## Specification of the functional characteristics of the ***Ple4Win*** software

(version 4.7.0)

1. **Functional characteristics of the Kernel (K) module.**

Design and analysis of three-dimensional, buried or unburied, pressurised transport pipelines.

*Input facilities:*

a. Configuration conditions

- three-dimensional pipeline axis configuration (pipe and bend elements)
- various end boundary conditions (free, fixed and infinite)
- linear elastic external supports (global and local coordinate systems)
- ground and groundwater level

b. Pipeline conditions

- linear elastic pipe material variable along pipeline axis
- variable diameter along pipeline axis
- variable wall thickness along pipeline axis
- pressurized toroidal shell bending stiffness properties

c. Soil conditions

- non-linear elastic soil deformation behaviour
- direction dependent lateral soil stiffness and ultimate soil support properties variable along pipeline axis
- soil friction stiffness and ultimate soil friction properties variable along pipeline axis
- uncertainty factors for easy soil parameter variation
- three-dimensional soil settlements and deformations

d. Operational conditions

- internal/external pressure, variable along pipeline axis
- temperature variations, variable along pipeline axis
- deadweight, variable along pipeline axis
- additional point loads (global and local coordinate systems)
- overall and component load factors

*Output facilities:*

- generated and compiled input data overviews
- internal forces and bending and twisting moments in the pipeline
- displacements and rotations along the pipeline axis
- soil reaction forces acting on the pipeline along its axis
- external support reactions
- bend stiffness and stress concentration factors
- detailed pipe/soil model iteration behaviour results.
- print facility for individual input- and output tables, possibility to only print groups or extreme values
- multiple tables print facility using a dedicated specification screen, table sequence can be adjusted and full table data/extrema's only can be selected per table

## 2. Functional characteristics of the Stress (S) module.

Detailed stress calculation in selected pipe cross sections.
Stresses are calculated in 48 equidistant points over the circumference at the inner and outer wall side.

*Input facilities:*

- neutral top soil weight along pipeline axis
- extra surface loading along pipeline axis
- various subsoil bearing angle functions depending on ratio of subsoil reaction and bearing capacity of the soil, variable along pipeline axis
- lateral horizontal soil support for vertical soil loadings, variable along pipeline axis

*Output facilities:*

- stress components resulting from internal/external pressure (hoop stress)
- stress components resulting from internal forces, bending and twisting moments in the pipeline, taking into account pressurized toroidal shell behaviour at the pipe bends
- stress components resulting from local soil reactions distributed over the circumference of the pipe cross section, taking into account the "pressurized ring rerounding" effect.
- summation of corresponding stress components
- determination of principal stresses according Mohr's circle
- determination of equivalent stresses according von Mises/Huber-Hencky yield criterion
- overview of governing stress components and overall stresses
- overview of governing Mohr, Tresca, Von Mises and uniaxial stresses

## 3. Functional characteristics of the Stress Weighing (A) module.

Calculation of Mohr, Tresca, Von Mises and uniaxial stresses from the calculated stress components taking into account weighing factors for each type of stress component (primary and secondary stresses).
A separate section weakening (stress-intensification) facility is available in the form of welding factors for circumferential and longitudinal welds in the pipe, which can be specified per type of stress component.

*Input facilities:*

- user accessible stress weighing factor table with predefinable default values
- user accessible welding factor table

*Output facilities:*

- result table with generated stress weighing factors per element
- result table with Mohr, Tresca, Von Mises and uniaxial stresses is calculated based on stress weighing and welding factors. (all other stress tables remain unaffected)

## 4. Functional characteristics of the Graphics (G) module.

4.1 Single Graph facility

The Single Graph facility provides at table level the option of quick graphical representation of results contained in that single table.
One or more graphs may be displayed along a freely selectable x-axis. The cross-sectional stress representation is in polar format, other representations are orthogonal.
Single Graphs may be (partly) displayed or printed (local or network printers, or file).
Printing is possible on user-selected paper format and margins.

4.2 Multi Graph facility

The Multi Graph facility provides at main level the option of graphical representation of results from various tables from various design databases in one graphical representation.
An unlimited number of lines may be specified in one graphical representation, horizontal and/or vertical axes can be combined as desired.
The Multi Graph is user-defined by means of a definition screen.
Predefined definition screens may be stored and copied between design databases.
Multi Graphs may be (partly) displayed or printed (local or network printers, or file).
Printing is possible on user-selected paper format and margins.

4.3 2D Drawing facility

The Pipeline Draw facility provides at main level the option of predefined drawings of the pipeline with various options:
- horizontal alignment drawing
- vertical alignment drawing
- additional information such as polygon points, bend indications, nodes, elements, constraints and more.

Pipeline drawings may be (partly) displayed or printed (local or network printers, or file).
Printing is possible on user-selected paper format and margins.

## 5/6. Functional characteristics of the Geometrical Non-Linear (N/L) module.

The geometrical non-linear module calculates the displacements and internal forces and related soil and support reactions, based on equilibrium of the external load system on the deformed pipe structure.
In this module elastic bends may be specified.

The geometric non-linear module is split into 2 separate modules:
Module N: rotations up to .3 rad. are allowed
Module L: extension to rotations larger than .3 rad.
The module NL contains both the modules N and L, and module N may be upgraded from N to NL by means of the extension module L.

## 7. Functional characteristics of the Phase (F) module.

The phase module allows the initialisation of the pipe/soil structure by means of import of a displacement/reaction vector from another design database on the condition that the number of pipe elements is equal.
There are four initialisation options:
- Initial option, introducing the initial pipe configuration
- Phasing option, introducing pipe deformations from a parent database together with elastic and plastic soil deformations
- Continue option, introducing pipe deformations from a parent database together with elastic soil deformations
- Pre-Displacement option, introducing fixed deformations for the pipeline from a parent database.

The method of calculation of internal forces and reactions in the receiving pipeline structure is the same as specified in the providing pipeline structure (linear or non-linear geometric analysis).

## 8. Functional characteristics of the NEN 3650 - Rules Check (T0) module.

A separate stress calculation facility as a parallel option to the general stress module (S) is available to calculate the stress components $S_p$ and $S_v$ according to the Dutch NEN 3650:2012 Rules for Pipelines. The stresses are expressed as unit-stresses to the specified limit stress of the pipe material. A stress classification facility is provided, showing as well the cross-sections in which yielding of the pipe material occurs. The stress-weighing facility is required for this module, but stress weighing factors are predefined implicitly. Load and/or partial factors for the neutral or real soil load (SOILNB) and the optional topload (TOPLOAD) have to be specified explicitly.
The check stress $S_{v:pm}$ relates to a primary membrane stress due to primary loads (force-induced loads) and the check stress $S_v$ relates to primary + secondary stresses (wall bending stresses) due to primary + secondary loads (displacement-induced loads).
A special stress module overview screen contains the specific stress checking results.

## 9. Functional characteristics of the Import / Export (E0) module.

### 9.1 Table data import and export

At main and table level a facility is available to import design table data or to export design and/or result table data. Communication occurs with one or more files with user-definable names in Microsoft Excel format (XLSX and XLS).
Unit checking is done as soon as the units are defined.
With multiple tables, the user specifies the tables to be imported/exported by means of a dedicated specification screen. These tables are written to/read from a single Excel Workbook, with each table on a separate Worksheet.
The table(s) to be imported require(s) Ple4Win-style table headings and a one-table-per-worksheet format. The facility allows the generation of the appropriate template(s). Note that the worksheets may contain additional columns; the workbook may contain additional worksheets. Both are skipped by if present. In case of missing table columns, only the available columns will be imported.

### 9.2 Graphic export

At Single Graph, Multi Graph and Pipeline Draw level a facility is available to copy the graphic to the Windows Clipboard for e.g. pasting into Microsoft Word documents. Furthermore it is possible to export the graphic to files with user-definable names, either in WMF vector format or in PNG bitmap format.

### 9.3 3D visualisation export

At both the graphical representation and data visualisation level a facility is available to copy the graphic to the Windows Clipboard for e.g. pasting into Microsoft Word documents. Furthermore it is possible to export the graphic in PNG bitmap format to files with user-definable names.

## 10. Functional characteristics of the Stress Redistribution (R) module.

In the stress module local stressing of the pipe cross section is calculated on basis of the "ring" stiffness, loaded by the local soil reactions.
The stress redistribution module provides a facility to design function 6.1 to redistribute local soil reactions according to the local ring stiffnesses and soil reaction loading/supporting angles. As such the redistribution of stresses due to the interrelation of consecutive rings is "translated" into a redistribution of soil loads.
The redistribution function may be activated or de-activated by selecting the model option in design function 1.
In the cross-sectional stress and deformation result tables it is reported whether or not the redistribution function was active to obtain the tables.
If, however, the length of elements chosen is larger than the redistribution characteristic wave length at that location the redistribution influence will be negligible.

## 11. Functional characteristics of the Soil Curve (C) module.

The soil curve module is an additional functionality to function 3.2 and enables the use of a spatial "slack" space around the initial position of the pipeline. Once the displacement of the pipeline becomes larger than the specified slack in that direction, the soil will provide a soil reaction. The slack is specified as a 3-D space around the pipeline (1 axis in vertical direction, with separate specification upward and downward, 1 axis in horizontal direction and 1 axis in longitudinal direction) shaped as an unsymmetrical ellipsoid.
As long as the pipeline moves in the lateral slack space, the friction is not activated. The slack space may vary along the pipeline axis.
The soil curve module provides as well the facility to shape the displacement/soil reaction curve as a TGH function with the derivative at the displacement = 0 equal to the specified k-value in that direction and an asymptotic axis equal to the specified ultimate soil reaction in that direction.
A third displacement/soil reaction curve is the so-called BGC-curve which represents a weaker soil.

## 12. Functional characteristics of the Branching (Y) module.

The branching module allows specifying branches to the main pipeline. Branches to branches are allowed as well. Branches may be looped.
The allowable number of branching points is unlimited.
The branching module includes a T-piece specification option including bending stiffness and stress intensification determination.

## 13. Functional characteristics of the Wave and Current Loading (W) module.

The wave and current loadings module is specifically applicable for offshore pipelines and riser tie-in structures.
The loading determination is based on Morison's formula with $C_d$, $C_m$ and $C_l$ factors to be specified.
The current profile is supplied as a higher order function of the water depth. The influence of the wave shape on the current profile is accounted for.
The wave is specified by its height and period, crest location and wave direction. The wave may be long- or short crested. Wave shape may be specified as Airy or $5^{th}$ order Stokes. The short crested wave is based on Airy.
Wave slamming in the splash zone is taken into account. The dynamic influence of the wave frequency or vortex shedding can be taken into account as well as nearby large diameter structural elements, which influence the local water velocity.
An adapted outer diameter due to external coatings and eventually weight coating and related adapted mass can be accounted for.
A series of wave types and current profiles can be specified; only one combination of wave and current can be activated at the time.
Apart from the generated wave/current forces, various determined wave, current and loading properties are shown in the result tables.

## 14. Functional characteristics of the Belgian Law Check (T1) module.

In Belgium the limit states of a pipeline are set by law and in case of gas pipelines specific details are referred to the ASME-B31.8 Pipeline Code.
The check criteria and performance of the checking are contained in this module. The kernel module is adapted to allow checking according to this law, e.g. on minimum wall thickness. The manufacturing tolerance on the wall thickness can be specified now as well in absolute wall thickness reduction.
A special stress module overview screen contains the specific stress checking results.

## 15. Functional characteristics of the ASME B31.8 - Rules Check (T8) module.

Checking on the criteria as contained in the ASME B31.8 Pipeline Code edition 2010 is now possible using this module. The specific stress checking in this module is based on the various criteria set for combinations of stresses. A special stress module overview screen contains the specific stress checking results.

## 16. Functional characteristics of the Non-Linear Geometric Section (Q) module.

In the kernel module the common, standard bend stiffness and stress intensification procedure is applied. This procedure is based on an “infinite” bend angle approach, meaning the bend is not stiffened by the adjoining straight pipe legs. In the Q module the limited bend angle is taken into account, based on an extensive pipe bending test program performed by TNO.
The stiffening from the adjoining pipe legs in general causes the bend stressing to be less than based on the standard method. In the standard method, the bend stiffness is independent of the bending curvature of the bend section. In reality the ovalisation of the cross section causes the stiffness factor to be non-linear with the curvature. This is taken into account.
As a result of the ovalisation in the bend the adjoining straight pipe legs will become ovalised as well, resulting in an ovalisation distribution over the legs and bend in between. This redistribution of the ovalisation and inherent stressing is taken into account.
The interaction between soil loads at bends and the resulting cross sectional ovalisation and related longitudinal pipe bending is taken into account. As a result the bend cross section is much stronger related to lateral soil loading. The module has been verified on the test results.

## 17. Functional characteristics of the Table Support (O) module.

This module enables the introduction of a special non-linear support in the sense that the support is active only in vertical downward direction and the resulting support reaction may generate a horizontal friction reaction force if the pipeline tends to move over the table support. In case of an upward movement of the pipe, the support is not active.
If no supporting angle has been specified, the support reaction force acting on the pipeline is introduced as a shear force based on the assumption of a local stiffening of the pipe cross section and as a result no wall bending stresses are introduced.

## 18. Functional characteristics of the Anisotropic Material (V) module.

The anisotropic material module enables to distinguish between the material stiffness modulus (E) in longitudinal and circumferential direction and to distinguish between normal and bending stressing. The Poisson ratio may be differentiated from axial to circumferential stressing and vice versa.
As a result sandwich wall composites can be simulated as well.

## 19. Functional characteristics of the Material Non-Linearity (M) module.

Due to yielding of the pipe material, the relationship between stress and strain becomes non-linear and resulting in permanent strains. The pipe cross sectional yielding and the circumferential wall yielding is taken into account and verified based on results from the sub module Q mentioned test program. A special overview screen in the stress module is added to account for the difference in stressing and straining.
Material non-linearity can be applied only in the last phase in case a phasing series is applied, unless the strain in the next phase is increasing. Then the option may be applied in the previous phase as well.
The stress/strain relationship may be based on a bilinear stress/strain diagram, but also on various built-in diagrams to account for micro-yielding at stresses lower than the specified yield stress. Stress stiffening is an option as well. Limits to straining are based on local buckling limits and on excessive yielding strains.

## 20. Functional characteristics of the Articulated Pipeline (J) module.

The articulated pipeline module allows specifying construction joints in a pipeline. At the moment 9 joint types are available, like among other things socket-spigot connections and ball and pin hinges, with their specific free degrees of freedom. Maximum values for free degrees of freedom can be specified.
Moreover there is the option to assign axial, lateral and rotational stiffnesses to a joint.

## 21. Functional characteristics of the Flexible Cross-Section (U) module.

The stiffness of the soil counteracting the ovalisation of a cross-section is taken into account both in the ‘beam’ calculation and the ‘ring’ calculation resulting in lower ovalisations and stresses, especially of importance for pressureless flexible and/or thin walled pipes. Horizontal soil support springs are applied at the points of the cross-section that move outward. To the soil springs the value of the horizontal or vertical bedding constant without uncertainty factors is assigned whichever is the smallest one. The soil resistance is maximised at 50 % of the smallest bearing capacity in accordance with the Dutch code NEN 3650.
The Flexible Cross-section approach can be considered as an improved application of the IOWA formula in the sense that it describes the cross-section behaviour in a more realistic way.
In case of pressureless thin walled steel pipe or pressureless plastic pipe the resulting ovalisation may be reduced by factors.
The Flexible Cross-section approach can be considered as an improved application of the IOWA formula in the sense that it describes the cross-section behaviour in a more realistic way.

## 22. Functional characteristics of the Soil Modelling Wizard (X0) module.

With help of the soil modelling wizard vertical soil profiles may be specified consisting of several layers each of a particular soil type with its typical properties and layer height. These soil profiles are assigned to specific points (idents) of the pipeline.
In addition to the 26 ‘standard’ soil types available in this module user-defined soil types with individual characteristics can be added.
After all sections of the pipeline have been provided with soil profiles, the required soil mechanical parameters will be calculated according to the formulae from NEN 3650 and be put into the input tables of design function 3.2.
All data specified in the Wizard are stored in the additional output tables of this design function.

## 23. Functional characteristics of the Upheaval Buckling (Z) module.

The upheaval buckling module accelerates the process of possibly occurring upward movement of the pipeline at location(s) where the soil resistance (ultimate passive soil reaction) is not sufficient to prevent the pipeline from moving upward. The danger of upheaval buckling exists if there is a vertical curved section, for instance a bend or an imperfection, in a high temperature pipeline resulting in high compressive axial forces. Dependent on the axial pipe-soil friction and the passive soil reaction the pipe may move upward and even come out of the ground. In the module the magnitude of the soil parameters is adapted to the current pipe level after each iteration.
The module does not predict upheaval buckling on basis of the input data, but calculates the vertical displacements of the pipeline. The user has to decide whether these displacements and the corresponding stresses and strains are acceptable.

## 24. Functional characteristics of the 3D Visualisation (X1) module.

There are two modes for the visualisation: Configuration mode and Result mode.

### 24.1 Configuration mode

This functionality will display the configuration as a greyed pipeline with correct diameter. The configuration can be zoomed in and out, panned in any direction and rotated in any direction as well. Additional information such as idents, connections/constraints, ground/water level etc. can be shown.
This mode mainly will be used to check the entered configuration: are the ground and water levels correct, are the constraints defined correctly, are the supports on the right position, and so on.

### 24.2 Result mode

This functionality will display the configuration as a coloured pipeline. The colour depends on the selected (output) data. The configuration can be zoomed in and out, panned in any direction and rotated in any direction as well. This mode mainly will be used to give an insight in the results like where are the largest displacements or where are the maximum stresses located. It can also be used to check input parameters.

*Note:*
The visualisation module is contained in the Educational version of Ple4Win, which may be downloaded and used for free.

## 25. Functional characteristics of the Steel-in-Steel (H) module.

The steel-in-steel (SIS) or steel-cased-pipeline (SCP) module allows modelling structures where an inner (medium) steel pipe is encased by an outer (casing) steel pipe for either thermal isolation or as an additional safety precaution. The two pipes can be connected by either fixed connections or roller connections. The latter allows axial movements of the inner pipe with respect to the outer pipe. Both trench-laid SIS sections and horizontally directional drilled (HDD) sections can be modelled. Any movement of the outer pipe is automatically transferred to the inner pipe through the rollers and fixed connections. Movements of the inner pipe (e.g. thermal loads or pre-stressing) are transferred to the outer pipe as well.

In combination with the phase (F) module it is also possible to simulate all stages of pipe laying and pre-stressing, as it is possible to have initially disconnected pipes being connected in a subsequent phase, or having (SIS and/or conventional) sections disconnected in one phase and possibly connected in the next.

## 26. Functional characteristics of the Mitre bend (I) module.

This module enables the user to configure mitre bends. Where a smooth bend consists of curved elements, a mitred bend is built up of straight parts with a kink in the middle.
The module calculates the bend stiffness and stress intensification factors on basis of an equivalent bend radius.

When the Analysis type is set to 'General' parameters are calculated according to the TGSL-1986. For the other analysis types the parameters are calculated according to NEN 3650-1+C1:2017. The General analysis option takes into account the possible mutual influence of two (or more) adjacent kinks dependent on the in-between distance.

The TGSL method has proven to give more accurate results than the NEN method. This concusion has been based on test results.

## 27. Functional characteristics of the PCF import (E1) module.

Allows the import of pipeline configurations through the Isogen PCF file format. This “pipe component format”-file can be generated by a variety of pipeline and piping design programs such as AutoCAD Plant3D, Intergraph Smart 3D, PDS, CADWorx etc.
Pipe data contained in *.pcf file is added into input data tables of the currently open project in Ple4Win. At this point data for the 'Pipeline origin', the 'Pipeline polygon points' and the 'Outer diameter' input tables is extracted from the file.

Note that the PCF file format is also used for piping, this module will only import pipe parts that can be used by the program. Irrelevant components and components which the program cannot model are ignored.

Note also that this import functionality will be expanded in future versions of the program, allowing the import of more data (e.g. materials) into Ple4Win.