	37	4.3	22
CL-I	2.4	1.35	Y	35	6	0	40	4.3	23
CL-I	2.7	1.35	Y	39	5	0	44	4.3	25
CL-I	3	1.3	N	42	4	0	46	4.17	26
CL-I	3.3	1.25	N	44	4	0	48	4.08	27
CL-I	3.6	1.2	N	46	3	0	49	4.01	28

If the pull-down lists are empty, perform a re-analysis by clicking the 

button.

More details on results table.

Available Buttons

Updates the pipe classes and the pull-down summary tables.

Shows a print preview of analyzed data.

Results

Pipe Depth:

The pipe depth is shown, rounded to the nearest tenth of a meter, as specified in the limits for minimum and maximum depth of fill and the increment entered in the Load/Installation form.

Earth Load:

The following headings appear under the Earth Load heading:

Arching Factor:

The arching factor is a means of quantifying the transfer of loads between the interior and exterior soil prisms. When the arching factor has a value greater than 1, load is transmitted from the exterior prisms to the interior, thus increasing the loading on the pipe. When the arching factor has a value less than 1, load is transmitted from the interior to the exterior prisms, thus decreasing the portion of the vertical load carried by the pipe.

> Trans:(This section is not applicable to Positive Projected Embankment and Jacked or Tunneled)

This column is extremely important as it indicates whether the trench, at a given depth, is at or beyond transition width. Once the trench width is at or beyond transition, the load on the pipe is then analyzed as in a Positive Projecting Embankment case.

A 'Y' in this column indicates that the trench width is at or beyond transition at the depth indicated and for the conditions specified. An 'N' indicates that the trench is NOT beyond transition width and that strict controls must be maintained in order to ensure that the trench width is maintained at the chosen width (below transition width) for the given depth.

FAILURE TO DO SO MAY RESULT IN THE PLACEMENT OF PIPE OF INADEQUATE STRENGTH SHOULD THE TRANSITION WIDTH BE EXCEEDED.

If the designer is unsure if the contractor can maintain A specified trench width less than the transition width, is suggested that the installation be modeled as a Positive Projected case. This will yield a worst case loading scenario.

In order to determine, more accurately, the depth at which the trench width is no longer beyond transition, the designer may wish to specify smaller increments for intermediate depths, specified in the load/installation form.

Earth Load:

This column is simply the earth load carried by the pipe at the specified depth.

Live Load:

This column lists the loading, due solely to live load, carried by the pipe at the specified depth. It can be seen that the effects of live load generally trail off rapidly after only a few meters depth.

Surch Load:

This column shows the load carried by the pipe, due solely to surcharge, at the specified depth.

Total Load:

This column is the summation of the earth load, live load, surcharge load and fluid load carried by the pipe at a given depth.

Bedding Factor:

The bedding factor influences the strength of pipe required to resist the applied loads. If the designer has selected a variable bedding from the second input screen, the bedding factor will be determined at every specified depth (note how the values change at different depths). This illustrates how support from material around the pipe helps to reduce the induced moment within it. The use of a variable bedding factor will yield realistic pipe strength requirements rather than the conservative strength requirements seen with the use of a .fixed. bedding factor. If a fixed bedding has been selected then the bedding factor is constant throughout the range of specified depths.

Required D-Load:

This is the most important column of the results section and determines the design strength of pipe required at a particular depth of installation. The total load in KN/m(or lb/ft) is converted to a 0.3mm(.01in.) crack load in terms of N/m/mm(or lb/ft/ft) by dividing by the diameter of the pipe.

The designer should ensure that the strength of pipe selected for placement is greater than the D-load shown at the depth of interest is selected for placement.

Summary Report

The Summary report includes: Project Description, Project Design Parameters and D-Loads for selected bedding types.

The D-Loads will be calculated for each pipe depth which includes all incremental depths from the minimum pipe depth to the maximum pipe depth.

Here is a sample Report

Three Edge Bearing Analysis - Summary

Project Description

Project Title:	Project2	**Consultant:**	
Project Location:		**Contractor:**	
Contract Number:		**Analyzed By:**	
Country:	Canada	**Date:**	3/27/2013
Units:	SI Units	**Comply To:**	ASTM (AASHTO)
Alternative:	Alternative1		

D-LOAD REQUIREMENTS FOR A 450 (mm) DIAMETER CIRCULAR PIPE

PIPE DATA

Nominal Diameter (mm)	450
Inner Diameter (mm)	457
Wall 'A' Thickness (mm)	50

INSTALLATION CONDITIONS

Minimum Depth of Fill (m)	0.30
Maxmum Depth of Fill (m)	6.00
Soil Density (kg/m^3)	1,922.0
Installation Type	Trench
Trench Width (m)	1.15
Soil Lateral Pressure/Friction Term (kμ)	0.1924
Parameters to compute Transition Width	
Positive Projection Ratio	0.50
Soil Lateral Pressure Ratio	0.33
Soil Lateral Pressure/Friction Term (kμ)	0.1
Soil Lateral Fraction 'm'	0.50
Settlement Ratio	0.70

ADDITIONAL LOADS

Live Load	AASHTO HS-SERIES (HS-20)
	Single Axle Load = 142 (kN), Double Axle - Load per Axle = 111 (kN), Space = 1.2 (m)
	Live Load Distribution Factor = 1.15
	Default I.F. Used.
No Surcharge Load	

FACTOR OF SAFETY

Factor of Safety on 0.3 MM Crack D-Load (Earth, Live)	1.00 1.00
Factor of Safety on Ultimate Earth and Live Load (ASTM C 76M)	
DL.03 Less Than or Equal To 100 N/m/mm	1.50
DL.03 Greater Than or Equal To 140 N/m/mm	1.25
DL.03 Between 100 and 140 N/m/mm	Interpolated

D-LOAD REQUIREMENTS FOR A 450 (mm) DIAMETER CIRCULAR PIPE
Comparison of required D-Load Values for Selected Bedding Types

Pipe Depth (m)	Type 1	Type 2	Type 3	Type 4	Type B	Type C
0.30	63 (CL-III)	64 (CL-III)	65 (CL-III)	85 (CL-IV)	60 (CL-III)	73 (CL-IV)
0.60	38 (CL-I)	40 (CL-I)	42 (CL-II)	56 (CL-III)	39 (CL-I)	47 (CL-II)
0.90	28 (CL-I)	31 (CL-I)	34 (CL-I)	46 (CL-II)	32 (CL-I)	38 (CL-I)
1.20	24 (CL-I)	28 (CL-I)	31 (CL-I)	44 (CL-II)	30 (CL-I)	36 (CL-I)
1.50	22 (CL-I)	27 (CL-I)	31 (CL-I)	44 (CL-II)	31 (CL-I)	37 (CL-I)
1.80	22 (CL-I)	28 (CL-I)	33 (CL-I)	47 (CL-II)	32 (CL-I)	39 (CL-I)
2.10	22 (CL-I)	29 (CL-I)	35 (CL-I)	51 (CL-III)	35 (CL-I)	42 (CL-II)
2.40	23 (CL-I)	31 (CL-I)	38 (CL-I)	54 (CL-III)	38 (CL-I)	46 (CL-II)
2.70	25 (CL-I)	33 (CL-I)	41 (CL-II)	57 (CL-III)	41 (CL-II)	50 (CL-II)
3.00	26 (CL-I)	35 (CL-I)	43 (CL-II)	60 (CL-III)	45 (CL-II)	54 (CL-III)
3.30	**27 (CL-I)**	**37 (CL-I)**	**45 (CL-II)**	**63 (CL-III)**	**47 (CL-II)**	**57 (CL-III)**
3.60	28 (CL-I)	38 (CL-I)	47 (CL-II)	65 (CL-III)	50 (CL-II)	60 (CL-III)
3.90	30 (CL-I)	40 (CL-I)	49 (CL-II)	67 (CL-IV)	52 (CL-III)	63 (CL-III)
4.20	31 (CL-I)	41 (CL-II)	51 (CL-III)	70 (CL-IV)	54 (CL-III)	65 (CL-III)
4.50	32 (CL-I)	43 (CL-II)	52 (CL-III)	71 (CL-IV)	55 (CL-III)	68 (CL-IV)
4.80	33 (CL-I)	44 (CL-II)	54 (CL-III)	73 (CL-IV)	57 (CL-III)	70 (CL-IV)
5.10	34 (CL-I)	45 (CL-II)	55 (CL-III)	75 (CL-IV)	58 (CL-III)	71 (CL-IV)
5.40	35 (CL-I)	47 (CL-II)	57 (CL-III)	76 (CL-IV)	59 (CL-III)	73 (CL-IV)
5.70	36 (CL-I)	48 (CL-II)	58 (CL-III)	78 (CL-IV)	61 (CL-III)	75 (CL-IV)
6.00	36 (CL-I)	49 (CL-II)	59 (CL-III)	79 (CL-IV)	62 (CL-III)	76 (CL-IV)

Selected Depth: 3 m (closest pipe depth: 3.3 m)
Reinforced Pipe Classes for 0.30 mm crack per ASTM C76M (N/m/mm):
CL I <= 40; CL II <= 50; CL III <= 65; CL IV <= 100; CL V <= 140

Detailed Report

The Detailed Analysis report includes: Project Description, Project Design Parameters and a detailed results table for the selected bedding types.

The results tables include: Pipe Depth, Arching Factor, Earth Load, Surch Load, Total Load, Bedding Factor, D-Load, for each pipe depth which includes all incremental depths from the minimum pipe depth to the maximum pipe depth.

Here is a sample Report

Three Edge Bearing Analysis - Results

Project Description

Project Title:	Project2	**Consultant:**	
Project Location:		**Contractor:**	
Contract Number:		**Analyzed By:**	
Country:	Canada	**Date:**	3/27/2013
Units:	SI Units	**Comply To:**	ASTM (AASHTO)

Alternative: Alternative1

D-LOAD REQUIREMENTS FOR A 450 (mm) DIAMETER CIRCULAR PIPE

PIPE DATA

Nominal Diameter (mm)	450
Inner Diameter (mm)	457
Wall 'A' Thickness (mm)	50

INSTALLATION CONDITIONS

Minimum Depth of Fill (m)	0.30
Maxmum Depth of Fill (m)	6.00
Soil Density (kg/m^3)	1,922.0
Installation Type	Trench
Trench Width (m)	1.15
Soil Lateral Pressure/Friction Term (kμ)	0.1924
Parameters to compute Transition Width	
Positive Projection Ratio	0.50
Soil Lateral Pressure Ratio	0.33
Soil Lateral Pressure/Friction Term (kμ)	0.1
Soil Lateral Fraction 'm'	0.50
Settlement Ratio	0.70

ADDITIONAL LOADS

Live Load — AASHTO HS-SERIES (HS-20)

Single Axle Load = 142 (kN), Double Axle - Load per Axle = 111 (kN), Space = 1.2 (m)

Live Load Distribution Factor = 1.15

Default I.F. Used.

No Surcharge Load

FACTOR OF SAFETY

Factor of Safety on 0.3 MM Crack D-Load (Earth, Live)	1.00 1.00
Factor of Safety on Ultimate Earth and Live Load (ASTM C 76M)	
DL.03 Less Than or Equal To 100 N/m/mm	1.50
DL.03 Greater Than or Equal To 140 N/m/mm	1.25
DL.03 Between 100 and 140 N/m/mm	Interpolated

D-LOAD REQUIREMENTS FOR 450 mm DIAMETER CIRCULAR PIPE
Results of Analysis for Bedding Type 1

Pipe Depth	Arch Fact	>Trans	Earth Load (kN/m)	Live Load (kN/m)	Surch Load (kN/m)	Total Load (kN/m)	Bed Fact DL	Bed Fact LL	Required D-Load 0.3 mm (N/m/mm)
0.30	**1.35**	**Y**	**5**	**61**	**0**	**66**	**4.30**	**2.19**	**63 (CL-III)**
0.60	**1.35**	**Y**	**9**	**33**	**0**	**43**	**4.30**	**2.20**	**38 (CL-I)**
0.90	1.35	Y	14	21	0	35	4.30	2.20	28 (CL-I)
1.20	1.35	Y	18	15	0	33	4.30	2.20	24 (CL-I)
1.50	1.35	Y	22	11	0	33	4.30	2.20	22 (CL-I)
1.80	1.35	Y	26	8	0	35	4.30	2.20	22 (CL-I)
2.10	1.35	Y	31	7	0	37	4.30	2.20	22 (CL-I)
2.40	1.35	Y	35	6	0	40	4.30	2.20	23 (CL-I)
2.70	1.35	Y	39	5	0	44	4.30	2.20	25 (CL-I)
3.00	1.30	N	42	4	0	46	4.17	2.20	26 (CL-I)
3.30	**1.25**	**N**	**44**	**4**	**0**	**48**	**4.08**	**2.20**	**27 (CL-I)**
3.60	1.20	N	46	3	0	49	4.01	2.20	28 (CL-I)
3.90	1.15	N	48	3	0	51	3.92	2.20	30 (CL-I)
4.20	1.11	N	50	3	0	52	3.86	2.20	31 (CL-I)
4.50	1.07	N	51	2	0	53	3.80	2.20	32 (CL-I)
4.80	1.03	N	52	2	0	55	3.75	2.20	33 (CL-I)
5.10	0.99	N	54	2	0	56	3.70	2.20	34 (CL-I)
5.40	0.96	N	55	2	0	57	3.65	2.20	35 (CL-I)
5.70	0.92	N	56	2	0	57	3.61	2.20	36 (CL-I)
6.00	0.89	N	57	2	0	58	3.57	2.20	36 (CL-I)

Selected Depth: 3 m (closest pipe depth: 3.3 m)
Reinforced Pipe Classes for 0.30 mm crack per ASTM C76M (N/m/mm):
CL I <= 40; CL II <= 50; CL III <= 65; CL IV <= 100; CL V <= 140

CAPE Help Contents

CAPE Standard

- **Design**
- **Soil Related Costs**
- **Results**
- **Results Report**
- **Cost Graph**

Standard Design

The Standard Design form allows the designer to enter required parameters used in standard installation cost calculations for Rigid and Flexible pipes. There are six standard installations for Rigid Pipe and a single installation for flexible pipe.

Common Parameters for Rigid and Flexible Pipes:

Pipe Diameter (mm/in.): The designer is presented with a list of standard pipe sizes in a pull down menu.

Pipe Use: The designer has option to select either Sanitary or Storm.

Default - Storm

Trench Slope: The choices for the trench slope are Vertical, 1:1, 1.5:1, 2:1, 3:1.

Default - Vertical

Shoulder Height (m/ft.): Height of trench shoulder if trench is not vertical.

Rigid Pipe Specific Parameters

Reinforced/Non-Reinforced: The designer can select pipe type according to the following table

Diameter (mm)	(in.)	ASTM C 14M-94 NON-REINFORCED	CSA-A257.1-M92 NON-REINFORCED	ASTM C 76M-94 REINFORCED	CSA-A257.2-M92 REINFORCED	SUGGESTED DEFAULTS
100	4	X	X			NR
150	6	X	X			NR
200	8	X	X			NR
225	9	N/A	N/A			NR
250	10	X	X			NR
300	12	X	X	X	X	R
375	15	X	X	X	X	R
450	18	X	X	X	X	R
525	21	X	X	X	X	R
600	24	X	X	X	X	R
675	27	X	X	X	X	R
750	30	X	X	X	X	R
825	33	X	X	X	X	R
900	36	X	X	X	X	R
1050	42			X	X	R
1200	48			X	X	R
1350	54			X	X	R
1500	60			X	X	R
1650	66			X	X	R
1800	72			X	X	R
1950	78			X	X	R
2100	84			X	X	R
2250	90			X	X	R
2400	96			X	X	R
2550	102			X	X	R
2700	108			X	X	R
3000	120			X	X	R

NR-Non-Reinforced, R-Reinforced

Designers will be cautioned if they have entered information contrary to currently used standards.

Wall Type: The choices for the Wall Type are Wall A, Wall B, Wall C and Other. The Wall Type is used to calculate the outside diameter.

Default - Wall A

Click 

to calculate the trench dimensions, outside pipe diameter and pipe costs. In order to get the pipe costs, the designer must first specify the pipe class in the Pipe Details form.

Rigid Trench Dimension: Based on the following two tables.

For Installation Type B and C: bottom width, bedding depth and cover thickness are based on OPSD standards and default values are calculated as shown

TRENCH DIMENSION	CALCULATION FOR DEFAULT VALUE (OPSD 802.030)
Bottom Width	= pipe outside diameter + 2 x (300mm or 12in. clearance) for pipe diameters less than or equal to 900mm or 36in.
	= pipe outside diameter + 2 x (500mm or 20in. clearance) for pipe diameters greater than 900mm or 36in.
Bedding Depth	= 0.15 x pipe diameter, not less than 150mm or 6 in.
	= 0.25 x pipe diameter, not greater than 300mm or 12 in.
Cover Thickness	= 150mm or 6in. for Class C bedding
	= 300mm or 12in. for Class B bedding

For Installation Type 1,2,3 and 4: bottom width, bedding depth and cover thickness are based on design data 40 and default values are calculated as shown

TRENCH DIMENSION	CALCULATION FOR DEFAULT VALUE (Design Data 40)
Bottom Width	= pipe outside diameter + 2 x (pipe outside diameter / 6 clearance)
Bedding Depth	= 75mm or 3in. for Type 1,2 and 3
	= 0 for Type 4
Cover Thickness	= pipe outside diameter / 6

Designers have the option at this point to accept the defaults or enter their own values.

Outside Pipe Diameter (mm/in.): Based on Pipe Configuration Table

Pipe cost ($): Based on Pipe Configuration Table

Flexible Pipe Specific Parameters

Installation Type: Flexible Installation Type choices are: Granular to Springline, Granular to top of cover, Granular to 6" above pipe, Granular to 12" above pipe, Bedding Only and Other.

Default - Granular to top of cover. OPSD 802.010 identifies 300mm as the cover requirement.

Click 

to calculate the trench dimensions, outside diameter and pipe cost.

Flexible Trench Dimension

Flexible trench dimensions are based on the following table:

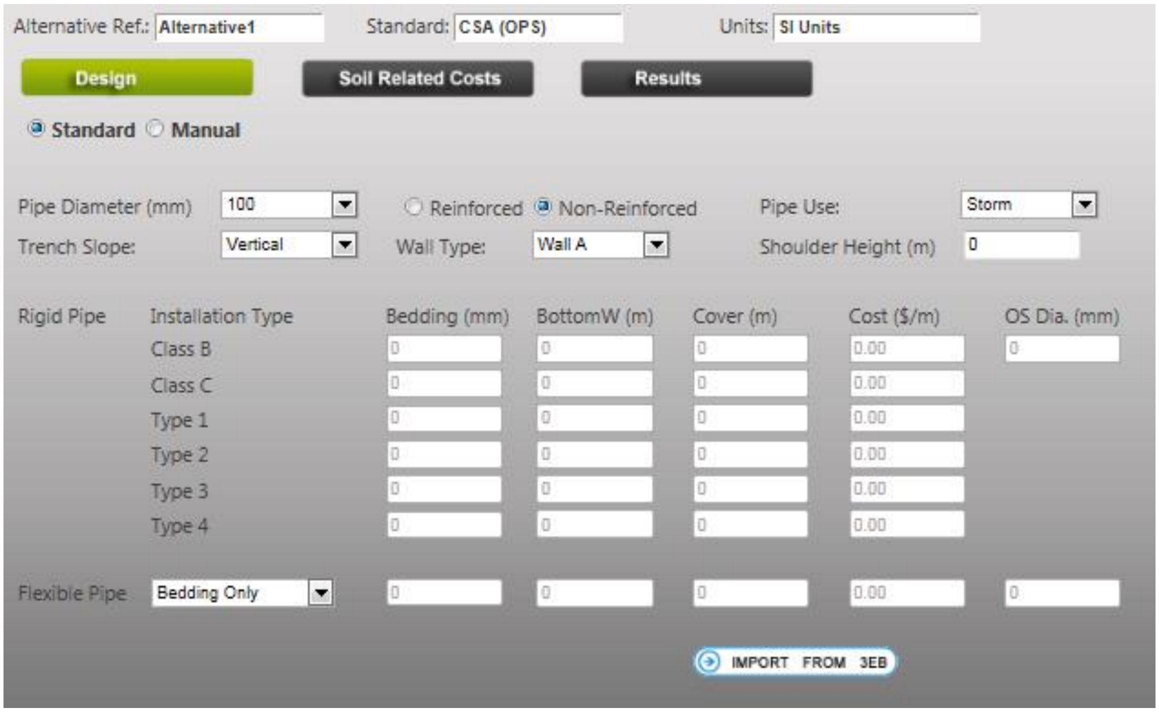
TRENCH DIMENSION	CALCULATION FOR DEFAULT VALUE (OPSD 802.010)
Bottom Width (W)	= Pipe outside diameter + 2 x (300mm or 12in. Clearance) for pipe diameters less than or equal to 900mm or 36in.
	= Pipe outside diameter + 2 x (500mm or 20in. Clearance) for pipe diameters greater than 900mm or 36in.
Bedding Depth	150mm or 6in.
Cover Thickness (c)	300mm or 12in.

Designers have the option at this point to accept the defaults or enter their own values.

Outside Pipe Diameter (mm/in.): Based on Pipe Configuration Table

Standard Design - Soil Related Costs

Soil Related Cost form allows the designer to set the following soil cost related parameters.



Soil Units: The designer can choose one of the following soil cost units: $/tonne, $/cu.m, $/ton, $/cu.yd

Default - $/tonne ($/ton)

Wastage Factor (%): Applies only to imported material.

Swelling Factor (%): Applies only to native material cost in $/cu.m of $/cu.yd

Haulage cost (Soil Units): The cost to remove the native material.

Tipping Fee (Soil Units): The cost to dispose of the native material.

Class B, C & Type 1 Cost (Soil Units): The imported material cost used in Class B, Class C, Type 1 and Flexible Pipe Installations.

Type 2 Cost (Soil Units): The imported material cost used in Type 2 Installation.

Type 3 Cost (Soil Units): The imported material cost used in Type 3 Installation.

Type 4 Cost (Soil Units): The imported material cost used in Type 4 Installation.

Soil Type: The designer is presented with a list of soil types and their maximum and minimum soil densities (see soil tables for more information). Selecting a soil type automatically assigns the maximum soil density to Insitu Soil Density.

Default Native Soil Type: Sand Silt

Default Granular Soil Type: Silty Sand

Insitu Soil Density: Soil densities are only used when soil cost in $/cu.m or $/cu.yd

Default Native Soil Density: 1890 kg/cu.m or 118 lb/cu.ft

Default Granular Soil Density: 1922 kg/cu.m or 120 lb/cu.ft

Standard Design - Results

The Standard Design Results form includes Rigid Pipe and Flexible Pipe Installation Cost Summaries.

Available Buttons

Updates the summary with current changes

Shows a print preview of Standard Design Results Report

Shows a print preview of Soil Table

Shows a print preview of Standard Design Cost Graph Report

Standard Design - Cost Graph

The Standard Design Cost Graph report includes: Project Description, Project Design Parameters, and installation cost bar graph for rigid and flexible pipes.

Here is a sample Report

Cost Analysis of Pipe Envelope - Results
(Standard Design)

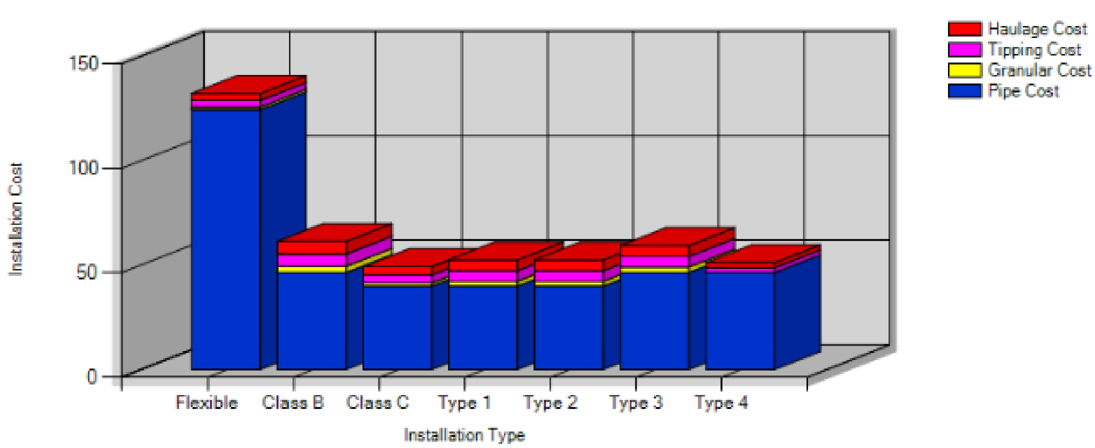
Project Description

Project Title:	Project1	**Consultant:**	
Project Location:		**Contractor:**	
Contract Number:		**Analyzed By:**	
Country:	Canada	**Date:**	3/27/2013
Units:	SI Units	**Comply To:**	CSA (OPS)
Alternative:	Alternative 1		

Project Design Parameter

Native Soil-Related Costs ($/tonne)		Granular Costs ($/tonne)	
Haulage Cost:	$5.00	**Installation Type 1:**	$5.00
Tipping Fee:	$5.00	**Installation Type 2:**	$5.00
Pipe Dimensions		**Installation Type 3:**	$5.00
Nominal Pipe Diamter (mm):	450	**Installation Type 4:**	$5.00
Inner Pipe Diameter (mm):	457	**Installation Type B:**	$5.00
Rigid Pipe Outside Diamter (mm):	559	**Installation Type C:**	$5.00
Flexible Pipe Outside Diameter (mm):	477	**Installation Type Flexible:**	$5.00
Wastage Factor:	3.00%		

Installation Cost Graph for Rigid and Flexible Pipes



Standard Design - Results Report

The Standard Design Results report includes: Project Description, Project Design Parameters, Pipe Cost Summary and detailed Installation trench diagrams along with cost components.

Here is a sample Report

Cost Analysis of Pipe Envelope - Results
(Standard Design)

Project Description

Project Title:	Project1	**Consultant:**	
Project Location:		**Contractor:**	
Contract Number:		**Analyzed By:**	
Country:	Canada	**Date:**	3/27/2013
Units:	SI Units	**Comply To:**	CSA (OPS)
Alternative:	Alternative 1		

Project Design Parameter

Native Soil-Related Costs ($/tonne)		Granular Costs ($/tonne)	
Haulage Cost:	$5.00	**Installation Type 1:**	$5.00
Tipping Fee:	$5.00	**Installation Type 2:**	$5.00
Pipe Dimensions		**Installation Type 3:**	$5.00
Nominal Pipe Diamter (mm):	450	**Installation Type 4:**	$5.00
Inner Pipe Diameter (mm):	457	**Installation Type B:**	$5.00
Rigid Pipe Outside Diamter (mm):	559	**Installation Type C:**	$5.00
Flexible Pipe Outside Diameter (mm):	477	**Installation Type Flexible:**	$5.00
Wastage Factor:	3.00%		

Pipe Cost Summary

Pipe Type	Installation Type	Granular Height (mm)	Envelope Width (mm)	Envelope Height (mm)	Granular Volume (m^3)	Granular Cost ($)	Haulage Cost ($)	Tipping Cost ($)	Pipe Cost ($)	Installed Pipe Cost ($/m)
Rigid	Class B	429.5	1,159.0	1,009.0	0.375	$3.03	$6.04	$5.86	$46.50	**$61.44**
Rigid	Class C	158.9	1,159.0	784.0	0.161	$1.50	$3.96	$3.84	$40.00	**$49.29**
Rigid	Type 1	354.5	1,159.0	820.3	0.288	$2.33	$5.19	$5.04	$40.00	**$52.57**
Rigid	Type 2	354.5	1,159.0	820.3	0.288	$2.33	$5.19	$5.04	$40.00	**$52.57**
Rigid	Type 3	354.5	1,159.0	820.3	0.288	$2.68	$5.19	$5.04	$46.50	**$59.41**
Rigid	Type 4	0.0	1,159.0	745.3	0.000	$0.00	$2.39	$2.32	$46.50	**$51.21**
Flexible	Bedding Only	150.0	1,077.0	927.0	0.162	$1.31	$3.31	$3.22	$124.62	**$132.45**

CAPE Manual

- **Design**
- **Soil Related Costs**
- **Results**
- **Results Report**
- **Cost Graph**

Manual Design

The Manual Design form allows the designer to enter trench and pipe dimensions for Rigid and Flexible pipes.

Common Parameters for Rigid and Flexible Pipes:

Pipe Diameter (mm/in.): The designer is presented with a list of standard pipe sizes in a pull down menu.

Pipe Use: The designer has the option to select either Sanitary or Storm.

Default - Storm

Rigid Pipe Specific Parameters

Reinforced/Non-Reinforced: The designer can select pipe type according to the following table:

Diameter (mm)	(in.)	ASTM C 14M-94 NON-REINFORCED	CSA-A257.1-M92 NON-REINFORCED	ASTM C 76M-94 REINFORCED	CSA-A257.2-M92 REINFORCED	SUGGESTED DEFAULTS
100	4	X	X			NR
150	6	X	X			NR
200	8	X	X			NR
225	9	N/A	N/A			NR
250	10	X	X			NR
300	12	X	X	X	X	R
375	15	X	X	X	X	R
450	18	X	X	X	X	R
525	21	X	X	X	X	R
600	24	X	X	X	X	R
675	27	X	X	X	X	R
750	30	X	X	X	X	R
825	33	X	X	X	X	R
900	36	X	X	X	X	R
1050	42			X	X	R
1200	48			X	X	R
1350	54			X	X	R
1500	60			X	X	R
1650	66			X	X	R
1800	72			X	X	R
1950	78			X	X	R
2100	84			X	X	R
2250	90			X	X	R
2400	96			X	X	R
2550	102			X	X	R
2700	108			X	X	R
3000	120			X	X	R

NR-Non-Reinforce, R-Reinforced

Designers will be cautioned if they have entered information contrary to currently used standards.

Wall Type: The choices for the Wall Type are Wall A, Wall B, Wall C and Other. The Wall Type is used to calculate the outside diameter.

Default - Wall A

Pipe Class: The Pipe class is based on the following table:

NON-REINFORCED	REINFORCED CSA	ASTM
Class 1	40-D	CL-I
Class 2	50-D	CL-II
Class 3	65-D	CL-III
	100-D	CL-IV
	140-D	CL-V

For higher DLoads, actual DLoad value will be used as the pipe class.

Rigid Trench Dimension

Trench Slope: Refers to the sides of the trench. The ratio is Vertical:Horizontal.

Default - 0:0 (Vertical)

Cover (m/ft.): Height of native backfill above the pipe.

Default - 0

Depth of Granular (mm/in.): Height of granular from the bottom of the pipe.

Default - 0

Bedding Depth (mm/in.): Height of bedding below the pipe.

Default - 0

Trench Width (m/ft.): Trench Width must be greater than outside diameter.

Default - Pipe Outside Diameter + 2 x (Pipe Outside Diameter / 6)

Shoulder Height (m/ft.): Height of trench shoulder if trench is not vertical.

Default - 0

Outside Pipe Diameter (mm/in.): Based on Pipe Configuration Table

Pipe cost ($): Based on Pipe Configuration Table

Flexible Pipe Specific Parameters

Flexible Trench Dimension

Trench Slope: Refers to the sides of the trench. The ratio is Vertical:Horizontal.

Default - 0:0 (Vertical)

Cover (m/ft.): Height of native backfill above the pipe.

Default - 0

Depth of Granular (mm/in.): Height of granular from the bottom of the pipe.

Default - 0

Bedding Depth (mm/in.): Height of bedding below the pipe.

Default - 0

Trench Width (m/ft.): Trench Width must be greater than outside diameter.

Default - Pipe Inside Diameter + 2 x (300mm or 12in.)

Shoulder Height (m/ft.): Height of trench shoulder if trench is not vertical.

Default - 0

Outside Pipe Diameter (mm/in.): Based on Pipe Configuration Table

Pipe cost ($): Based on Pipe Configuration Table

Manual Design - Soil Related Costs

The Soil Related Cost form allows the designer to set the following soil cost related parameters.

Soil Units: The designer can choose one of the following: $/tonne, $/cu.m, $/ton, or $/cu.yd

Default - $/tonne

Wastage Factor (%): Applies only to imported material.

Swelling Factor (%): Applies only to native material cost in $/cu.m or $/cu.yd

Haulage cost (Soil Units): The cost to remove the native material.

Tipping Fee (Soil Units): The cost to dispose of the native material.

Flexible & Rigid Cost (Soil Units): The imported material cost used in Rigid Pipe and Flexible Pipe Installations.

Soil Type: The designer is presented with a list of soil types and their maximum and minimum soil densities (see soil tables for more information). Selecting a soil type automatically assigns the maximum soil density to Insitu Soil Density.

Default Native Soil Type: Sand Silt

Default Granular Soil Type: Silty Sand

Insitu Soil Density: Soil densities are only used when soil cost in $/cu.m or $/cu.yd

Default Native Soil Density: 1890 kg/cu.m or 118 lb/cu.ft

Default Granular Soil Density: 1922 kg/cu.m or 120 lb/cu.ft

Manual Design - Results

Manual Design Results form includes Rigid Pipe and Flexible Pipe Installation Cost Summary.

Available Buttons

ANALYZE	Updates the summary with current changes
RESULTS	Shows a print preview of Manual Design Results Report
SOIL TABLE	Shows a print preview of Soil Table
COST GRAPH	Shows a print preview of Manual Design Cost Graph Report

Manual Design - Cost Graph

The Manual Design Cost Graph report includes Project Description, Project Design Parameters, and installation cost bar graph for rigid and flexible pipes.

Here is a sample Report

Cost Analysis of Pipe Envelope - Results
(Manual Design)

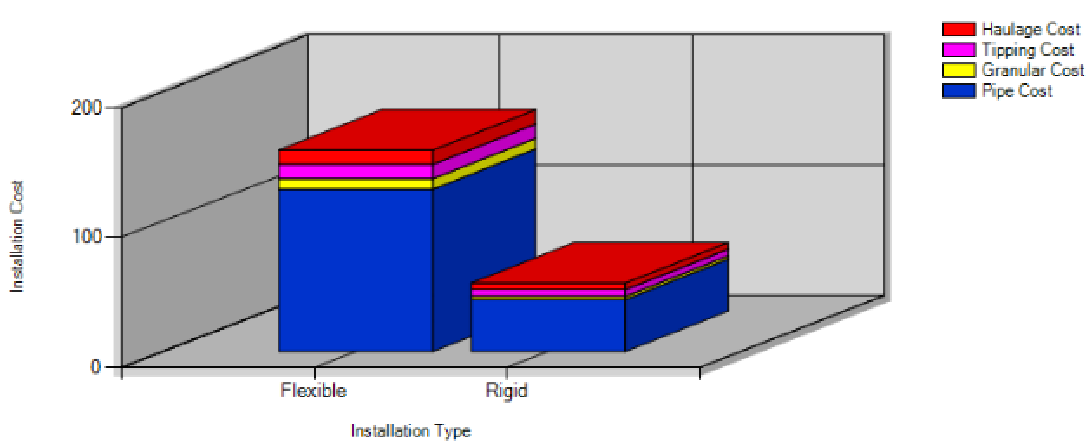
Project Description

Project Title:	Project1	**Consultant:**	
Project Location:		**Contractor:**	
Contract Number:		**Analyzed By:**	
Country:	Canada	**Date:**	3/27/2013
Units:	SI Units	**Comply To:**	CSA (OPS)
Alternative:	Alternative1		

Project Design Parameter

Soil-Related Costs ($/tonne)				
Haulage Cost:		$5.00	**Nominal Pipe Diamter (mm):**	450
Tipping Fee:		$5.00	**Inner Pipe Diameter (mm):**	457
	Rigid	**Flexible**	**Rigid Pipe Outside Diamter (mm):**	559
Granular Cost:	$5.00	$5.00	**Flexible Pipe Outside Diameter (mm):**	477

Installation Cost Graph for Rigid and Flexible Pipes



Manual Design - Results Report

The Manual Design Results report includes Project Description, Project Design Parameters, Pipe Cost Summary and detailed Installation trench diagrams along with cost components.

Here is a sample Report

Cost Analysis of Pipe Envelope - Results
(Manual Design)

Project Description

Project Title:	Project1	**Consultant:**	
Project Location:		**Contractor:**	
Contract Number:		**Analyzed By:**	
Country:	Canada	**Date:**	3/27/2013
Units:	SI Units	**Comply To:**	CSA (OPS)
Alternative:	Alternative1		

Project Design Parameter

Soil-Related Costs ($/tonne)				
Haulage Cost:		$5.00	**Nominal Pipe Diamter (mm):**	450
Tipping Fee:		$5.00	**Inner Pipe Diameter (mm):**	457
	Rigid	**Flexible**	**Rigid Pipe Outside Diamter (mm):**	559
Granular Cost:	$5.00	$5.00	**Flexible Pipe Outside Diameter (mm):**	477

Pipe Cost Summary

Pipe Type	Granular Height (mm)	Envelope Width (mm)	Envelope Height (mm)	Granular Volume (m^3)	Granular Cost ($)	Haulage Cost ($)	Tipping Cost ($)	Pipe Cost ($)	Installed Pipe Cost ($/m)
Rigid	300.0	1,159.0	1,709.0	0.295	$2.46	$5.10	$5.10	$40.00	**$52.66**
Flexible	1,077.0	1,077.0	927.0	0.981	$8.18	$10.96	$10.96	$124.62	**$154.72**

Other Bedding

3EB provides the ability for the designer to enter alternate bedding information within the "Other" field under bedding types. If the "Other" option is chosen, the "Standard" analysis within CAPE cannot be utilized to undertake the cost evaluation. However, the "Manual" analysis within CAPE can be utilized to undertake the evaluation by inputting the appropriate trench configuration and bedding information.

Soil Tables

The soil table presents the following information.

Table 1: EQUIVALENT USCS AND AASHTO SOIL CLASSSIFICATIONS FOR CAPE SOIL DESIGNATIONS

CAPE SOIL	REPRESENTATIVE SOIL TYPE		PERCENT COMPACTION	
	UCSC	AASHTO	STANDARD PROCTOR	MODIFIED PROCTOR
Gravelly Sand (SW)	SW, SP GW, GP	A1, A3	100 95 90 85 80 61	95 90 85 80 75 59
Sandy Silt (ML)	GM, SM, ML Also GC, SC with less than 20% passing #200 sieve	A2, A4	100 95 90 85 80	95 90 85 80 75
Silty Clay (CL)	GL, MH GC, SC	A5, A6	100 95 90 85 80 45	90 85 80 75 70 40
	CH	A7	100 95 90 45	90 85 80 40

USCS Soil Type Legend:

First Character	Second Character
C- Clay	H - High Plasticity fines
G - Gravel	L - Low Plasticity fines
M - Silt	M - Non-plastic fines
S - Sand	P - Poorly Graded
	W - Well Graded

Information presented in the above table is not used directly in the CAPE Analysis but is provided as a quick reference so that designers can determine the suitability of the existing native material as embedment material.

Typical Standard Proctor Dry Densities and Optimum Moisture Contents

TYPE	MATERIAL	MAXIMUM STANDARD PROCTOR DRY DENSITIES (pcf)	(kg/m³)	OPTIMUM MOISTURE CONTENT(%)
Asphalt	HL6, HL8	148 - 154	2370 - 2467	-
	HL3	149 - 152	2367 - 2439	-
Base Course	Granular "A" 20mm (3/4 in)	133 - 145	2130 - 2323	5 - 8
	Crusher Run	135 - 138	2162 - 2211	5 - 8
Sub-Base	Granular "B" 50mm (2 in)	117 - 138	1874 - 2211	6 - 10
	Crusher Run	132 - 138	2114 - 2211	5 - 7
	Screenings	132 - 136	2114 - 2179	5 - 9
Subgrade Soils	Gravelly Sand	126 - 133	2018 - 2130	7 - 9
	Granular "C"	115 - 123	1842 - 1970	9 - 12
	Fine Sand	110 - 116	1762 - 1858	9 - 12
	Silty Sand	113 - 120	1810 - 1922	9 - 12
	Sandy Silt	110 - 118	1762 - 1890	9 - 12
	Silty Sand Silt	124 - 130	1986 - 2082	7 - 10
	Sandy Silt Till	120 - 128	1922 - 2050	8 - 12
	Clayey Silt Till	115 - 125	1842 - 2002	8 - 13
	Silty Clay Till	118 - 125	1890 - 2002	10 - 15
	Silty Clay	116 - 124	1858 - 1936	12 - 18
	Clayey Silt	115 - 122	1842 - 1954	10 - 15
	Silty Clay/ Weathered Shale	116 - 124	1858 - 1986	10 - 15

Information presented in this table is used when selecting soil types and densities.

LCA Help Contents

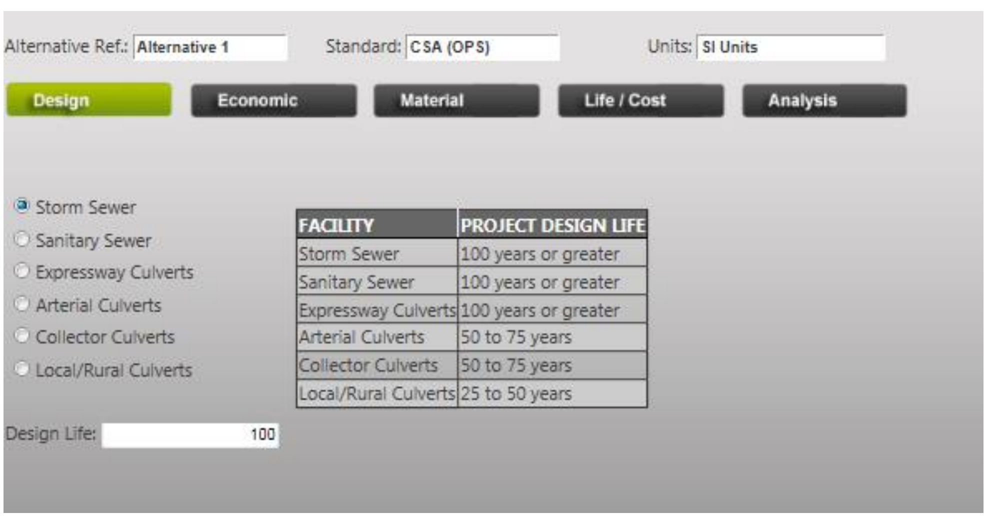
- **Design**
- **Economic**
- **Material**
- **Analysis**

Project Design

Project design life is normally set by the owner or authority responsible for the project, and varies according to system classification, end use and location. In cases where a roadway or facility cannot be disrupted to replace the pipe, a project design life of 100 years or greater is warranted. Typical of such cases are heavily traveled urban roadways, interstate highways, storm water systems, and sanitary sewers. In addition, long project design lives should be considered for special installations, such as under high fills, in remote areas with poor access, or environmentally sensitive areas. The selection of an appropriate project design life should reflect the transportation and commercial importance of the roadway, its effect on traffic, the difficulty of replacement and the construction hazards to the traveling public.

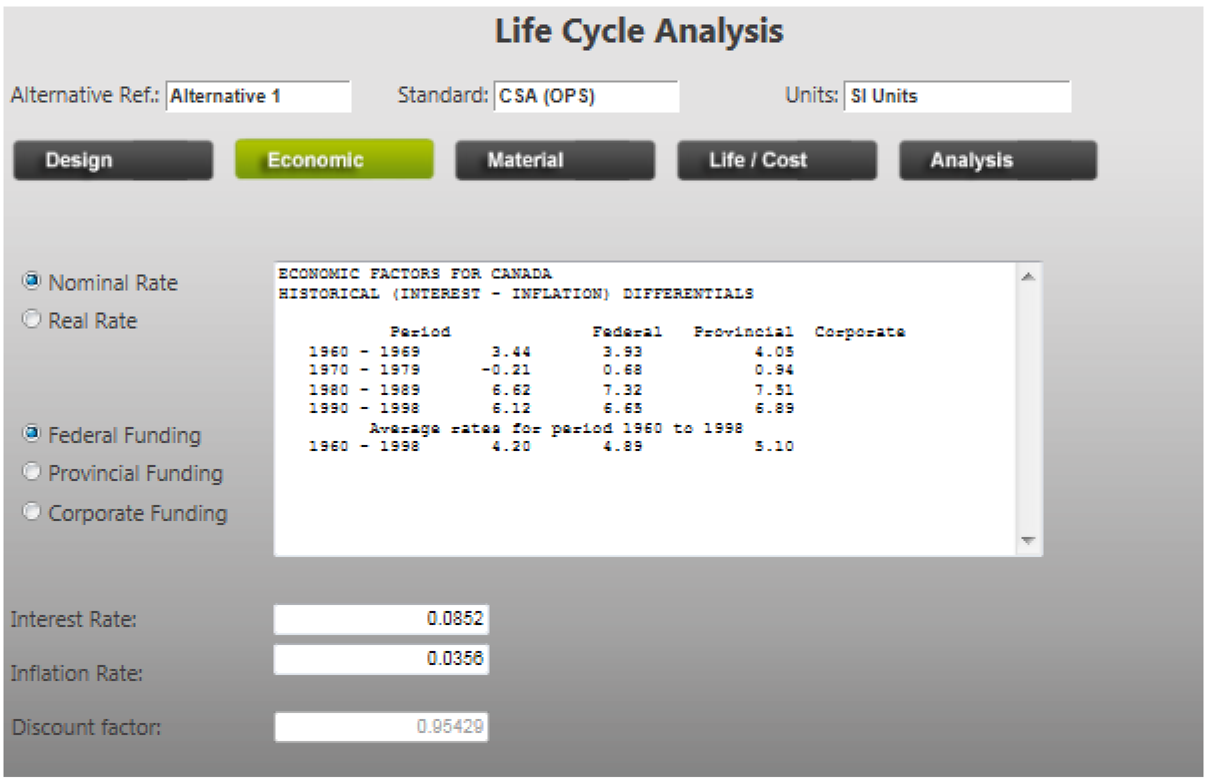
As a guideline, ranges for the project design lives of the various types of facilities are provided. Minimum design lives are provided as recommended values in the program's short help screens.

FACILITY	**PROJECT DESIGN LIFE**
Storm Sewer System	100 years or greater
Sanitary Sewer System	100 years or greater
Arterial Culverts	50 to 75 years
Collector Culverts	50 to 75 years
Local/Rural Culverts	25 to 50 years



Economic

- **Definitions**
- **Interest & Inflation Relationship**
- **Interest & Inflation Differential**
- **Recommendations**



Definitions

Interest
Interest is usually expressed as a rate over a specific time. For example, $1,000 borrowed for one year that requires repayment of $1,150 has an interest rate of 15% per year ($150/$1,000). Interest rates have two major components: real interest and inflation.

Interest Rate
Payment for the use of money. It is the excess cash received or repaid over the amount lent or borrowed.

Real Interest
Represents the purchasing power of the money lent. The real interest rate can only be calculated by subtracting inflation from the historical interest rate.

Inflation
When inflation is increasing, the value of goods increases, which means more money is required to buy them. Inflation (deflation) is measured by determining how much the value of a set group of commodities has increased (or decreased) from year to year.

Time Value of Money
Represents the purchasing power of the money lent. The real interest rate can only be calculated by subtracting inflation from the historical interest rate.

Discount Rate
A cash flow in the future is worth less than a similar cash flow today because:

- Individuals prefer present consumption to future consumption.
- When there is monetary inflation, the value of currency decreases over time. The greater the inflation, the greater the difference in value between a dollar today than a dollar in the future.
- Any uncertainty (risk) associated with the cash flow in the future reduces the value of the cash flow.

  The process by which future cash flows are adjusted to reflect these factors is called discounting, and the magnitude of these factors is reflected in the discount rate.

  The discount rate is a rate at which present and future cash flows are traded off. It incorporates:
- The preference for current consumption (greater preference? higher discount rate).
- Expected inflation (higher inflation? higher discount rate).
- The uncertainty in the future cash flows (higher risk? higher discount rate).

  A higher discount rate will lead to a lower present value for future cash flows.

Nominal Discount Rate
The discount rate which takes into account the actual earning potential of money (including the effects of inflation) over time.

Real Discount Rate
The discount rate which takes into account the actual earning potential of money (excluding the effects of inflation) over time.

Interest & Inflation Relationship

Historical relationships between interest rates and inflation rates provide meaningful information. The relationship between the interest rate and the inflation rate is well substantiated in history and economic literature.

The two rates interact and influence each other so that in the long run they tend to move together, resulting in a relatively constant differential between the two. When prices increase (or investor's expectations of future price levels rise), market forces work to change or adapt investment behavior so the differential remains positive and relatively constant in the long-run. If interest rates rise faster than inflation, the real rate of return will rise for lenders inducing a greater supply of funds to financial markets. At the same time, borrowers will face increased real costs for borrowing funds and therefore will tend to reduce their borrowing. The increasing supply of funds and the reduced demand for funds will, over time, force down the price of money, or the interest rate.

If interest rates fall relative to inflation the reverse occurs. The return to lenders falls and the real cost of borrowed money drops. The supply of funds will shrink and the demand for funds will increase introducing upward pressure on interest rates and reestablishing a positive differential of interest rates over inflation.

In Canada, during the 55-year period from 1944 through 1998, wide and unpredictable swings occurred in both interest rates and inflation. Interest rates (represented by the chartered bank prime rate) varied from 4.5 percent for the decade 1945 to 1955 to 19.29 percent in 1981. Inflation rates (represented by the Consumer Price Index or CPI) varied from lows of -0.89 and -0.15 percent in 1959 and 1955 to highs of 14.43 and 12.35 percent in 1948 and 1985.

In the United States, during the 55-year period from 1944 through 1998, similar changes occurred in both interest rates and inflation. Interest rates (represented by the prime rate) varied from 2.10 percent for the decade 1944 to 1953 to 11.38 percent in the decade ending in 1983. Inflation rates (represented by the Consumer Price Index or CPI) varied from 1.37 percent per year in the 1954 and 1963 period to 8.45 percent from 1974 and 1998.

Despite these drastic changes, the overall average differential between the two rates remained relatively stable. Throughout the entire period it averaged 2.92 percent in Canada and 1.38 percent in the United States. Decade-long averages were noticeably stable during the entire postwar period. During this period, the differential averaged between 2 percent and 5 percent in Canada and between 2 percent and 3 percent in the United States.

In the short-run, interest rate/inflation rate differentials vary more widely. This volatility has been particularly noticeable since the 1970s. Since then, in Canada, the differentials have ranged from -1.36 percent in 1975 to 9.24 percent in 1990 and in the United States the differentials have ranged from -0.17 percent in 1974 to 8.73 percent in 1982. Bankers were slow to raise interest rates in response to higher inflation during much of the 1970s, probably because they did not expect such high inflation rates to last. The result was very low real rates of interest by long-run historical standards. In contrast, in the early 1990s, inflation decreased noticeably but interest rates remained very high, probably due to the fear of banks that higher rates of inflation would return. The result was relatively high real interest rates.

Such extreme short-run variations in the interest rate/inflation rate differential as have been seen during the previous decade tend to even out once market forces run their course. During the mid to late 1970s, when the differential was small or negative, lenders found it unprofitable to lend at existing rates of interest. Interest rates eventually rose in response to unsatisfied and rising borrowing demands. Situations where real rates of interest exceed 7 percent cannot last long; it is too profitable to lend and too costly to borrow. Both sides of the market, lenders and borrowers, work to bring the rates back to their long-run levels.

Interest & Inflation Differential

The short-run volatility of inflation rates or interest rates should not concern engineers or cost analysts when considering lifetime costs of capital projects. The long-run relationship between interest and inflation rates provides the best source of information for an estimate of the appropriate differential for least cost analysis. The long-term stability of the differential is a product of market factors asserted with varying time lags after external events cause either interest or inflation rates to move away from equilibrium. Over the life of a 50-year or a 100-year project, year-to-year variations in the differential are insignificant to the project's overall economic value.

Another factor that should be considered is which interest rate and inflation rate is most applicable to the project being appraised. The most appropriate interest rate is the one which reflects the cost of funds, or rate of return, for the borrowing entity. The following factors must be considered:

- Is the project's financing being undertaken by a private or a public entity?
- Is the project to be financed by borrowed money or by capital assets?
- What is the rate of return for the industry?

The cost of borrowing for an entity reflects its credit rating in the marketplace. Interest costs vary substantially among different types of entities and are considerably lower in the public sector than for the private sector.

In Canada, if the project under analysis is being sponsored by a provincial or municipal government, the appropriate interest rate would be the long-term provincial bond rate. The long-term corporate bond rate may be a good indicator if a private firm is undertaking the project without public funds. If a federal government agency is involved the appropriate interest rate would be the rate for long-term Government of Canada bonds.

In the U.S., if the project under analysis is being sponsored by a state or local government, the appropriate interest rate would be the municipal bond rate. The prime rate may be a good indicator if a private firm is undertaking the project without public funds. If a federal government agency is involved the appropriate interest rate would be the rate for long-term Treasury obligations.

For inflation rate indicators, the selection of the correct rate is less important than interest rates. The Consumer Price Index (CPI) is a good indicator of overall price trends, although it is not the best indication of inflation rates for construction cost as it may not accurately reflect the escalation of prices of materials used in such projects. The CPI is based on the cost of a basket of goods, typically bought by an individual consumer. More specific inflation indicators exist that are based upon prices of intermediate or finished products and for specific materials such as concrete products and steel mill products.

In Canada, Statistics Canada prepares the Industrial Products Price Index (IPPI), which provides monthly prices for specific industrial materials. The IPPI represents the broadest measure of producer prices. Therefore, the IPPI is preferred over the CPI and is used in this program for analysis. The following table lists the three interest rates that have been considered and the calculated historical differentials with the IPPI. During the 30 year period from 1960 to 1989, the differential with the IPPI was 4.36 percent for the provincial bond rate, 3.63 percent for the long-term federal bond rate, and 4.56 percent for the long term corporate rate.

HISTORICAL INTEREST/INFLATION RELATIONSHIP FOR CANADA

DIFFERENTIALS	**FEDERAL**	**PROVINCIAL**	**CORPORATE**
1960 - 1969	3.44	3.93	4.05
1970 - 1979	-0.21	0.68	0.94
1980 - 1989	6.62	7.32	7.51
1990 - 1998	6.12	6.65	6.89
1960 - 1998 average:	4.20	4.89	5.10

In the U.S., the producer price index(PPI), which covers all material or specific materials such as steel mill products and concrete products, is available from the Department of Labor's Bureau of Labor Statistics. The PPI represents the broadest measure of producer prices. Therefore, the PPI is preferred over the CPI and is used in this program for analysis. The following table lists the three interest rates that have been considered and the calculated historical differentials with the PPI. During the 30 year period from 1954 to 1983, the differential with the PPI was 0.52 percent for the municipal bond rate, 1.66 percent for the long-term Treasury Bill rate, and 2.86 percent for the prime rate.

HISTORICAL INTEREST/INFLATION RELATIONSHIP FOR U.S.

DIFFERENTIALS	**FEDERAL**	**STATE AND LOCAL**	**CORPORATE**
1954 - 1963	2.74	2.08	-3.29
1964 - 1973	1.69	0.81	2.48
1974 - 1983	0.55	-1.32	2.81
1984 - 1993	7.03	5.76	7.18
1994 - 1998	5.52	4.59	7.10
1954 - 1998 average:	3.28	2.14	4.29

Recommendations

It is recommended that the relatively stable long-term differential between interest and inflation rates be used for Least Cost Analysis. Use of this differential rather than forecasts of interest and inflation rates will free engineers from errors related to short-term volatility of rate forecasting.

In Canada, the differential recommended is that between the IPPI and the cost of funds for the borrower in question. For provincial and municipal government agencies, the historical differential between the provincial bond rate and the IPPI is appropriate. For private firms, the corporate bond rate differential is preferred and for Federal agencies, the differential derived from long-term government of Canada bonds is appropriate.

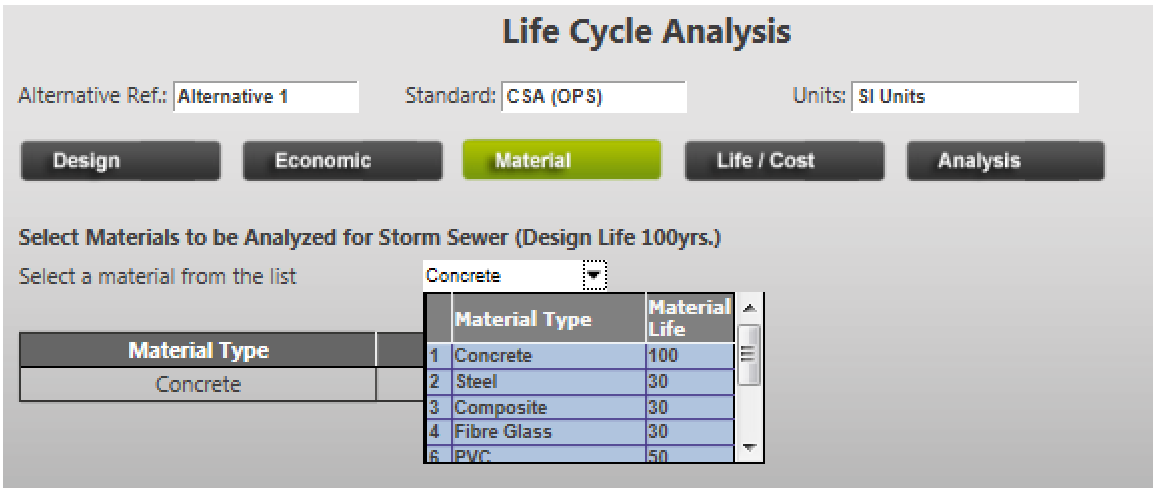
In the United States, the differential recommended is that between the PPI and the cost of funds for the borrower in question. For state and local government agencies, the historical differential between the municipal bond rate and the PPI is appropriate. For private firms, the prime rate differential is preferred and for Federal agencies, the differential derived from long-term Treasury instruments is appropriate.

Least cost analysis is appropriate when considering alternate materials with different service lives for capital projects. The method can be applied easily and problems inherent in forecasting interest and inflation rates are avoided by using the relatively constant long-term ratio between interest rates and inflation rates. The values of the Inflation/Interest Factors shown above represent the historical relationships that are applicable for the Canadian economy and the U. S. economy in the post-World War II period, and are appropriate to use when evaluating specific projects.

Material

Select the material to be analyzed from the pull-down menu. You may keep the default material-life value for the selected material or change by typing over the existing value.

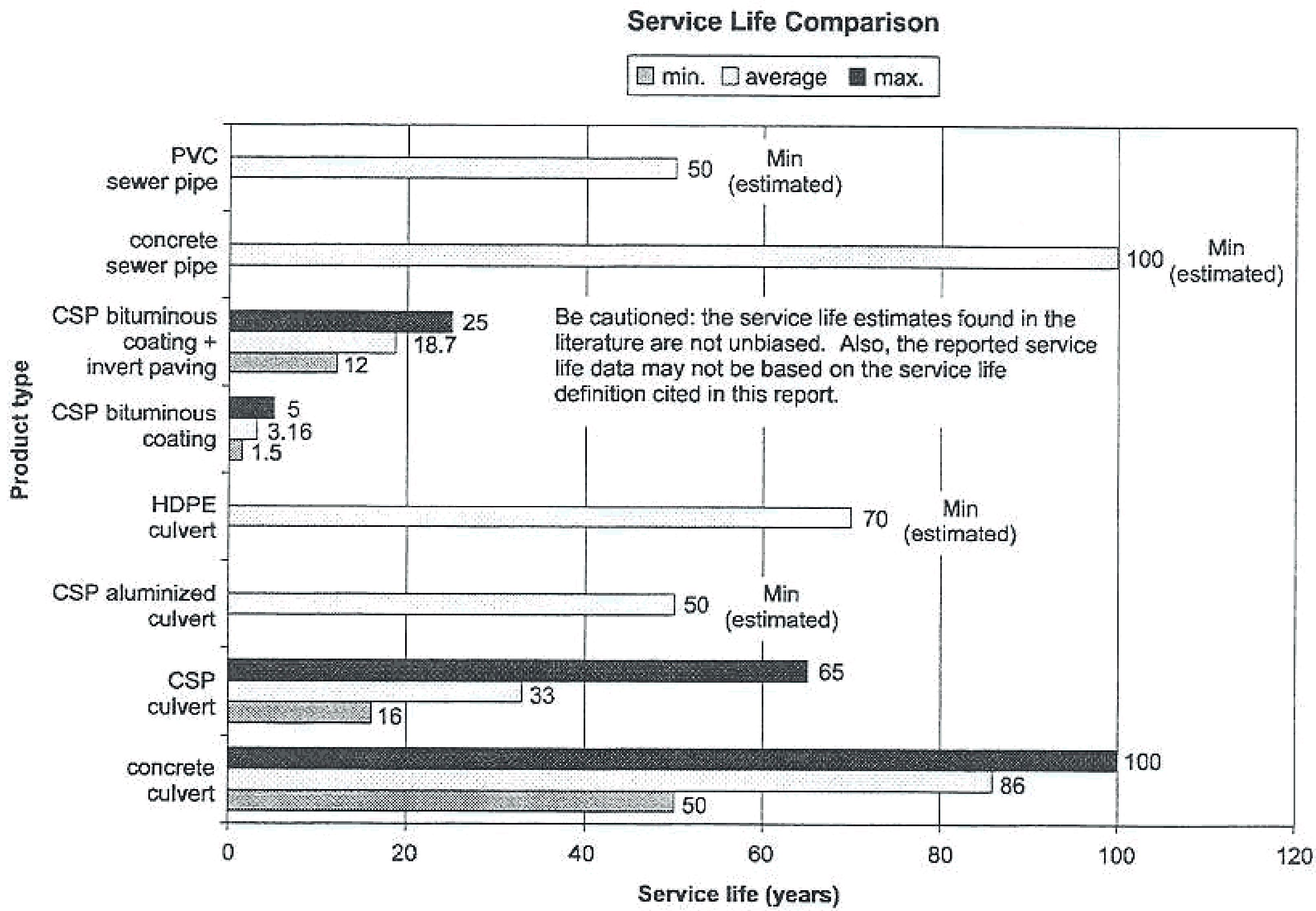
Click **'Update Material Types'** button to update material and material-life.



In here, you may add new materials, edit or delete existing materials.

MATERIAL SERVICE LIVES

Different pipe materials have different service lives, which depend on the material and the environmental and functional conditions of the installation. The durability of pipe materials has been researched by government (federal, state and provincial) agencies and others, and numerous reports have been published. The service life of a pipe material is either specified as a certain number of years, or determined as a function of various environmental and functional factors. Here is a comparison of the service life of studied pipes:


Service Life Comparison
min.
average
max.
Product type
PVC sewer pipe
50
Min (estimated)
concrete sewer pipe
100
Min (estimated)
CSP bituminous coating + invert paving
25
18.7
12
Be cautioned: the service life estimates found in the literature are not unbiased. Also, the reported service life data may not be based on the service life definition cited in this report.
CSP bituminous coating
5
3.16
1.5
HDPE culvert
70
Min (estimated)
CSP aluminized culvert
50
Min (estimated)
CSP culvert
65
33
16
concrete culvert
100
86
50
0
20
40
60
80
100
120
Service life (years)

Service Life Comparison

Reference: Durability and Performance of Gravity Pipes: A State-of-the-Art Literature Review, Jack Q. Zhao, S. Kuraoka, T.H.W. Baker, P. Gu, J-F. Masson, S. Boudreau, R. Brousseau, National Research Council of Canada, August 1998, page 38, figure 4.

> Note: The above study was initiated in 1996, at a time when AASHTO was considering amendments to Section 18 of the AASHTO Standard Specifications for Highway Bridges. At the May 1996 AASHTO Bridge Committee meeting, the Committee considered the Final Report of NCHRP Project 20-7, Task 68 Polyethylene Pipe Specifications by Lester H. Gabriel, Orin N. Bennett, and Bernard Scheier. The Final Report recommended modifications to the cell classification for polyethylene resins used in the production of gravity pipe. Included in the recommendations was the removal of the Hydrostatic Design Basis (HDB) requirement for gravity pipe, after the design of a new test to replace HBD was proven. The recommendation, contained in the Blended HDPE Resins: Virgin and Post-Consumer Recycled Materials section stated;
>
> > "6. The Section 18 requirement of an HDB material quality control test for blended virgin and PCR HDPE resins, for use in gravity flow non-pressure pipe, should be abandoned, but not until a reliable post-production slow crack growth test, designed to reflect wall geometries and load conditions of gravity drainage pipes, has been developed, proven and adopted (see 5 above)."
>
> Notwithstanding the recommendation, the Committee removed the HDB requirement.
>
> Based on the above, the Service Life Comparison in the Zhao, et. al. Report must be considered with some apprehension. The Service Life estimate was based on materials which predate the modifications to AASHTO, and will only be able to be substantiated after the new test, known as the SP-NCTL test has been in place for a period of time and new polyethylene resins used in the manufacture of pipe evaluated.

Other References:
The Ohio (ODOT) Culvert Durability Study (Comparative Study #11), one of the most comprehensive studies available.

People interested in specific information pertaining to a site should consult the appropriate reference. All references are available from the Ontario Concrete Pipe Association, 447 Frederick St, Second Floor, Kitchener, Ontario N2H 2P4 or the American Concrete Pipe Association, 8445 Freeport Parkway, Suite 350, Irving, TX 75063. These reports have been sorted by type - comparative studies, concrete, metal (aluminum and steel), plastic (ABS, PVC, and PE) - and are listed in reverse chronological order.

- **Comparative Studies**
- **Concrete**
- **Metal (Aluminum & Steel)**
- **Plastic (ABS, PVC, PE)**

Comparative Studies

1. NCHRP, Synthesis of Highway Practice 254, "Service Life of Drainage Pipe", Lester Gabriel, Eric Moran, 1998
2. "The Economic Cost of Culvert Failures", Joseph Perrin Jr., Chintan Jhaveri, Transportation Research Board, November, 2003
3. Durability and Performance of Gravity Pipes: A State-of-the-Art Literature Review, Jack Q. Zhao, S. Kuraoka, T.H.W. Baker, P. Gu, J-F. Masson, S. Boudreau, R. Brousseau, National Research Council of Canada, August 1998.
4. Standard Practice for Least Cost (life Cycle) Analysis of Culvert, Storm Sewer and Sanitary Sewer Systems, ASTM Standard, C1131.
5. Current State of Life Cycle Design for Local Protection Structures: A Literature Search, Civil Engineering Research Foundation, April 20, 1992.
6. A Look Back in Time to Verify Life Cycle Cost Analyses, ASCE Pipelines Div. Conference, March 1990.
7. Pipe Culverts Durability, Utah Department of Transportation, Report MR-89-001, August 1989.
8. Evaluation of Drainage Pipe by Field Experimentation and Supplemental Laboratory Experimentation, Louisiana Highway Research, 1985.
9. Symposium on Durability of Culverts and Storm Drains, Transportation Research Record 1001, TRB, Washington, DC, 1984.
10. Buried Fact No. 1 - Fires in Sewers and Culverts, American Concrete Pipe Association, May 1982.
11. Durability of Drainage Structures, Maine DOT, June 1982
12. What Type Sewer Pipe Is Best? Life-Cycle Cost Analysis Yields Answer, Civil Engineering Magazine, October 1982.
13. Tucson Verifies Pipe's Durability, Public Works Magazine, December 1982.
14. Ohio Culvert Durability Study, Ohio DOT, 1982.
15. Report on the Condition of Two-Year Old PVC and Concrete Sewers in Sweden, P. Svenshammar, Swedish Concrete Pipe Association, 1982.
16. Corrosion Evaluation of Culvert Pipe in Wisconsin, Wisconsin DOT, Patenaude, R., 1981.
17. National Survey of State Culvert Use and Policies, Wallace W. Renfrew and Robert M. Pyskadio, Special Report 68, New York State DOT, May 1980.
18. Kentucky Culvert Study, Byrd, Tallamy, MacDonald and Lewis, Kentucky DOT, June 1979.
19. Performance of Culvert Materials in Various Colorado Environments, Colorado Division of Highways, Report No. CDOH-P&R-R-77-7, September 1977.
20. Corrosion of Highway Structures, James S. Dana and Rowan J. Peters, Arizona Department of Transportation, January 1975.
21. Durability and Performance of Gravity Pipes: State of Current Practice, Shelley McDonald, National Research Council of Canada, August 1998.

Concrete

1. Analysis of Reinforced Concrete-Pipe Performance Data, Potter, J., Journal of Transportation Engineering, Volume 114, No. 2, March, 1988.
2. Service Life Assessments of Concrete Pipe Culverts, Hadipriono, F. C., Larew, R. E., Lee, O., Journal of Transportation Engineering, Volume 114, No. 2, March, 1988.
3. Culvert Durability Rating Systems, Kurdziel, J. M., Transportation Research Record, No. 1191, 1988.
4. Service Life Model Verification for Concrete Pipe Culverts in Ohio, Hurd, John O., Transportation Research Record, No. 1191, 1988.
5. Concrete Pipe Expedites Interstate Reopening, American Concrete Pipe Association News, December 1986.
6. Field Performance of Concrete Pipe Culverts At Acidic Flow Sites in Ohio, Hurd, J. O., Paper Presented 64th TRB, January 1985.

Metal (Aluminum & Steel)

1. Abrasion Resistance of Aluminum Culvert Based on Long-Term Field Performance, Koepf, A. H. and Ryan, P. H., Transportation Research Record, No. 1087, 1986.
2. Evaluation Of Metal Drainage Pipe Durability After Ten Years, Temple, W. H. and Cumbaa, S. L., Transportation Research Record, No. 1087, 1986.
3. Durability of Bituminous-Lined Corrugated Steel Pipe Storm Sewers, Ohio DOT, April 1985.
4. Metal-Loss Rates of Uncoated Steel and Aluminum Culverts in New York, Belcair, P. J. and Ewing, J. P., New York DOT, October 1984.
5. Pipe Coating Study, Sudol, Indiana Dept. of Highways., Sept. 1982.
6. Survey of State Highway Departments on Use of Corrugated Metal Pipe in Storm Sewers, Oregon DOT, August 1982.
7. Evaluation of the Durability of Metal Drainage Pipe, Kinchen, R. W., Transportation Research Record 762, TRB, Washington, DC,1981.
8. Cooperative Field Survey of Aluminum Culverts - 1979, Apostoleous, J. A., Myhres, F. A., California, DOT, April 1980.
9. Evaluation of Highway Culvert Coating Performance, Federal Highway Administration, Report No. FHWA/RD-30-059, June 1980.
10. Corrosion Performance of Metallic Coated Steel Culvert, Wheeling Pittsburgh teel Corporation, Metallurgical Engineering Laboratory, 1980.
11. Michigan Galvanized Metal Culvert Corrosion Study, Michigan Department of tate Highways and Transportation, 1979.
12. Polymer Coating for Corrugated Steel Pipe, Special Report 64, New York. DOT, 979.
13. Corrugated Metal Pipe Durability Guidelines, Federal Highway Administration Technical Advisory T5040.2, 1978.
14. Study of Corrosion of Corrugated Steel Pipe Spillways in Structures Designed by the Soil Conservation Service, Soil Conservation Service, 1978.
15. Idaho - Aluminum Pipe Report, State of Idaho Transportation Department, 1977.
16. Corrugated Metal Pipe Study - Corps of Engineers (Omaha Report), Corps of Engineers, 1975.
17. Corrugated Steel Pipe for Storm Drains, Los Angeles County Flood Control District, 1973.
18. Corrosion and Service Life of Corrugated Metal Pipe in Kansas, Worley H. E., and Crumption, C. F., Highway Research Record No. 412, 1972.
19. A Comparative Study of Aluminum and Steel Culverts, McKeel, W. T., Jr., Culvert Studies Progress Report No. 4, Virginia Highway Research Council, May 1971.
20. Comparative Study of Coatings on Corrugated Metal Culvert Pipe, David K. Curtice and John E. Funnell, Southwest Research Institute, US Steel Corp., March 15, 1971.

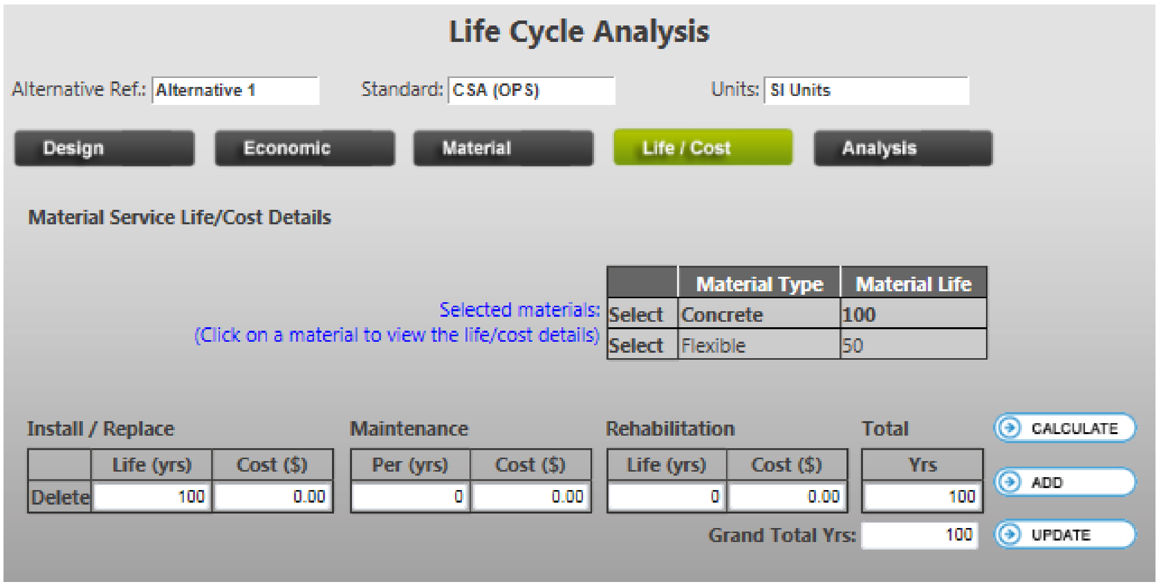
21. A Study of the Durability of Corrugated Steel Culverts in Oklahoma, C. J. Hayes, Oklahoma Department of Highways, 1971.

Plastic (ABS, PVC, PE)

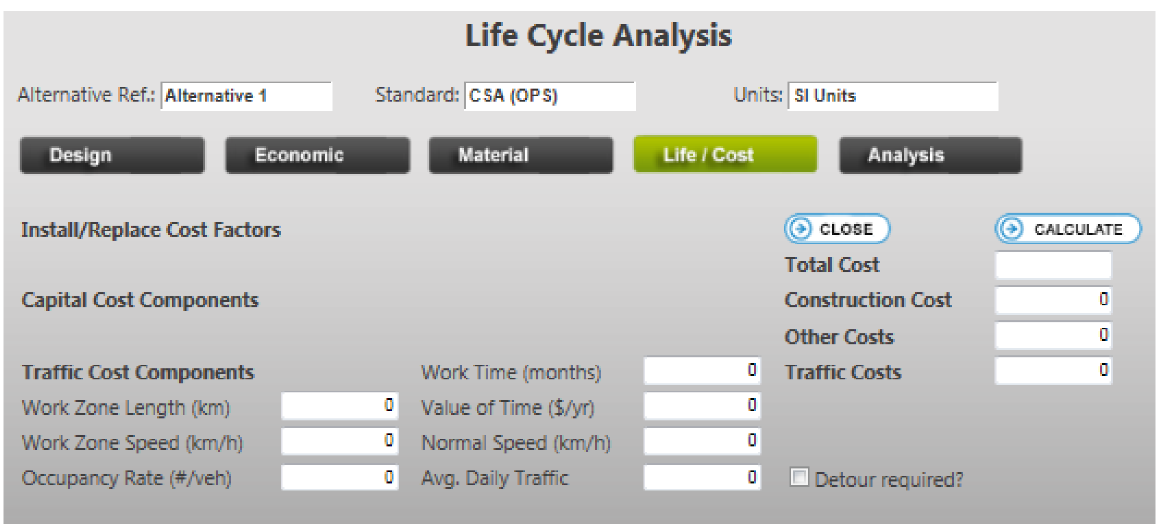
1. The Durability of Polyethylene Piping, Mruk, S. A., Buried Plastic Pipe Technology, 1990
2. The Fatigue Response of Polyvinyl Chloride and Polyethylene Pipe Systems, Bowman, J. A., Buried Plastic Pipe Technology, 1990
3. Performance of Plastic Drainage Pipe, Nazar, Steve, Plastics Technology Section, Industrial Materials Technology Centre, ORF Contract No. 68-10830 for Ministry of Transportation of Ontario, 1988.
4. Field Performance of Corrugated Polyethylene Pipe Culverts in Ohio, Hurd, John O., Transportation Research Record, No 1087,1986.
5. Literature Review of Potential Hazards to Human Health of Using PVC and CPVC Pipe for Potable Water Distribution, Southern Research Institute, February 1983.
6. A Literature Study of the Combustion Hazards of PVC and ABS, University of Calgary, 1981.
7. National Co-operative Highway Research Report 225 - Plastic Pipe for Subsurface Drainage of Transportation Facilities, Transportation Research Board, National Research Council, October 1980.

Material Life/Cost

Specify the Maintenance, Replacement, and Rehabilitation Life/cost values for each of the selected materials.



Use the cost calculator for detailed calculations. To open the cost calculator, click on either Maintenance cost or Rehabilitation cost boxes and then click the **Calc. Cost** button.



Maintenance

Maintenance is any action taken periodically to help a material reach its service life and ensure the facility functions as originally intended. Typical maintenance activities for pipe installations include removal of debris, flushing, deposition or silt removal, and repair of localized damage. Actions to maintain or improve the pipe's structural integrity are considered remedial actions and are addressed as either rehabilitation or replacement projects.

Maintenance costs in this program are handled as an expense per period or cost per number of years, and not as an annual expense. For example, if routine maintenance costs $1,000 every three years, the input would be an expense of $1,000 for a period equal to three years. However, to consider maintenance as an annual expense, the input would be the annual cost for a period equal to one year.

Maintenance costs should only be added to the program if they are different for different materials.

Replacement

Replacement entails the removal of an existing facility and the installation of a new structure. The material life of the replaced facility should equal that of the original material life. Costs associated with replacement actions include the construction and material costs for the work and any other direct or indirect related costs. These may include easements, engineering, safety, detour roadway deterioration and traffic related costs.

Provisions have been made within the program to incorporate traffic related costs into the analysis at the option of the user. Costs associated with vehicle deterioration, passenger time, and construction-related accidents have been included. The calculations for traffic costs (cost of passenger's time and vehicle deterioration costs) are derived from the US Federal Highway Administration's publication, "The Design of Encroachments on Flood Plains Using Risk Analysis." Cost of passenger's time is based on the additional time to travel through the construction zone. Vehicle deterioration costs reflect additional wear on vehicles from the extra traveling distance for detours.

Cost associated with construction related accidents reflect the number and cost of vehicle accidents through the construction zone. These costs include property damage, injuries and fatalities.

Rehabilitation

Rehabilitation entails any remedial action taken on a pipe facility to upgrade its structure condition. Rehabilitation actions cannot restore the pipe to its original condition but may extend its service life by a number of years depending on the type and amount of deterioration. The years the material life is extended should be judged on the condition of the pipe and current rate of deterioration. Costs associated with rehabilitation actions not only include the construction and material costs for the work but any other direct or indirect related costs. These may include easements, engineering, safety, detour roadway deterioration and traffic related costs.

Provisions have been made within the program to incorporate traffic related costs into the analysis at the option of the user. Costs associated with vehicle deterioration, passenger time, and construction-related accidents have been included. The calculations for traffic costs (cost of passenger's time and vehicle deterioration costs) are derived from the US Federal Highway Administration's publication, "The Design of Encroachments on Flood Plains Using Risk Analysis." Cost of passenger's time is based on the additional time to travel through the construction zone. Vehicle deterioration costs reflect additional wear on vehicles from the extra traveling distance for detours.

Cost associated with construction related accidents reflect the number and cost of vehicle accidents through the construction zone. These costs include property damage, injuries and fatalities.

Analysis

Comparison of equations used in PipePac and those established in ASTM C 1131, Lease Cost (Life Cycle) Analysis of Concrete Culvert, Storm Sewer, and Sanitary Sewer Systems.

- **Present Value (PV)**
- **Annualized Costs (AC)**
- **Future Value (FV)**
- **ASTM C 1131 - 95:**

Present Value (PV)

Present value is calculated based on the equivalent costs at the current or present time. In other words, this would be the amount of money that would have to set aside today to meet all costs for the life of desired design project.

Present value calculations are made by first inflating estimates of cost expenditures, made in original dollar terms, into the future to the time they will be made. These inflated costs are then discounted to present value terms using an appropriate interest rate.

When using the nominal discount rate, the inflating and discounting of each future cost or value is done by the equation:

$PV = C[(1 + I)/(1 + i)]^n$

where:PV = Present value or initial cost

C = Original cost

I = Inflation rate

i = Actual Interest rate

n = Period or number of years

If a real discount rate is used, the future costs are discounted to the present value using the same equation where the value for inflation (I) is zero and the interest rate is the difference between interest and inflation (i - I).

$PV = C[(1)/(1 + (i - I))]^n$

Here is a sample Report

Life Cycle Analysis - Results

Project Description

Project Title: Project1
Project Location:
Contract Number:
Country: Canada
Units: SI Units

Consultant:
Contractor:
Analyzed By:
Date: 3/27/2013
Comply To: CSA (OPS)

Alternative: Alternative 1

Project Design Parameters

Type of Facility:
Design Life: 100

Economic Factors

Discount Method: Nominal Rate
Type of Funding: Federal Funding
Interest Rate: 0.085
Inflation Rate: 0.036

Discount Factor: 0.954

Present Value - Equivalent Costs ($)

Material	Installation	Maintenance	Rehabilitation	Replacement	Residual	Total	Total - Residual
Concrete	$232,000.00	$0.00	$0.00	$0.00	$0.00	$232,000.00	**$232,000.00**
Flexible	$180,000.00	$77,624.07	$0.00	$0.00	$0.00	$257,624.07	**$257,624.07**

Comments:

Life Cycle Analysis Parameters for Concrete

For the period of: 0 yrs TO 100 yrs

Installation Life:	100	**Installation Cost:**	$232,000.00
Maintenance Period:	0	**Maintenance Cost:**	$0.00
Rehabilitation Life:	0	**Rehabilitation Cost:**	$0.00

Life Cycle Analysis Parameters for Flexible

For the period of: 0 yrs TO 50 yrs

Installation Life:	50	**Installation Cost:**	$180,000.00
Maintenance Period:	25	**Maintenance Cost:**	$250,000.00
Rehabilitation Life:	0	**Rehabilitation Cost:**	$0.00

Annualized Costs (AC)

Annualized costs are annual yearly costs or what an agency would have to outlay every year for the life of the project. This may also be computed on a period basis as an outlay every number of months or years by modifying the value of "n" in the equation:

$AC = PV\ [i(1+i)^n/((1+i)^n - 1)]$

where:AC = Annualized cost

PV = Present value or initial cost

Here is a sample Report

Life Cycle Analysis - Results

Project Description

Project Title: Project1
Project Location:
Contract Number:
Country: Canada
Units: SI Units
Alternative: Alternative 1

Consultant:
Contractor:
Analyzed By:
Date: 3/27/2013
Comply To: CSA (OPS)

Project Design Parameters

Type of Facility:
Design Life: 100

Economic Factors

Discount Method: Nominal Rate
Type of Funding: Federal Funding
Interest Rate: 0.085
Inflation Rate: 0.036
Discount Factor: 0.954

Annualized Value - Equivalent Costs ($)

Material	Installation	Maintenance	Rehabilitation	Replacement	Residual	Total	Total - Residual
Concrete	$19,771.96	$0.00	$0.00	$0.00	$0.00	$19,771.96	**$19,771.96**
Flexible	$15,340.31	$6,615.43	$0.00	$0.00	$0.00	$21,955.75	**$21,955.75**

Future Value (FV)

Future value is simply the cost of the project at a future date. Costs can be discounted to a future value with the following equation:

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

where:FV = Future value

PV = Present value or initial cost

Here is a sample Report

Life Cycle Analysis - Results

Project Description

Project Title: Project1

Project Location:

Contract Number:

Country: Canada

Units: SI Units

Consultant:

Contractor:

Analyzed By:

Date: 3/27/2013

Comply To: CSA (OPS)

Alternative: Alternative 1

Project Design Parameters

Type of Facility:

Design Life: 100

Economic Factors

Discount Method: Nominal Rate

Type of Funding: Federal Funding

Interest Rate: 0.085

Inflation Rate: 0.036

Discount Factor: 0.954

Future Value - Equivalent Costs ($)

Material	Installation	Maintenance	Rehabilitation	Replacement	Residual	Total	Total - Residual
Concrete	$825,023.83	$0.00	$0.00	$0.00	$0.00	$825,023.83	**$825,023.83**
Flexible	$640,104.70	$276,041.85	$0.00	$0.00	$0.00	$916,146.55	**$916,146.55**

ASTM C 1131-95

Although some of the equations used in the LCA portion of PipePac may not appear the same as those found in ASTM C 1131 “Least Cost (Life Cycle) Analysis of Concrete Culvert, Storm Sewer, and Sanitary Sewer Systems” it is merely a matter of notation. All results obtained from the LCA portion of PipePac confirm with ASTM C 1131. Following is a brief description of the notation differences.

Present Value (PV)

PipePac Expression	ASTM C 1131 Expression
$PV = C[(1 + I)/(1 + i)]^n$	$PV = A(F)^n$
PV = Present value or initial cost	PV = Present value or initial cost
C = Original cost	A = Constant Dollar Value
n = Period or number of years	F = Inflation/Interest Factor
I = Inflation rate	n = Period or number of years.
i = Actual Interest rate	$F = [(1+I)/(1+i)]$

As can be seen from the above expressions, the Inflation/Interest Factor “F” of ASTM C 1131 is synonymous with the expression $[(1+I)/(1+i)]$ used in the PipePac. As discussed in ASTM C 1131, constant dollars are, “costs stated at price levels for a specific reference year, usually the particular time that the LCA is being conducted”. The constant dollar value is equal to the original cost of the item or service. Therefore, both equations provide the same results.

Future Value (FV)

PipePac Expression	ASTM C 1131 Expression
$FV = PV(1 + i)^n$	$FV = A(1+i)^n$

In the PipePac expression the future value of an item or service is a result of the effect of inflation on the present value (or initial cost) of that item or service. As noted above, the constant dollar value is equal to the original (or initial) cost of an item or service. Therefore, both equations provide the same results.

Annualized Costs (AC)

PipePac Expression	ASTM C 1131 Expression
$AC = PV[i(1 + i)^n / (1+i)^{n-1}]$	$AC = PV[(1/F-1) / (1-F^n)]$

AC = Annualized Costs

ASTM Standard C 1131 - 95 does not contain an expression for annualized cost. The expression given here is derived from a revision to be incorporated into the 1998 or 1999 edition of the standard. Both expressions give the same results. However, the nominal discount rate must be used in the C 1131 equation as compared to the real discount rate in the PipePac equation.

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PipePac - Concrete Pipe Associations

- Ontario Concrete Pipe Association

447 Frederick St, Second Floor, Kitchener, Ontario, Canada N2H 2P4

- American Concrete Pipe Association

8445 Freeport Parkway, Suite 350, Irving, TX, U.S.A. 75063-2595

- Canadian Concrete Pipe Association

138 Mill Street, Georgetown, Ontario, Canada L7G 2C1

PipePac designed and developed by Cion Corp
2 International Blvd., Toronto, Ontario, Canada M9W 1A2