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Final Report

Canadian Energy Pipeline Association (CEPA)
Surface Loading Calculator User Manual

Mark Van Auker and Bob Francini

January 28, 2014

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on

CANADIAN ENERGY PIPELINE ASSOCIATION (CEPA)

SURFACE LOADING CALCULATOR USER MANUAL

to

CANADIAN ENERGY PIPELINE ASSOCIATION (CEPA)

January 28, 2014

by

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Canadian Energy Pipeline Association (CEPA) Surface Loading Calculator User Manual

Mark Van Auker and Bob Francini

BASIC DESCRIPTION

The CEPA Surface Loading Calculator is used to determine the stresses experienced by a buried pipeline as a vehicle traverses the pipeline at the surface. The program primarily uses the gross vehicle weight, size of the vehicle footprint (or ground contact area), and the pipeline depth of cover to calculate the load (or pressure) experienced at the pipeline depth. The calculated load is used to determine the corresponding circumferential and longitudinal stresses produced in the pipe. The stresses caused by the external load are combined with the circumferential and longitudinal stresses present under normal operating conditions in order to determine the equivalent stress experienced by the pipeline.

The program is capable of calculating three pre-loaded vehicle types:

- 2-Axle, 4-Wheel vehicle ("Wheel Vehicle INPUT" tab),
- 3-Axle, 6-Wheel vehicle ("Wheel Vehicle 3-Axle INPUT" tab),
- Track vehicle ("Track INPUT" tab).

A custom vehicle type ("Grid INPUT" tab), in which the user creates and inputs an array of point loads representing a custom vehicle foot print or surface load is also capable of being analyzed.

APPROACH

As a vehicle traverses over a buried pipeline, the surface load is transmitted through the soil to the pipeline. The load experienced at pipeline depth is primarily a function of the depth of cover, gross vehicle weight, and size of the vehicle footprint (or ground contact area). The external load on the pipeline causes a deflection in the pipe cross section and local circumferential and longitudinal stresses, which combine with the circumferential and longitudinal stresses that are present under normal operating conditions. Resistance to the overall cross-section deflection (also known as ovalization) of the pipe comes from the stiffness of the pipe cross section, internal pressure, and lateral restraint from the soil that is in contact with the sides of the pipe. The Spangler and Iowa equations[1] have been generally accepted and incorporated into industry guidelines such as API Recommended Practice 1102 Steel

[1] Spangler, Merlin G. and Handy, Richard L., Soil Engineering. Third Edition. Intext Press, Inc. 1973.

Pipelines Crossing Railroads and Highways[2], and American Lifelines Alliance Guidelines for the Design of Buried Steel Pipe[3] for calculating circumferential bending stress in buried pipe due to the deflection caused by external loads. The Spangler and Iowa equations both consider pipe stiffness but consider the effects of pressure stiffening and lateral soil restraint separately. The 'CEPA' equation[4] effectively combines the internal pressure and lateral soil restraint deflection resistance terms into a single equation for circumferential bending stress. In the absence of internal pressure, the CEPA equation reverts back to the Iowa equation, and similarly it reverts back to the Spangler equation if lateral soil restraint is negligible. The CEPA equation is used in this analysis to calculate the circumferential bending stress due to surface loads.

The external load on the pipe also causes a local longitudinal stress. If the load is assumed to act over a finite area on the pipe surface, then it can be analyzed similarly to integral structural attachments to straight pipe as described in Secondary Stress Indices for Integral Structural Attachments to Straight Pipe[5]. The surface load can also cause an overall deflection of the pipe and the soil with respect to the pipe along with the soil outside of the influence of the surface load. The longitudinal stress as a result of overall pipe deflection is calculated using beam on elastic foundation principles.

The circumferential and longitudinal stresses that are present due to normal operating conditions are also calculated. These stresses are namely the circumferential (hoop) stress due to internal pressure, circumferential stress due to the weight of fill above the pipeline, longitudinal stress due to the Poisson effect of pressurized pipelines restrained in soil, the Poisson effect from the soil load, and longitudinal stress due to any temperature difference between the pipe at the time of installation and the normal operating temperature.

The circumferential and longitudinal stresses due to the normal operating condition and surface loading condition are totaled and compared to the allowable limits for each stress component given in the applicable design code[6, 7, or 8]. The combined equivalent stress (Tresca or von Mises stress) is also compared to allowable limits. If the surface loading is expected to be frequent, then fatigue is also considered.

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[2] API Recommended Practice 1102, "Steel Pipelines Crossing Railroads and Highways," American Petroleum Institute, Sixth Edition, April 1993, reaffirmed July 2002.
[3] Guidelines for the Design of Buried Steel Pipe. AmericanLifelinesAlliance. July 2001 with addenda through February 2005. www.americanlifelinesalliance.com.
[4] Warman, D. J. and Hart, J.D. "Development of a Pipeline Surface Loading Screening Process & Assessment of Surface Loading Dispersing Methods," Final Report 05-44 to the Canadian Energy Pipeline Association (CEPA). June 17, 2005.
[5] Dodge W.G. "Secondary Stress Indices for Integral Structural Attachments to Straight Pipe," WRC Bulletin 198, New York, 1974.
[6] CSA Z662-11, "Oil and Gas Pipeline Systems," CSA, Ontario, Canada, 2011.
[7] ASME B31.4-2009, "Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids", ASME, New York, 2009.
[8] ASME B31.8-2010, "Gas Transmission and Distribution Piping Systems", ASME, New York, 2010.

EQUATIONS

The pressure exerted on the pipe at pipeline depth due to a load at the surface can be calculated using Boussinesq's equation:

$$P_{live} = \frac{W_{live}}{D} = \frac{3 \cdot F}{2\pi H^2 \left[1 + \left(\frac{d}{H}\right)^2\right]^{2.5}} \qquad (1)$$

where

P_{live} = pressure on the pipe due to the live load (psi)

W_{live} = live load on the pipe (lb/in)

D = diameter of the pipe (in)

F = point load at the surface (lb)

H = depth of soil cover (in)

d = offset distance from the pipe to the line of application of the surface load (in)

Using this equation, a tire, track, or any other load with a known contact area can be represented by a series of point loads at the surface, and the total load on the pipe is calculated as the summation of the effect of the individual loads.

As recommended by Moser[9], the soil load above the pipeline is calculated as the weight of a prism of soil having a width equal to the diameter of the pipe and height equal to the depth of cover:

$$P_{soil} = \frac{W_{soil}}{D} = \rho \cdot H \qquad (2)$$

where

P_{soil} = pressure on the pipe due to the soil load (psi)

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[9] Moser, AP, Buried Pipe Design, Second Edition, 2001, McGraw Hill.

W_{soil} = soil load on the pipe (lb/in)

ρ = density of soil (lb/in^3)

The vehicle live load and the soil load cause a deflection in the ring cross section of the pipe and circumferential bending in the pipe wall.

The CEPA equation combines the pressure stiffening and soil restraint terms into a single equation for determining circumferential (hoop) bending stresses due to live or soil loads:

$$\sigma_{H\_live} = \frac{3 \cdot K_b \cdot P_{live} \cdot \left(\frac{D}{t}\right)^2}{1 + 3 \cdot K_z \cdot \frac{P}{E} \cdot \left(\frac{D}{t}\right)^3 + 0.0915 \cdot \frac{E'}{E} \cdot \left(\frac{D}{t}\right)^3} \qquad (3)$$

where

σ_{H_live} = circumferential (hoop) bending stress due to the live load (psi)

K_b = soil parameter

t = wall thickness (in)

K_z = soil parameter

P = internal pressure (psig)

E = Young's modulus of elasticity for steel (30x10^6 psi)

E' = modulus of soil reaction (psi)

and

$$\sigma_{H\_soil} = \frac{3 \cdot K_b \cdot P_{soil} \cdot \left(\frac{D}{t}\right)^2}{1 + 3 \cdot K_z \cdot \frac{P}{E} \cdot \left(\frac{D}{t}\right)^3 + 0.0915 \cdot \frac{E'}{E} \cdot \left(\frac{D}{t}\right)^3} \qquad (4)$$

where

σ_{H_soil} = circumferential (hoop) bending stress due to the soil load (psi)

The circumferential (hoop) stress due to internal pressure is given as:

$$\sigma_{H\_internal} = \frac{P \cdot D}{2 \cdot t} \quad (5)$$

where

$\sigma_{H\_internal}$ = circumferential (hoop) stress due to internal pressure (psi)

The total circumferential stress, σ_{H_Total}, is the sum of the stresses due to circumferential bending along with the hoop stress due to internal pressure. The total circumferential stress is compared to the allowable limit.

Internal pressure in pipelines restrained in soil causes a longitudinal stress equal to:

$$\sigma_{L\_internal} = \nu \cdot \sigma_{H\_internal} \quad (6)$$

where

$\sigma_{L\_internal}$ = longitudinal stress due to internal pressure (psi)

ν = Poisson's ratio for steel (0.3)

In a manner similar to the longitudinal stress from pressure, the soil load causes a longitudinal stress equal to:

$$\sigma_{L\_soil} = \nu \cdot \sigma_{H\_soil} \quad (7)$$

where

σ_{L_soil} = longitudinal stress due to soil load (psi)

The longitudinal stress due to the live load is determined as a combination of stress due to local bending and beam deflection. The calculation for the local longitudinal stress caused by the surface load is estimated using Bjilaard's solutions for local loading on a pipe found in Roark's Formulas for Stress and Strain[10].

[10] Young, W.C., Roark's Formulas for Stress & Strain, Sixth Edition. RR Donnelley & Sons Company, 1989.

$$\sigma_{L\_local} = \frac{0.153}{1.56} \cdot \beta^4 \cdot \sigma_{H\_live} \quad (8)$$

where

σ_{L_local} = local bending stress (psi)

and

$$\beta = [12 \cdot (1 - \nu^2)]^{1/8} \quad (9)$$

The vehicle load causes an axial pipeline deflection, which adds to the longitudinal stress due to internal pressure and temperature differential. If the pipeline is modeled as a beam on an elastic foundation, the maximum bending moment is given by Hetenyi[11] as:

$$M = \frac{P_{pipe} \cdot D}{4\lambda^2} \left(2e^{-\lambda x} \sin \lambda x\right) \quad (10)$$

where

M = bending moment (in-lb)

P_{pipe} = Pressure on pipe from an equivalent point load (psi)

λ = characteristic length (in^{-1})

x = distance along the pipeline (in)

and

$$\lambda = \sqrt[4]{\frac{E' \cdot D \cdot \theta}{4 \cdot E \cdot I}} \quad (11)$$

where

θ = bedding angle of pipe (degrees)

I = pipe moment of inertia (in^4)

P_{pipe} is the uniformly distributed pressure on the pipe due to an equivalent point load at the surface that spreads at the soil distribution angle of 29.9 degrees from the surface point[12].

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[11] Hetenyi, M. Beams on Elastic Foundation. 6th Edition. University of Michigan. 1961.
[12] Design Data 1: Highway Live Loads on Concrete Pipe, American Concrete Pipe Association, October 2007.

The longitudinal bending stress is given as:

$$\sigma_{L\_bend} = \frac{M \cdot D}{2I} \tag{12}$$

where

σ_{L_bend} = longitudinal bending stress (psi)

The total longitudinal stress due to temperature differential is given as:

$$\sigma_{L\_thermal} = E \cdot \alpha \cdot \Delta T \tag{13}$$

where

$\sigma_{L\_thermal}$ = longitudinal thermal stress (psi)

α = coefficient of thermal expansion for steel (6.67×10^{-6} in/in deg F)

ΔT = temperature differential (installation – operation)

The total longitudinal stress, σ_{L_Total}, is the sum of the stresses from internal pressure, soil load, surface loads, axial deflection, and temperature differential. The total longitudinal stress is compared to the allowable limit.

The combined equivalent (Tresca – Equation 14; von Mises – Equation 15) stress is calculated as:

$$\sigma_E = \max\left(\left|\sigma_{H\_Total}\right|, \left|\sigma_{L\_Total}\right|, \left|\sigma_{H\_Total} - \sigma_{L\_Total}\right|\right) \tag{14}$$

$$\sigma_E = \sqrt{\sigma^2_{H\_Total} - \sigma_{H\_Total} \cdot \sigma_{L\_Total} + \sigma^2_{L\_Total}} \tag{15}$$

where

σ_E = combined equivalent stress (psi)

The combined equivalent stress is then compared to the allowable limits. If the surface loading is expected to be frequent, then fatigue should be considered. Refer to "Table 3-Fatigue Endurance Limits, S_{FG} and S_{FL}, for Various Steel Grades" on page 18 in API Recommended Practice 1102 for standard guidelines on performing fatigue check calculations.

ANALYSIS – ENTERING CASE SPECIFIC DATA IN THE "GENERAL INPUT" TAB

Each of the data input fields in the "General INPUT" tab are described below, categorized by section. These sections are designated by gray headings in the spreadsheet. There are two types of inputs: Keyed Entry and Option Button selection. The Keyed Entry input fields are designated by the light yellow cell color. All input fields and option buttons must be populated in order for the program to run.

Pipeline Information, Location, & Date Section

- **Pipeline Information** – In Cell E4 enter pertinent information about the pipeline (name, identification number, etc.).
- **Pipeline Location** – In Cell E5 enter the location of the pipeline. This can be a numerical value (such as station) or text.

Select Units Section

- **Units** – Use the option buttons to select the units (English or Metric) to perform the analysis.

Pipe Input Data Section

- **Outside Diameter** – In Cell C12 enter the actual outside diameter of the pipeline.
- **Wall Thickness** – In Cell C13 enter the nominal wall thickness of the pipeline.
- **Maximum Operating Pressure** – In Cell C14 enter the stated MOP of the pipeline.
- **Specified Minimum Yield Strength** – In Cell C15 enter the SMYS of the pipeline.
- **Temperature Differential ($T_{installed}$ – $T_{operating}$)** – In Cell C16 enter the temperature difference between the pipe at the time of installation and the normal operating temperature. If this information is unknown, a default value of 20°F (11.1°C) should be utilized.

Soil Input Data Section

- **Soil Density** – In Cell C21 enter the soil density in which the pipeline is buried.
- **Depth of Cover** – In Cell C22 enter the depth of cover of the pipeline (i.e. the depth from the surface to the top of the pipeline).
- **Bedding Angle** – Use the option buttons to select the bedding angle of the pipeline. If this information is unknown, a default value of 30 degrees should be utilized.
- **Modulus of Soil Reaction** – Use the option buttons to select either "User Defined:" or "Calculated from Lookup Tables:". If "User Defined:" is selected, in Cell C32 enter the Modulus of Soil Reaction. If "Calculated from Lookup Tables:" is selected, use the option buttons to select the "Soil Type:" and "Soil Compaction:". If this information is unknown, a default value for "Soil Type:" of "Fine-grained with less than 25% sand content" and a default value for "Soil Compaction:" of 80% should be utilized.
- **Soil Load Equation** – Use the option buttons to select the desired soil load equation for the program to utilize in the analysis. If the "Trap Door Equation" is selected, in Cell C48 enter the Angle of Shearing Resistance (or Friction Angle). If unsure which soil load equation to utilize, select the "Prism Load Equation" as the default equation. Note: The trap door equation is used

to account for bridging of the soil over the pipeline. It should not be used unless the user understands the principles behind its use[13]. The results may not be conservative.

Miscellaneous Input Section

- **Impact Factor** – Use the option buttons to select a "Vehicle Type:" and a "Pavement Type:".
  - Note 1: In this calculator, a "Highway Vehicle" is considered to be a vehicle with high-pressure tires (greater than or equal to 30 psi), while "Farm/Construction Equipment" vehicles are considered to be vehicles with low-pressure tires (less than 30 psi).
  - Note 2: For thick concrete slab crossings, such as highways, negligible energy is transmitted to the pipe. Typically, pipe under highways is buried at a depth greater than 5-feet, however if this is not the case, or a conservative result is desired, then the "Flexible Pavement (i.e. Asphalt, Gravel, or Bare Soil)" option should be selected.
- **Equivalent Stress Equation** – Use the option buttons to select the desired equivalent stress equation to utilize in the analysis. If unsure which equivalent stress equation to utilize, select the "Tresca Equation" which is slightly more conservative, as the default equation.
- **Pipeline Regulatory Code** – Use the option buttons to select the desired pipeline regulatory code allowable limits in which to compare the analysis results. If the "User Defined Pipeline Stress Limits:" is selected, in Cell E72, E73, & E74 enter the allowable hoop stress, longitudinal stress, and equivalent stress as a percent of SMYS, respectively.

[13] Bulson, PS, Buried Structures Static and Dynamic Strength, 1985, Chapman & Hall.

ANALYSIS – ENTERING CASE SPECIFIC DATA IN THE "WHEEL VEHICLE INPUT", "WHEEL VEHICLE 3-AXLE INPUT", "TRACK VEHICLE INPUT", OR "GRID INPUT" TAB

After the "General INPUT" tab has been populated, each of the data input fields in one of the desired vehicle input tabs, categorized by type, must be populated. There are four types of vehicles the program is able to analyze:

- 2-Axle, 4-Wheel vehicle ("Wheel Vehicle INPUT" tab),
- 3-Axle, 6-Wheel vehicle ("Wheel Vehicle 3-Axle INPUT" tab),
- Track vehicle ("Track INPUT" tab),
- Custom vehicle ("Grid INPUT" tab).

Only one vehicle type is capable of being analyzed at a time, so it is only necessary to populate the inputs for the vehicle type in which the analysis is to be performed. The input fields on the other vehicle type tabs should be left blank. All input fields, designated by light yellow cell color, on the selected vehicle type tab must be populated in order for the program to run.

Wheel Vehicle INPUT

- **Vehicle Information** – In Cell E4 enter pertinent information about the vehicle (brand, model, year, etc.).
- **Axle Load 1** – In Cell G13 enter the gross weight of the vehicle's front axle.
- **Axle Load 2** – In Cell G30 enter the gross weight of the vehicle's rear axle.
- **Axle Width** – In Cell G33 enter the axle width of the vehicle. If this specification is not provided by the manufacturer, the width can be measured. For single tire axles, measure the distance along the axle between the centerlines of each tire. For dual tire axles, measure the distance along the axle from the space between the dual tires on one side of the axle to the space between the dual tires on the other side of the axle.
- **Axle Separation** – In Cell G21 enter the axle separation of the vehicle. If this specification is not provided by the manufacturer, the separation can be measured as the perpendicular distance from the front axle to the rear axle.
- **Contact Width 1** – In Cell K10 enter the ground contact width of a front axle tire. If dual tires exist, treat them as one tire and enter the overall ground contact width of both tires including the space between the tires.
- **Tire Pressure 1** – In Cell L14 enter the tire pressure of the front axle tires.
- **Contact Width 2** – In Cell K24 enter the ground contact width of a rear axle tire. If dual tires exist, treat them as one tire and enter the overall ground contact width of both tires including the space between the tires.
- **Tire Pressure 2** – In Cell L28 enter the tire pressure of the rear axle tires.

Wheel Vehicle 3-Axle INPUT

- **Vehicle Information** – In Cell E4 enter pertinent information about the vehicle (brand, model, year, etc.).
- **Axle Load 1** – In Cell F13 enter the gross weight of the vehicle's front axle.
- **Axle Load 2** – In Cell F27 enter the gross weight of the vehicle's middle axle.
- **Axle Load 3** – In Cell F36 enter the gross weight of the vehicle's rear axle.
- **Axle Width** – In Cell G42 enter the axle width of the vehicle. If this specification is not provided by the manufacturer, the width can be measured. For single tire axles, measure the distance along the axle between the centerlines of each tire. For dual tire axles, measure the distance along the axle from the space between the dual tires on one side of the axle to the space between the dual tires on the other side of the axle.
- **Axle Separation 1** – In Cell H21 enter the axle separation between the front and middle axles of the vehicle. If this specification is not provided by the manufacturer, the separation can be measured as the perpendicular distance from the front axle to the middle axle.
- **Axle Separation 2** – In Cell H33 enter the axle separation between the middle and rear axles of the vehicle. If this specification is not provided by the manufacturer, the separation can be measured as the perpendicular distance from the middle axle to the rear axle.
- **Contact Width 1** – In Cell K10 enter the ground contact width of a front axle tire. If dual tires exist, treat them as one tire and enter the overall ground contact width of both tires including the space between the tires.
- **Tire Pressure 1** – In Cell L14 enter the tire pressure of the front axle tires.
- **Contact Width 2** – In Cell K24 enter the ground contact width of a middle axle tire. If dual tires exist, treat them as one tire and enter the overall ground contact width of both tires including the space between the tires.
- **Tire Pressure 2** – In Cell L28 enter the tire pressure of the middle axle tires.
- **Contact Width 3** – In Cell K33 enter the ground contact width of a rear axle tire. If dual tires exist, treat them as one tire and enter the overall ground contact width of both tires including the space between the tires.
- **Tire Pressure 3** – In Cell L37 enter the tire pressure of the rear axle tires.

Track Vehicle INPUT

- **Vehicle Information** – In Cell E4 enter pertinent information about the vehicle (brand, model, year, etc.).
- **Vehicle Load** – In Cell G14 enter the gross weight of the vehicle.
- **Track Length** – In Cell C21 enter the track length of the vehicle. If this specification is not provided by the manufacturer, the length can be measured as the distance along the track which is in direct contact with the ground. Note: Some manufacturers specify a ground pressure for their equipment. In this case an effective track length can be estimated based on the width and pressure.
- **Track Separation** – In Cell G32 enter the track separation. If this specification is not provided by the manufacturer, the separation can be measured as the perpendicular distance from the centerline of the left track to the centerline of the right track.
- **Contact Width** – In Cell J11 enter the ground contact width of a vehicle track.

Grid INPUT

The "Grid INPUT" tab is intended for advanced users that wish to analyze a specific portion of a vehicle (e.g. a specific axle on a vehicle) or a custom vehicle type with a footprint (or ground contact area) which cannot be analyzed using one of the specific vehicle type tabs. The input field descriptions for this tab are listed below. Appendix A provides further instructions for using the "Grid INPUT" tab.

- **Vehicle Information** – In Cell E4 enter pertinent information about the vehicle (brand, model, year, etc.).
- **Vehicle Type** – In Cell E5 enter pertinent information about the vehicle type (Wheel, Track, 2-Axle, 3-Axle, etc.).
- **Measurement Point X-coordinate** – In Cell F11 enter the X-coordinate of the location where the program will calculate the pressure exerted on the surface of the pipe due to the vehicle load.
- **Measurement Point Y-coordinate** – In Cell F12 enter the Y-coordinate of the location where the program will calculate the pressure exerted on the surface of the pipe due to the vehicle load.
- **Load (column of values)** – In Column I, starting at Cell I12 enter the user defined array of point loads representing the custom vehicle foot print.
- **X & Y (column of values)** – In Column J and K, starting at Cell J12 and K12 enter the user defined array of X-Y-coordinates corresponding to the array of point loads listed in Column I, which represent the location of each point load in the custom vehicle foot print.

After all input fields on the "General INPUT" tab and desired vehicle type tab have been populated, click the corresponding vehicle type "CALCULATE:" button to run the analysis. Each vehicle type tab includes a "CALCULATE:" button that runs the program analysis for that specific vehicle type. Appendix B gives a complete list of all the worksheet tabs and corresponding functions (or buttons) that reside on each tab.

NOTE: An error check is performed prior to the program initiating subroutines. If there is an issue with how an input has been entered, an error message will pop up alerting the user as to which input cell is causing the issue.

ANALYSIS – "RESULTS" TAB

Once the program has finished running, it will automatically bring up the "Results" tab, which will display an overview of the user inputs along with the results of the analysis calculated by the program.

Summary of Input Information

The top portion of the "Results" tab summarizes inputs from the general and vehicle type tabs such as the pipeline/vehicle information, pipe geometry, soil characteristics, and vehicle specifications used in the analysis. The bottom portion of the "Results" tab includes the "Pipeline Regulatory Code" section, which lists the regulatory code, selected by the user, in which the calculated stresses will be compared.

Summary of Output Information

The top portion of the results tab includes the "Location of Maximum Load" output section, which describes where the maximum load occurs.

The bottom portion of the results tab gives the output of the CEPA Surface Loading Calculator program. A description of these results is given below, categorized by section.

Calculated Stress Data

- **Hoop Stress** – components of hoop stress calculated by the program are listed below.
  - Hoop Stress due to:
    - Internal Pressure at MOP.
    - Live Load at Zero Pressure.
    - Live Load at MOP.
  - Total Hoop Stress at Zero Pressure.
  - Total Hoop Stress at MOP.
  - Hoop Stress as a percent of SMYS at Zero Pressure.
  - Hoop Stress as a percent of SMYS at MOP.
- **Longitudinal Stress** – components of longitudinal stress calculated by the program are listed below.
  - Longitudinal Stress due to:
    - Live Load at Zero Pressure
    - Live Load at MOP.
  - Total Longitudinal Stress at Zero Pressure.
  - Total Longitudinal Stress at MOP.
  - Longitudinal Stress as a percent of SMYS at Zero Pressure.
  - Longitudinal Stress as a percent of SMYS at MOP.
- **Equivalent Stress** – equivalent stresses calculated by the program are listed below.
  - Equivalent Stress at Zero Pressure.
  - Equivalent Stress at MOP.
  - Equivalent Stress as a percent of SMYS at Zero Pressure.
  - Equivalent Stress as a percent of SMYS at MOP.

Pass/Fail

- This section lists whether each calculated stress passes or fails as compared to the allowable stress limits provided in the pipeline regulatory code selected by the user.

QUICK REFERENCE INFORMATION

"Variable Tables" tab

The sole purpose of the "Variable Tables" tab is to provide the user with a quick reference to common tables utilized when calculating surface loads. The tables included on this tab are not intended to be an all-encompassing list of variable values. The user should determine whether the use of these tables is appropriate for their specific situation.

"API RP 1102 Fatigue Table" tab

The table on this tab is reproduced courtesy of the American Petroleum Institute. Kiefner & Associates, Inc., is grateful to the American Petroleum Institute for granting permission as of 15 January 2013 for the reproduction of Table 3- Fatigue Endurance Limits, SFG and SFL, for Various Steel Grades from API RP 1102, 6th edition, April 1993 Reaffirmed July 2002: Steel Pipelines Crossing Railroads and Highways. The purpose of this tab is to provide the user with a quick reference to the aforementioned table when assessing scenarios where surface loading is expected to be frequent and fatigue must be considered.

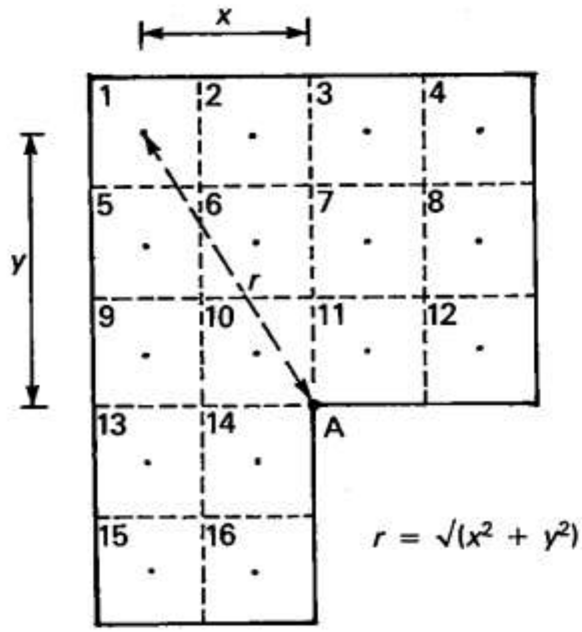
APPENDIX A – ADVANCED USER INSTRUCTIONS FOR USING THE "GRID INPUT" TAB

The "Grid INPUT" tab (or Advanced User tab) was created to allow the user to define a grid of point loads matching the layout of their particular vehicle, instead of using one of the calculator's default vehicle layouts. This tab enables the user to make a vehicle point load grid as simple or as complex as desired. This tab also allows the user to analyze a single axle on a particular vehicle or can be used for surcharge loads.

The four components of the grid input tab are the: "Measurement Point X-Y-coordinates", "Load (point load)" value and its associated "X-coordinate" and "Y-coordinate".

1. START by creating a grid of point loads within each contact area of the vehicle wheels/tracks that represents the layout of the overall vehicle.
    a. NOTE: This could consist of a single point load located at the center of each wheel/track in the vehicle layout or it could be more complex and consist of many point loads distributed equally throughout the contact area of each wheel/track of the vehicle layout to mimic a surface pressure. See Figure 1 which shows the relation between Measurement Point "A" and the point loads at the center of each grid within the entire grid area.
    b. Each point load in a vehicle grid must be defined on the "Grid INPUT" tab by entering a value for "Load" (point load), "X" (which is the x-coordinate of the point load), and "Y" (which is the y-coordinate of the point load) in the respective input columns.
    c. NOTE: The reference origin, where (x, y) = (0, 0), is relative and its placement is user defined. It is essential that the reference origin remain the same for all coordinates utilized in the Grid INPUT tab analysis.
2. NEXT the user must enter the coordinates for the Measurement Point (i.e. the location where the user wishes the program to calculate the pressure exerted on the surface of the pipe due to the vehicle load).
3. THEN after the point load grid and the measurement point coordinates have been entered, CLICK the "CALCULATE: Vehicle Grid Input" button to run the program.
    a. NOTE: ALL columns, "Load", "X", and "Y" <u>MUST</u> contain a value for <u>EACH</u> point load, otherwise the program will return an error.
    b. <u>IMPORTANT:</u> As noted on the "Grid INPUT" tab, a "Run-time error '13': Type mismatch" error will occur if one of the user inputs is non-numeric. If this error occurs, the user will need to find the non-numeric input and correct it to a numeric value in order to run the program.
4. LASTLY the program will automatically bring up the "Results" tab when it is finished running.

Figure 1: Grid point load relation to Measurement Point "A"



(b)

APPENDIX B – LIST OF WORKSHEETS AND FUNCTIONS

1. **General INPUT**
2. **Wheel Vehicle INPUT**
    a. **CALCULATE: Wheel Vehicle (2-Axles)**
3. **Wheel Vehicle 3-Axle INPUT**
    a. **CALCULATE: Wheel Vehicle (3-Axles)**
4. **Track Vehicle INPUT**
    a. **CALCULATE: Track Vehicle**
5. **Grid INPUT**
    a. **CALCULATE: Vehicle Grid Input**
6. **Results**
7. **Variable Tables**
8. **API RP 1102 Fatigue Table**

APPENDIX C – EXAMPLE ANALYSES

Example 1 and Example 2 both involve the scenario of crossing Pipeline A, described hereafter, except with two different types of construction equipment. Example 3 involves the scenario of crossing Pipeline B, described later, with a third type of construction equipment.

Pipeline A runs parallel to a major interstate highway which is under construction. The operator of Pipeline A has been contacted by the project manager overseeing the highway construction to inquire whether a couple different types of construction equipment will be able to safely cross the line. Pipeline A is a liquids line consisting of 16-inch outside diameter, 0.500-inch wall thickness, API Grade X42 pipe with a maximum operating pressure (MOP) of 1,074 psig. The line is buried 6.667-feet (80-inches) deep in a fine-grained soil with a density of 120-lb/ft^3. The soil compaction is 90%. The temperature differential, and bedding angle are unknown for this line.

Example 1 Scenario – Wheel Vehicle (3-Axle) crossing Pipeline A

Example 1 involves the scenario of Pipeline A being crossed by a Caterpillar D400 Articulated Dump Truck. This off-road piece of construction equipment has a total loaded vehicle weight of 141,776-lbs, which is distributed across its three axles as follows: Front Axle 48,204-lbs, Center Axle 46,786-lbs, and Rear Axle 46,786-lbs. Specifications from the manufacturer confirm the axle width is 8.3-feet, while the axle separation between the front and center axles is 16-feet, and between the center and rear axles is 7.6-feet. All tires on the dump truck are the same size. The tire contact width is 30-inches and the tire pressure is 50-psi.

General Inputs – Example 1:

General Input for Surface Loading Calculations

PIPELINE INFORMATION:	Pipeline A
PIPELINE LOCATION:	Parallel to Interstate Highway
DATE:	11/14/13 10:37 AM

SELECT UNITS:	(●) **English**	( ) **Metric**

PIPE INPUT DATA			Variable Description	Notes
D =	16	inches	<----- Outside Diameter	
t =	0.5	inches	<----- Wall Thickness	
$P_{internal}$ =	1074	psig	<----- Maximum Operating Pressure	
SMYS =	42,000	psi	<----- Specified Minimum Yield Strength	
ΔT =	20	°F	<----- Temperature Differential ($T_{installed}$ - $T_{operating}$) --------->	See NOTE #1

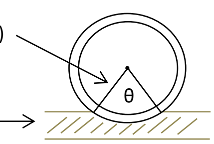
SOIL INPUT DATA			Variable Description	Notes
ρ =	120	lb/ft^3	<----- Soil Density	
H =	6.667	ft	<----- Depth of Cover	

Bedding Angle (θ):

θ =
- ( ) 0 degrees
- (●) 30 degrees
- ( ) 60 degrees
- ( ) 90 degrees
- ( ) 120 degrees
- ( ) 150 degrees
- ( ) 180 degrees

<----- Bedding Angle (degrees)

Soil (Pipe Bedding)



Modulus of Soil Reaction (E'):

( ) User Defined:

E' = N/A psi

<----- Modulus of Soil Reaction (Defined by User)

(●) Calculated from Lookup Tables:

<----- Modulus of Soil Reaction (Calculated from tables)

Soil Type:
- (●) Fine-grained with less than 25% sand content
- ( ) Coarse-grained with fines
- ( ) Coarse-grained with little or no fines

Soil Compaction:
- ( ) 80%
- (●) 90%
- ( ) 95%
- ( ) 100%

Select Soil Load Equation:
- (●) Prism Load Equation
- ( ) Trap Door Equation

ϕ = N/A degrees

<----- Angle of Shearing Resistance (Friction Angle) ------> See NOTE #2

MISCELLANEOUS INPUT	Variable Description	Notes
Impact Factor (IF):		
Vehicle Type:	<----- Vehicle Type: Used to determine Impact Factor	
○ Highway Vehicle (i.e. Semi-truck)	<----- Vehicles with high-pressure tires --------------------->	See NOTE #3
◉ Farm/Construction Equipment (i.e. Vehicle with large, off-road tires)	<----- Vehicles with low-pressure tires ---------------------->	See NOTE #4
○ Track Vehicle (i.e. Dozer or Excavator)	<----- Track Vehicles with steel or rubber tracks	
Pavement Type:	<----- Pavement Type: Used to determine Impact Factor	
○ Rigid Pavement (i.e. Concrete)		
◉ Flexible Pavement (i.e. Asphalt, Gravel, or Bare Soil)		
Select Equivalent Stress Equation:		
◉ Tresca Equation	<----- MORE conservative Equivalent stress equation	
○ Von Mises Equation	<----- LESS conservative Equivalent stress equation	
Select Pipeline Regulatory Code:		
◉ B31.4	<----- ASME Code for Liquid Pressure Piping (2012) ------->	See NOTE #5
○ B31.8	<----- ASME Code for Gas Pressure Piping (2010) ----------->	See NOTE #5
○ CSA-Z662	<----- CSA Code for Oil and Gas Pipeline Systems (2011) --->	See NOTE #6
○ User Defined Pipeline Stress Limits:	<----- Pipeline stress limits manually input by user -------->	See NOTE #7
$\sigma_{Hoop\_\%SMYS}$ = N/A		
$\sigma_{Longitudinal\_\%SMYS}$ = N/A		
$\sigma_{Equivalent\_\%SMYS}$ = N/A		

NOTE #1: 20°F or 11.1°C are DEFAULT values and should only be used if the actual temperature differential is unknown.

NOTE #2: To remain conservative when utilizing the Trap Door Equation, the program assumes soil cohesion is equal to zero.

NOTE #3: Tire pressures GREATER THAN OR EQUAL TO 30 psi should be considered high-pressure tires when using this calculator.

NOTE #4: Tire pressures LESS THAN 30 psi should be considered low-pressure tires when using this calculator.

NOTE #5: Pipeline stress limits programmed into this calculator are based on the current versions of the ASME codes. Future revisions to these codes will require the programming for this calculator to be modified in order to maintain proper functionality in accoordance with the latest versions of the ASME pipeline codes.

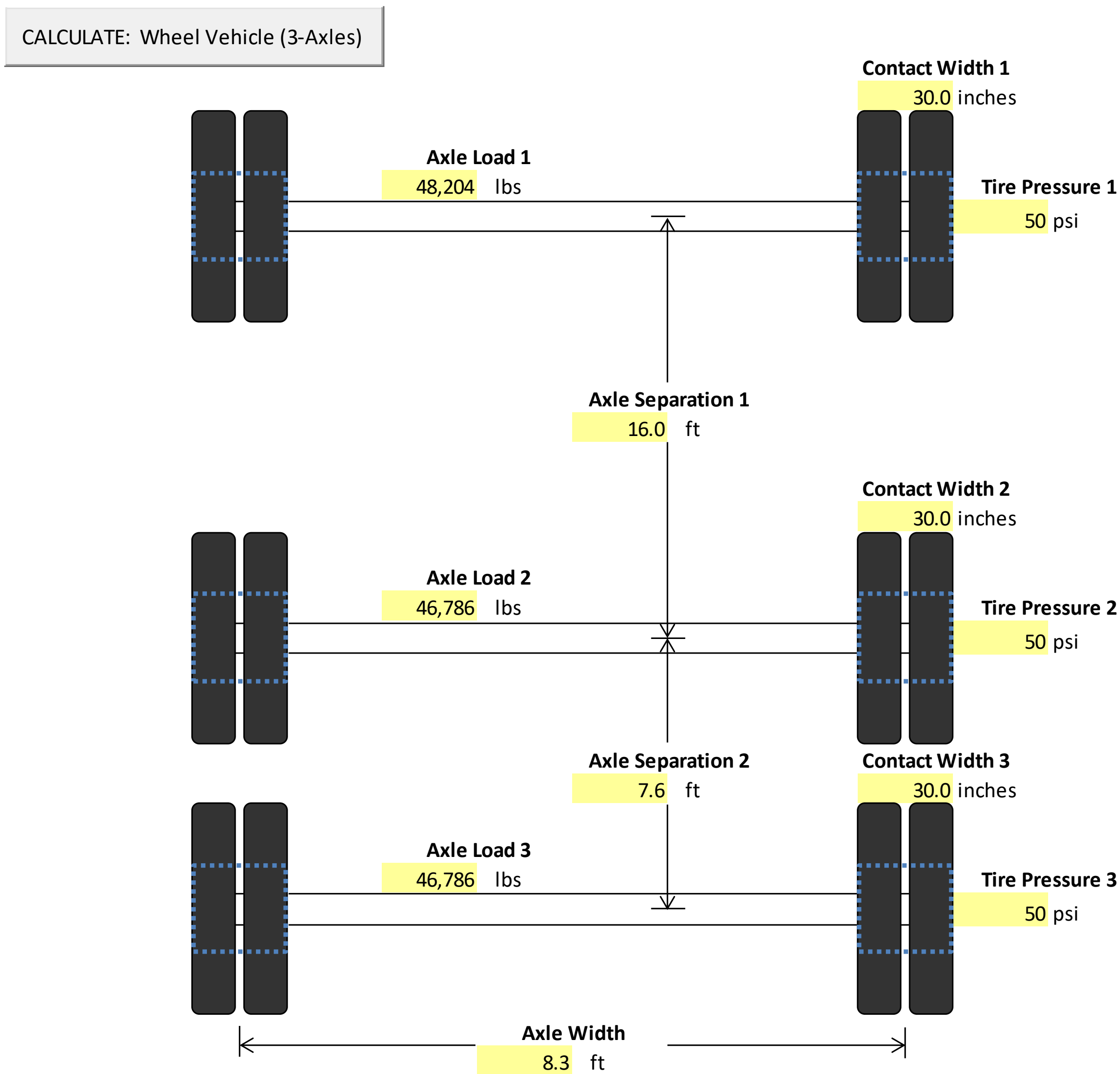
NOTE #6: The Canadian Standards Association (CSA) recommends in CSA-Z662 that the pipeline owner/operator develop stress limits for their specific pipeline based on the design requirements set forth in the CSA-Z662 code. However, if these limits are unknown, the user may select the "CSA-Z662" pipeline regulatory code, which has the following default stress limits: σ_{Hoop} = 0.9 SMYS, $\sigma_{Longitudinal}$ = 0.9 SMYS, and $\sigma_{Equivalent}$ = 0.9 SMYS.

NOTE #7: Stress Limits defined by user must be entered in terms of percent SMYS (i.e. a stress limit of 90% should be entered as 0.9).

Vehicle Inputs – Example 1:

Input for Surface Vehicle Live Load

VEHICLE INFORMATION:	Caterpillar D400 Articulated Dump Truck
VEHICLE TYPE:	Wheel: 3-Axles, 6-Wheels



GENERAL NOTES:

- Loading configuration should always be perpendicular to pipeline.
- Dual tires as seen on pick-up and semi-trucks can be treated as a single tire due to their close proximity to one another.

Results – Example 1:

Results for Surface Loading Calculation

PIPELINE INFORMATION:	Pipeline A
PIPELINE LOCATION:	Parallel to Interstate Highway
VEHICLE INFORMATION:	Caterpillar D400 Articulated Dump Truck
VEHICLE TYPE:	Wheel: 3-Axles, 6-Wheels
DATE:	11/14/2013 10:54

GENERAL INPUTS

D =	16 inches	(Outside Diameter)
t =	0.5 inches	(Wall Thickness)
$P_{internal}$ =	1074 psig	(Maximum Operating Pressure)
SMYS =	42000 psi	(Specified Minimum Yield Strength)
ΔT =	20 °F	(Temperature Differential)
ρ =	120 lb/ft^3	(Density)
H =	6.667 ft	(Depth of Cover)
θ =	30 degrees	(Bedding Angle)
E' =	N/A psi	(Modulus of Soil Reaction)
IF =	1.20	(Impact Factor)
Soil Load Equation:	Prism Load Equation	
ϕ =	N/A degrees	
Equivalent Stress Equation:	Tresca Equation	

VEHICLE INPUTS

Axle or Track Separation 1 :	16 ft
Axle Separation 2 :	7.6 ft
Axle Width :	8.3 ft
Track Length :	N/A ft
Axle 1 or Track Vehicle Load :	48204 lbs
Contact Width 1 :	30 inches
Tire Pressure 1 :	50 psi
Axle Load 2 :	46786 lbs
Contact Width 2 :	30 inches
Tire Pressure 2 :	50 psi
Axle Load 3 :	46786 lbs
Contact Width 3 :	30 inches
Tire Pressure 3 :	50 psi
Measurement Point X-coord :	N/A inches
Measurement Point Y-coord :	N/A inches

LOCATION OF MAXIMUM LOAD

The maximum pressure exerted on the surface of the pipe due to vehicle point load occurs:

Under the middle tires.

CALCULATED STRESS DATA		Variable Description	Pipeline Regulatory Code	Pass / Fail
Hoop Stress (σ_H):				
$\sigma_{H\_Internal\_MOP}$ =	17184 psi	<----- Internal Pressure @ MOP		
$\sigma_{H\_Live\_Zero}$ =	1708 psi	<----- Live Load @ Zero pressure		
$\sigma_{H\_Live\_MOP}$ =	1268 psi	<----- Live Load @ MOP		
$\sigma_{H\_Total\_Zero}$ =	5367 psi	<----- Total Hoop Stress @ Zero pressure		
$\sigma_{H\_Total\_MOP}$ =	21169 psi	<----- Total Hoop Stress @ MOP		
$\sigma_{H\_\%SMYS\_Zero}$ =	12.8%	<----- Hoop Stress %SMYS @ Zero pressure	ASME B31.4-2012	**PASS**
$\sigma_{H\_\%SMYS\_MOP}$ =	50.4%	<----- Hoop Stress %SMYS @ MOP	ASME B31.4-2012	**PASS**
Longitudinal Stress (σ_L):				
$\sigma_{L\_Live\_Zero}$ =	1658 psi	<----- Live Load @ Zero pressure		
$\sigma_{L\_Live\_MOP}$ =	1516 psi	<----- Live Load @ MOP		
$\sigma_{L\_Total\_Zero}$ =	6656 psi	<----- Total Longitudinal Stress @ Zero pressure		
$\sigma_{L\_Total\_MOP}$ =	11386 psi	<----- Total Longitudinal Stress @ MOP		
$\sigma_{L\_\%SMYS\_Zero}$ =	15.8%	<----- Longitudinal Stress %SMYS @ Zero pressure	ASME B31.4-2012	**PASS**
$\sigma_{L\_\%SMYS\_MOP}$ =	27.1%	<----- Longitudinal Stress %SMYS @ MOP	ASME B31.4-2012	**PASS**
Equivalent Stress (σ_E):				
σ_{E_Zero} =	12023 psi	<----- Equivalent Stress @ Zero pressure		
σ_{E_MOP} =	21169 psi	<----- Equivalent Stress @ MOP		
$\sigma_{E\_\%SMYS\_Zero}$ =	28.6%	<----- Equivalent Stress %SMYS @ Zero pressure	ASME B31.4-2012	**PASS**
$\sigma_{E\_\%SMYS\_MOP}$ =	50.4%	<----- Equivalent Stress %SMYS @ MOP	ASME B31.4-2012	**PASS**

GENERAL NOTES:

- Please refer to "Table 3-Fatigue Endurance Limits, S_{FG} and S_{FL}, for Various Steel Grades" on page 18 in API Recommended Practice 1102 when performing fatigue check calculations.

Example 2 Scenario – Track Vehicle crossing Pipeline A

Example 2 involves the scenario of Pipeline A being crossed by a Komatsu Hydraulic Excavator PC400 Trackhoe. This off-road piece of construction equipment has a total vehicle operating weight of 93,916-lbs, which is equally distributed across its two tracks. Specifications from the manufacturer confirm the track separation is 9-feet, while the track ground contact length is 14.3-feet. The width of each vehicle track is 27.6-inches.

General Inputs – Example 2:

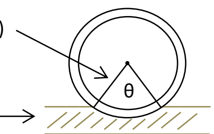
General Input for Surface Loading Calculations

PIPELINE INFORMATION:	Pipeline A
PIPELINE LOCATION:	Parallel to Interstate Highway
DATE:	11/14/13 11:03 AM

SELECT UNITS:	(●) **English**	( ) **Metric**

PIPE INPUT DATA	Variable Description	Notes
D = 16 inches	<----- Outside Diameter	
t = 0.5 inches	<----- Wall Thickness	
$P_{internal}$ = 1074 psig	<----- Maximum Operating Pressure	
SMYS = 42,000 psi	<----- Specified Minimum Yield Strength	
ΔT = 20 °F	<----- Temperature Differential ($T_{installed}$ - $T_{operating}$) --------->	See NOTE #1

SOIL INPUT DATA	Variable Description	Notes
ρ = 120 lb/ft^3	<----- Soil Density	
H = 6.667 ft	<----- Depth of Cover	
Bedding Angle (θ): θ = ( ) 0 degrees, (●) 30 degrees, ( ) 60 degrees, ( ) 90 degrees, ( ) 120 degrees, ( ) 150 degrees, ( ) 180 degrees	<----- Bedding Angle (degrees) Soil (Pipe Bedding)	
Modulus of Soil Reaction (E'): ( ) User Defined: E' = N/A psi	<----- Modulus of Soil Reaction (Defined by User)	
(●) Calculated from Lookup Tables:	<----- Modulus of Soil Reaction (Calculated from tables)	
Soil Type: (●) Fine-grained with less than 25% sand content; ( ) Coarse-grained with fines; ( ) Coarse-grained with little or no fines		
Soil Compaction: ( ) 80%; (●) 90%; ( ) 95%; ( ) 100%		
Select Soil Load Equation: (●) Prism Load Equation; ( ) Trap Door Equation		
ϕ = N/A degrees	<----- Angle of Shearing Resistance (Friction Angle) ------>	See NOTE #2



MISCELLANEOUS INPUT	Variable Description	Notes
Impact Factor (IF):		
Vehicle Type:	<----- Vehicle Type: Used to determine Impact Factor	
( ) Highway Vehicle (i.e. Semi-truck)	<----- Vehicles with high-pressure tires --------------------->	See NOTE #3
( ) Farm/Construction Equipment (i.e. Vehicle with large, off-road tires)	<----- Vehicles with low-pressure tires ---------------------->	See NOTE #4
(•) Track Vehicle (i.e. Dozer or Excavator)	<----- Track Vehicles with steel or rubber tracks	
Pavement Type:	<----- Pavement Type: Used to determine Impact Factor	
( ) Rigid Pavement (i.e. Concrete)		
(•) Flexible Pavement (i.e. Asphalt, Gravel, or Bare Soil)		
Select Equivalent Stress Equation:		
(•) Tresca Equation	<----- MORE conservative Equivalent stress equation	
( ) Von Mises Equation	<----- LESS conservative Equivalent stress equation	
Select Pipeline Regulatory Code:		
(•) B31.4	<----- ASME Code for Liquid Pressure Piping (2012) ------->	See NOTE #5
( ) B31.8	<----- ASME Code for Gas Pressure Piping (2010) ----------->	See NOTE #5
( ) CSA-Z662	<----- CSA Code for Oil and Gas Pipeline Systems (2011) --->	See NOTE #6
( ) User Defined Pipeline Stress Limits:	<----- Pipeline stress limits manually input by user -------->	See NOTE #7
$\sigma_{Hoop\_\%SMYS}$ = N/A		
$\sigma_{Longitudinal\_\%SMYS}$ = N/A		
$\sigma_{Equivalent\_\%SMYS}$ = N/A		

NOTE #1: 20°F or 11.1°C are DEFAULT values and should only be used if the actual temperature differential is unknown.

NOTE #2: To remain conservative when utilizing the Trap Door Equation, the program assumes soil cohesion is equal to zero.

NOTE #3: Tire pressures GREATER THAN OR EQUAL TO 30 psi should be considered high-pressure tires when using this calculator.

NOTE #4: Tire pressures LESS THAN 30 psi should be considered low-pressure tires when using this calculator.

NOTE #5: Pipeline stress limits programmed into this calculator are based on the current versions of the ASME codes. Future revisions to these codes will require the programming for this calculator to be modified in order to maintain proper functionality in accoordance with the latest versions of the ASME pipeline codes.

NOTE #6: The Canadian Standards Association (CSA) recommends in CSA-Z662 that the pipeline owner/operator develop stress limits for their specific pipeline based on the design requirements set forth in the CSA-Z662 code. However, if these limits are unknown, the user may select the "CSA-Z662" pipeline regulatory code, which has the following default stress limits:
σ_{Hoop} = 0.9 SMYS, $\sigma_{Longitudinal}$ = 0.9 SMYS, and $\sigma_{Equivalent}$ = 0.9 SMYS.

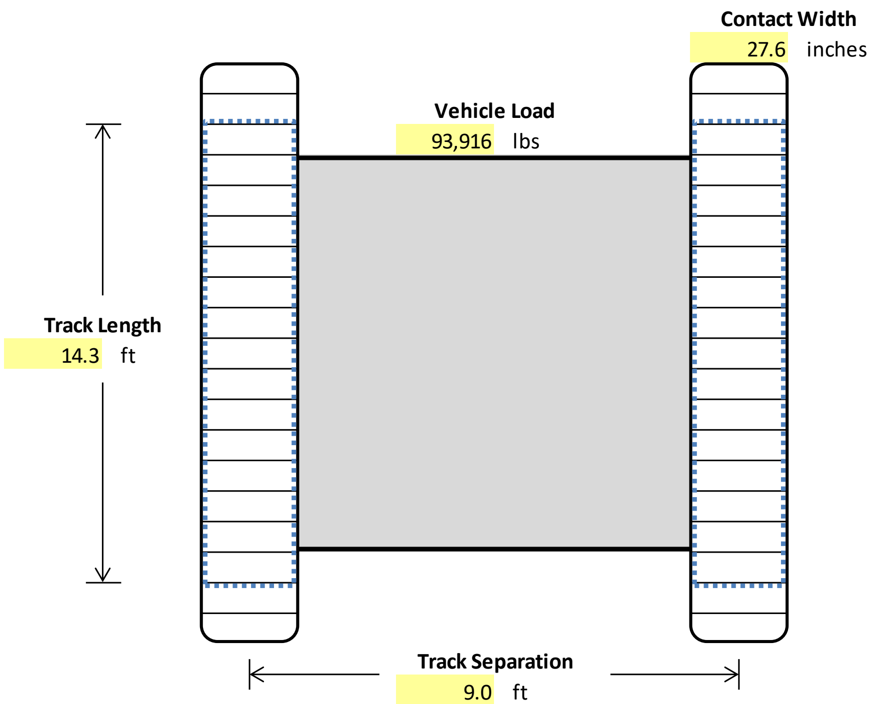
NOTE #7: Stress Limits defined by user must be entered in terms of percent SMYS (i.e. a stress limit of 90% should be entered as 0.9).

Vehicle Inputs – Example 2:

Input for Surface Vehicle Live Load

VEHICLE INFORMATION:	Komatsu Hydraulic Excavator PC400 Trackhoe
VEHICLE TYPE:	Track

CALCULATE: Track Vehicle



GENERAL NOTES:

- Loading configuration should always be perpendicular to pipeline.

Results – Example 2:

Results for Surface Loading Calculation

PIPELINE INFORMATION:	Pipeline A
PIPELINE LOCATION:	Parallel to Interstate Highway
VEHICLE INFORMATION:	Komatsu Hydraulic Excavator PC400 Trackhoe
VEHICLE TYPE:	Track
DATE:	11/14/2013 11:09

GENERAL INPUTS				VEHICLE INPUTS			LOCATION OF MAXIMUM LOAD
D =	16	inches	(Outside Diameter)	Axle or Track Separation 1 :	9	ft	The maximum pressure exerted on the surface of the pipe due to vehicle point load occurs:
t =	0.5	inches	(Wall Thickness)	Axle Separation 2 :	N/A	ft	
$P_{internal}$ =	1074	psig	(Maximum Operating Pressure)	Axle Width :	N/A	ft	
SMYS =	42000	psi	(Specified Minimum Yield Strength)	Track Length :	14.3	ft	
ΔT =	20	°F	(Temperature Differential)	Axle 1 or Track Vehicle Load :	93916	lbs	
ρ =	120	lb/ft^3	(Density)	Contact Width 1 :	27.6	inches	**Under the tracks of the vehicle.**
H =	6.667	ft	(Depth of Cover)	Tire Pressure 1 :	N/A	psi	
θ =	30	degrees	(Bedding Angle)	Axle Load 2 :	N/A	lbs	
E' =	N/A	psi	(Modulus of Soil Reaction)	Contact Width 2 :	N/A	inches	
IF =	1.45		(Impact Factor)	Tire Pressure 2 :	N/A	psi	
Soil Load Equation:	Prism Load Equation			Axle Load 3 :	N/A	lbs	
ϕ =	N/A	degrees		Contact Width 3 :	N/A	inches	
Equivalent Stress Equation:	Tresca Equation			Tire Pressure 3 :	N/A	psi	
				Measurement Point X-coord :	N/A	inches	
				Measurement Point Y-coord :	N/A	inches	

CALCULATED STRESS DATA			Variable Description	Pipeline Regulatory Code	Pass / Fail
Hoop Stress (σ_H):					
$\sigma_{H\_Internal\_MOP}$ =	17184	psi	<----- Internal Pressure @ MOP		
$\sigma_{H\_Live\_Zero}$ =	2032	psi	<----- Live Load @ Zero pressure		
$\sigma_{H\_Live\_MOP}$ =	1509	psi	<----- Live Load @ MOP		
$\sigma_{H\_Total\_Zero}$ =	5691	psi	<----- Total Hoop Stress @ Zero pressure		
$\sigma_{H\_Total\_MOP}$ =	21410	psi	<----- Total Hoop Stress @ MOP		
$\sigma_{H\_\%SMYS\_Zero}$ =	13.6%		<----- Hoop Stress %SMYS @ Zero pressure	ASME B31.4-2012	**PASS**
$\sigma_{H\_\%SMYS\_MOP}$ =	51.0%		<----- Hoop Stress %SMYS @ MOP	ASME B31.4-2012	**PASS**
Longitudinal Stress (σ_L):					
$\sigma_{L\_Live\_Zero}$ =	1973	psi	<----- Live Load @ Zero pressure		
$\sigma_{L\_Live\_MOP}$ =	1804	psi	<----- Live Load @ MOP		
$\sigma_{L\_Total\_Zero}$ =	6971	psi	<----- Total Longitudinal Stress @ Zero pressure		
$\sigma_{L\_Total\_MOP}$ =	11674	psi	<----- Total Longitudinal Stress @ MOP		
$\sigma_{L\_\%SMYS\_Zero}$ =	16.6%		<----- Longitudinal Stress %SMYS @ Zero pressure	ASME B31.4-2012	**PASS**
$\sigma_{L\_\%SMYS\_MOP}$ =	27.8%		<----- Longitudinal Stress %SMYS @ MOP	ASME B31.4-2012	**PASS**
Equivalent Stress (σ_E):					
σ_{E_Zero} =	12662	psi	<----- Equivalent Stress @ Zero pressure		
σ_{E_MOP} =	21410	psi	<----- Equivalent Stress @ MOP		
$\sigma_{E\_\%SMYS\_Zero}$ =	30.1%		<----- Equivalent Stress %SMYS @ Zero pressure	ASME B31.4-2012	**PASS**
$\sigma_{E\_\%SMYS\_MOP}$ =	51.0%		<----- Equivalent Stress %SMYS @ MOP	ASME B31.4-2012	**PASS**

GENERAL NOTES:

- Please refer to "Table 3-Fatigue Endurance Limits, S_{FG} and S_{FL}, for Various Steel Grades" on page 18 in API Recommended Practice 1102 when performing fatigue check calculations.

Example 3 Scenario – Drum Roller (Grid INPUT) Vehicle crossing Pipeline B

Pipeline B runs parallel to a rural road which is in the process of being re-paved. The operator of Pipeline B has been contacted by the project manager overseeing the paving to inquire whether a drum roller being used on the project will be able to safely cross the line. Pipeline B is a liquids line consisting of 6.625-inch outside diameter, 0.188-inch wall thickness, API Grade B pipe with a maximum operating pressure (MOP) of 720 psig. The line is buried 2.667-feet (32-inches) deep in a coarse-grained soil with a density of 120-lb/ft^3. The soil compaction is 95%. The temperature differential is 12°F, and the bedding angle is 60 degrees for this line.

Example 3 involves the scenario of Pipeline B being crossed by an Ingersoll Rand SD45 Vibratory Smooth Drum Roller. This piece of construction equipment has a total vehicle operating weight of 10,598-lbs, which is distributed across its axles as follows: Drum Axle 5,399-lbs, and Tire Axle 5,199-lbs. Specifications from the manufacturer confirm the tire axle width is 5.2-feet, the drum axle width is 4.5-feet, and the axle separation is 6-feet. The tire contact width is 12-inches. In this example, the point under the center of the drum roller has been selected as measurement point to perform the surface loading analysis. The coordinates for this measurement point are (x, y) = (0, 48), which are relative to the origin (0, 0), which was arbitrarily placed at the center of the vehicle.

General Inputs – Example 3:

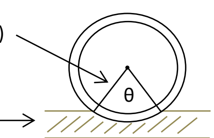
General Input for Surface Loading Calculations

PIPELINE INFORMATION:	Pipeline B
PIPELINE LOCATION:	Parallel to Rural Road
DATE:	11/14/13 1:37 PM

SELECT UNITS:	(•) English	( ) Metric

PIPE INPUT DATA	Variable Description	Notes
D = 6.625 inches	<----- Outside Diameter	
t = 0.188 inches	<----- Wall Thickness	
$P_{internal}$ = 720 psig	<----- Maximum Operating Pressure	
SMYS = 35,000 psi	<----- Specified Minimum Yield Strength	
ΔT = 12 °F	<----- Temperature Differential ($T_{installed}$ - $T_{operating}$) --------->	See NOTE #1

SOIL INPUT DATA	Variable Description	Notes
ρ = 120 lb/ft^3	<----- Soil Density	
H = 2.667 ft	<----- Depth of Cover	
Bedding Angle (θ): θ = ( ) 0 degrees, ( ) 30 degrees, (•) 60 degrees, ( ) 90 degrees, ( ) 120 degrees, ( ) 150 degrees, ( ) 180 degrees	<----- Bedding Angle (degrees) Soil (Pipe Bedding)	
Modulus of Soil Reaction (E'): ( ) User Defined: E' = N/A psi	<----- Modulus of Soil Reaction (Defined by User)	
(•) Calculated from Lookup Tables: Soil Type: ( ) Fine-grained with less than 25% sand content; (•) Coarse-grained with fines; ( ) Coarse-grained with little or no fines. Soil Compaction: ( ) 80%; ( ) 90%; (•) 95%; ( ) 100%	<----- Modulus of Soil Reaction (Calculated from tables)	
Select Soil Load Equation: (•) Prism Load Equation; ( ) Trap Door Equation; ϕ = N/A degrees	<----- Angle of Shearing Resistance (Friction Angle) ------>	See NOTE #2



MISCELLANEOUS INPUT	Variable Description	Notes
Impact Factor (IF):		
Vehicle Type:	<----- Vehicle Type: Used to determine Impact Factor	
○ Highway Vehicle (i.e. Semi-truck)	<----- Vehicles with high-pressure tires --------------------->	See NOTE #3
◉ Farm/Construction Equipment (i.e. Vehicle with large, off-road tires)	<----- Vehicles with low-pressure tires ---------------------->	See NOTE #4
○ Track Vehicle (i.e. Dozer or Excavator)	<----- Track Vehicles with steel or rubber tracks	
Pavement Type:	<----- Pavement Type: Used to determine Impact Factor	
○ Rigid Pavement (i.e. Concrete)		
◉ Flexible Pavement (i.e. Asphalt, Gravel, or Bare Soil)		
Select Equivalent Stress Equation:		
◉ Tresca Equation	<----- MORE conservative Equivalent stress equation	
○ Von Mises Equation	<----- LESS conservative Equivalent stress equation	
Select Pipeline Regulatory Code:		
◉ B31.4	<----- ASME Code for Liquid Pressure Piping (2012) ------->	See NOTE #5
○ B31.8	<----- ASME Code for Gas Pressure Piping (2010) ----------->	See NOTE #5
○ CSA-Z662	<----- CSA Code for Oil and Gas Pipeline Systems (2011) --->	See NOTE #6
○ User Defined Pipeline Stress Limits:	<----- Pipeline stress limits manually input by user -------->	See NOTE #7
$\sigma_{Hoop\_\%SMYS}$ = N/A		
$\sigma_{Longitudinal\_\%SMYS}$ = N/A		
$\sigma_{Equivalent\_\%SMYS}$ = N/A		

NOTE #1: 20°F or 11.1°C are DEFAULT values and should only be used if the actual temperature differential is unknown.

NOTE #2: To remain conservative when utilizing the Trap Door Equation, the program assumes soil cohesion is equal to zero.

NOTE #3: Tire pressures GREATER THAN OR EQUAL TO 30 psi should be considered high-pressure tires when using this calculator.

NOTE #4: Tire pressures LESS THAN 30 psi should be considered low-pressure tires when using this calculator.

NOTE #5: Pipeline stress limits programmed into this calculator are based on the current versions of the ASME codes. Future revisions to these codes will require the programming for this calculator to be modified in order to maintain proper functionality in accoordance with the latest versions of the ASME pipeline codes.

NOTE #6: The Canadian Standards Association (CSA) recommends in CSA-Z662 that the pipeline owner/operator develop stress limits for their specific pipeline based on the design requirements set forth in the CSA-Z662 code. However, if these limits are unknown, the user may select the "CSA-Z662" pipeline regulatory code, which has the following default stress limits: σ_{Hoop} = 0.9 SMYS, $\sigma_{Longitudinal}$ = 0.9 SMYS, and $\sigma_{Equivalent}$ = 0.9 SMYS.

NOTE #7: Stress Limits defined by user must be entered in terms of percent SMYS (i.e. a stress limit of 90% should be entered as 0.9).

Vehicle Inputs – Example 3:

Input for Surface Vehicle Live Load

VEHICLE INFORMATION:	Ingersoll Rand SD45 Vibratory Smooth Drum Roller
VEHICLE TYPE:	Drum Front Axle with Tire Rear Axle

CALCULATE: Vehicle Grid Input

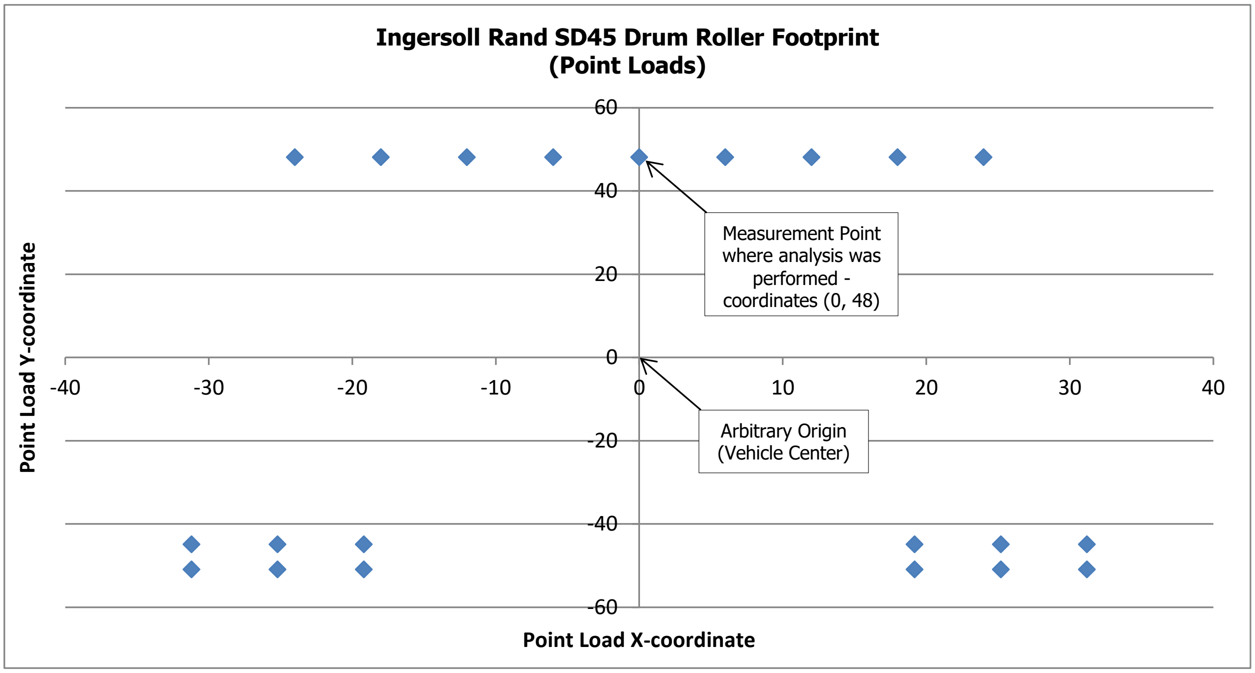
Measurement Point X-coordinate, in:	0.0
Measurement Point Y-coordinate, in:	48.0

GENERAL NOTES:
- A "Run-time error '13' : Type mismatch" error indicates that one of the user inputs in the "Load", "X", or "Y" columns is non-numeric. This input must be corrected to a numeric value for the program to function properly.

Load, lbs	X, in	Y, in
599.8889	-24	48
599.8889	-18	48
599.8889	-12	48
599.8889	-6	48
599.8889	0	48
599.8889	6	48
599.8889	12	48
599.8889	18	48
599.8889	24	48
216.625	-31.2	-45
216.625	-25.2	-45
216.625	-19.2	-45
216.625	-31.2	-51
216.625	-25.2	-51
216.625	-19.2	-51
216.625	19.2	-45
216.625	25.2	-45
216.625	31.2	-45
216.625	19.2	-51
216.625	25.2	-51
216.625	31.2	-51

Graph of Vehicle Footprint (Point Loads):

Below is a graph of the vehicle footprint (or point loads), which was created to analyze the Ingersoll Rand SD45 Vibratory Smooth Drum Roller vehicle type. The X-Y-coordinates for this graph are given in the above screen capture of the "Grid INPUT" tab. It is important to note that while this specific example decided to analyze the pressure exerted on the surface of the pipe due to the vehicle load that occurs under the drum roller, measurement point (0, 48), any measurement point relative to the arbitrary origin could have been selected and analyzed.



Results – Example 3:

Results for Surface Loading Calculation

PIPELINE INFORMATION:	Pipeline B
PIPELINE LOCATION:	Parallel to Rural Road
VEHICLE INFORMATION:	Ingersoll Rand SD45 Vibratory Smooth Drum Roller
VEHICLE TYPE:	Drum Front Axle with Tire Rear Axle
DATE:	11/14/2013 14:39

GENERAL INPUTS

D =	6.625 inches	(Outside Diameter)
t =	0.188 inches	(Wall Thickness)
$P_{internal}$ =	720 psig	(Maximum Operating Pressure)
SMYS =	35000 psi	(Specified Minimum Yield Strength)
ΔT =	12 °F	(Temperature Differential)
ρ =	120 lb/ft^3	(Density)
H =	2.667 ft	(Depth of Cover)
θ =	60 degrees	(Bedding Angle)
E' =	N/A psi	(Modulus of Soil Reaction)
IF =	1.25	(Impact Factor)
Soil Load Equation:	Prism Load Equation	
ϕ =	N/A degrees	
Equivalent Stress Equation:	Tresca Equation	

VEHICLE INPUTS

Axle or Track Separation 1 :	N/A ft
Axle Separation 2 :	N/A ft
Axle Width :	N/A ft
Track Length :	N/A ft
Axle 1 or Track Vehicle Load :	N/A lbs
Contact Width 1 :	N/A inches
Tire Pressure 1 :	N/A psi
Axle Load 2 :	N/A lbs
Contact Width 2 :	N/A inches
Tire Pressure 2 :	N/A psi
Axle Load 3 :	N/A lbs
Contact Width 3 :	N/A inches
Tire Pressure 3 :	N/A psi
Measurement Point X-coord :	0 inches
Measurement Point Y-coord :	48 inches

LOCATION OF MAXIMUM LOAD

The maximum pressure exerted on the surface of the pipe due to vehicle point load occurs:

N/A: For Grid INPUT tab calculations, the location of the maximum point load is determined manually by the user.

CALCULATED STRESS DATA		Variable Description	Pipeline Regulatory Code	Pass / Fail
Hoop Stress (σ_H):				
$\sigma_{H\_Internal\_MOP}$ =	12686 psi	<----- Internal Pressure @ MOP		
$\sigma_{H\_Live\_Zero}$ =	1207 psi	<----- Live Load @ Zero pressure		
$\sigma_{H\_Live\_MOP}$ =	952 psi	<----- Live Load @ MOP		
$\sigma_{H\_Total\_Zero}$ =	2496 psi	<----- Total Hoop Stress @ Zero pressure		
$\sigma_{H\_Total\_MOP}$ =	14656 psi	<----- Total Hoop Stress @ MOP		
$\sigma_{H\_\%SMYS\_Zero}$ =	7.1%	<----- Hoop Stress %SMYS @ Zero pressure	ASME B31.4-2012	**PASS**
$\sigma_{H\_\%SMYS\_MOP}$ =	41.9%	<----- Hoop Stress %SMYS @ MOP	ASME B31.4-2012	**PASS**
Longitudinal Stress (σ_L):				
$\sigma_{L\_Live\_Zero}$ =	1201 psi	<----- Live Load @ Zero pressure		
$\sigma_{L\_Live\_MOP}$ =	1119 psi	<----- Live Load @ MOP		
$\sigma_{L\_Total\_Zero}$ =	3928 psi	<----- Total Longitudinal Stress @ Zero pressure		
$\sigma_{L\_Total\_MOP}$ =	7570 psi	<----- Total Longitudinal Stress @ MOP		
$\sigma_{L\_\%SMYS\_Zero}$ =	11.2%	<----- Longitudinal Stress %SMYS @ Zero pressure	ASME B31.4-2012	**PASS**
$\sigma_{L\_\%SMYS\_MOP}$ =	21.6%	<----- Longitudinal Stress %SMYS @ MOP	ASME B31.4-2012	**PASS**
Equivalent Stress (σ_E):				
σ_{E_Zero} =	6425 psi	<----- Equivalent Stress @ Zero pressure		
σ_{E_MOP} =	14656 psi	<----- Equivalent Stress @ MOP		
$\sigma_{E\_\%SMYS\_Zero}$ =	18.4%	<----- Equivalent Stress %SMYS @ Zero pressure	ASME B31.4-2012	**PASS**
$\sigma_{E\_\%SMYS\_MOP}$ =	41.9%	<----- Equivalent Stress %SMYS @ MOP	ASME B31.4-2012	**PASS**

GENERAL NOTES:

- Please refer to "Table 3-Fatigue Endurance Limits, S_{FG} and S_{FL}, for Various Steel Grades" on page 18 in API Recommended Practice 1102 when performing fatigue check calculations.