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SINTEF REPORT

TITLE

CARE-S WP2 Load model description

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ABSTRACT

Under the CARE-S project, Computer Aided Rehabilitation of Sewer Networks, the structural condition of sewer pipes is determined and their future condition calculated. Several probabilistic, empirical and deterministic tools are included to define current and future condition. The empirical-deterministic approach includes the assessment of external and internal corrosion depths and the resulting strength of the sewer pipe. The latter is calculated by the Load_model which is described in this report.

The Load_model is a computer program for gravity sewer pipes that calculates stress values in rigid, circular and non-reinforced concrete pipes based on external loads and pipe characteristics. The relation between load and resistance results in a security factor that is translated into reliability for structural failure.

External loads that are considered in the model are soil, traffic, groundwater and additional static surface loads. The resulting stress is calculated in circumferential and longitudinal direction. It is additionally dependent on bedding conditions, side support and unsupported length caused by external soil erosion.

This report contains a mathematical description of the tool, its strengths and limitations and a user guideline to run the tool.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	pipe condition	ledningstilstand
GROUP 2	pipe load	rørlast
SELECTED BY AUTHOR	ring stress	tangentialspenning

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User guide for the Load_model under CARE-S

Tool version number: 1.0.2

Author(s): SINTEF

Date: 2005-09-06

1 General description

The Load_model is a computer program for gravity sewer pipes that calculates stress values in rigid, circular and non-reinforced concrete pipes based on external loads and pipe characteristics. The relation between load and resistance results in a security factor that is translated into reliability for structural failure. Nomenclature and calculation methods used in this model are based on the European standard CEN EN 1295-1.

The Load_model is published either as a stand-alone program or as an integrated facility within the CARE-S software package.

2 Scope of application

A pipe will structurally collapse when its resistance gets lower than the stress inducing external and internal loads. The resistance is based on pipe material, diameter and wall thickness. External loads that are considered in the model are soil, traffic, groundwater and additional static surface loads. Frost load is not included since its effect is very dependent on further factors. Internal loads are water volume and pressure gradients. Pressurized pipes are not considered and internal load from water volume can be neglected in this approach. The resulting stress is calculated in circumferential and longitudinal direction. It is additionally dependent on bedding conditions, side support and unsupported length caused by external soil erosion.

The pipe strength calculation will be based on the initial pipe strength at the time of installation. Combined with the loads, each pipe will have an initial risk factor for structural failure. The weakening factors over time are internal and external corrosion that will reduce wall thickness, weakening of pipe material caused by aging (leaching) and erosion of surrounding filling material that will increase the unsupported length. Two other models under CARE-S are calculating the external and internal corrosion of a pipe and are an essential input for the Load_model. Information from CCTV inspections can be used alternatively or additionally to those models. The reduced wall thickness will then result in a new risk factor for the prediction year chosen by the end user.

3 Strengths and limitations

The tool is designed to take into account the probable data availability at the end user site for sewer assets. The aim is to provide a tool that gives a qualified answer with a minimum of data demands, but the flexibility to model varying conditions.

This is reflected in the editable data for sewer bedding conditions. Construction methods and type and compaction of filling material have changed over the last decades. This will fundamentally influence the stress distribution in the pipe walls and therewith the resistance against structural failure. There is normally very little knowledge of those conditions for older sewers, especially with respect to unsupported lengths caused by soil erosion, which is quite common with leaking pipes. The following parameters are therefore designed to give rough answers to those bedding conditions without special knowledge on each pipe:

- *Unsupported pipe*: The end user can chose 'no' for newer pipes, unlikely to be exposed to soil erosion and a specific length in meter for the most likely unsupported length.
- *Compaction conditions*: A good compaction of filling material helps to lead vertical loads in the soil around a pipe through to friction and deflects therewith part of the load on the pipe. As a very rough rule, the tool asks for the year of construction where the practice of compaction has improved.
- *Bedding conditions*: Basically, the bedding conditions for a pipe can be distinguished into three types: a) The pipe is placed on a level foundation and supported along the bottom line only. b) The pipe is embedded in the foundation and the loads are deflected in a 45 degree angle. c) Additional to embedding, the pipe has a good side support through compaction. A good bedding condition and compaction of filling material will provide a sufficient support around the pipe and prevents an early deformation of the pipe.

Those parameters can be used to perform a sensitivity analysis for the structural strength of a pipe in case the construction conditions are unknown. The effect of trench width and the silo effect are not considered in the calculations due to expected uncertainty of that information.

The calculation of traffic load on a pipe is based on Boussinesq equations, meaning that the earth body above the pipe is regarded as homogenous, isotropic and fully elastic. The traffic is considered as a point load and based on an axle load of 260 kN. The dynamic characteristic of the traffic load is simplified reflected in various coefficients. More advanced calculations could be easily implemented, but would demand a data quality and quantity that does not justify the tool goals.

One of the most important input data is the external and internal corrosion and therewith the remaining wall thickness. Without this data the tool produces only uniform results for the original pipe strength. In case of a missing input, the Load_model provides the possibility to assign a constant corrosion speed in millimetre per year for external and internal corrosion.

Tool version 1.0.2 of the Load_model is aimed at demonstrating the basic functionality of calculation of the load bearing capacity. Some functionalities that will improve user friendliness and increase the flexibility of the tool are planned for the following versions. That includes basically the consideration of heavy traffic and conversion tables for missing values, e.g. wall thickness and construction year.

Degrading cement based pipes are the main problem for most existing sewer networks. The tool focuses therefore on rigid pipes. The extension of the load model with other materials like plastic pipes is reserved for a later version. Other degradation equations will have to be included for this purpose. Most problems with plastic pipes today are related to production and installation flaws.

Load bearing calculations are only applicable for circular pipes in this tool version. Additionally, only gravity sewers are considered since pressure pipes for pumping lines consist of other material. Internal pipe pressure is therefore not considered either. Internal water load can be

neglected compared to the external loads. For future extensions of the model, the data input file is already prepared for the coming versions of the Load_model.

4 Mathematical description

External and internal loads are causing tangential and axial stress in the pipe wall. Tangential stress, or ring or hoop stress, is caused by earth load, traffic load, additional surface load, groundwater and frost load as external loads and water pressure and water load as internal loads. Depending on the characteristics of the surrounding soil and the pipe, those loads can not be simply added and compared to the strength of the pipe. The performance limit of a pipe is basically a deformation rather than a stress. For rigid pipes, the stress theory provides an acceptable analysis.

4.1 Loads resulting in ring stress

4.1.1 Soil load

Calculation of earth load is based on the Marston theory and modified by Sprangler to include the impact of side fill compaction and arching action of the soil above the pipe. The empiric formulas have been adapted to Norwegian conditions by Vaslestad in 1990.

The calculation of soil load is based on wide trenches without an effect of trench walls on the pipe directly or via filling material. It includes the weight of the earth column above the pipe and an arching effect through soil friction along the surrounding masses.

In case of a good compaction of the filling material, the pipe will receive side support and ring stress is deflected to the soil through deformation. The Load_model distinguishes therefore between two cases for the calculation of the soil load, with and without side support. Since this information is not expected to be available for individual pipes the Load_model asks for an installation year from which on the quality of installation has improved and the filling material has been compacted.

The following equations are used:

$$(1) \quad Q_s = \gamma \cdot d_e^2 (1.624 \cdot h_0/d_e - 0,690) \quad \text{without side support}$$

$$(2) \quad Q_s = \gamma \cdot d_e^2 (1.157 \cdot h_0/d_e - 0,477) \quad \text{with side support}$$

With Q_s : soil load [kN/m]
 γ : unit weight [kg/m³]
 h_0 : pipe depth to top of the pipe [m]
 d_e : external diameter [m]

Additional static surface load per unit area is calculated as equivalent to soil load of a certain height. This case is not expected to be a separate input to CARE-S and should therefore be added to soil load by data pre-processing.

4.1.2 Traffic load

For calculation of traffic load on the pipe, the surrounding soil is taken as homogeneous, isotropic and elastic as a presumption for using the elasticity theory by Boussinesq. The effect of traffic load on the pipe decreases with increasing pipe depth. At depths over two meter this load gets insignificant compared to the soil load.

Traffic load is typically dynamic and there exist several approaches to calculate the exact forces on an underground pipe. Most equations demand details on traffic and vehicles that are unreasonable to obtain within the framework of CARE-S.

The chosen approach is based on an axle pressure of 260 kN that is distributed on two equal tire loads with two meters distance (Vaslestad 1987). The load is basically calculated as a static load with the Boussinesq equations. This is considered with the factor C_t in the calculations. The fatigue effect of the dynamic is considered by increasing the load by 75 %. The resulting point load over the pipe is 75 kN.

An additional load is coming from the vibrations of passing vehicles, caused by the street roughness. This impact is considered with the factor Ψ .

Finally, a rigid pipe disturbs the elasticity of the soil. The equation contains therefore the concentration factor K to take into account the increased load on the pipe. K is dependent on the relation between pipe depth and diameter.

The resulting equation for the calculation of traffic load is:

$$(3) \quad Q_t = 75 \cdot C_t \cdot \Psi \cdot (1 + K)$$

$$\Psi = 1.3 - h_0 / d_e$$

$$K = \frac{0.7}{4.5} \cdot \frac{h_0}{d_e} \quad \text{for } \frac{h_0}{d_e} > 4.5$$

$$K = 0.7 \quad \text{for } \frac{h_0}{d_e} \leq 4.5$$

With Q_t : traffic load on pipe [kN/m]

C_t : coefficient as substitute for Boussinesq equations (figure 1)

Ψ : impact factor

K : concentration factor

h_0 : pipe depths [m]

d_e : external pipe diameter [m]

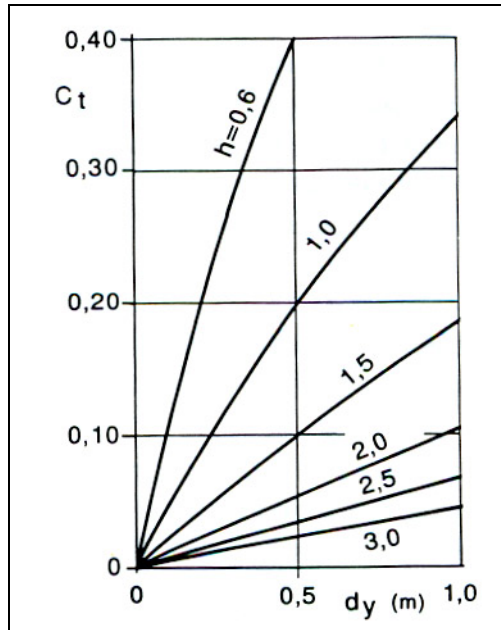


Figure 1: Coefficient C_t (Ekbäck, 1983), d_y equal to d_e

4.1.3 Resulting moment in tangential direction

The resulting load that causes tangential ringstress is:

$$(4) \quad Q_{\tan} = Q_s + Q_t$$

The pipe receives a moment with a maximum at the top and bottom for rigid materials. The resulting moment is dependent on the embedding of the pipe. It can be distinguished between three general cases as pictured in figure 2.

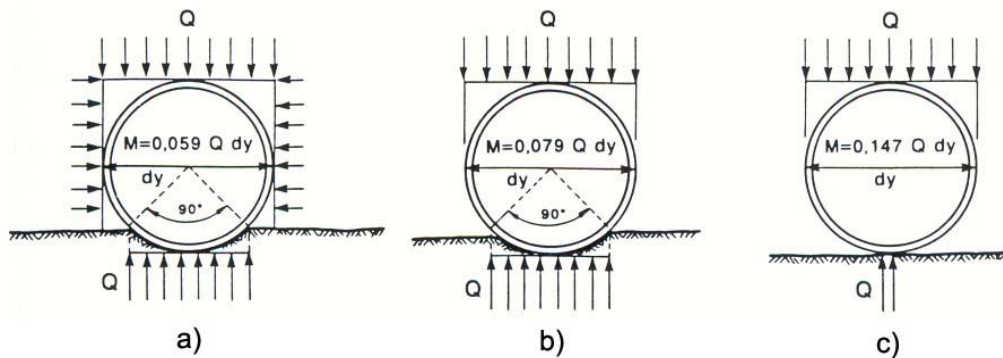


Figure 2: Resulting tangential moment at pipe top and bottom (Sprangler and Handy, 1982):

a) The pipe is embedded in the foundation and the loads are deflected in a 45 degree angle. Additionally, the pipe has a good side support through compaction. b) The pipe is embedded in the foundation and the loads are deflected in a 45 degree angle. c) The pipe is placed on a level foundation and supported along the bottom line only.

The resulting moment for the three cases are (Ekbäck, 1983):

$$(5) \quad M_{\tan} = 0.059 \cdot Q_{\tan} \cdot d_e \quad \text{case a): full embedment and side support}$$

$$(6) \quad M_{\tan} = 0.085 \cdot Q_{\tan} \cdot d_e \quad \text{case b): full embedment without side compaction}$$

$$(7) \quad M_{\tan} = 0.159 \cdot Q_{\tan} \cdot d_e \quad \text{case c): bottom line support}$$

Older pipes are often laid on compacted soil and should be calculated with case c). The Load_{model} request a year of installation from when on the general quality of installation has been improved. For both periods, before and after, the conditions can be chosen individually.

4.1.4 Resulting ring stress

The moments in the pipe wall cause a ring stress that is decisive for a structural failure. For pipes with a small wall thickness compared to the diameter the stress can be calculated as:

$$(8) \quad \sigma_{\tan} = 6 \cdot M_{\tan} / s^2$$

With σ_{\tan} : ring stress [kN/m²]
 M_{\tan} : maximal tangential moment [kNm/m]
 s : wall thickness [m]

4.2 Loads resulting in axial stress

Loads that result in ring stress will also cause stress in the pipes longitudinal direction. Significant stress originates from unsupported lengths at the bottom of the pipe. This is often caused by leakage that erodes the surrounding soil, but also by faulty installation. Concrete sewer pipes with a standard length of one meter are normally not exposed to a structural failure due to axial stress. The failure is normally expected to happen in the joint between two pipes.

Additionally to the vertical loads, temperature has normally to be considered for calculating axial stresses. This has however no effect on concrete pipes of small lengths.

4.2.1 Soil load

Moulin-Olofsson has developed a simplified method for the calculation of the bending moment in longitudinal direction caused by soil load:

$$(9) \quad M_{\text{ax-s}} = 4 \cdot K \cdot Q_s \cdot L^2 / 8$$

$K = 12 d_e / Q_s$ well compacted filling material
 $K = 12 d_e / Q_s + 0.05$ badly compacted filling material
 $K = 12 d_e / Q_s + 0.15$ no compaction and side support

With $M_{\text{ax-s}}$: axial moment caused by soil load [kNm]
 Q_s : soil load [kN/m]
 L : unsupported length [m]
 K : empirical factor for compaction of filling material

4.2.2 Traffic load

Larsson (1961) has developed a simplified model for calculation of the axial moment for traffic load. He presumes the pipe as a beam with free ends and the load placed on the centre. The chosen approach is again based on an axle pressure of 260 kN that is distributed on two equal tire

loads with two meters distance (chapter 4.1.2.) and therewith on a point load of 130 kN (Myhre, 1992). The maximum moment is then:

$$(10) \quad M_{ax-t} = P \cdot d_e \cdot ((1 - \cos(\varphi_0)) \cdot (2 + \cos(\varphi_0)) / (2 \cdot \pi \cdot \cos(\varphi_0)))$$

With M_{ax-t} : axial moment caused by traffic load [kNm]

P: traffic load [kN/m]

d_e : external diameter [m]

φ_0 : angle between the vertical line below the load and the bearing point of the pipe, see figure 3.

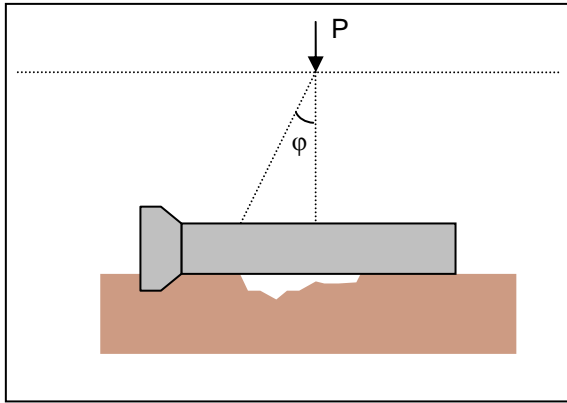


Figure 3: Angle between load and bearing point of the pipe

As shown in figure 3, the angle φ is dependent on pipe depth and unsupported length. The latter will probably be unknown to the asset owner but can be used as a sensitive parameter in the Load_model calculations.

4.2.3 Resulting longitudinal stress

The resulting longitudinal stress from soil and traffic load is calculated with an equation developed by Ekbäck (1983):

$$(11) \quad \sigma_{ax} = \frac{32 \cdot (M_{ax-s} + M_{ax-t}) \cdot d_e}{\pi \cdot (d_e^4 - d_i^4)}$$

With M_{ax-s} : axial moment from soil load [kNm]

M_{ax-t} : axial moment from traffic load [kNm]

d_e : external pipe diameter [m]

d_i : internal pipe diameter [m]

4.3 Resulting total stress in the pipe wall

The resulting stress from tangential and longitudinal stress is the vector product of both:

$$(12) \quad \sigma = (\sigma_{tan}^2 + \sigma_{ax}^2)^{0.5}$$

With σ : resulting stress in pipe wall [kN/m²]

σ_{tan} : tangential stress in pipe wall [kN/m²]

σ_{ax} : axial stress in pipe wall [kN/m²]

4.4 Calculation of security factor and probability of failure

The security factor is the relation between the materials strength and the calculated resulting stress from chapter 4.3. The pipe strength is measured by the traditional method of the load test. American literature refers to it as three-edge-bearing (TEB) test. It allows no lateral support for the pipe and applies forces that are virtually point loads. The crushing load at failure per unit length of pipe is called the D-Load. The bending tensile strength for the pipe material can be derived from that test.

$$(13) \quad W = \frac{M}{\sigma}$$

With W: security factor

M: Pipe strength at crushing load, bending tensile strength [kN/m²]

σ : affected pipe stress [kN/m²]

The Load_model distinguishes between older and newer pipe and sets as default pipe strength values of 7 MPa for pipes manufactured before 1970 and 13 MPa for pipes from that year on. Those data can be edited by the user.

CARE-S demands a probability of failure as an input to the Manager in order to calculate the overall rehabilitation scheme. Being a deterministic-empirical tool, the Load_model can not calculate a probability. This step is therefore made by applying a conversion table to the security factor, where bands of the factor are related to a probability of failure. This table is not based on statistical analysis and should therefore be applied with care and adapted by the user if necessary.

5 Data demand

5.1 Pre-processing

An input file with the pipe data is needed. This file is a text file with these values:

PipeName=	<pipe identification>	any pipe identification
Shape=	<circular>	all pipes assumed to be circular
Width=	<pipe width [mm]>	assumed to be diameter
Height=	<pipe height [mm]>	not used
Year=	<installation year>	construction year, when the pipe is laid
Length=	<pipe length [m]>	pipe length, not used
WallThick=	<pipe wall thickness [mm]>	
Depth=	<pipe depth [m]>	
SDR=	<standard dimension ratio>	
PN=	<pressure class>	
Mat=	<pipe material>	all pipes assumed to be concrete
Soil=	<soil class>	valid values: non, med, high
GW=	<ground water level [m]>	positive value
Traf=	<yes or no>	'yes' means high traffic load, 'no' means no traffic
ExCor=	<external corrosion [mm]>	total corrosion depth from ExtCorr model

InCor= <internal corrosion [mm]> total corrosion depth from WATS model

Example (3 pipes):

PipeName=7879
Shape=
Width=225
Height=0
Year=1971
Length=40.05
WallThick=32
Depth=2.68
SDR=
PN=
Mat=
Soil=high
GW=
Traf=
ExCor=
InCor=

PipeName=13466
Shape=
Width=300
Height=0
Year=1958
Length=26.35
WallThick=30
Depth=3.30
SDR=
PN=
Mat=
Soil=high
GW=
Traf=
ExCor=
InCor=

PipeName=193703
Shape=
Width=250
Height=0
Year=1995
Length=6.03
WallThick=37
Depth=2.61
SDR=
PN=
Mat=
Soil=high
GW=
Traf=
ExCor=
InCor=

5.2 Minimum input data requirements

For each pipe the following data is required:

- pipe identification
- diameter [mm] (is derived from shape, width and height. Width is equal to diameter)
- installation year
- wall thickness [mm]
- installation depth [m]

5.3 Additional data for version 1.0.2

- traffic load (external load from (heavy) traffic, can also be edited under calculating rules)
- external corrosion [mm] (can also be edited under calculating rules, but there more user friendly as mm/year)
- internal corrosion [mm] (can also be edited under calculating rules, but there more user friendly as mm/year)
- ground water level (equivalent to pipe installation depth, measured from surface)

In case missing wall thickness values, estimations can be done using SDR (standard dimension ratio). This has to be done manually in version 1.0.2, but is planned to implement at later versions.

5.4 Additional input data options

Further data that is not provided by an input file can be changed under 'calculating rules':

- Unsupported pipe length (sensitivity analysis for longitudinal stress failure)
- Compaction condition (Load deflection in filling material)
- Bedding condition (3 standard types of embedment)
- Filling material [kN/m^3] (specific weight)
- Traffic load table (if necessary, the default values can be changed, see mathematical description)
- Pipe design strength [MPa] (manufactures value from load test)

Additional input data have already been assigned default values. The suggested values will be reset again each time the program is started.

6 Output data

The safety factor (W) and probability of failure (P) given for the chosen prediction year is the output from the Load_model. From a previous version, the year of failure (Y) is included in the output file as a fourth parameter. This result has no meaning in this version of the Load_model and should be ignored. It is only kept as a parameter to ensure safe data transfer between Load_Model and Rehab Manager. The user has several possibilities to extract the results from the tool: saving to the database, exporting to an MS Excel File or listing in a tabular form.

Example of output file:

PipeName=7879

W= 2.798392

P= 0.1

Y= 0

PipeName=13466

W= 0.2860925

P= 1

Y= 0

PipeName=193703

W= 4.39363

P= 0.05

Y= 0

7 How-to guide

The Load_model is developed independently from the CARE-S Rehab Manager and can therefore also be used as a stand alone version. In that case, the user starts directly with step 2.

- Step 1.1 Select a set of pipes, using the GIS viewer facility and/or Expression Builder of the Rehab Manager. This active dataset will be analysed using the Load_model for the prediction year chosen by the user. It is recommended to run the Load_model only for pipes where the external and internal corrosion has been calculated before. Otherwise, the corrosion speed specified in the tool itself should be verified by measurements.
- Step 1.2 From the tools menu in the Rehab Manager select Load_model tool. A pre-defined data set is transferred from the Manager to the tool for the chosen pipes.
- Step 1.3 Once the relevant auto-load has been completed, select run 'Load_model tool' from the Load_model menu option. The tool will then be started and the opening page is shown (figure 4) for a few seconds before the tool switches over to the main page (figure 5). Continue with step 3 if the tool is run from the Rehab Manager

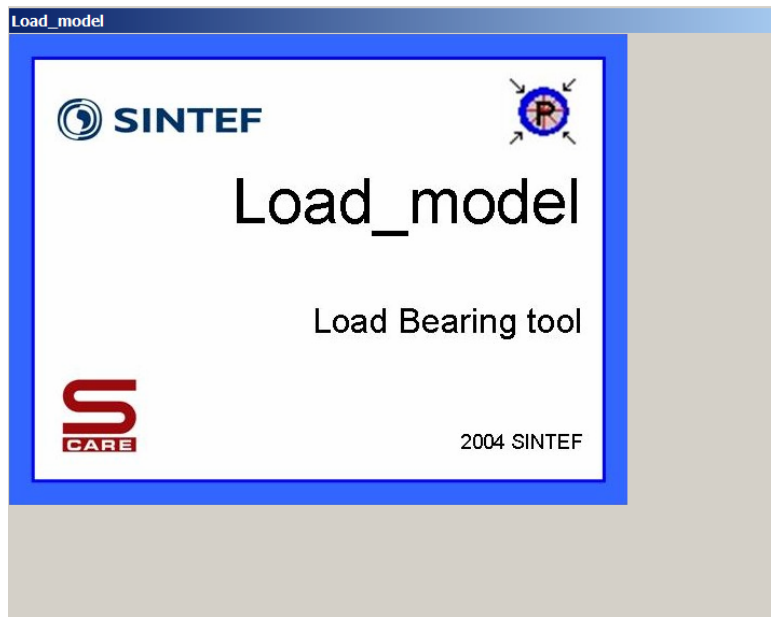


Figure 4: Opening page of the Load_model

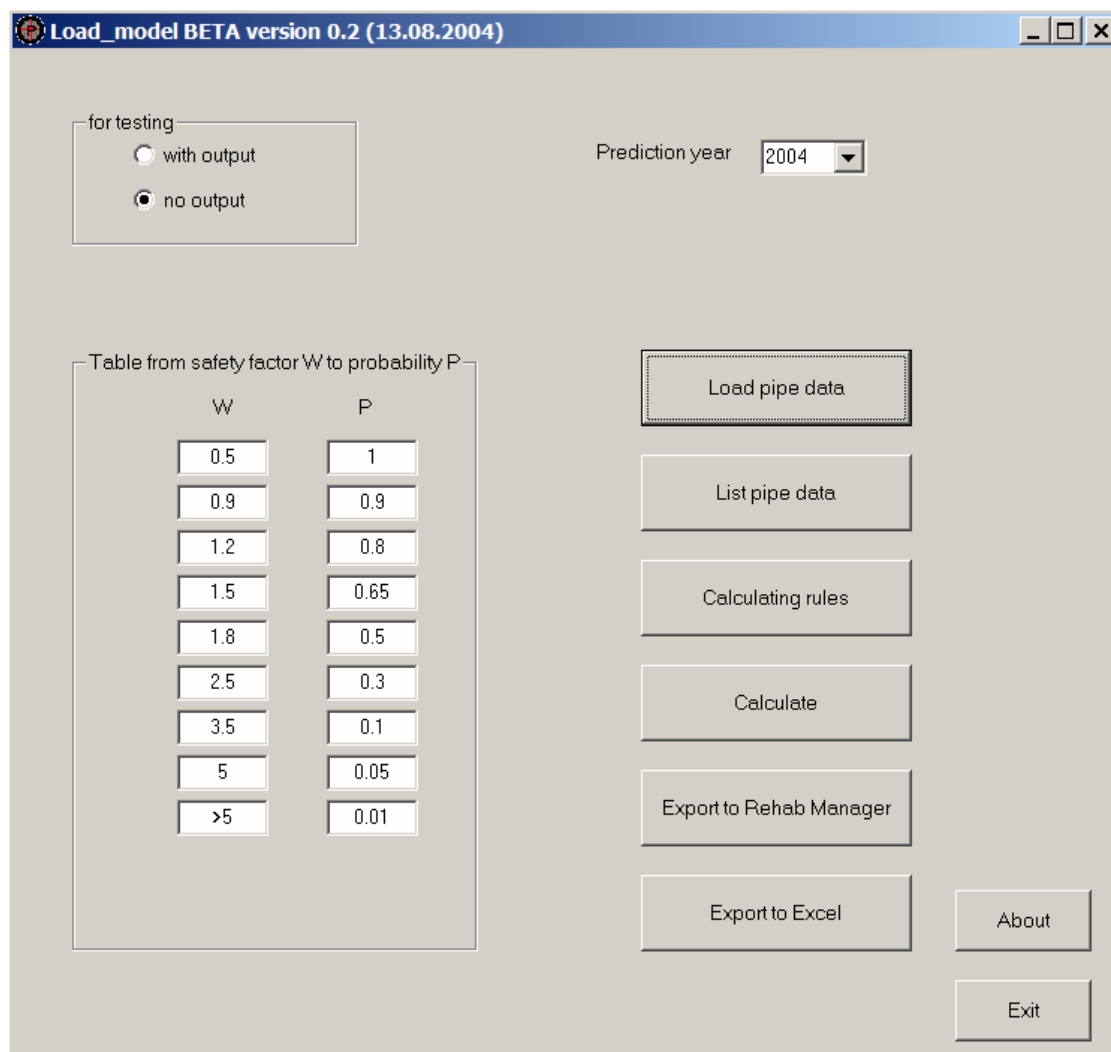
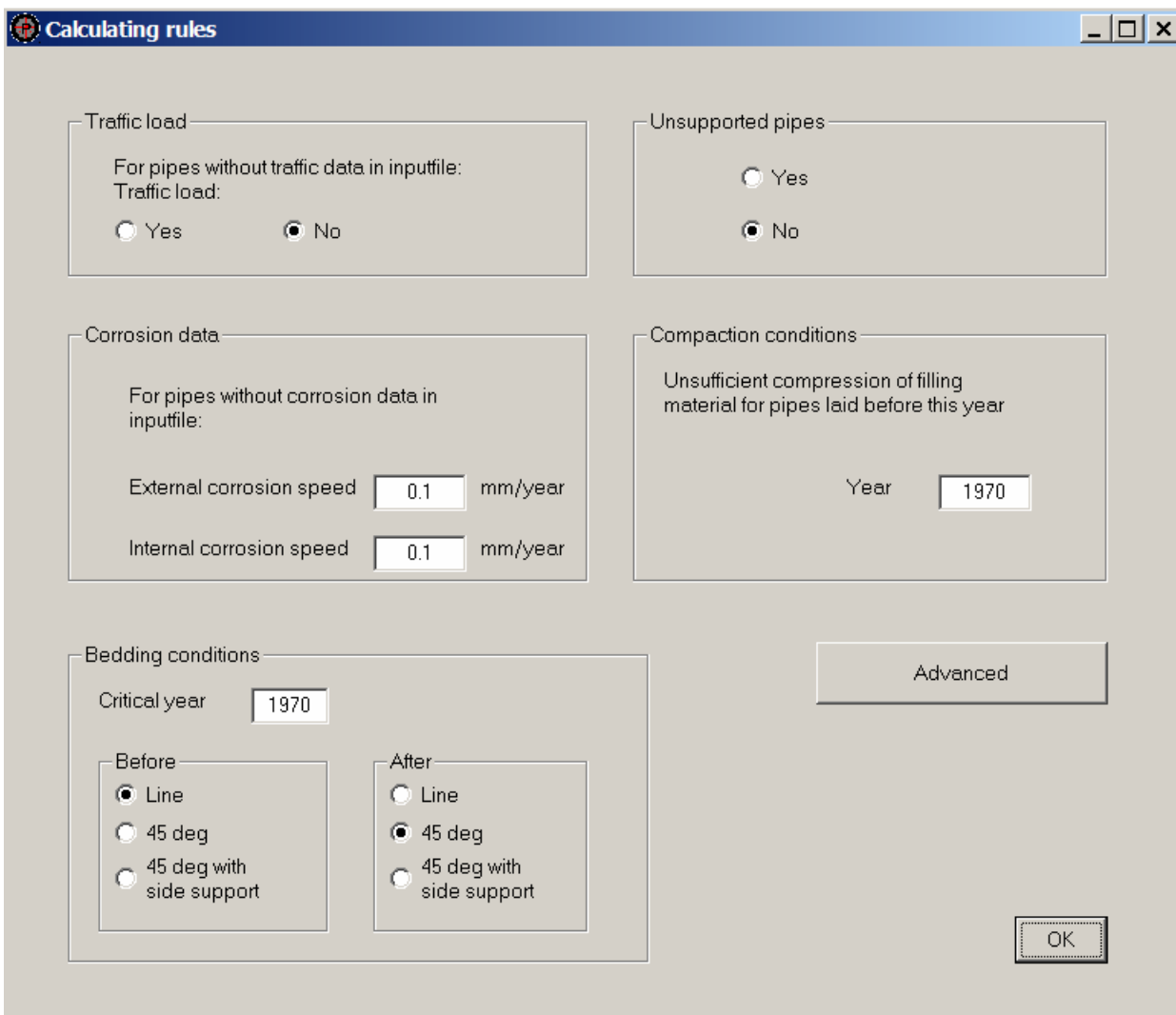


Figure 5: Main screen picture

- Step 2.1 For stand alone application of the Load_model step 2.1 and 2.2 must be carried out. First, the prediction year for the load bearing calculation must be chosen in the upper right hand corner of the main screen.
- Step 2.2 In a second step, the input data has to be uploaded, which otherwise is transferred from the Rehab Manager. Press 'Load data' button and choose a file in text format corresponding to description in chapter 5.1.
- Step 3 *Optional:* The requested output format in the Rehab Manager is probability of failure for a pipe. The main screen contains the conversion table from safety factor to probability of failure. The safety factor is the relation between load induced stress and remaining strength in the pipe wall. Theoretically, a pipe collapses when this factor reaches 1. Due to several effects not included in the calculations, a collapse can also take place at safety factors below or above 1. The table can therefore be edited to reflect the user policy.



Calculating rules

Traffic load
For pipes without traffic data in inputfile:
Traffic load:
☐ Yes ☒ No

Unsupported pipes
☐ Yes
☒ No

Corrosion data
For pipes without corrosion data in inputfile:
External corrosion speed mm/year
Internal corrosion speed mm/year

Compaction conditions
Unsufficient compression of filling material for pipes laid before this year
Year

Bedding conditions
Critical year

Before
☒ Line
☐ 45 deg
☐ 45 deg with side support

After
☐ Line
☒ 45 deg
☐ 45 deg with side support

Advanced

OK

Figure 6: Calculating rules menu

- Step 4 *Optional:* Data reflecting environmental conditions can be edited under the button 'calculating rules'. A new window opens (figure 6). Data given under this window are batch values and valid for the complete set of pipes that is imported. Those data are not imported from the Rehab Manager with the exception of existence of heavy traffic and corrosion speed. Traffic and corrosion that is imported is individual for each pipe, else the whole data set receives batch values for those items. If environmental conditions are known in more detail for single pipes, it is recommended to run the tool separately for those. Data items under this window can be primarily used for sensitivity analysis. The following data items are included under calculating rules:

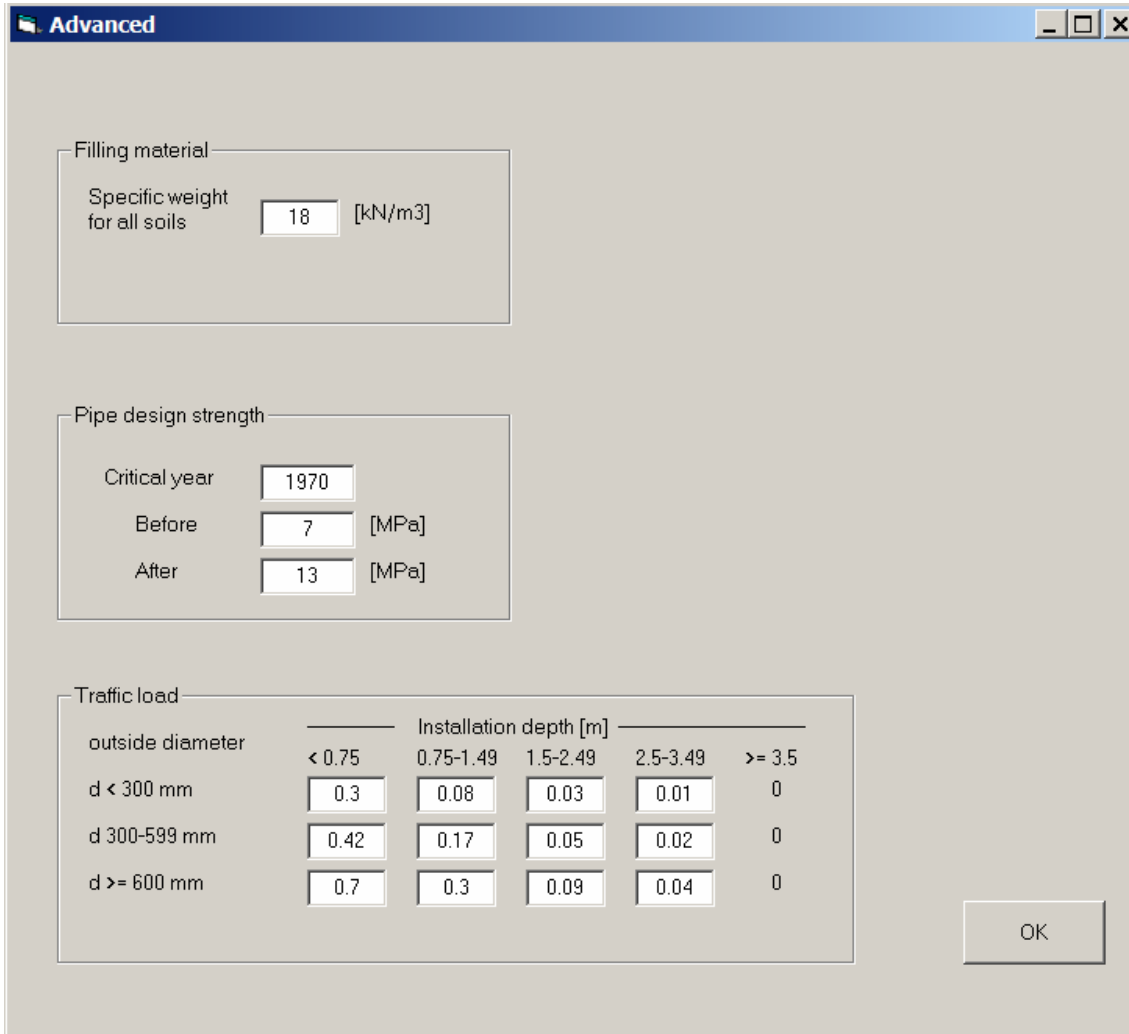
'Traffic load': If information on traffic is not imported from the Rehab Manager the default value is no traffic load. The user can add traffic load to the external loads for all pipes without imported information on traffic (blank field) by changing the button from 'no' to 'yes'.

'Corrosion data': The user can apply a linear internal and external corrosion speed for all pipes without imported information on corrosion depth (blank fields). As default values the corrosion is set to 0,1 mm per year.

'Bedding conditions': Basically, the bedding conditions for a pipe can be distinguished into three types. a) the pipe is placed on a level foundation and supported along the bottom line only. b) the pipe is embedded in the foundation and the loads are deflected in a 45 degree angle. c) Additional to embedding, the pipe has a good side support through compaction. Default values are line support before 1970 and 45 degree embedding after 1970.

'Unsupported pipes': The user can chose 'no' for newer pipes, unlikely to be exposed to soil erosion and a specific length in meter for the most likely unsupported length. Default value is no unsupported length.

'Compaction conditions': A good compaction of filling material helps to lead vertical loads in the soil around a pipe through to friction and deflects therewith part of the load on the pipe. As a very rough rule, the tool asks for the year of construction where the practice of compaction has improved. Default value is 1970.



Advanced

Filling material

Specific weight for all soils [kN/m³]

Pipe design strength

Critical year

Before [MPa]

After [MPa]

Traffic load

outside diameter	Installation depth [m]				
	< 0.75	0.75-1.49	1.5-2.49	2.5-3.49	>= 3.5
d < 300 mm	<input type="text" value="0.3"/>	<input type="text" value="0.08"/>	<input type="text" value="0.03"/>	<input type="text" value="0.01"/>	<input type="text" value="0"/>
d 300-599 mm	<input type="text" value="0.42"/>	<input type="text" value="0.17"/>	<input type="text" value="0.05"/>	<input type="text" value="0.02"/>	<input type="text" value="0"/>
d >= 600 mm	<input type="text" value="0.7"/>	<input type="text" value="0.3"/>	<input type="text" value="0.09"/>	<input type="text" value="0.04"/>	<input type="text" value="0"/>

OK

Figure 7: Advanced calculating rules menu

- Step 5 *Optional:* The button 'Advanced' under the calculation rule window leads to further specifications of the load bearing calculations:

'Filling material': The soil or filling material above the pipe is regarded to be homogenous in the calculations. The specific weight is set to 18 kN/m³ as a default value.

'Pipe design strength': The tool is designed for the calculation of rigid non-reinforced concrete pipes. The pipe strength is measured by the traditional method of the load test. It allows no lateral support for the pipe and applies forces that are virtually point loads. The load carrying capacity of a rigid pipe when installed is increased by up to four-fold because of active soil pressure. The tool distinguishes between older and newer pipe and sets as default values 7 MPa for pipes manufactured before 1970 and 13 MPa for pipes from that year on.

'Traffic load': This table originates from the traffic load calculation by Ekbäck (1983) and provides the C_t values depending on installation depth and external diameter (see mathematical description).

- Step 6 *Optional:* Under the main screen, it is possible to review pipe data by selecting the button 'List pipe data'. Empty fields mean that there was no data transferred from the Rehab Manager. 'N/A' is shown in result fields before calculation is done. Note that you can change the view by adding or deleting columns in this list and sorting the list for any parameter.
- Step 5 Carry out calculations by pressing the button 'Calculate'. This button changes to "Calculation done" afterwards.
- Step 6 *Optional:* It is possible to review the results through 'List pipe data'. The column 'security' is the ratio between stress induced load and pipe strength, 'P' is the failure reliability regarding the conversion table and 'rem thick' is the remaining wall thickness for the prediction year.
- Step 7 Export the result data to Rehab Manager and/or Excel and exit the Load_model.