



Oasys Xdisp

Help Guide

Oasys

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13 Fitzroy Street
London
W1T 4BQ
Telephone: +44 (0) 20 7755 3302
Facsimile: +44 (0) 20 7755 3720

Central Square
Forth Street
Newcastle Upon Tyne
NE1 3PL
Telephone: +44 (0) 191 238 7559
Facsimile: +44 (0) 191 238 7555

e-mail: oasys@arup.com
Website: <http://www.oasys-software.com/>

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Part I

1 About Xdisp

1.1 General Program Description

Xdisp Excavation Induced Ground Displacements

Xdisp calculates the ground movements induced by tunnelling, embedded wall excavations or mining works, in terms of three dimensional displacements and horizontal strains. It also allows subsequent building and utility damage assessments to be carried out from the calculated displacements.

Tunnels are taken as cylindrical excavations in soil. Several methods of solution are available to define the profile of the settlement curves.

The equations used are based on the normal probability (Gaussian) distribution theory.

The user is required to define the estimated [Volume Loss](#) (V_L) above the tunnel due to deformation.

Xdisp will then use this to define the settlement profile at the surface or specified depth.

Embedded wall excavations are described in plan as polygons with a level at each corner or as circles with a single base level. Each wall of a polygonal excavation, and each circular excavation is assigned horizontal and vertical ground movement curves that are used to calculate soil displacements. Settlements and horizontal ground displacements may be calculated for the construction of retaining walls and for excavation in front of the retaining walls to form restrained cuts or basements.

Total displacements are calculated by summing those that result from each tunnel and embedded wall excavation.

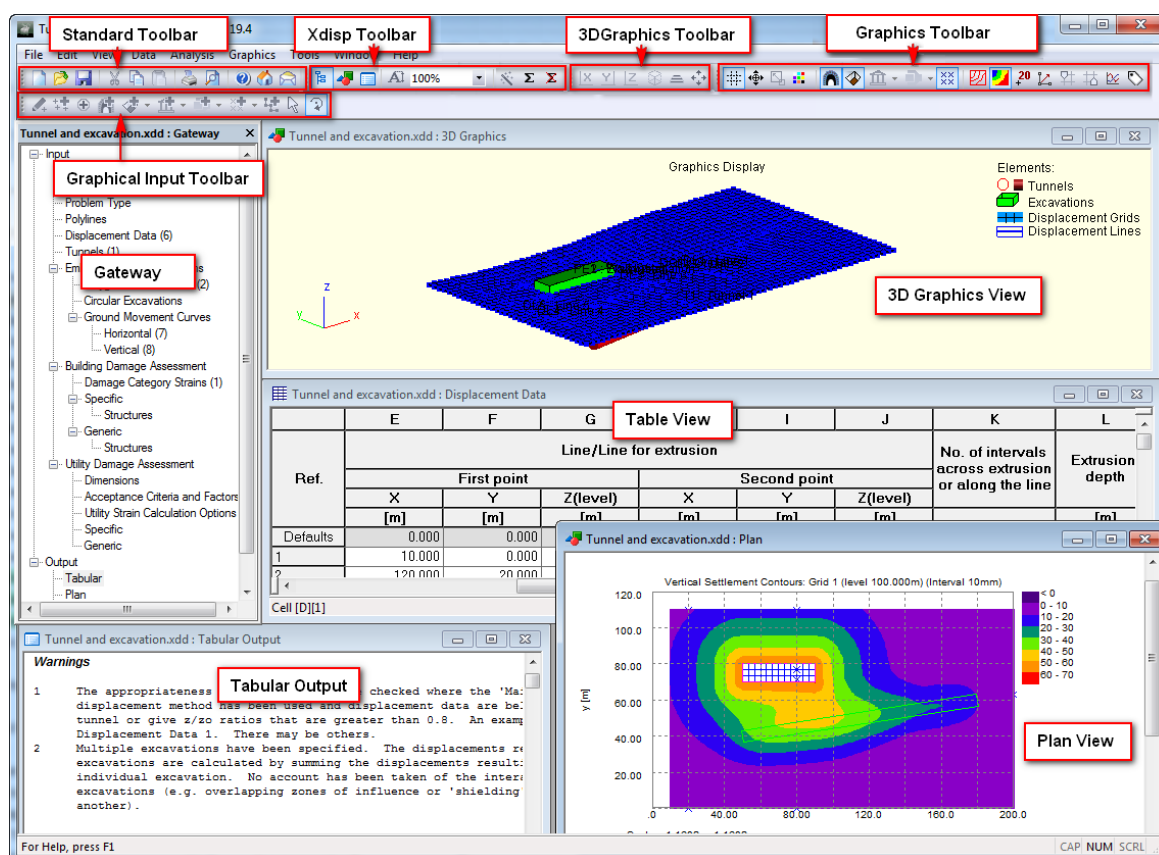
Building Damage Assessment may be calculated using the Burland (1995) assessment method. Sub-structures are specified by their locations and bending properties and associated with lines of displacement points and a set of damage category tensile strains that define the thresholds of each damage category.

Utility Damage Assessment may be calculated by assessing the extent of rotation of joints, pullout of joints and axial and flexural strain.

Mines are taken as excavations of rectangular cross-section in rock. Only one method of solution is available. The equations used are based on an influence function/zone area approach to subsidence and horizontal displacement calculation as described by [Ren et al \(1987\)](#). Stochastic influence functions are used.

1.2 Components of the User Interface

The principal components of Xdisp's user interface are the Gateway, Table Views, 3D Graphics View, Plan View, Tabular Output, toolbars, menus and input dialogs. These are illustrated below.



1.3 Sample Files

Sample files are provided during the installation process. These demonstrate Xdisp's features. By default they are installed in the folder 'C:\Program Files\Oasys\Xdisp n\Samples', where *n* indicates the version of the program. These files may be opened and inspected in Xdisp in order to become familiar with the typical input data that is required to create an Xdisp model.

The sample files are named to indicate the features of the program that they demonstrate.

DXF files are also provided to demonstrate [DXF import](#).

Whilst dealing with utility related models, the user can use the sample utility dimensions and criteria provided by Xdisp, by loading the sample file 'SampleDimensionsAndCriteria.xdd' and copying the required dimensions and criteria data from their respective table views in the sample file. Alternatively the sample file may be saved with a new name and opened to form the basis of a new data file.

1.4 Program Features

The following features are separated into those applicable either to tunnels or mines and those applicable to both.

1.4.1 Tunnels

A tunnel is taken as an excavation of circular cross-section in soil. Several methods of solution are available to create the profile of settlement above the tunnels. These include methods for the following.

- Analysis methods to model settlements in both fine (cohesive) and coarse (granular) grained soils
- Two-layer systems with level or inclined soil interfaces
- Settlement profiles due to multiple tunnels
- Deformation and strain data plots for lines of any orientation and level above tunnel axis level
- Sub-surface displacement methods

1.4.2 Embedded Wall Excavations

An embedded wall excavation is defined by a polygon or circle describing its plan area, top and bottom levels, and its associated vertical and horizontal ground movement curves. It is used to model soil displacements caused by installation of, or excavation in front of, embedded walls. The following features are available.

- Ground movement curves chosen from a library of pre-programmed curves, or specified by the user explicitly
- Soil displacements arising from either installation of, and excavation beside, retaining walls by selecting appropriate ground movement curves
- Multiple embedded wall excavations
- Both embedded wall excavations and tunnels
- Deformation data plots for lines of any orientation and level

1.4.3 Mines

A mine is taken as an excavation of rectangular cross-section in rock. The following features are available.

- Overlying strata may form a two-layer system, but with a horizontal interface
- Only one method of solution is available and results are only available at ground surface level
- Deformation data may only be plotted for horizontal lines at ground level

1.4.4 Combined Features

The following features can be applied to tunnels, embedded wall excavations and mines.

- Tunnel and mine end points, and embedded wall excavations' plan positions can have any spatial location
- The program calculates the three-dimensional displacements (and strains for pure tunnelling problems)
- Vertical displacements may be positive or negative (settlement or heave)
- Displacements are calculated for a grid or a line of points
- Output is available in tabular and graphical forms
- Displacements from other programs can be imported for inclusion in the building damage assessment calculation.

1.4.5 Building Damage Assessment

Building Damage Assessment is performed using the [Burland \(1995\)](#) assessment method.

- Each 'sub-structure' wall or facade is given a location by association with a displacement line.
- Horizontal displacements are calculated for the position of that displacement line.
- Vertical displacements are calculated for three vertical offsets of the displacement line. Building damage calculations are performed for each of those vertical offsets, using the horizontal displacements calculated at the level of the displacement line.
- Each 'sub-structure' is given a set of damage category strains to define the threshold of 5 damage categories based upon the geometry defined for the structure.
- Either user-defined damage category strains, or pre-defined values from Burland (1995), may be chosen.
- Damage categories are calculated for each hogging and sagging segment along the length of each sub-structure.
- Adjacent hogging and sagging segments may be combined for damage category assessment as one segment.
- Graphs of vertical and horizontal displacement may be viewed for each sub-structure.
- Damage category interaction charts may be viewed for each segment of each sub-structure.

1.4.6 Utility Damage Assessment

Xdisp performs detailed damage assessment of a utility by calculating the pullout, rotation, axial strain and flexural strain values at different points along the utility's length. It then checks whether these values are falling within acceptance criteria.

- Each 'sub-utility' is given a location by association with a displacement line.
- Each 'sub-utility' is given a set of cross-sectional dimensions (internal diameter and wall thickness).
- Each 'sub-utility' is given a set of parameters and acceptance criteria to determine the damage limits.
- Displacements are calculated for the position of the displacement line.
- 'Sub-Utility' damage is calculated using those displacements to determine joint rotations, pullout and axial and flexural strains along the length of the utility.
- Graphs of rotation, pullout and strains along the 'sub-utility' length may be viewed for each 'sub-utility'.

1.5 Step by Step Guide

To perform a calculation of ground movements due to tunnelling or due to installation of, or excavation beside, embedded wall excavations follow the steps listed below. The data file should be saved at frequent intervals.

Item Description

- 1 Begin a new data file by selecting "File | New" on the program menu.
- 2 Set the preferred units for data input and output in the [Units dialog](#). That dialog is accessible by double-clicking "Units" in the [Gateway](#), or via "Data | Units" on the program menu. Choose, via the [Problem Type dialog](#), whether analysis is to be of tunnels/excavations/building damage assessment or of mines. The Problem Type dialog is accessible by double-clicking "Problem Type" in the Gateway or via "Data | Problem Type" on the program menu.

Tunnels/Excavations/Building Damage Assessment

- 3.1 Specify any tunnels in the [Tunnels table view](#). That view is accessible by double-clicking "Tunnels | All Data" in the [Gateway](#) or via "Data | Tunnels" on the program menu.
- 3.2 Specify any embedded wall excavations in the [Polygonal Excavations dialog](#) or [Circular Excavations dialog](#). These are accessible by double-clicking "Polygonal Excavations" or "Circular Excavations" in the [Gateway](#) or via "Data | Polygonal Excavations" or "Data | Circular Excavations" on the program menu. If user-specified Ground Movement Curves are required, then specify these in the Ground Movement Curves' view. That view is accessible by double-clicking "Ground Movement Curves" in the [Gateway](#), or via "Data | Ground Movement Curves" on the program menu.

Or Mines

- 3 Specify any mines in the [Mines table view](#). That view is accessible by double-clicking "Mines" in the [Gateway](#), or via "Data | Mines" on the program menu.
- 4 Enter, in the [Displacement Data table view](#), the locations in the ground at which ground movements are to be calculated. The Displacement Data table view is accessible by double-clicking "Displacement Data" in the [Gateway](#) or via "Data | Displacement Data" on the program menu.
- 5 Enter, in the [Polylines table view](#), the areas in the ground over which Generic Building Damage Assessment and Generic Utility Damage Assessment are to be performed. The Polylines table view is accessible by double clicking "Polylines" in the [Gateway](#) or via "Data | Polylines" on the program menu.
- 6 Inspect the [3D Graphics view](#) to confirm that the geometry of input data appears to be correct. That view is accessible by double-clicking "Output | 3D Graphics" in the [Gateway](#), via "View | 3D Graphics, or by clicking the 3D Graphics button in the [Xdisp toolbar](#).
- 7 If [Specific Building Damage Assessment](#) is required, enter details of the specific building in the [Specific Buildings table view](#). That table view is accessible by double-clicking "Specific -> Structures" in the [Gateway](#), or via "Data | Building Damage Assessment | Specific | Structures" on the program menu. Building Damage Category Strains may be entered into the Damage Category Strains' table view that is accessible by double-clicking "Damage Category Strains" in the [Gateway](#), or via "Data | Damage Category Strains" on the program menu.
- 8 If [Generic Building Damage Assessment](#) is required, enter details of the generic building in the [Generic Buildings table view](#). That table view is accessible by double-clicking "Generic -> Structures" in the [Gateway](#), or via "Data | Building Damage Assessment | Generic | Structures" on the program menu. Building Damage Category Strains may be entered into the Damage Category Strains' table view that is accessible by double-clicking "Damage Category Strains" in the [Gateway](#), or via "Data | Damage Category Strains" on the program menu.
- 9 If [Specific Utility Damage Assessment](#) is required, enter the utility dimensions via the [Utility Dimensions table view](#), the acceptance criteria and parameters via the Acceptance Criteria/Parameters table view and other information related to utilities via the Specific Utilities table view. These three table views are accessed by double clicking "Utility Dimensions", "Acceptance Criteria/Parameters" and "Utilities" respectively in the [Gateway](#). They can also be accessed via the program menu items "Data | Utility Damage Assessment | Utility Dimensions", "Data | Utility Damage Assessment | Acceptance Criteria/Parameters" and "Data | Utility Damage Assessment | Specific Utilities" respectively.
- 10 If [Generic Utility Damage Assessment](#) is required, enter the utility dimensions via the [Utility Dimensions table view](#), the acceptance criteria and parameters via the Acceptance Criteria/Parameters table view and other information related to generic utilities via the [Generic Utilities table view](#). These three table views are accessed by double clicking "Utility Dimensions", "Acceptance Criteria/Parameters" and "Utilities" respectively in the [Gateway](#). They can also be accessed via the program menu items "Data | Utility Damage Assessment | Utility Dimensions", "Data | Utility Damage Assessment | Acceptance Criteria/Parameters" and "Data | Utility Damage Assessment | Generic Utilities" respectively.
- 11 Perform an analysis by clicking the Analyse button on the [Xdisp toolbar](#), or via "Analysis | Analyse" on the program menu.

-
- 12 Xdisp performs a check on data for consistency. Correct any errors that are shown in the subsequent report of warnings and errors.
 - 13 Inspect the results in the [Tabular Output view](#), the [Plan View](#) and/or the [3D Graphics view](#). These are accessible by double-clicking the "Output | Tabular", "Output | Plan", "Output | 3D Graphics" in the [Gateway](#), via "View | Tabular Output", "View | Plan", "View | 3D Graphics" on the program menu, or via the appropriate buttons on the [Xdisp toolbar](#).
 - 14 Adjust data and re-analyse as necessary.

Part II

Corners: Coordinates and Stiffening

x and **y** - specify the plan coordinates of one corner of the excavation. Plans that specify re-entrant corners are prohibited.

Base Level - specifies the level of the base of the excavation at this corner. Base levels represent the base of the excavation (for excavation induced movements) or the toe of the Embedded Wall (for wall installation movements).

Stiffened - specifies whether stiffening effects should be applied to the corner in accordance with [Fuentes and Devriendt](#). If "yes" then the stiffening parameters in the following columns must be entered. For further discussion of the use of these parameters see [Corner Stiffening](#).

d - the distance from the corner to the centre point of the side in plan, or the distance to where plane strain movements start to occur, whichever is the lesser.

p1* - calibrated value of p1 for given ground conditions for corners that form a 90° angle - where p1 is the percentage of the ground movements for the previous and next sides' d, in a section that passes through the corner and is perpendicular to the side.

p2* - calibrated value of p2 for given ground conditions for corners that form a 90° angle - where p2 is the percentage of 100%_{previous} and 100%_{next} in a section that bisects the excavation at the given corner, and where 100%_{previous} and 100%_{next} are plane strain ground movements perpendicular and behind the previous and next sides respectively.

The values of **p1*** and **p2*** may change for different ground conditions and should be calibrated for those for each particular predominant soil. This calibration should be made by comparing the calculated corner movements to the observed movements at the corner. However, [Fuentes and Devriendt](#) shows, values of $p_1 = 67\%$ and $p_2 = 25\%$ are reasonable for the case histories considered.

[1]

Sides: Ground Movement Curves

Ground Movement Curves - specify the vertical and horizontal [ground movement curves](#) that are to be associated with this side of the excavation.

Enabled - if unchecked the excavation will be ignored in ground movement calculations. It will have no effect on results.

Notes

[1] Reproduced with kind permission of the American Society of Civil Engineers (ASCE).

Part III

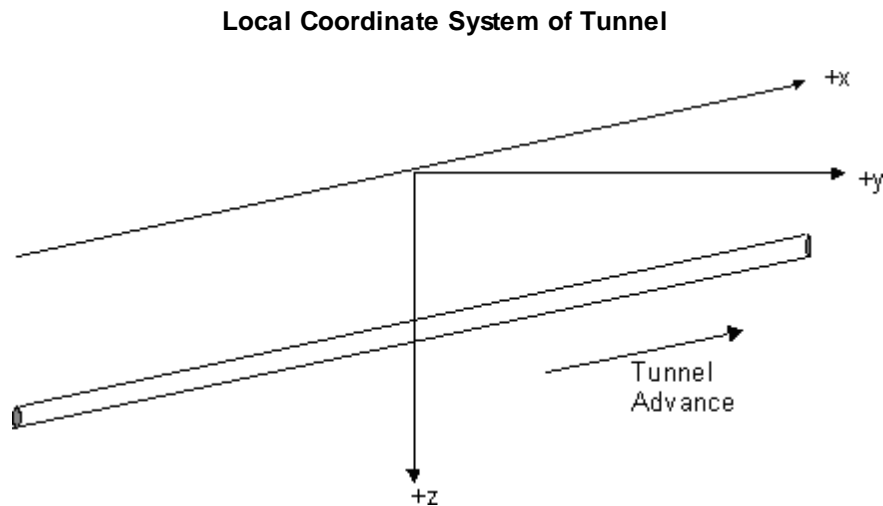
3 Analysis Methods

3.1 Tunnel Analysis Methods

Xdisp's tunnel analysis method calculates the settlement profile above an excavated tunnel, once the user has entered the estimated ground loss.

For the purposes of displacement calculations within the program, and where describing analysis methods and their profile widths and depths elsewhere in this manual, a local coordinate system is used. This is shown in the diagram below.

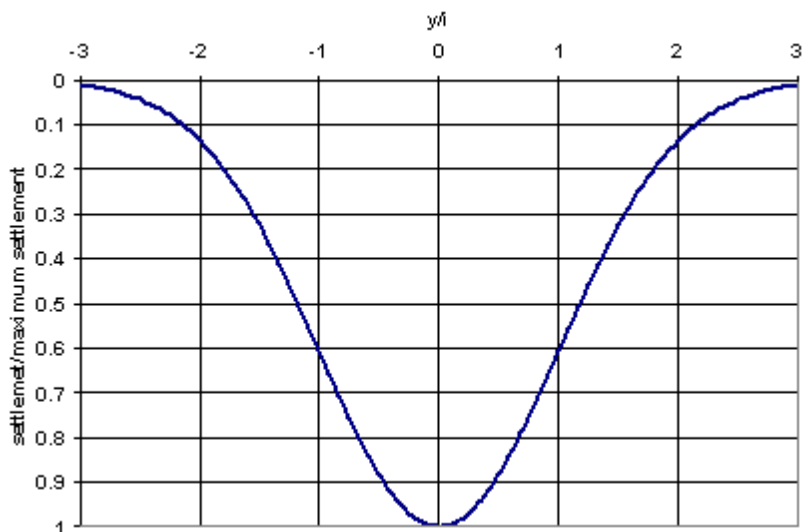
The 'global' x, y and z coordinates, that are used in the program's interface to specify tunnel and displacement grid locations, are converted into this local coordinate system in order to apply the analysis methods. Displacement Lines', Grids' and Points' results are output in the global coordinate system. Horizontal displacements that are shown graphically for sub-structure displacement graphs are reported as those in the direction of the sub-structure's alignment.



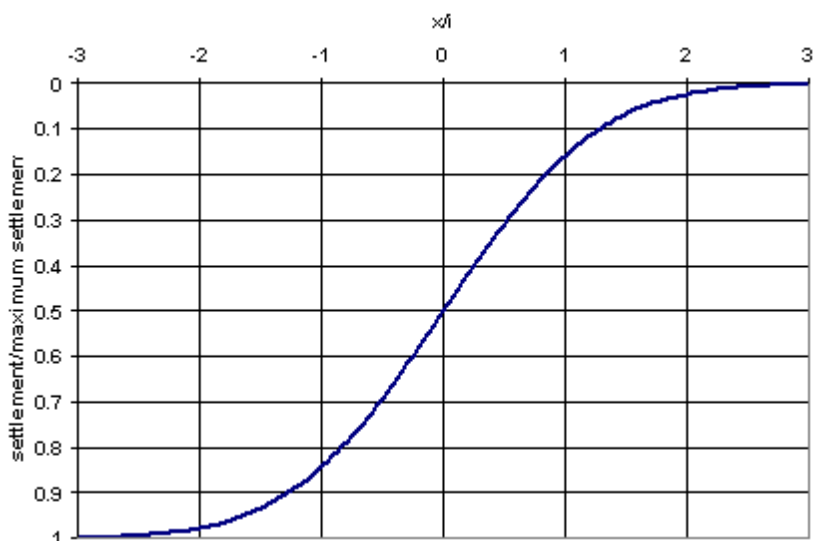
3.1.1 General Assumptions

Greenfield calculations are typically based on the assumption that the “settlement trough” at the ground surface (or at any level in the ground above the tunnel) normal or “transverse” to the line of the tunnel can be approximated by an inverted normal probability (or “Gaussian”) curve as shown in the first figure below. Vertical displacements in the longitudinal direction can similarly be approximated by a cumulative probability curve (second figure below). These are empirically based assumptions that have been developed in the past from consideration of monitoring case history data. The two figures below are presented in a normalised form for a single tunnel.

General Form of the Transverse Settlement Trough



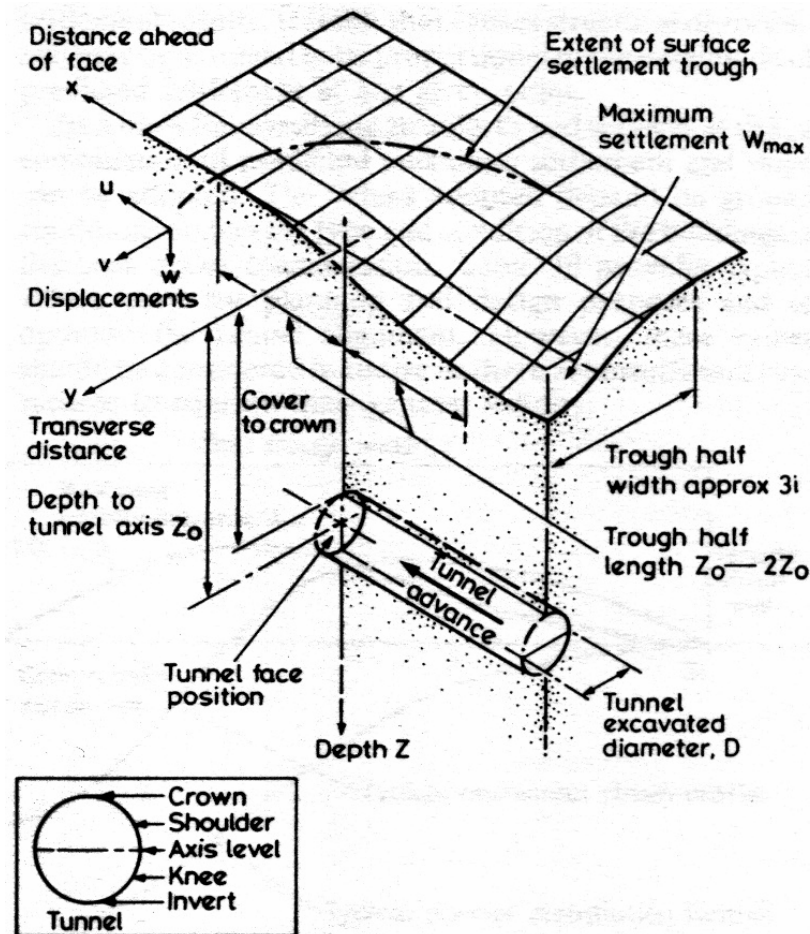
General Form of the Longitudinal Settlement Trough



The geometry of the settlement trough is uniquely defined by selecting values for the volume loss and the width of the trough relative to the depth of the tunnel – termed the “trough width parameter”. In the figures above the tunnel face is located at $y/i = x/i = 0$, with i representing the point of inflexion on the transverse profile, equivalent to one standard deviation in a normal probability distribution.

The complete 3D form of a tunnelling induced settlement trough appears as illustrated in the figure below after [Yeates \(1985\)](#). The equations that define the form and extent of the settlement trough will be discussed in the sections [Volume Loss](#) and [Tunnel Settlement Trough Width](#).

3D Schematic of the Settlement Trough (from Yeates (1985))



As identified in this figure the settlement profile in the direction of the tunnel advance is often described by analogy to a “bow wave” of an advancing ship. In the direction of the tunnel axis this is termed the longitudinal settlement trough, which can be obtained from a cumulative normal probability distribution.

In many practical situations it may be necessary to estimate ground movements on a plane that is not normal to or parallel to the tunnel axis. Depending on the analysis method chosen, the equations proposed by [Attewell and Woodman \(1982\)](#) (surface and sub-surface), or [Harris and Alvarado](#) (sub-surface only) are used in **Xdisp** for this situation in terms of a *G-function* obtained from the numerical integration of the normal probability function. See [Three Dimensional Form of Movement Equations](#) for details of these equations. The Attewell and Woodman equations are used in combination with a range of published [k derivation methods](#). Harris and Alvarado defines its own [k derivation method](#).

3.1.2 Volume Loss

The fundamental parameter that underlies all empirical methods of estimating tunnelling settlement is the volume loss. Volume loss can be defined as the ratio of the *additional volume of excavated ground removed* (V_s) over the *theoretical volume of the tunnel* (V_0) when short-term equilibrium has been attained. It is usually defined in a two dimensional sense as a percentage of the excavated

face area. That is, the volume loss is equivalent to a proportion of the cross sectional area:

$$V_L \% = (V_s / V_o) * 100\%$$

$$V_s = \text{additional excavated volume (per m run)}$$

$$= A_{exc} - A_o \text{ (m}^2 \text{ or m}^3/\text{m run)}$$

$$V_o = \text{theoretical volume of tunnel}$$

$$A_{exc} = \text{actual excavated area}$$

$$A_o = \text{theoretical cross-sectional area of tunnel excavation}$$

Short-term volume loss may be separated into the following components:

- a) ground lost at the face due to movements in an axial direction (face intrusion or face "take");
- b) radial movements due to over-excavation as a result of the use of a bead on a shield or over cutting on a tunnel boring machine (TBM), or due to "diving", "pitching", "yawing" of the shield or TBM or driving on a curve;
- c) radial movements due to temporary loss of support at the rear of the shield or TBM during lining construction;
- d) closure of the ungrouted annulus around the newly completed ring (non-expanded type of linings);
- e) initial distortion of the completed tunnel ring due to gravitational loading.

N.B. Xdisp takes the volume loss to be volume loss per unit horizontal length. However, the user generally inputs volume loss per unit length of tunnel which means that for inclined tunnels total volume loss, and hence settlements, are underestimated. Without modifying the Tunset code it is possible to divide the volume loss per unit length of tunnel by the cosine of angle of inclination of the tunnel to get the volume loss per unit horizontal length and input this into the program. The Xdisp calculation will then be correct.

3.1.3 Three Dimensional Form of Movement Equations

Either of two sets of three-dimensional forms of movement equations may be used: [Attewell and Woodman \(1982\)](#) (surface and sub-surface) or Harris and Alvarado (sub-surface only). The Attewell and Woodman equations are used in combination with a range of published [k derivation methods](#). Harris and Alvarado defines its own [k derivation method](#).

Note that the [O'Reilly and New \(1982\)](#) and [Mair et al \(1993\)/Taylor \(1995\)](#) Analysis Methods have their own definitions for the horizontal displacements transverse to the tunnel. See [Analysis Methods](#).

Attewell and Woodman

The following equations giving displacements and strains at any point are derived from [Attewell and Woodman \(1982\)](#). These are used for all ground movement calculations, in combination with a specified [k derivation method](#), unless the Harris and Alvarado method for sub-surface movements (see below) is chosen. These equations are applicable to surface and sub-surface movements.

$$w = \frac{V_s}{\sqrt{2\pi i}} \exp\left(-\frac{y^2}{2i^2}\right) \left\{ G\left(\frac{x-x_i}{i}\right) - G\left(\frac{x-x_f}{i}\right) \right\}$$

$$v = -\frac{n}{(z_0 - z)} y w$$

$$u = \frac{nV_s}{2\pi(z_0 - z)} \exp\left(-\frac{y^2}{2i^2}\right) \left\{ \exp\left(-\frac{(x-x_i)^2}{2i^2}\right) - \exp\left(-\frac{(x-x_f)^2}{2i^2}\right) \right\}$$

$$\varepsilon_z = -\frac{nV_s}{\sqrt{2\pi i}(z_0 - z)} \exp\left(-\frac{y^2}{2i^2}\right) \left(-\frac{1}{\sqrt{2\pi}}\right)$$

$$\left\{ \left(\frac{x-x_i}{i}\right) \exp\left(-\frac{(x-x_i)^2}{2i^2}\right) - \left(\frac{x-x_f}{i}\right) \exp\left(-\frac{(x-x_f)^2}{2i^2}\right) + \left(\frac{y^2}{i^2} - 1\right) \left[G\left(\frac{x-x_i}{i}\right) - G\left(\frac{x-x_f}{i}\right) \right] \right\}$$

$$\varepsilon_y = -\frac{n}{(z_0 - z)} w \left(\frac{y^2}{i^2} - 1\right)$$

$$\varepsilon_x = -\frac{nV_s}{2\pi i(z_0 - z)} \exp\left(-\frac{y^2}{2i^2}\right) \left\{ \left(\frac{x-x_i}{i}\right) \exp\left(-\frac{(x-x_i)^2}{2i^2}\right) - \left(\frac{x-x_f}{i}\right) \exp\left(-\frac{(x-x_f)^2}{2i^2}\right) \right\}$$

$$\gamma_{xy} = \frac{V_s}{2\pi(z_0 - z)} \exp\left(-\frac{y^2}{2i^2}\right) \left(-\frac{y}{i^2}\right) \left\{ \exp\left(-\frac{(x-x_i)^2}{2i^2}\right) - \exp\left(-\frac{(x-x_f)^2}{2i^2}\right) \right\}$$

$$-\frac{1}{(z_0 - z)} \frac{V_s}{\sqrt{2\pi i}} \exp\left(-\frac{y^2}{2i^2}\right) \left\{ \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{(x-x_i)^2}{2i^2}\right) - \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{(x-x_f)^2}{2i^2}\right) \right\}$$

where:

x, y, z = cartesian coordinates of any point in the ground deformation field (z positive downward).

u, v, w = ground displacements in the x, y, z directions respectively. u and v are always towards the origin of the cartesian coordinate system. w (settlement) is always positive downwards.

$\varepsilon_x, \varepsilon_y, \varepsilon_z$ = ground strains in the x, y, z directions respectively. These strains can change from tensile (positive) to compressive (negative) depending upon position in the deformation field. Tensile ground strains are more likely to have a serious effect upon the brittle foundation of a building or upon a brittle pipe than are compressive ground strains.

γ_{xy} = ground shear strain in a horizontal plane.

z_0 = depth of the effective source of ground loss (taken as approximating to the tunnel axis).

n = power of $(z_0 - z)$ to which i_x , i_y and i are proportional.

V_s = volume of the settlement trough per unit distance of tunnel advance, the settlement being attributable to ground losses and not incorporating any longer term consolidation.

i = parameter defining the form and span of the settlement trough on the assumption that the semi-transverse (y-axis) settlement profile can be described by a normal probability equation ([Schmidt \(1969\)](#), [Peck \(1969\)](#), [Attewell \(1978\)](#)).

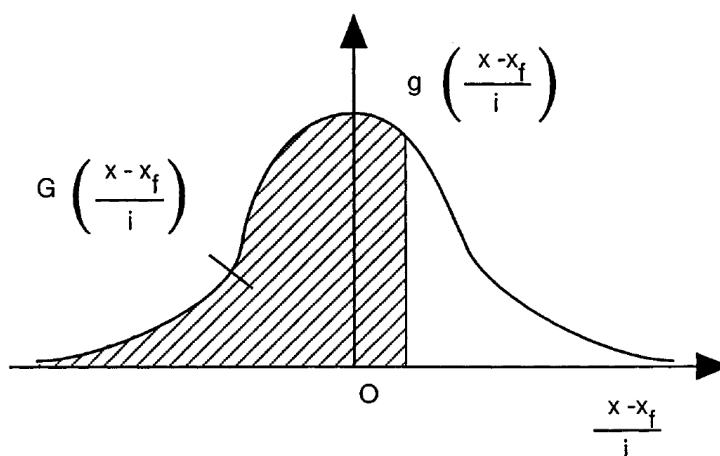
It is the horizontal surface distance from a vertical line through the centre of the tunnel to the point of inflexion of the settlement trough.

x_i = initial or tunnel start point ($y=0$).

x_f = face or final tunnel position ($y=0$).

$G\left(\frac{x-x_f}{i}\right)$ = a function of the normal probability curve which is described by the following equation:

$$G(a) = -\frac{1}{\sqrt{2\pi}} \int_{-\infty}^a \exp\left(-\frac{B^2}{2}\right) dB$$



The two-dimensional form of movements transverse to a tunnel reduces to.

$$S = S_{\max} e^{-y^2/2i^2}$$

$$V_s = (2\pi)^{0.5} i S_{\max}$$

where:

S = settlement at horizontal distance y from tunnel axis

S_{\max} = maximum settlement (above tunnel axis alignment)

Harris and Alvarado

The Harris and Alvarado movement equations are applicable to sub-surface movements only.

$$S = \frac{V_s}{2i\sqrt{2\pi}} \exp\left(\frac{-\hat{y}^2}{2}\right) \left[\operatorname{erf}\left(\frac{\hat{x}_i}{\sqrt{2}}\right) - \operatorname{erf}\left(\frac{\hat{x}_f}{\sqrt{2}}\right) \right]$$

$$h_y = -\frac{mV_s y}{2i(z_{\text{inv}} - z)\sqrt{2\pi}} \exp\left(\frac{-\hat{y}^2}{2}\right) \left[\operatorname{erf}\left(\frac{\hat{x}_i}{\sqrt{2}}\right) - \operatorname{erf}\left(\frac{\hat{x}_f}{\sqrt{2}}\right) \right]$$

$$h_x = \left[\frac{mV_s}{2\pi(z_{\text{inv}} - z)} \right] \left[\exp\left(-\frac{(\hat{x}_i^2 + \hat{y}^2)}{2}\right) - \exp\left(-\frac{(\hat{x}_f^2 + \hat{y}^2)}{2}\right) \right]$$

$$\operatorname{erf}\left(\frac{\hat{x}_i}{\sqrt{2}}\right) = \frac{2}{\sqrt{\pi}} \int_0^{\frac{\hat{x}_i}{\sqrt{2}}} e^{-t^2} dt$$

$$i = i_0 \left(\frac{z_{\text{inv}} - z}{z_{\text{inv}}} \right)^m$$

$$i_0 = i_{\text{ref}} \left(1 - \left(\frac{z_{\text{ref}} - z}{z_{\text{ref}}} \right) \right)^n$$

$$\hat{x}_i = \frac{x - x_i}{i}$$

$$\hat{x}_f = \frac{x - x_f}{i}$$

$$\hat{y}_i = \frac{y}{i}$$

where:

S = settlement at depth z , at transverse horizontal distance y from tunnel axis, and at longitudinal horizontal distance x (start of tunnel being at x_i ; end of tunnel being at x_f)

h_y = horizontal ground movement in direction transverse to tunnel axis, at transverse horizontal distance y from tunnel axis, and at longitudinal horizontal distance x (start of tunnel being at x_i ; end of tunnel being at x_f)

h_x = horizontal ground movement in direction parallel to tunnel axis, at transverse horizontal distance y from tunnel axis, and at longitudinal horizontal distance x (start of tunnel being at x_i ; end of tunnel being at x_f)

V_s = volume of soil displaced in settlement trough

i = distance from tunnel axis to point of inflexion at depth z

i_0 = distance from tunnel axis to point of inflexion at surface

i_{ref} = 12.5 metres

z = depth below ground surface

z_{in} = depth of tunnel invert below ground surface

v

z_{re} = 30 metres

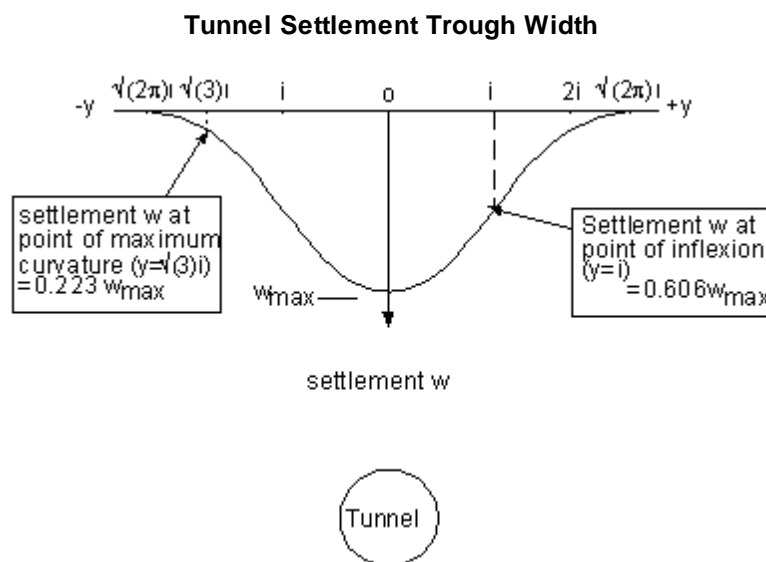
f

n = 0.8

m = user-specified exponent (for a typical London clay Harris and Alvarado recommend m of 0.5)

3.1.4 Tunnel Settlement Trough Width

The width of the settlement trough perpendicular to the tunnel is defined in terms of distance 'i' in metres from the tunnel centre-line to the point of inflexion on the curve.



Xdisp provides a number of options to calculate 'i' via selection of a 'k Derivation Method'. A 'k' value provides a relationship between the distance 'i' and the depth to tunnel axis level. Lower values lead to steeper and narrower troughs. Higher values lead to wider shallower troughs. The methods listed

in the table below describe the relationship between 'k' and 'i' and the calculation of settlement and horizontal movement using those 'k' or 'i' values.

These methods have varying applicability. Some apply to the calculation of surface displacements for single-layered soil. Some apply to the calculation of sub-surface displacements for single-layered soil. One applies to surface displacements for two-layered soil. The table below summarises the applicability of each method/k Derivation Method combination.

Three-Dimensional Form of Movement Equations	Analysis Method	k Derivation Method	Applicability			
			Surface Displacements	Sub-surface Displacements	Single-layered Soil	Dual-layered Soil
Attewell and Woodman	-	User-specified k	✓	-	✓	-
		O'Reilly and New	✓	-	✓	-
		Boscardin	✓	-	✓	-
		Selby	✓	-	-	✓
	Mair et al	-	-	✓	✓	-
	New and Bowers	User-specified k	-	✓	✓	-
Harris and Alvarado	Harris and Alvarado	-	-	✓	✓	-

When specifying sub-surface displacement calculation points, the user is presented with the choice of either the [Mair et al \(1993\)](#) method, the [New and Bowers \(1994\)](#) method, or the [Harris and Alvarado](#) method. These are described in [Analysis Methods](#). The [O'Reilly and New \(1982\)](#), [Boscardin and Selby \(1988\)](#) k derivation methods are described in [k derivation methods](#).

Mair et al is applicable for surface displacements if a k value of 0.5 can be relied upon - which would potentially be the case for clay. Similarly, it could be argued that the New and Bowers/User-specified method could be used for surface displacements as it has been validated for those the Heathrow Express Trial tunnel, see [New and Bowers \(1994\)](#).

Users should check movements below a 45° line from the invert of the tunnel are bench-marked against case study data.

3.1.4.1 Analysis Methods

(All length dimensions in these equations are in metres. Volume is in cubic metres.)

a) O'Reilly and New (1982)

$$k = \frac{i}{z}$$

$$h = \frac{yS}{z_0}$$

where:

y	= horizontal distance from tunnel axis
z	= the axis level of the tunnel to the ground surface
z_0	= distance from surface level to tunnel axis
S	= settlement at horizontal distance y from tunnel axis
S_{max}	= maximum settlement (above tunnel axis alignment)
i	= horizontal distance from tunnel axis to point of inflexion of settlement trough
V_S	= volume of soil displaced in settlement trough
V_L	= volume loss (can be expressed as a percentage by multiplying by 100%)
h	= horizontal displacement at distance y from tunnel axis
D	= tunnel diameter

b) Mair et al (1993)

$$i = z_0 \left(0.175 + 0.325 \left(1 - \frac{z}{z_0} \right) \right)$$

$$h = \frac{-0.325yS}{i}$$

where:

y	= horizontal distance from tunnel axis
z_0	= distance from surface to tunnel axis level
z	= depth below ground surface
i	= distance from axis to point of inflexion at depth z
S	= settlement at depth z and at transverse horizontal distance of y from tunnel axis (as calculated in (a) above)
R	= radius of tunnel
h	= horizontal displacement at depth z and at distance y from tunnel axis

The calculation of h is based on the [Taylor \(1995\)](#) extension to Mair et al's method.

A warning is issued if z/z_0 is greater than 0.8 or z is greater than the depth to the tunnel crown. In such circumstances calculations are moving outside the scenarios covered by the case study data on which the Mair et al method is based.

c) New and Bowers (1994)

This method assumes displacements are directed towards a 'ribbon' of volume loss taking place at the tunnel invert level. For details of this method see [references](#). This method may also be referred to as the 'Ribbon Sink' method.

d) Harris and Alvarado (in preparation)

See also [Three Dimensional Form of Movement Equations](#).

3.1.4.2 k Derivation Methods

a) User-specified k

Typical user-specified k values for soils would be:

Soil	Range of k
Stiff, fissured clay	0.4 to 0.5
Glacial deposits	0.5 to 0.6
Recent soft, silty clay	0.6 to 0.7
Granular soils above water table	0.2 to 0.3

(See [O'Reilly and New \(1982\)](#).)

b) O'Reilly and New (1982)

Cohesive soils: $i = 0.43z_0 + 1.1$ metres

Granular soils*: $i = 0.28z_0 - 0.12$ metres

* From Fig.4 of [O'Reilly and New \(1982\)](#).

(i and z_0 in metres.)

Before version 18.3 of Tunset (Xdisp's predecessor), the program referred to this method as the Attewell method.

c) Boscardin

Cohesive soils: $i = 0.5z_0$ metres

Granular soils: $i = 0.25z_0$ metres

(i and z_0 in metres.)

d) Selby (1988)

Clay overlain by sand: $i = 0.43z_2 + 0.28z_1 + 1.1$ metres

Sand overlain by clay: $i = 0.28z_2 + 0.43z_1 - 0.1$ metres

where: z_1 = thickness of upper layer

z_2 = thickness of tunnel stratum

(i, z_1 and z_2 in metres.)

3.2 Embedded Wall Excavations Method

This methodology follows that which is proposed in [CIRIA Report C580](#) for ground movements beside embedded retaining walls. It calculates movements due to the installation of an embedded wall and due to the excavation in front of the embedded wall.

An embedded wall excavation is defined by a polygon or circle in plan with top and bottom levels. Re-entrant internal angles (i.e. greater than 180°) are prohibited in the plan polygon. Bottom levels may vary from one corner to another for a polygonal excavation. Circular excavations have single vertical and horizontal ground movement curves. Polygonal excavations have multiple ground movement curves - one for each side of the excavation.

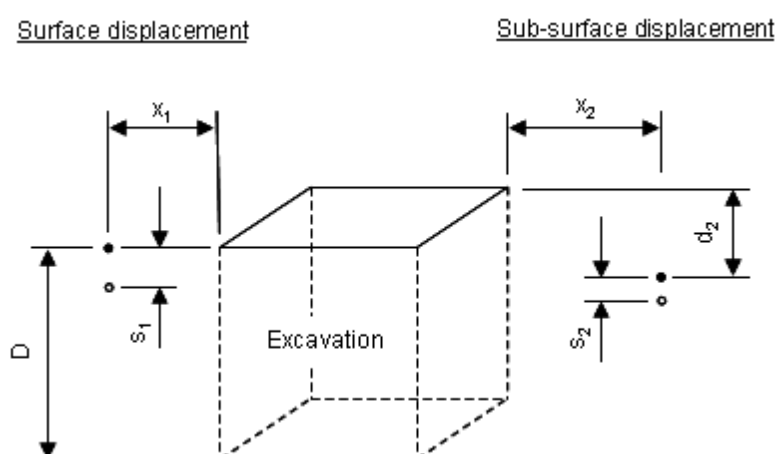
Ground movement curves may be specified for movements at the soil surface and sub-surface or for movements at the surface only. The former are specified by a series of local x, y and z coordinates, while the latter are specified by a series of local x and z coordinates only. The x coordinates represent the ratio of a point's distance from the wall or excavation to the depth of the wall or excavation. The y coordinates represent the ratio of a point's depth below the top of the wall or excavation to the depth of the wall or excavation. The z coordinates represent the ratio of the movement of the point to the depth of the wall or excavation. Vertical and horizontal movements are specified independently.

A curve is fitted to these sets of coordinates, either as a 2 dimensional line graph (for surface movement data sets) or a 3 dimensional surface graph (for surface and sub-surface movement data sets).

Positions at which soil movements are to be calculated are specified, as for tunnels and mines, via displacement grids, lines and points. The movement of each position is calculated as shown below. This method is used to calculate both vertical and horizontal displacements. If displacement points are sited above the surface level of the excavation, then their displacements are calculated as though they were at the surface level.

Irregularly shaped excavations may be modelled following the procedure outlined in [Irregularly Shaped Excavations](#).

Schematic Diagram of Excavation

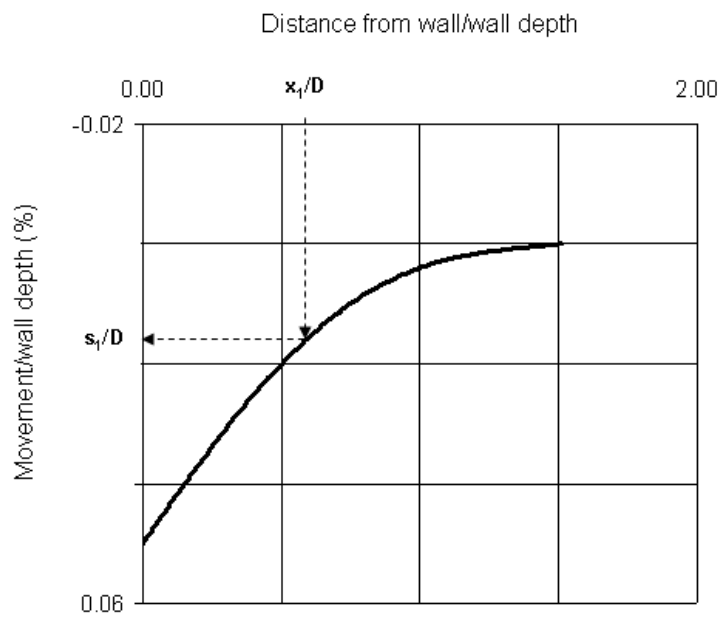


x = distance to wall or excavation

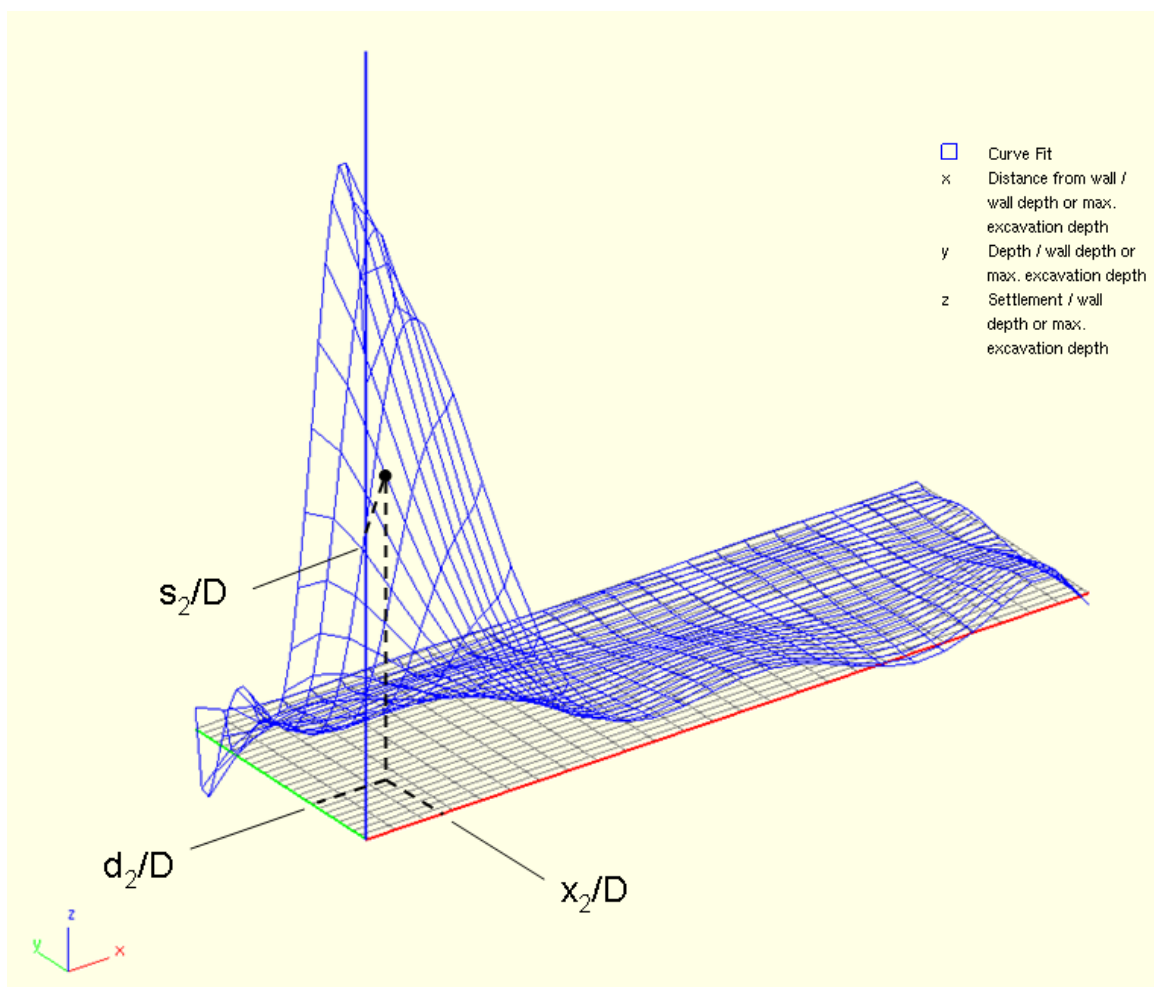
- s = movement due to wall installation or excavation (either vertical or horizontal)
- D = wall or excavation depth
- d = depth of sub-surface point below top of excavation
- = soil position before wall installation or excavation
- o = soil position after wall installation or excavation

If an excavation has a variable depth then the depth D is taken to be the depth of the wall or excavation at the position on the side from which a line drawn normal to that side will intersect the displacement point.

Ground Movement Curve - Surface Movements Only



Ground Movement Curve - Surface and Sub-surface Movements



Xdisp performs the following steps for each excavation to calculate the displacement of each displacement point.

(a) If the excavation has been associated with a curve of surface movement only and the displacement point is level with the top of that excavation

1. calculate the distance of the point from the wall/excavation (x)
2. calculate the depth (D) of the excavation at the side closest to the point
3. calculate x/D
4. calculate s/D from x/D and the appropriate ground movement curve
5. calculate s

(b) If the excavation has been associated with a curve of surface movement only and

(i) the displacement point is below the top of that excavation, then s is set to zero.

or

(ii) the displacement point is above the top of that excavation, then s is calculated as though the displacement point were at the level of the surface of the excavation

(c) If the excavation has been associated with a curve of surface and sub-surface movement, and the displacement point is level with or below the top of that excavation

1. calculate the distance of the point from the wall/excavation (x)
2. calculate the depth (D) of the excavation at the side closest to the point
3. calculate x/D
4. calculate the depth of the point from the top of the wall/excavation (y)
5. calculate y/D
6. calculate s/D from x/D and y/D and the appropriate ground movement curve
7. calculate s

(d) If the excavation has been associated with a curve of surface and sub-surface movement and

(i) the displacement point is below the top of that excavation, then s is set to zero.

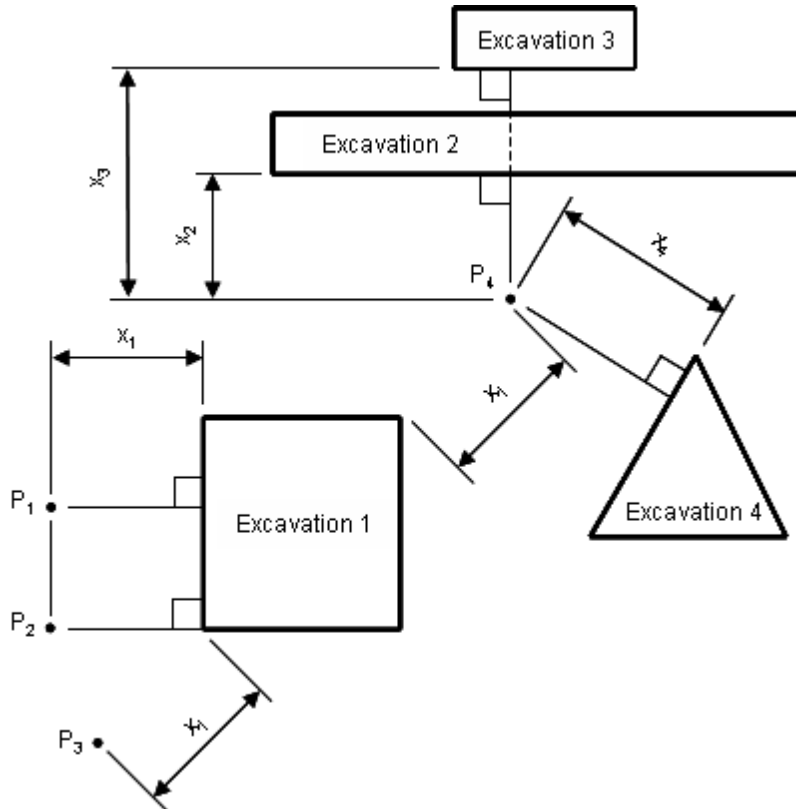
or

(ii) the displacement point is above the top of that excavation, then s is calculated as though the displacement point were at the level of the surface of the excavation

The total horizontal and vertical displacement of the displacement point is calculated by a vector sum of the horizontal and vertical displacements arising from each excavation.

N.B. Warnings

**Plan of Multiple Excavations
(to demonstrate cautionary notes)**



- 1) If [corner stiffening](#) is not invoked then the displacements that are calculated for positions that are within the arc of an excavation's corner (i.e. positions that cannot be reached by drawing a perpendicular line from any side of the excavation) are based on the distance measured to the corner. Hence the magnitude of the horizontal and vertical movements of positions P_1 and P_3 , in the plan above, will be calculated to be equal.
- 2) No adjustment is made to the calculation to allow for the distance of the point along the length of a side of the excavation. Hence the magnitude of the horizontal and vertical movements of positions P_1 and P_2 , in the plan above, will be calculated to be equal.
- 3) Multiple excavations may be specified. The displacements resulting from these excavations are calculated by summing the displacements resulting from each individual excavation. No account has been taken of the interactions between excavations (e.g. overlapping zones of influence or 'shielding' of one excavation by another). Hence the horizontal and vertical displacement of position P_4 in the plan above will be calculated as the sum of the results calculated for each of the four excavations.

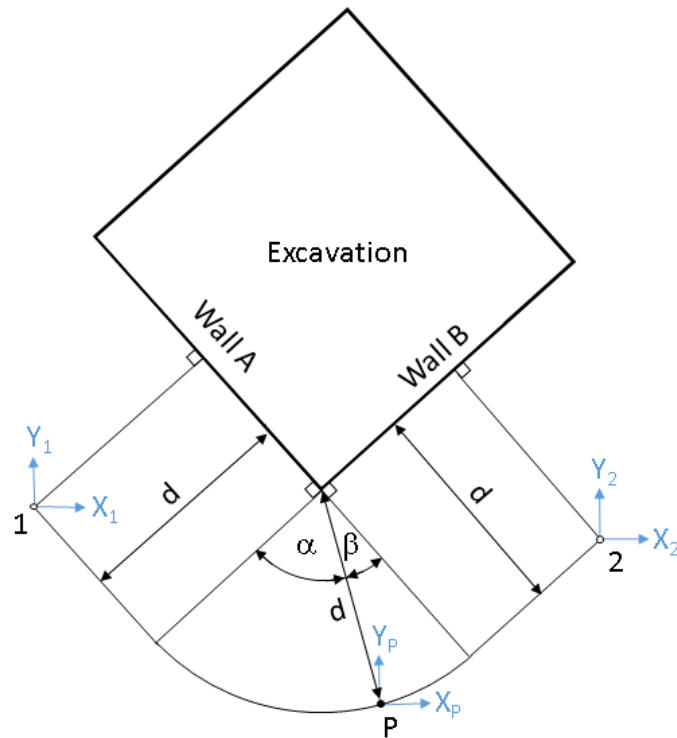
3.2.1 Horizontal Components of Ground Movements around Corners

Embedded Wall Excavations Method describes the calculation of ground movements for displacement points under the direct influence of sides of excavations (i.e. displacement points to which a line can be subtended from sides of one or more excavations). The horizontal movement is always considered to be towards the excavation, i.e. along that subtended line.

The calculation of the horizontal ground movements for a displacement point that is located in the arc of a corner, and a distance d from the corner, depends on the magnitudes and directions of the horizontal movements at the adjacent sides for points an equivalent distance d from those sides.

The method is summarised below.

Plan of Excavation



If P is a displacement point in the arc of the corner of an excavation, then its horizontal ground movement components (X_p and Y_p) are given by:

$$X_p = p_a X_1 + p_b X_2$$

$$Y_p = p_a Y_1 + p_b Y_2$$

where, for unstiffened corners,

$$p_a = \frac{\beta}{\alpha + \beta}$$

$$p_b = \frac{\alpha}{\alpha + \beta}$$

and for stiffened corners p_a and p_b are as defined in [Corner Stiffening](#).

Vertical movements are calculated similarly, using factored contributions from each wall.

3.2.2 Corner Stiffening

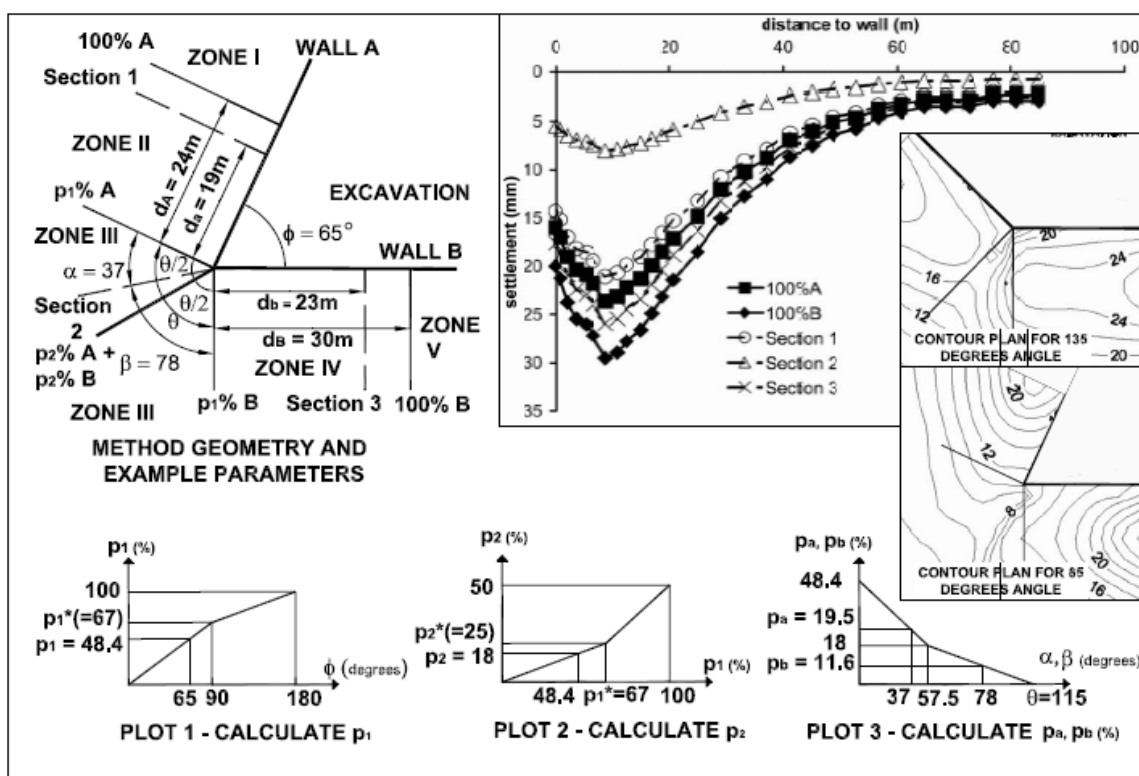
The ground movement curves are considered to represent 100% ground movement profile. However, this is not really true for retained cut excavations (for instance basement excavations), as there is increased stiffness at corners. From case studies, it has been observed that such effects result in smaller ground movements. Xdisp considers such corner effects and adjusts the ground movement based on the method suggested by [Fuentes and Devriendt](#). This method works for all corners except for re-entrant corners.

Implementation of the Method:

The "Zone Identification" figure and discussion below from [Fuentes and Devriendt](#) explains the implementation of this method through an example.

The input parameters which are required for this method apart from the geometry are:

- p_1^* : the percentage of the "100% ground movement profile" that occurs along the line which is normal to a wall adjacent to the corner of the excavation (See figure below).
- p_2^* : the percentage of the "100% ground movement profile" that occurs along the line which is at an angle $\theta/2$ to the line along which p_1^* is calculated. Where, θ is the angle at the corner of the excavation between the lines normal to the two retaining walls (See figure below).
- Settlement at 100% A
- Settlement at 100% B



Zone Identification, method's parameters, geometry, and plots (Plot 1-calculation of p_1 , Plot 2-calculation of p_2 , Plot 3-calculation of p_a and p_b) and example of method application

The percentage factors that are to be applied to 100% movements in sides A and B, to calculate the settlement at the point under consideration, are calculated from this input.

The plots to be used to calculate these factors, and the equation used to calculate the settlement, depend on the zone in which the point lies. The zones are illustrated in the figure above. The table below from [Fuentes and Devriendt](#) lists the plots and equations used for different zones.

Plots and equations used for

different zones

Plot	Input	Zones I and V	Zones II and IV	Zone III
1	p_1^* and \emptyset	X	✓	✓
2	p_1^* and p_2^*	X	✓	✓
3	p_1^* , p_2^* , α , and β	X	X	✓
Equations		$p = \%A$ or $p = \%B$	$p = p_1 + (100 - p_1) \frac{d_a}{d_A} \%A$ or $p = p_1 + (100 - p_1) \frac{d_b}{d_B} \%B$	$p = p_a \times \%A + p_b \times \%B$

Note: d_a and d_b are the distances, from the point where the ground movements are to be calculated, to the position of d_A and d_B (see figure below). %A and %B represent the 100%A and 100%B sections.

The figure and table above are reproduced with kind permission of the American Society of Civil Engineers (ASCE).

3.2.3 Excavations with Stepped Bases

There are a number of way in which excavations with stepped bases may be modelled.

These methods are predominantly geometrical approximations. They are not based on published geotechnical engineering theory but may be considered to provide an adequate approximation to soil movement caused by excavations with stepped bases. Engineering judgment should be used in choosing the most appropriate method given the conditions, and the results reviewed carefully e.g. by validation of the ground movements calculated by Xdisp against similar case studies or alternative methods of analysis to ensure they meet expectations..

Four methods are described below. By way of comparison, sample graphical output of contours of vertical ground movement are provided. In the samples, the same vertical movement curve applied to all walls - "Excavation in front of low stiffness wall in stiff clay (CIRIA C580 Fig. 2.11(b)).

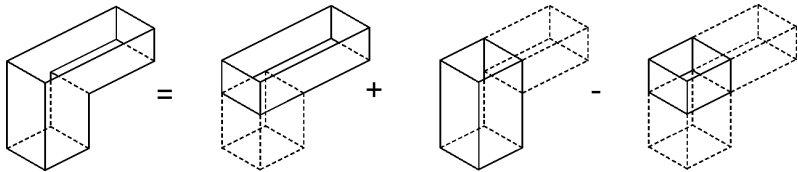
In versions of Xdisp before version 19.4, only methods 1 and 2 were available and so may occur in legacy data files, for which the input field "contribution" in the [excavation data](#) dialog is required. Methods 3 and 4 are available from version Xdisp 19.4.

Method 1 - Composite Excavation

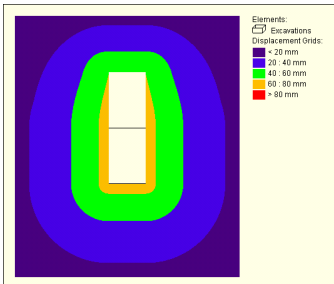
Excavations with stepped bases may be modelled by breaking them into sufficient cuboid constituents. Each constituent is specified to have either a positive or negative contribution to soil displacement. Xdisp will calculate the soil displacements arising from each excavation. These results are then summed.

Care should be taken when deriving the cuboid constituents in order to ensure that the correct relationship has been specified.

**Method 1
Illustration of Excavations Required**



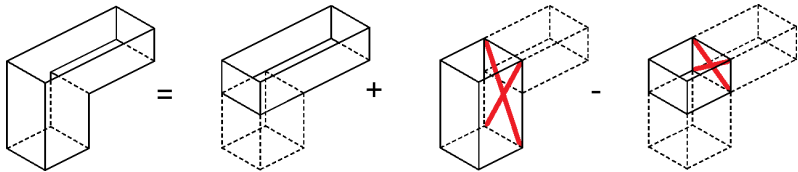
**Method 1
Vertical Ground Movement at Surface
Sample Contours**



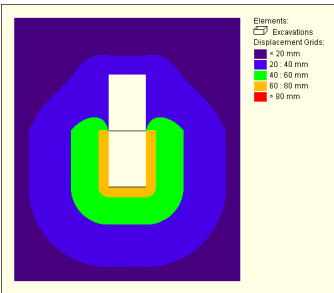
Method 2 - Composite Excavation (with zero ground movement applied to internal walls)

This method is the same as Method 1, but with ground movement curves of zero ground movement being applied to the internal walls, since they would not be present within the excavation in reality. This avoids those "phoney" walls contributing to ground movements. However, the influence of their portions which extend beneath the excavation as "true" walls would also be ignored.

**Method 2
Illustration of Excavations Required**



**Method 2
Vertical Ground Movement at Surface
Sample Contours**

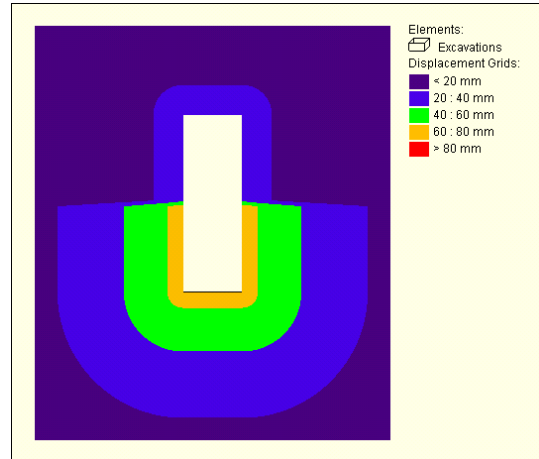
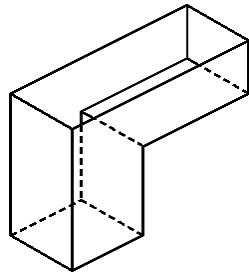


Method 3 - Single Excavation (with stepped base)

Polygonal excavations may be assigned duplicate plan coordinates with different base levels, in this way one wall with one base level may join another wall with a different base level, causing an immediate step in the base. Hence the excavation with the stepped base can be input as a single excavation. However, as shown in the sample contour results below, this can lead to Xdisp calculating drastic discontinuities in ground movements alongside the junction with may be unrealistic. If buildings or utilities lie in this area, then their damage results may be unrealistically adversely affected.

**Method 3
Illustration of Excavation Required**

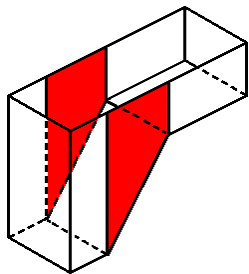
**Method 3
Vertical Ground Movement at Surface
Sample Contours**



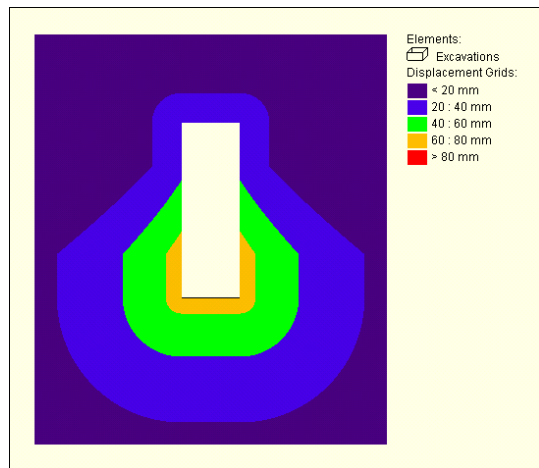
Method 4 - Single Excavation (with sloping base along short walls)

Drastic discontinuities in ground movements arising from the use of Method 3 may be avoided by the introduction of short sides of excavation designed to change the base level of the excavation more gradually than at a single point in plan. Although these walls may not exist in reality, they have the effect of "smoothing" the contours and may prove useful in achieving more realistic ground movement results, contour plots, and building and utility damage assessment results.

**Method 4
Illustration of Excavation Required**



**Method 4
Vertical Ground Movement at Surface
Sample Contours**

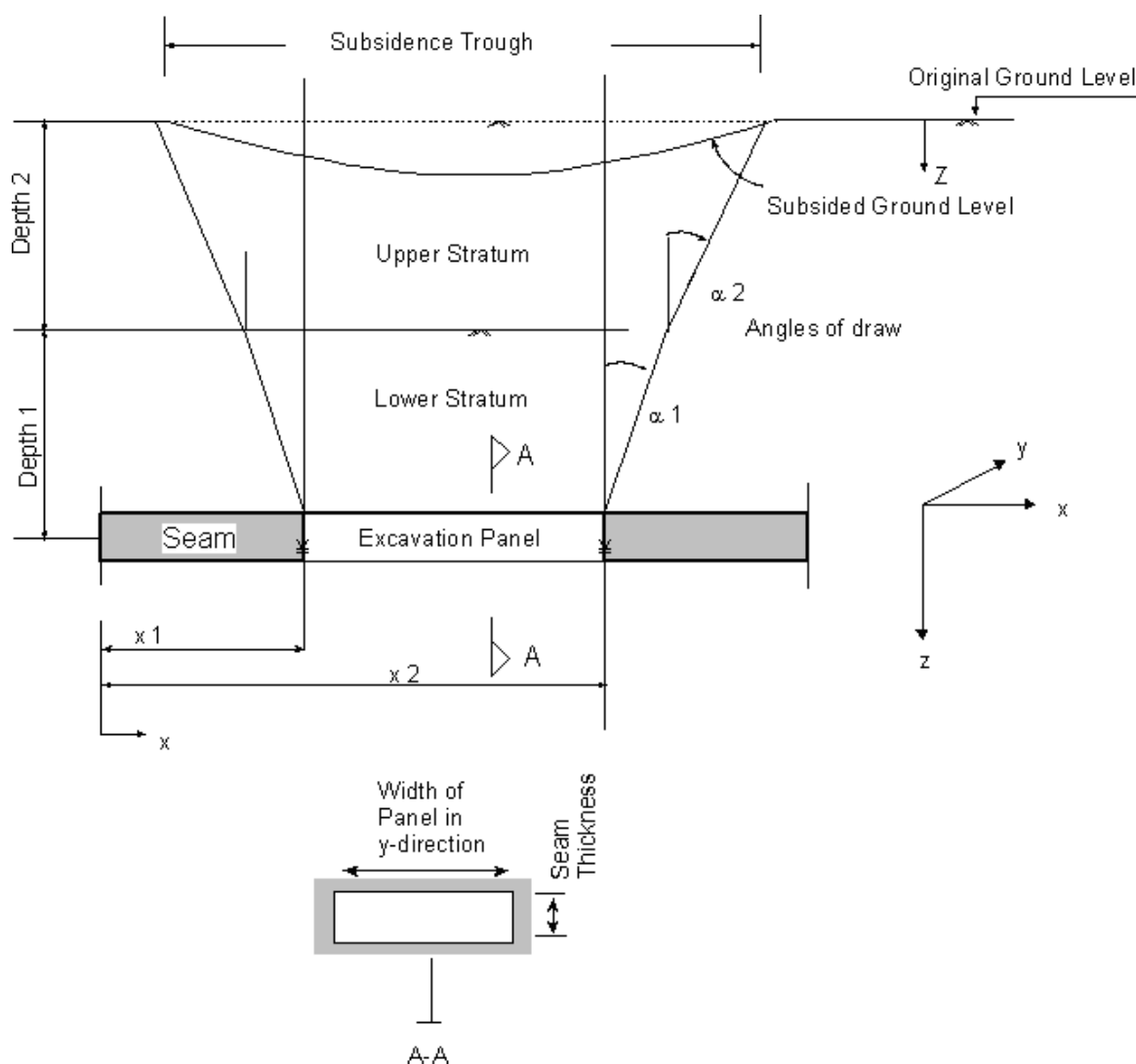


3.3 Mining Analysis Method

Mines are taken as being excavations of rectangular cross-section in rock.

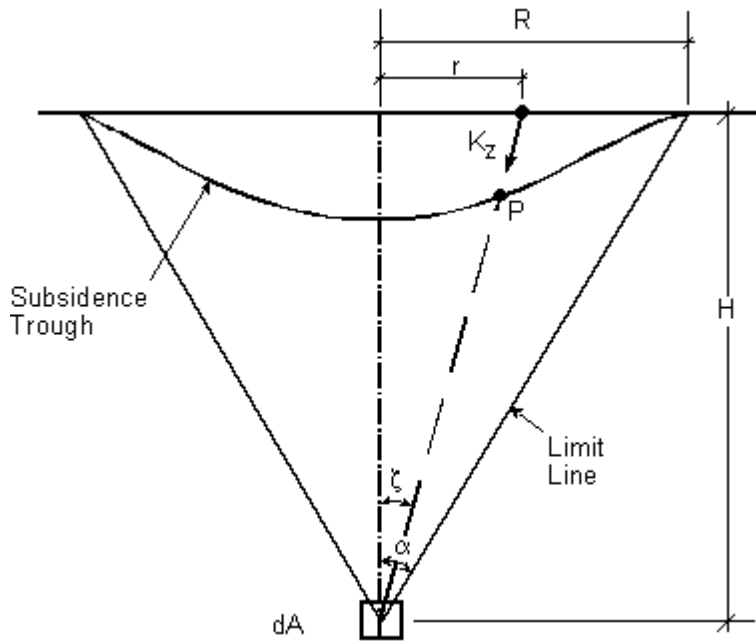
Xdisp calculates the subsidence at ground level, due to deformation within the mine cavity, at every specified displacement grid point. Subsidence contours are then determined from the values at each point to define the whole area of the settlement trough. The spacing of the [displacement grids](#) is therefore fundamental to the accuracy of any contour plots.

The subsidence calculations are divided into vertical and horizontal displacement at each point. A single method of calculation exists in each case.



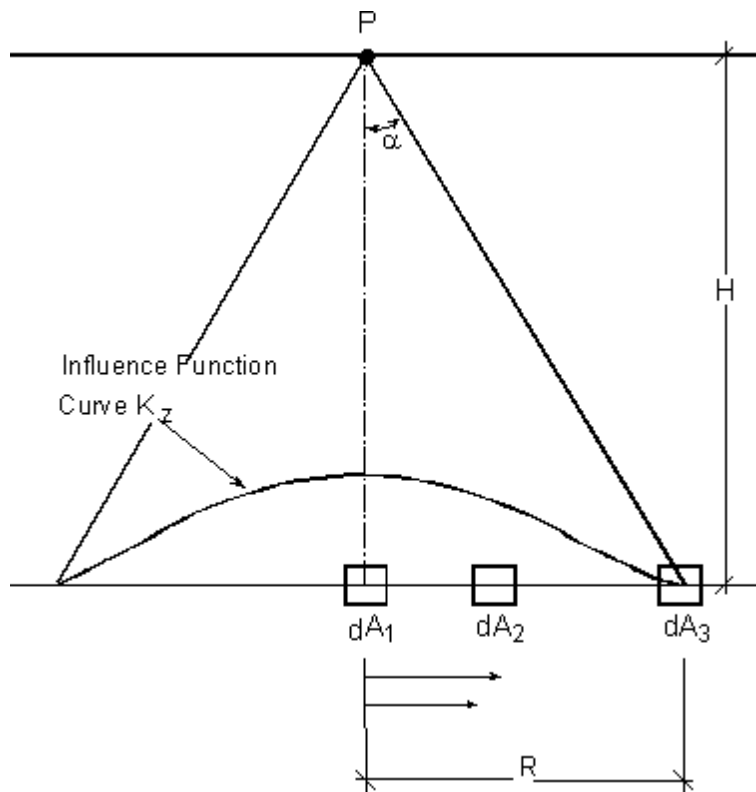
3.3.1 Vertical Displacement

The method of calculation of vertical displacement is based on the use of an influence factor (K_z). The area of subsidence created due to the extraction of an element dA at the same depth of the mine is calculated. The factor then defines the influence of the subsidence trough on the displacement grid points located at the surface.



Full details of the derivation of the influence factor can be found in [Ren et al \(1987\)](#).

The following describes the calculation procedure taken by **Xdisp**.



Here the above statement is reversed. Each displacement grid point (P) is deemed to be over a point of maximum displacement. The influence of the actual area of extraction within the mine is then determined.

1. The vertical displacement at each displacement grid point is taken as:

$$S = S_p S_0$$

where:

S_0 is the maximum possible subsidence above the excavation.
 = (Subsidence Factor)x(Seam Thickness)

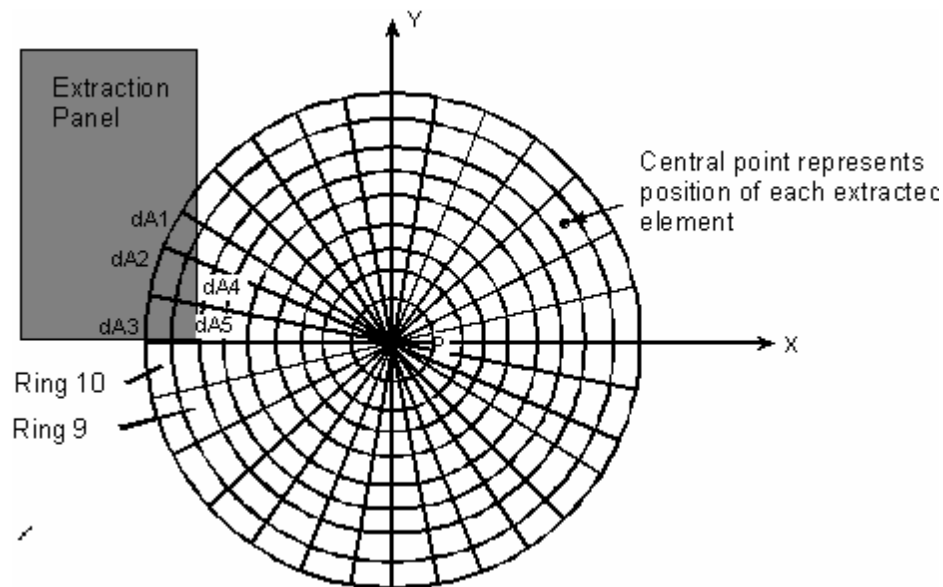
S_p is the influence of the mine subsidence on the displacement grid point.

2. A circle of influence is defined around each grid point (P).

The radius (R) of this circle is taken as;

$$R = H \tan \alpha$$

where H = depth to the centre of the seam



α = Angle of draw

3. The circle is divided into 10 rings, increasing in size around the centre. The displacement at the central point is then determined by calculating the influence on the centre if extraction is made of each encircling ring.

e.g. Each ring has an area A and width r_i to r_{i+1} . The amount of relative subsidence at the central point P after the ring is extracted is taken as $S_{(i)}$, the Annular Influence Factor. Where:

$$S_{(i)} = \left\{ \exp \left[-\pi \left(\frac{r_{i-1}}{R} \right)^2 \right] - \exp \left[-\pi \left(\frac{r_i}{R} \right)^2 \right] \right\}$$

4. Each ring is divided into 64 sectors. Each sector has an individual sector element influence factor $S_{(i)s} = S_{(i)}/64$. This indicates the amount of influence, extraction beneath that sector

exerts on the central point P at the surface.

In the example figure above the calculated values of $S_{(i)s}$ for each sector are:

Ring No.	1	2	3	4	5	6	7	8	9	10
$S_{(i)s} \times 10^{-6}$	505	1423	2094	2430	2433	2195	1767	1315	905	577

5. **Xdisp** then calculates which sectors lie over the extracted panel. If a sector is within the area of the panel then its element influence factor $S_{(i)s}$ is summed to obtain the variable S_p .

$$S_p = \sum S_{(i)s}$$

e.g. for the above example where two sectors in ring 9 and three in ring 10 are extracted:

$$S_p = (2S_{(9)s} + 3S_{(10)s}) = (2 \times 905 + 3 \times 577) \times 10^{-6} = 0.003541$$

6. Then settlement S at point P is:

$$S = S_p S_0$$

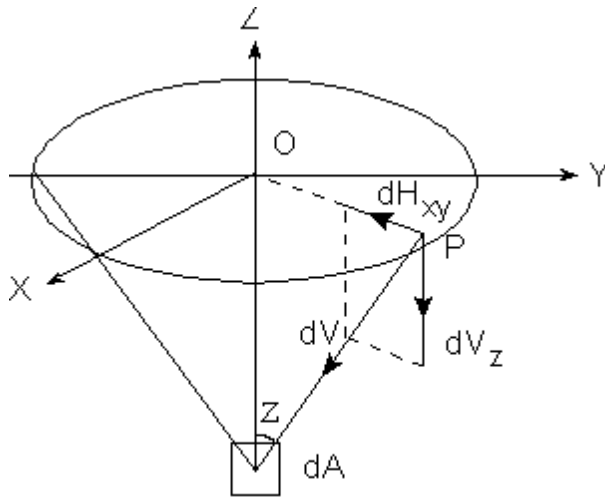
$$\text{e.g. } S = 0.003541 \times S_0$$

3.3.2 Horizontal Displacement

Xdisp calculates the horizontal movement of each displacement grid point due to subsidence in the mine. The calculation uses focal point theory and the same division of circles and sectors derived for the calculation of [vertical displacement](#).

Focal point theory assumes that each extracted sector area dA exerts an influence on the surface point P by attracting P towards A by an amount dV . This movement can be defined in terms of a horizontal radial vector dH_{xy} , and vertical vector dV_z .

Using this assumption it is possible to calculate the horizontal displacements in conjunction with the subsidence. Where focal point theory provides the **direction** of movement and influence functions provide the **magnitude** of subsidence.



Extraction Element

The use of these two components allows the amount of horizontal movement to be determined: dH_{xy}
 $= \tan \zeta dV_z$

where:

ζ = angle between the vertical and the line joining the surface point P with the extraction element dA
 dV = vertical displacement.

The total horizontal displacement at point P is the summation of the horizontal movement vectors dH caused by extraction at each individual element.

In order to allow summation, each movement vector is divided into its horizontal components x and y where:

$$dH_x = dH_{xy} \cos \alpha$$

$$dH_y = dH_{xy} \sin \alpha$$

Therefore the total horizontal displacement at point P is:

$$H_x = \Sigma dH_x$$

$$H_y = \Sigma dH_y$$

These values are resolved to give the total movement vector $H_{xy(p)}$ at point P.

3.4 Building Damage Assessment

An approach to assessing the risk of damage to buildings and structures was described by [Burland \(1995\)](#). This approach is adopted by **Xdisp**.

For the purposes of this section, the term "building" signifies a building's facade, i.e. a "sub-structure" in Xdisp.

The methodology of considering the structure being assessed to act as a linear elastic beam and using the concept of limiting tensile strain derives from the approach proposed by [Burland and Wroth \(1974\)](#) and [Boscardin and Cording \(1989\)](#). This guide briefly describes the approach. Interaction diagrams are plotted based upon definable building characteristics and parameters. These relate contours of limiting tensile strain (corresponding to boundaries between damage categories) to imposed deflection ratio and horizontal ground strain determined from a ground movement assessment.

Xdisp assumes that the calculated average horizontal ground strain is transferred directly into the structure that is being assessed. The Xdisp user should note that this is potentially an onerous assumption where:

- horizontal compressive ground strains are not completely transferred from ground to the structure (ie a stiffened response to horizontal compressive strains); and
- a greenfield response of the structure results from vertical ground movements (ie resulting in a greenfield deflection ratio structural response).

3.4.1 Specific Building Damage Assessment

If building locations and properties are known then Specific Building Damage Assessment may be performed to calculate damage categories for precise locations. If precise locations and properties are not known, or a rapid general assessment of likely building damage across an area is required, without the need to input precise locations and properties, then Generic Building Damage Assessment may be performed.

3.4.1.1 Limiting Tensile Strain and Linear Elastic Isotropic Beams

Cracking in masonry walls and finishes usually, but not always, results from tensile strain. [Burland and Wroth \(1974\)](#) noted the following.

- (i) The average values of strain at which visible cracking occurs, ϵ_{crit} are very similar for a variety of types of brickwork and blockwork and are in the range of 0.05% to 0.1%.
- (ii) For reinforced concrete beams, the onset of visible cracking occurs at lower values of tensile strain in the range 0.03% to 0.05%.
- (iii) The values of ϵ_{crit} in (i) and (ii) are much larger than the local tensile strains corresponding to tensile failure.
- (iv) The onset of visible cracking does not necessarily represent a limit of serviceability. Provided the cracking is controlled, it may be acceptable to allow deformations well beyond the initiation of visible cracking.

[Burland et al \(1977\)](#) introduced the concept of limiting tensile strain, ϵ_{lim} as a serviceability parameter which can be varied to take account of differing material and serviceability limit states. [Boscardin and Cording \(1989\)](#) developed this concept assessing 17 case records of damage due to excavation induced subsidence. They related the ranges of ϵ_{lim} to the likely severity of damage. [Burland et al \(1977\)](#) had previously assigned categories of damage severity to descriptions of typical damage. The

table below is the commonly used building/structure damage risk classification table summarising the above.

Building / Structure Damage Risk Classification (Burland (1997))

Damage Category	Category of damage	Description of typical damage+ (Ease of repair is underlined)	Approx. crack width* (mm)	Limiting tensile strain (%)
0	Negligible	Hairline cracks	< 0.1	< 0.05
1	Very Slight	Fine cracks that can easily be <u>treated during normal decoration.</u> Perhaps isolated slight fracture in buildings. Cracks in external brickwork visible on inspection.	< 1	0.05 - 0.075
2	Slight	<u>Cracks easily filled. Redecorating probably required.</u> Several slight fractures showing inside of building. Cracks are visible externally and <u>some repointing may be required externally to ensure weather tightness.</u> Doors and windows may stick slightly.	< 5	0.075 - 0.15
3	Moderate	<u>The cracks require some opening up and can be patched by a mason.</u> <u>Recurrent cracks can be masked by suitable linings. Repointing of external brickwork and possibly a small amount of brickwork to be replaced.</u> Doors and windows sticking. Service pipes may fracture. Weather tightness often impaired.	5 - 15 or a number of cracks > 3	0.15 – 0.3
4	Severe	<u>Extensive repair work involving breaking out and replacing sections of walls, especially over doors and windows.</u> Windows and door frames distorted, floor sloping noticeably. Walls leaning and bulging noticeably, some loss of bearing in beams. Service pipes disrupted.	15 - 25 but also depends on number of cracks	> 0.3
5	Very Severe	<u>This requires a major repair job involving partial or complete rebuilding.</u> Beams lose bearing, walls lean badly and require shoring. Windows broken due to distortion. Danger of instability.	Usually > 25 but depends on number of cracks.	-

Notes

+ In assessing the degree of damage, account must be taken of its location in the building or structure.

* Crack width is only one aspect of damage and should not be used on its own as a direct measure.

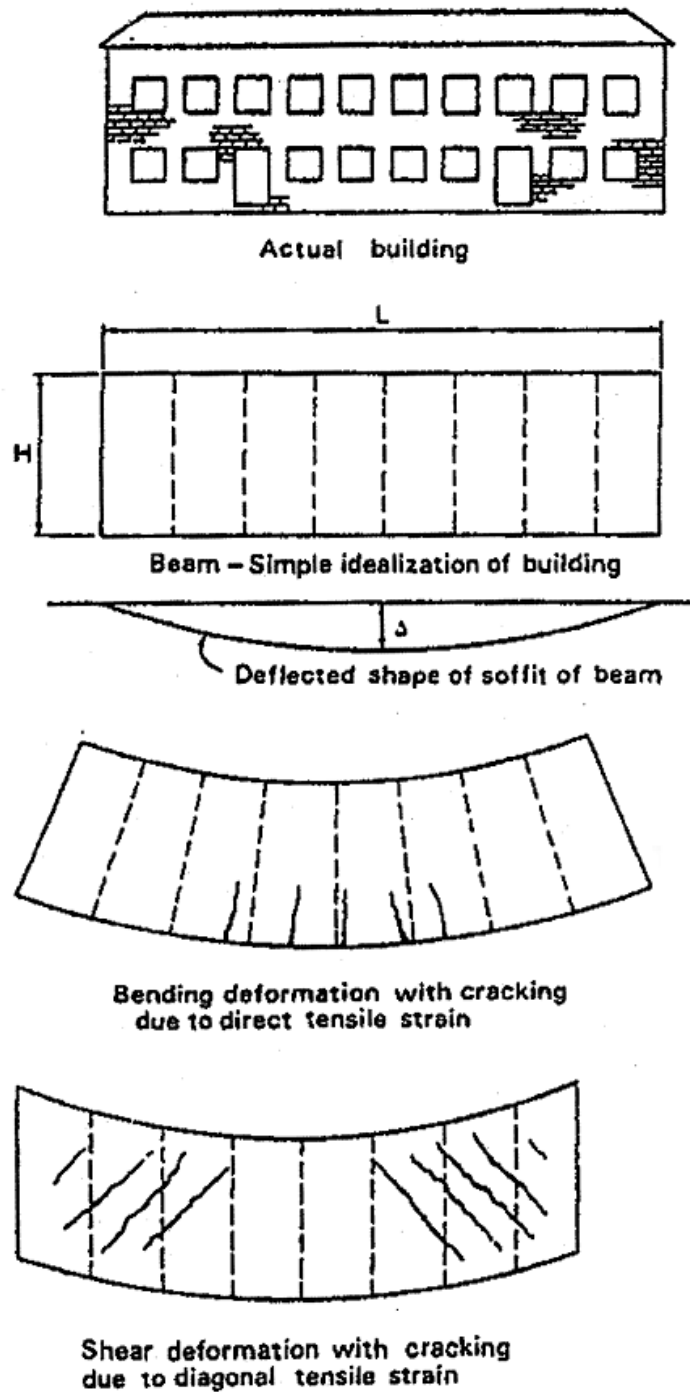
3.4.1.2 Linear Elastic Isotropic Beams

[Burland and Wroth \(1974\)](#) and [Burland \(1995\)](#) used the concept of limiting tensile strain to study the onset of cracking in simple weightless elastic beams undergoing sagging and hogging modes of deformation. [Burland \(1974\)](#) demonstrated that the criteria for initial cracking of simple beams are in very good agreement with the case records of damaged and undamaged building. Therefore, in many circumstances, it is reasonable to represent the façade of a building by means of a simple rectangular beam.

3.4.1.3 Sagging and Hogging

The approach adopted by [Burland and Wroth \(1974\)](#) is illustrated in the figure below where the building is represented by a rectangular beam of length L and height H . The problem is to calculate the tensile strains in the beam for a given deflected shape of the building foundations and hence obtain the deflection ratio δ/L at which cracking is initiated. It is immediately obvious that little can be said about the distribution of strains within the beam unless we know its mode of deformation. Two extreme modes are bending only about a neutral axis at the centre and shearing only. In the case of bending only, the maximum tensile strain occurs in the bottom fibre and that is where cracking will initiate as shown. In the case of shear only, the maximum tensile strains are inclined at 45° giving rise to diagonal cracking. In general both modes of deformation will occur simultaneously and it is necessary to calculate both bending and diagonal tensile strains to ascertain which type is limiting.

Hogging and Sagging Deformations and Definitions of L and H (Burland 1995)



The expression for the total mid-span deflection of a central point loaded beam having both bending and shear stiffness is given by [Timoshenko \(1957\)](#) as:

$$\Delta = \frac{PL^3}{48EI} \left(1 + \frac{18EI}{L^2HG} \right)$$

where:

- E = Young's modulus
- G = shear modulus
- I = second moment of area
- P = point load.

[Burland \(1974\)](#) established that, considering structures behaving in pure bending, “the limiting relationship between Δ/L and L/H is not very sensitive to the form of load distribution”.

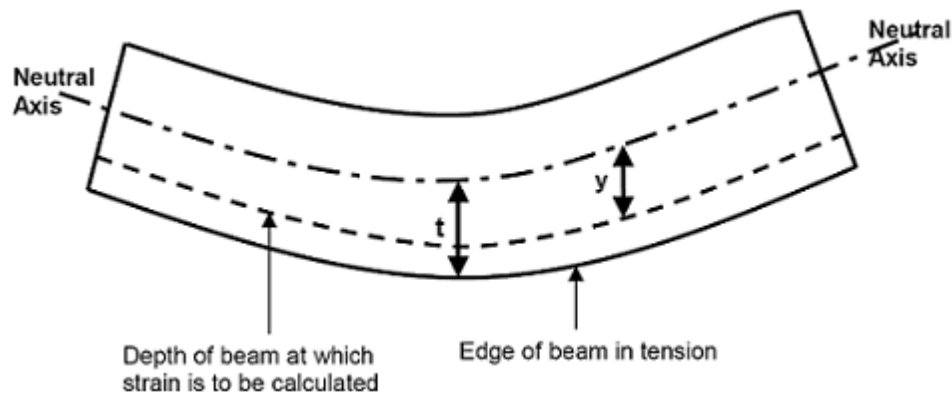
The equation for Δ above can be re-written in terms of the deflection ratio Δ/L and the maximum extreme fibre strain ϵ_{bmax} as follows:

$$\frac{\Delta}{L} = \left(\frac{L}{12t} + \frac{3IE}{2yLHG} \right) \epsilon_{bmax}$$

where:

- t = distance of the neutral axis from the edge of the beam in tension
- y = distance from the neutral axis to the position where strain is to be calculated (see figure below for diagram illustrating y and t).

Definitions of y and t



Similarly, for the maximum diagonal strain ϵ_{dmax} , the equation for Δ becomes:

$$\frac{\Delta}{L} = \left(1 + \frac{HL^2G}{18IE} \right) \epsilon_{dmax}$$

Expressions are also obtained for the case of a uniformly distributed load with the diagonal strains calculated at the quarter points. Therefore the maximum tensile strains are much more sensitive to the value of Δ/L than to the distribution of loading.

By setting the value of ϵ_{dmax} or $\epsilon_{bmax} = \epsilon_{lim}$, in the two equations for δ/L above, the limiting values of δ/L for the deflection of simple beams are defined. It is evident that, for a given value of ϵ_{lim} , the limiting value of δ/L (whichever is the lowest in the two equations) depends on L/H , E/G and the position of the neutral axis. For example, during hogging the foundations are likely to offer considerable restraint causing the neutral axis to move downwards. [Burland and Wroth \(1974\)](#) showed that hogging with the neutral axis at the bottom edge is much more damaging than sagging with the neutral axis in the middle – a result that is well borne out in practice and illustrated by [Burland and Wroth \(1974\)](#) in a sequence of model brick wall diagrams given in their paper.

3.4.1.4 The Influence of Horizontal Strain

Ground movements associated with tunnelling and excavation not only involve sagging and hogging profiles but significant horizontal strains as well. [Boscardin and Cording \(1989\)](#) included horizontal tensile strain ϵ_h in the above analysis using simple superposition, i.e. it is assumed that the deflected beam is subjected to uniform extension over its full depth. The resultant extreme fibre strain ϵ_{br} is given by:

$$\epsilon_{br} = \epsilon_{bmax} + \epsilon_h$$

In the shearing region, the resultant diagonal tensile strain ϵ_{dr} can be evaluated using the Mohr's circle of strain. The value of ϵ_{dr} is then given by:

$$\epsilon_{dr} = \epsilon_h \left(\frac{1-\nu}{2} \right) + \sqrt{\epsilon_h^2 \left(\frac{1+\nu}{2} \right)^2 + \epsilon_{dmax}^2}$$

where:

ν = Poisson's ratio.

The maximum tensile strain is the greater of ϵ_{br} and ϵ_{dr} . Thus, for a beam of length L and height H , it is a straight-forward matter to calculate the maximum value of tensile strain ϵ_{max} for a given value of ϵ_h , in terms of t , E/G and ν , where ϵ_{max} is the lesser of ϵ_{dmax} or ϵ_{bmax} . This value can then be used in conjunction with the table in [Limiting Tensile Strain and Linear Elastic Isotropic Beams](#) to assess the potential associated damage.

3.4.1.5 Interaction Charts

By adopting the values of ϵ_{lim} associated with the various categories of damage given in the table in [Limiting Tensile Strain and Linear Elastic Isotropic Beams](#), and by using the equations for δ/L , ϵ_{br} and ϵ_{dr} (given in [Sagging and Hogging](#) and [The Influence of Horizontal Strain](#)), an [Interaction Diagram](#) can be developed showing the relationship between δ/L and ϵ_h for appropriate values of L/H , E/G , I , ν , y and t selected for the structure being assessed. Xdisp calculates δ/L and ϵ_h parameters for the structure (or each hogging or sagging segment) and determines damage categories by comparing these values with the category boundaries of the [Interaction Chart](#). This method is based on a prediction of the deformation of the structure, which may differ from the 'green field' deformation of the ground. As a conservative initial assumption it is often assumed that the deformation of the structure will be the same as that assessed for the 'green field' situation. More rigorous analyses may take

account of the stiffness of the structure in reducing the deformation, allowing appropriately for the effects of the development of cracking in the structure on its stiffness.

3.4.1.6 Points of Inflexion, Gradient and Radius of Curvature

For building damage assessment calculations **Xdisp** must first determine the hogging and sagging zones along the length of a building. **Xdisp** relies on the ground movement results for the displacement line that is associated with the building. It uses horizontal displacements that are calculated at the position of the displacement line, and vertical displacements that are calculated for three vertical offsets of this line. It therefore performs building damage assessments for three sets of vertical displacements. It fits a cubic spline to these results and, by differentiation, determines the curvature and points of inflexion which demarcate hogging and sagging zones. Building damage calculations then proceed using these zones. Points of inflexion, and therefore the segment lengths that are used in calculating deflection ratios and building damage categories, take account of imposed horizontal strains. Points of inflexion are based upon vertical displacements on the offset lines. Horizontal strains are calculated using the horizontal displacements at zero vertical offset, between these points of inflexion.

Increasing or decreasing the number of intervals at which ground movement calculations are to be performed on a displacement line will affect the definition of the cubic spline that is fitted to the results, and so will affect the building damage assessment results too.

Curvature:

$$k = \frac{d^2 y}{dx^2}$$

where y = settlement of beam
 x = location of the displacement point

Radius of curvature:

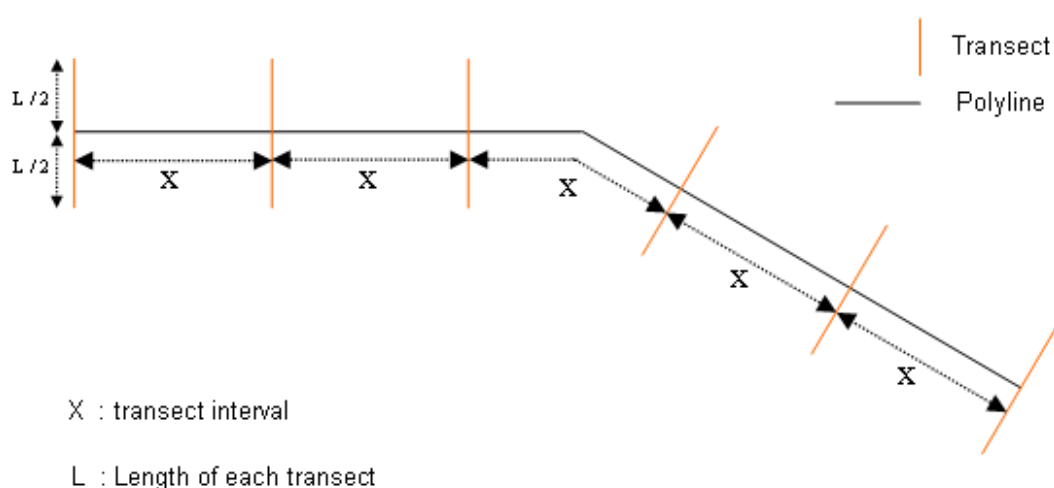
$$R = \frac{1}{k}$$

Adjacent hogging or sagging zones, or segments, may be combined so that building damage calculations are performed for the aggregated zone. This can only be specified after an analysis has been performed to determine the curvature of the displacement line. See [Segment Combinations](#).

3.4.2 Generic Building Damage Assessment

Generic Building Damage Assessment allows a rapid assessment of likely building damage over an area without the need to specify precise building locations or properties.

A polyline is input whose transects are treated as plan alignments of sub-structures.



Transects

- These are perpendicular lines to the polyline created at an interval specified by the user in the [Polylines Table View](#).
- The length and number of displacement points of these transects are specified by the user in the [Polylines Table View](#).
- By default a transect is provided at the start point of the polyline.
- All transects are bisected by the polyline.

[Building Damage Assessment](#) of each transect is performed for all L/H values (input in the [Generic Building Damage Assessment Table](#)) following the Burland calculation method described in [Specific Building Damage Assessment](#) and the results reported in the tabular output.

3.5 Utility Damage Assessment

Two types of utility damage assessment can be performed. These are:

- [Specific Utility Damage Assessment](#)
- [Generic Utility Damage Assessment](#)

If utility locations and properties are known then Specific Utility Damage Assessment may be performed to calculate utility damage for precise locations. If precise locations and properties are not known, or a rapid general assessment of likely utility damage across an area is required without the need to input precise locations and properties, then Generic Utility Damage Assessment may be performed.

3.5.1 Specific Utility Damage Assessment

Specific Utility Damage Assessment provides an assessment of utility damage along a specific displacement line. It therefore differs from [Generic Utility Damage Assessment](#), which allows a rapid assessment of likely utility damage over an area without the need to specify precise locations or properties of utilities.

Assessments are performed for

- pullout
- rotation
- strain

Utilities are specified to be either jointed or unjointed. Pullout and rotation assessment calculations are performed only for jointed utilities, which require the assignment of a pipe length. Strain assessment calculations are performed for both jointed and unjointed utilities, with both types then considered as a continuum.

The determination of assessment locations for pullout and rotation differs from that for strain. Pullout and rotation assessments are performed only at those displacement points along a utility's displacement line which have a pipe length of utility both upstream and downstream. Strain assessment is performed at every displacement point along a utility's displacement line except the first and last. For further details see [Assessment Locations for Pullout and Rotation](#), and [Strain Calculations](#).

In the discussions that follow the terms "upstream" and "downstream" are used to distinguish the part of the utility to one side of an assessment location from the part to the other side, when describing the calculations performed. Their use does not imply a direction of flow within a utility.

3.5.1.1 Ground Movements Along Utilities

The location of utilities is specified by each referring to a displacement line. Displacement lines are divided by displacement intervals into a series of displacement points at which ground movements are calculated directly by the program using the methodologies described for tunnels and embedded wall excavations. However, the calculation of pullout, rotation and strain along a utility may require estimation of ground movements at locations between these displacement points. Xdisp therefore fits a cubic spline to the displacements that are calculated directly by the program at all the displacement points of the utility's displacement line. It then uses that spline to estimate the displacements anywhere along the utility - whether at the location of a displacement point, or between displacement points. The spline will give the same ground movements at the displacement points as the program calculates directly, but additionally enables the estimation of ground movements at locations between those displacement points.

Increasing or decreasing the number of intervals at which ground movement calculations are to be performed on a utility's displacement line will affect the definition of the cubic spline that is fitted to the results, and so will affect the utility damage assessment results in assessment cases where ground movements are required to be estimated for locations between displacement points. If assessments are to be reliant only on the ground movements calculated directly by the program at the displacement points, and not on estimates between those points using the spline, then the pipe length and the displacement interval of the utility's displacement line must be set so that the pipe length is a multiple of the displacement interval.

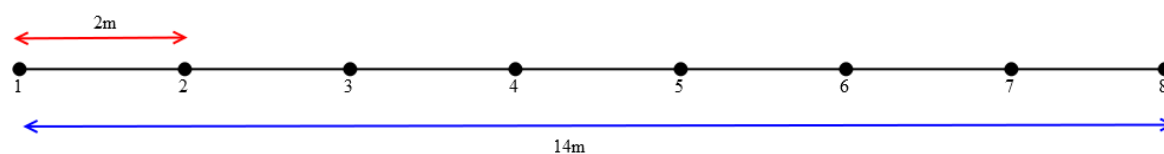
3.5.1.2 Assessment Locations for Pullout and Rotation

See [Ground Movements Along Utilities](#) for a discussion of the specification of a utility's location using displacement lines, and for the significance of displacement intervals and displacement points.

Utilities are made up of pipes, each of which has a pipe length.

Consider assessment locations to be defined as those displacement points on a utility which have a pipe length of utility both upstream and downstream. Therefore the first and last displacement points along a utility will not qualify as assessment locations, neither will other displacement points near the start and end of a utility if the pipe length is greater than one displacement interval.

Pullout and rotation assessment calculations are performed at assessment locations in a series of iterations. Each of these iterations contains a group of assessment locations.



Consider the utility of 14m length shown above. The displacement interval is 2m. 1, 2, 3, 4, 5, 6, 7 and 8 are the displacement points along the displacement line.

There are 2 possible cases for the determination of assessment locations. Case 1 applies if the pipe length is a multiple of the displacement interval. Case 2 applies if the pipe length is not a multiple of the displacement interval.

Case 1

Assume the pipe length is 4m and the displacement interval is 2m. Since the pipe length is a multiple of the displacement interval Case 1 applies.

Only displacement points 3, 4, 5 and 6 are assessment locations. Displacement points 1, 2, 7 and 8 are ignored as they do not satisfy the condition of having a pipe length of utility both upstream and downstream.

Iteration 1 (assessments at displacement points 3 and 5)

The first iteration starts at the first available assessment location, i.e. at displacement point 3. The next and last assessment location in this iteration is one pipe length away from displacement point 3, i.e. at displacement point 5.

Iteration 2 (assessments at displacement points 4 and 6)

The second and last iteration starts with an assessment location at displacement point 4. The next and last assessment location in this iteration is one pipe length away from displacement point 4, i.e. at displacement point 6.

There are no more iterations carried out for this case as all the possible assessment locations along the utility have now been considered.

Case 2

Assume the pipe length is 3m and the displacement interval is 2m. Since the pipe length is not a multiple of the displacement interval this case applies.

Only displacement points 3, 4, 5 and 6 are assessment locations. Displacement points 1, 2, 7 and 8 are ignored as they do not satisfy the condition of having a pipe length of utility both upstream and downstream.

Iteration 1 (assessments at displacement points 3 and 5)

The first iteration in this case also starts at the first available assessment location, i.e. at displacement point 3. Since there is no displacement point exactly one pipe length downstream from displacement point 3, the next displacement point beyond is taken as the next assessment location, i.e. displacement point 5.

Iteration 2 (assessments at displacement points 4 and 6)

The second and last iteration starts with an assessment location at displacement point 4. Since there is no displacement point exactly one pipe length downstream of point 4, the next displacement point beyond is taken as the next assessment location, i.e. displacement point 6.

There are no more iterations carried out for this case as all the possible assessment locations along the utility have now been considered.

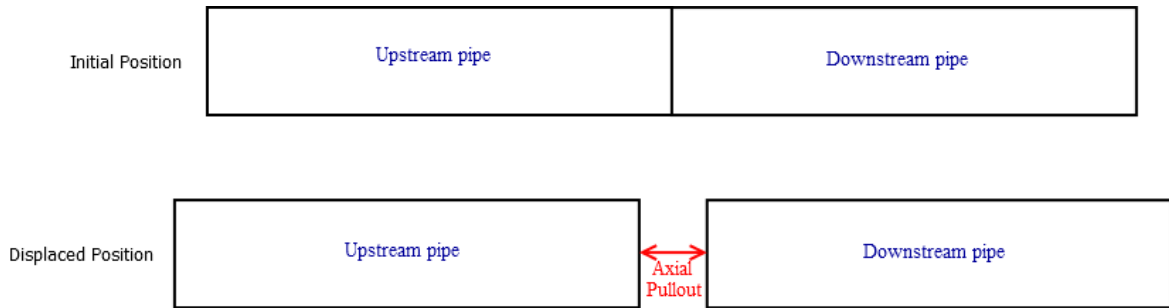
For assessment locations to be spaced at intervals matching the pipe length, the pipe length and the displacement interval of the utility's displacement line must be set so that the pipe length is a multiple of the displacement interval.

3.5.1.3 Pullout

An assessment of pullout, comprising axial and flexural pullout, is performed for jointed utilities only, and uses [Ground Movements Along Utilities](#). For the determination of assessment locations see [Assessment Locations for Pullout and Rotation](#).

Pullout calculations are performed by considering the relative movements of the pipes upstream and downstream of an [assessment location](#). Pipes are considered to be infinitely rigid. The movement of the upstream and downstream pipes with respect to the assessment location is the average of the horizontal component of ground movements parallel to (i.e. along) the pipe's axis, for all displacement points within one pipe length of the assessment point, multiplied by a coefficient to take into account the soil-pipe interaction. The contraction of the upstream pipe is then added to the contraction of the downstream pipe to obtain the total pullout at the assessment location. Neither friction between pipes nor interlocking due to the rotation of joints are considered.

Axial Pullout



If the assessment location is displacement point 'n' along the utility, then the contributions to axial pullout from the upstream and downstream pipes are considered to be given by:

$$PO_{axial-upstream} = - \left(\frac{D_{//(n)} + D_{//(n-1)} + D_{//(n-2)} + \dots + D_{//(n-L_p)}}{N} \right)$$

$$PO_{axial-downstream} = \left(\frac{D_{//(n)} + D_{//(n+1)} + D_{//(n+2)} + \dots + D_{//(n+L_p)}}{N} \right)$$

where:

- $PO_{axial-upstream}$ = contribution to axial pullout from the upstream pipe
- $PO_{axial-downstream}$ = contribution to axial pullout from the downstream pipe
- $D_{//(n)}$ = horizontal component of ground movement that is along the utility at the nth displacement point
- $D_{//(n-1)}$ = horizontal component of ground movement that is along the utility at (n - 1)th displacement point, i.e. the point that is immediately upstream of 'n'
- $D_{//(n-L_p)}$ = horizontal component of ground movement that is along the utility at a point a distance L_p upstream of 'n'
- N = number of points in the numerator

The factored values of these pullouts are given by:

$$PO_{axial-upstream-factored} = f_{pullout\ axial} * PO_{axial-upstream}$$

$$PO_{axial-downstream-factored} = f_{pullout\ axial} * PO_{axial-downstream}$$

where:

- $f_{pullout-axial}$ = axial pullout factor as specified in the Factors table

The total axial pullout at an assessment location (PO_{axial}) is then given by:

$$PO_{axial} = PO_{axial-downstream} + PO_{axial-upstream}$$

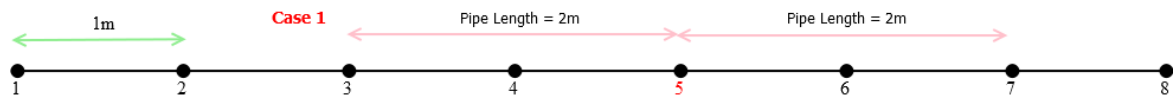
The factored total axial pullout is given by:

$$PO_{axial-factored} = PO_{axial-downstream-factored} + PO_{axial-upstream-factored}$$

However when later combined with flexural strain to calculate total strain, this axial component (PO_{axial}) is included only if it is positive, i.e. if it represents pullout of a joint at the assessment location. If it represents compression of a joint at the assessment location then it is ignored.

Examples are given below. The distinction between Case 1 and Case 2 is clarified in [Locations of Assessment Calculations](#).

Case 1 (if pipe length is a multiple of displacement interval)

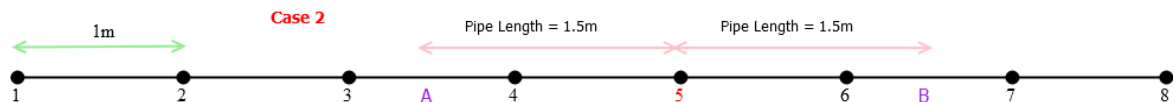


Contributions to axial pullout for the assessment location at displacement point 5 are given as:

$$PO_{axial-upstream} = - \left(\frac{D_{///(5)} + D_{///(4)} + D_{///(3)}}{3} \right)$$

$$PO_{axial-downstream} = \left(\frac{D_{///(5)} + D_{///(6)} + D_{///(7)}}{3} \right)$$

Case 2 (if pipe length is not a multiple of displacement interval)



In this case there are no displacement points available at locations A and B, which are a pipe length upstream and a pipe length downstream of displacement point 5. However, the cubic spline discussed in [Ground Movements Along Utilities](#) is available to provide an estimate of displacements at A and B.

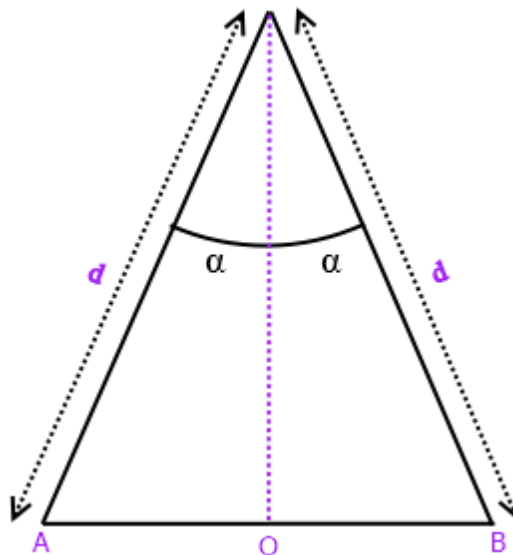
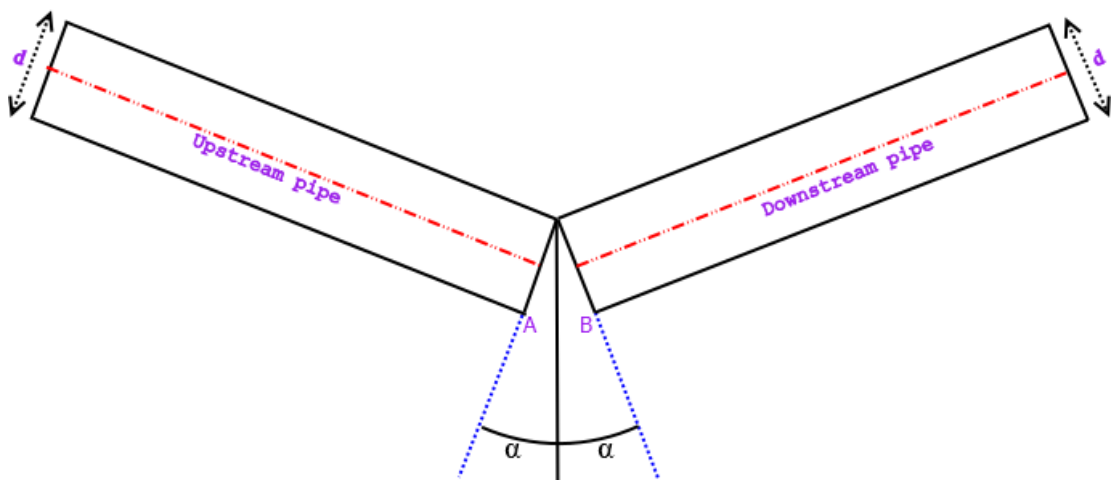
Contributions to axial pullout for the assessment location at displacement point 5 are given as:

$$PO_{axial-upstream} = - \left(\frac{D_{///(5)} + D_{///(4)} + D_{///(A)}}{3} \right)$$

$$PO_{axial-downstream} = \left(\frac{D_{//}(5) + D_{//}(6) + D_{//}(B)}{3} \right)$$

Flexural Pullout

When considering flexural pullout at the assessment location any bending in the adjacent pipes is ignored. Pipes are assumed to remain straight and all ground movements are accommodated by rotation of a nominal joint at the assessment location.



Figures illustrating flexural pullout

If θ is the rotation of the joint then the total flexural pullout at the joint is given by:

$$PO_{flexural} = PO_{flexural-upstream} + PO_{flexural-downstream}$$

where

$$\begin{aligned} PO_{flexural-upstream} &= \text{contribution to flexural pullout from upstream pipe} \\ &= AO \\ &= d \times \sin \theta \end{aligned}$$

and

$$\begin{aligned} PO_{flexural-downstream} &= \text{contribution to flexural pullout from downstream pipe} \\ &= OB \\ &= d \times \sin \theta \end{aligned}$$

where

$$\begin{aligned} \theta &= \text{half the rotation of the angle at the joint} \\ d &= \text{the external diameter of the utility given by} \\ &= P_{dia} + 2P_{wt} \\ \text{where} \\ P_{dia} &= \text{internal diameter of the utility} \\ P_{wt} &= \text{wall thickness of the utility} \end{aligned}$$

The factored values of flexural pullout are given by:

$$\begin{aligned} PO_{flexural-upstream-factored} &= f_{pullout-flexural} * PO_{flexural-upstream} \\ PO_{flexural-downstream-factored} &= f_{pullout-flexural} * PO_{flexural-downstream} \\ PO_{flexural-factored} &= PO_{flexural-upstream-factored} + PO_{flexural-downstream-factored} \end{aligned}$$

As for axial pullout, in cases where the displacement interval is not a multiple of the pipe length, Xdisp fits a cubic spline to the displacements that are calculated at all the displacement points of the utility's displacement line and uses that to estimate the displacements at the far ends of the upstream and downstream pipes.

Note : Users may be familiar with the term "reduction factor". Pullout reduction factors are achieved by setting the factor of pullout to less than 1.

Total Pullout

The total pullout at the assessment location 'n' is then given by:

$$PO = PO_{axial} + PO_{flexural}$$

where

- PO_{axial} = total axial pullout (considered only if it is positive)
- $PO_{flexural}$ = total flexural pullout

The total factored pullout is given by

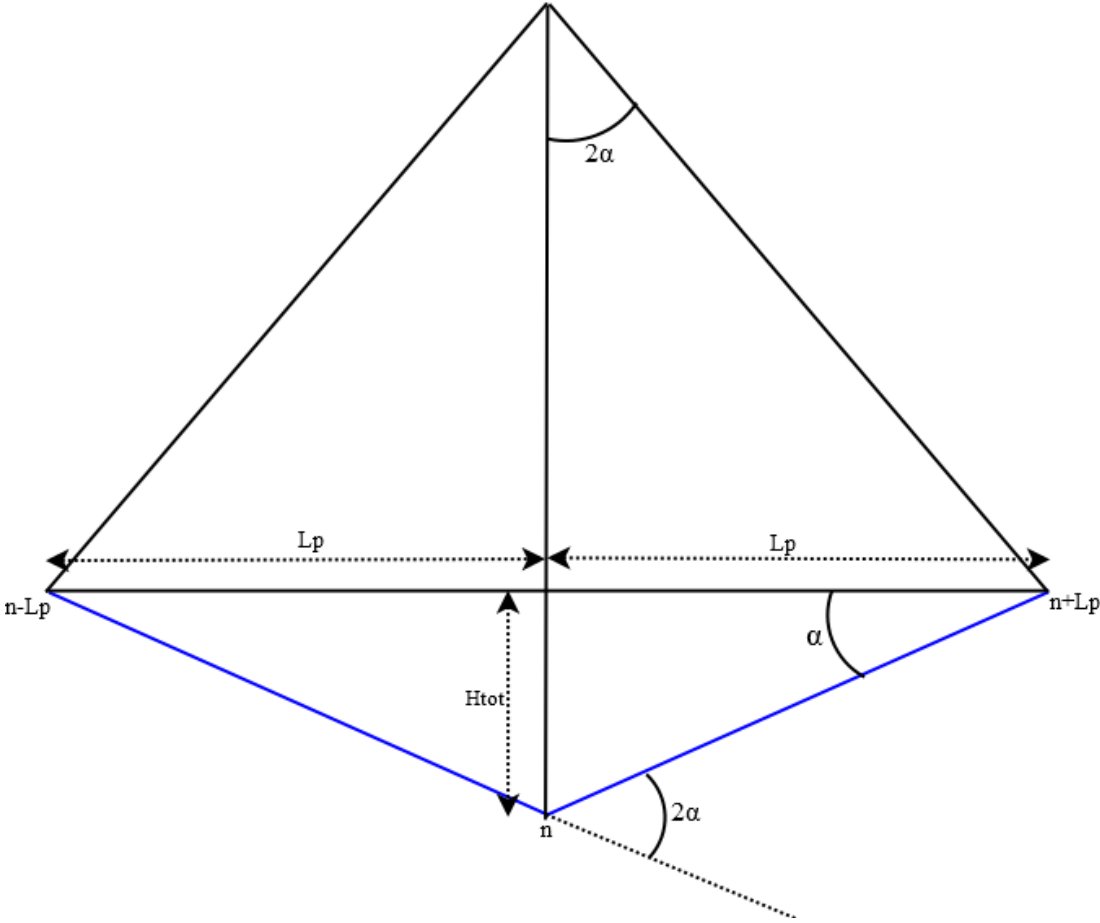
$$PO_{factored} = PO_{axial-factored} + PO_{flexural-factored}$$

3.5.1.4 Rotation

An assessment of rotation is performed for jointed utilities only, and uses [Ground Movements Along Utilities](#). For the determination of assessment locations see [Assessment Locations for Pullout and Rotation](#).

When considering rotation at the assessment location any bending in the adjacent pipes is ignored. Pipes are assumed to remain straight and all ground movements are accommodated by rotation of a nominal joint at the assessment location.

The rotation angle, 2α , between the upstream pipe and the downstream pipe at each assessment location is calculated as follows.



Rotation at an Assessment Location

Consider an assessment location at displacement point 'n'.

- L_p = length of the pipe
- $n-L_p$ = point at a distance of L_p upstream of the assessment location
- $n+L_p$ = point at a distance of L_p downstream of the assessment location

The horizontal offset in the perpendicular direction H_{\perp} between the ends of the pipe is given by:

$$H_{\perp} = D_{\perp(n)} - \left(\frac{D_{\perp(n-L_p)} + D_{\perp(n+L_p)}}{2} \right)$$

where:

- $D_{\perp(n)}$ = displacement perpendicular to the utility at the assessment location
- $D_{\perp(n-L_p)}$ = displacement perpendicular to the utility at a distance L_p upstream of the assessment location
- $D_{\perp(n+L_p)}$ = displacement perpendicular to the utility at a distance L_p downstream of the assessment location

Similarly, replacing H with V , the vertical offset V between the ends of the pipe is given by:

$$V = V_{(n)} - \left(\frac{V_{(n-L_p)} + V_{(n+L_p)}}{2} \right)$$

where:

- $V_{(n)}$ = vertical displacement at the assessment location
- $V_{(n-L_p)}$ = vertical displacement at a distance L_p upstream of the assessment location
- $V_{(n+L_p)}$ = vertical displacement at a distance L_p downstream of the assessment location

Positive V indicates hogging and negative V indicates sagging

The total offset H_{tot} is given by:

$$H_{tot} = \sqrt{(H_{\perp})^2 + (V)^2}$$

The rotation in the pipe at the assessment location is 2α , where α is given by:

$$\alpha = \tan^{-1} \left(\frac{H_{tot}}{L_p} \right)$$

$$\text{Rotation} = 2$$

$$\text{Factored rotation} = f_{\text{rotation}} * 2$$

where:

f_{rotation} = rotation factor as specified in the Factors table

3.5.1.5 Strain

An assessment of total strain, comprising axial and bending strains, is performed for all utilities - i.e. both jointed and unjointed, and uses [Ground Movements Along Utilities](#). Strains are calculated and reported for every displacement point on the utility that has another displacement point both upstream and downstream, so not the first and last.

The assumptions made are described by [Bracegirdle et al. \(1996\)](#). Bending strains along the utility are calculated assuming the utility follows the movement of ground.

Axial Strain

Axial strain is calculated as the ratio of change in length between adjacent mid-points of displacement intervals, to original length.



Given that:

- d = displacement interval
- 1...5 = displacement points
- A = the mid-point between displacement points 2 and 3
- B = the mid-point between displacement points 3 and 4
- AB = the portion of utility used to calculate the axial strain at displacement point 3

The axial strain for the utility at displacement point 3 is given by:

$$\text{change in length of AB} / \text{original length of AB}$$

The original distance between the points A and B is given by:

$$L_{iAB} = \sqrt{(X_{iA} - X_{iB})^2 + (Y_{iA} - Y_{iB})^2 + (Z_{iA} - Z_{iB})^2}$$

where

(X_{iA}, Y_{iA}, Z_{iA}) = initial position of point A

(X_{iB}, Y_{iB}, Z_{iB}) = initial position of point B

The final distance between the points A and B is given by:

$$L_{fAB} = \sqrt{(X_{fA} - X_{fB})^2 + (Y_{fA} - Y_{fB})^2 + (Z_{fA} - Z_{fB})^2}$$

where

(X_{fA}, Y_{fA}, Z_{fA}) = final position of point A

(X_{fB}, Y_{fB}, Z_{fB}) = final position of point B

The change in length, DL , is given by:

$$DL = L_{fAB} - L_{iAB}$$

The axial strain in the ground over the given interval AB is given by:

$$\varepsilon_{axial} = \frac{DL}{L_i}$$

The factored axial strain is given by:

$$\varepsilon_{axial-factored} = f_{axial} * \frac{DL}{L_i}$$

where

if axial strain is tensile in nature

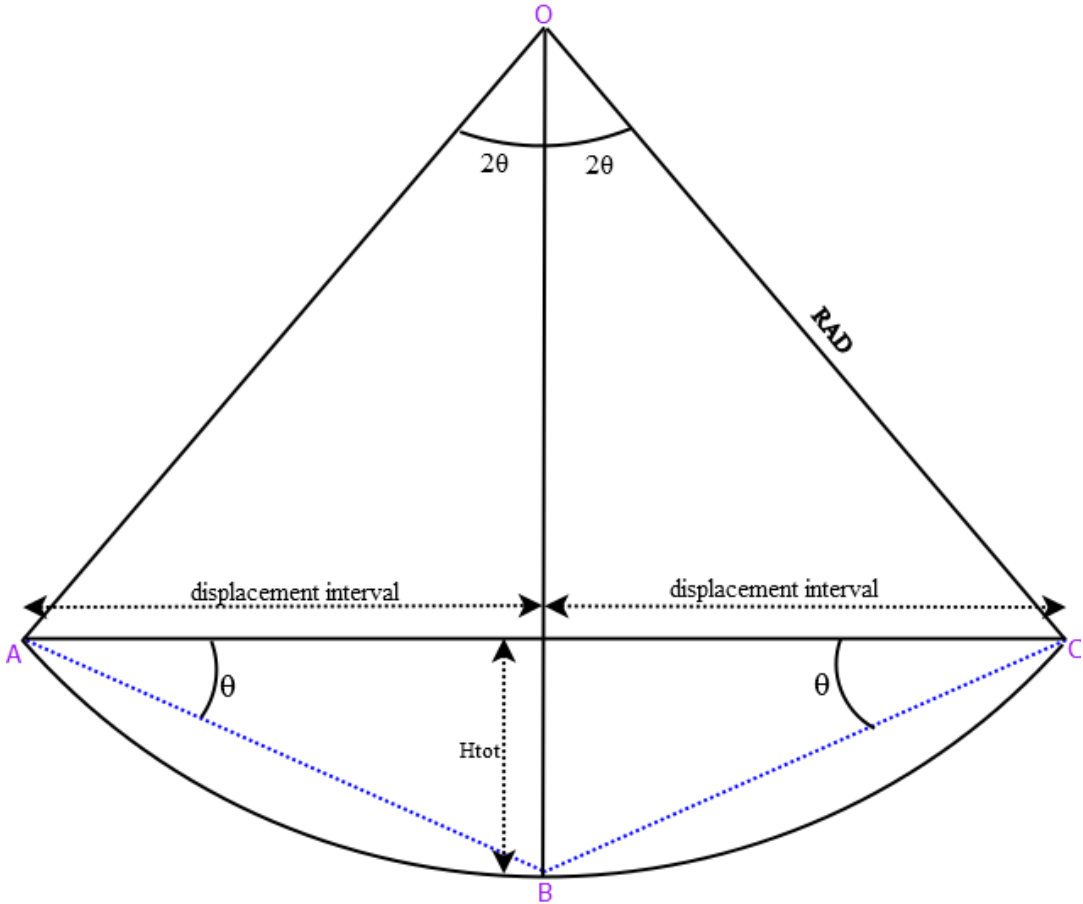
f_{axial} = Axial strain factor in tension as specified in the Factors table

if axial strain is compressive in nature

f_{axial} = Axial strain factor in compression as specified in the Factors table

The factor applied to axial strain might be a reduction factor to account for the slippage between pipe and the surrounding soil.

Bending Strain



Schematic Representation of Utility Bending

For illustrative purposes the above diagram is shown in two dimensions. However, the calculations are performed for three dimensional movements with horizontal and vertical movements separated as discussed below.

When considering bending strain, any rotation that arises from the asymmetric opening of joints at the displacement points being used for assessment (e.g. B in the figure above) is ignored. Ground movements are considered to induce flexural bending only. So the pipes are considered continuous at B.

The horizontal offset at displacement point B, perpendicular to the utility's axis and relative to AC, is given by:

$$H_{\perp} = D_{\perp(B)} - \left(\frac{D_{\perp(A)} + D_{\perp(C)}}{2} \right)$$

where:

$D_{\perp(B)}$ = displacement perpendicular to the utility at the displacement point B.

$D_{\perp(A)}$ = displacement perpendicular to the utility at the displacement point A.

$D_{\perp(C)}$ = displacement perpendicular to the utility at the displacement point C.

Similarly the vertical offset V of displacement point B relative to AC is given by:

$$V = V_{(B)} - \left(\frac{V_{(A)} + V_{(C)}}{2} \right)$$

where:

$V_{(B)}$ = vertical displacement at the displacement point B.

$V_{(A)}$ = vertical displacement at the displacement point A.

$V_{(C)}$ = vertical displacement at the displacement point C.

Positive V indicates hogging and negative V indicates sagging.

The total offset of B relative to AC is given by:

$$H_{tot} = \sqrt{(H_{\perp})^2 + (V)^2}$$

Considering the diagram above, let $\angle BCA = \theta$, then $\angle BOA = 2\theta$, $\angle BAC = \theta$ and $\angle BOC = 2\theta$ - from

the angle at centre theorem and from symmetry.
can be calculated as:

$$\theta = \tan^{-1} \left(\frac{H_{tot}}{\text{displacement interval}} \right)$$

The bending strain is proportional to the distance from the centre line to the outer edge of the pipe and inversely proportional to the radius of curvature.

The effective radius of curvature RAD of the deformed pipes is given by:

$$RAD = \left(\frac{\text{displacement interval}}{\sin 2\theta} \right)$$

The bending strain in the utility is given by:

The figure above illustrates a pipe bending.

where:

AB = neutral axis whose length (L) remains the same before and after bending.

r = radius of the utility.

R = radius of curvature.

d = diameter of the utility.

L_c = length of external fibre (in compression) most shortened by bending.

L_e = length of external fibre (in tension) most lengthened by bending.

L_d = length of imaginary fibre at a distance ' d ' from the neutral axis.

Bending strain in the extreme fibre (CD) under tension = $(L_e - L)/L = +r/R$

Bending strain in the extreme fibre (EF) under compression = $(L_c - L)/L = -r/R$

Factored Bending Strain = $f_{\text{bending}} * r/R$

The factor on bending strain could be interpreted as determining what some users may term "lever arm". A factor of 2 would represent a lever arm of pipe diameter, i.e. with factored bending strain being that for L_d , whereas a factor of 1 would represent a lever arm of pipe radius, with a factored bending strain being that for L_e .

Total Strain

The axial strain is combined with the positive value of the flexural bending strain in the extreme fibre under tension, and with the negative value of the flexural bending strain in the extreme fibre under compression to give the total strain.

The total strain is therefore given by:

$$\varepsilon_{\text{total}} = \varepsilon_{\text{axial}} + \varepsilon_{\text{bending}}$$

The factored total strain is given by:

$$\varepsilon_{\text{total-factored}} = \varepsilon_{\text{axial-factored}} + \varepsilon_{\text{bending-factored}}$$

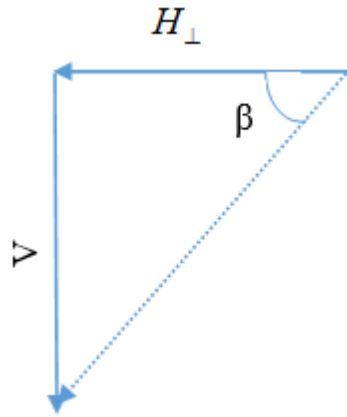
If "Neglect beneficial contribution of axial strains" is checked in the [Utility strain calculation options](#) dialog, then the calculation of total strains, both factored and unfactored, is influenced as below:

- Total tensile strain : If axial strain is compressive, then $\varepsilon_{\text{axial}}$ is assumed to be zero.
- Total compressive strain : If axial strain is tensile, then $\varepsilon_{\text{axial}}$ is assumed to be zero.

The factored total strain values are verified against their limiting values specified in the Criteria table.

Strain Orientation Angle

The strain orientation angle gives the direction in which peak flexural strain occurs. It is the resultant of V and H_x .



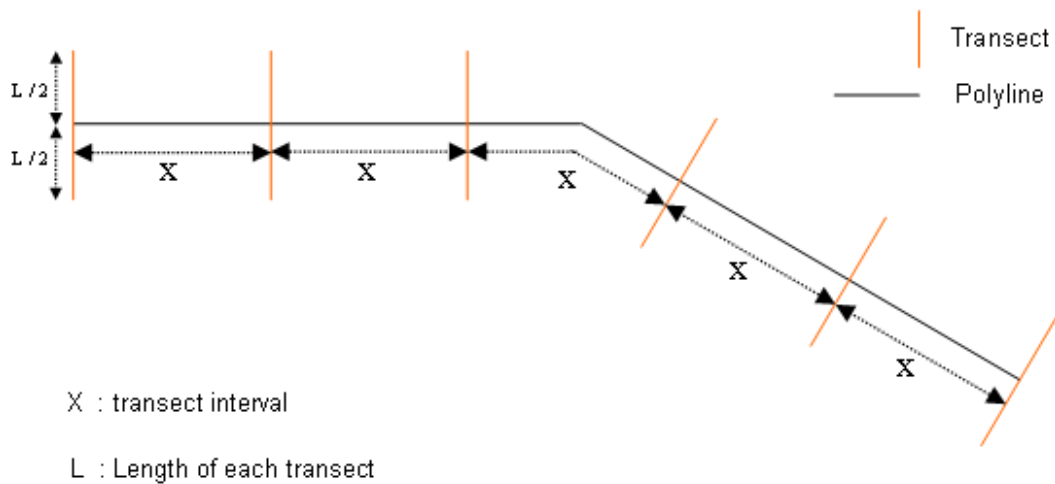
$$\beta = \tan^{-1}\left(\frac{V}{H_{\perp}}\right)$$

This is reported as 90°+ , and so is the angle from the global Z axis

3.5.2 Generic Utility Damage Assessment

Generic Utility Damage Assessment allows a rapid assessment of likely utility damage over an area without the need to specify precise utility locations or properties. It therefore differs from [Specific Utility Damage Assessment](#), which provides an assessment of utility damage along a specific displacement line.

The plan area for Generic Utility Damage Assessment is specified by a polyline with equally spaced transects. Each of these transects represents the alignment of a utility which is used for assessment purposes. Generic Utility Damage Assessment will therefore not give accurate assessment results for locations of utilities that differ from these transects. [Specific Utility Damage Assessment](#) is recommended for such utilities whose precise location is known.



Transects

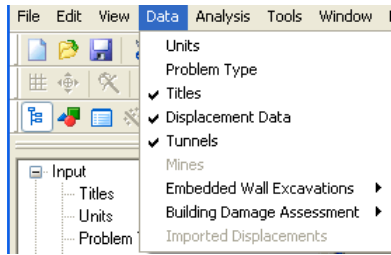
- These are perpendicular lines to the polyline created at an interval specified by the user in the [Polylines Table View](#).
- The length and number of displacement points of these transects are specified by the user in the [Polylines Table View](#).
- By default a transect is provided at the start point of the polyline.
- All transects are bisected by the polyline.

Utility damage assessment is then performed for each transect following the procedure for Specific Utility Damage Assessment, but with the specific utility now located along each and every transect rather than along a single specific displacement line. The results are reported in the [Tabular Output](#).

Part IV

4 Data Input

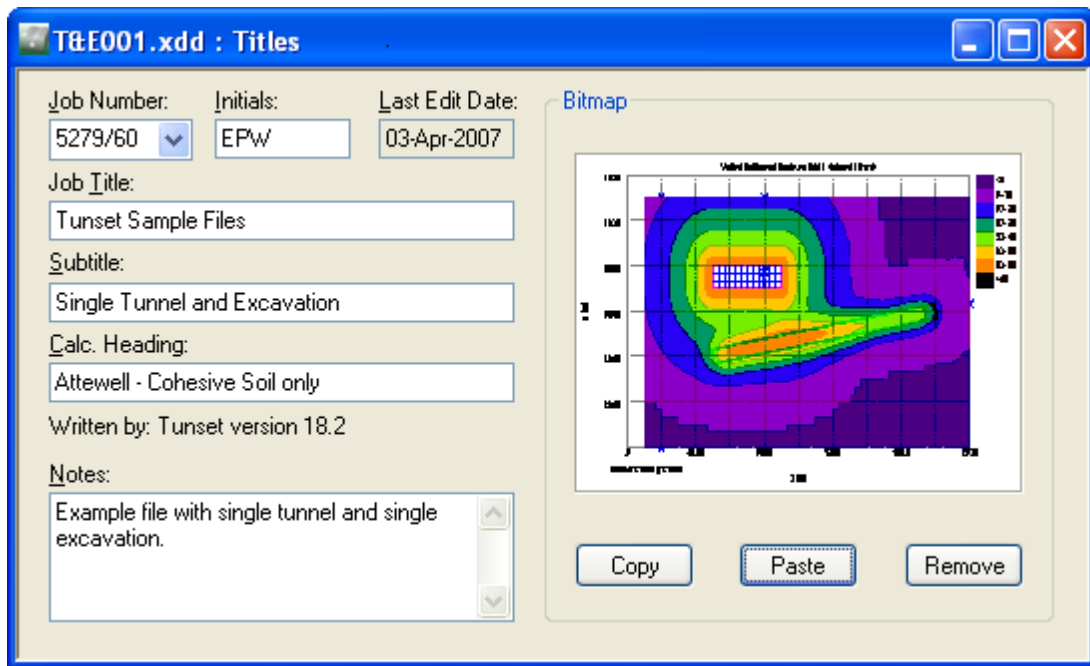
Data is input via options that are available from the Data menu, or from the [Gateway](#).



The information can be entered in any order though it is advisable to enter displacement lines before the buildings which refer to them. Once the data has been entered the program places a tick against that item in the menu list. The section for entry of Mining Data only becomes available on selection of a mining problem in [Problem Type](#).

4.1 Titles

Upon creating a new file or opening an existing one the first window to appear, for entry of data into **Xdisp**, is the Titles window.



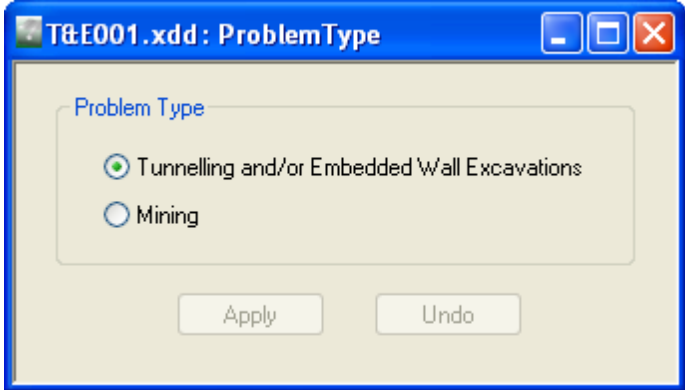
This window allows entry of identification data for each program file. The following fields are available:

Job Number	allows entry of an identifying job number
Initials	for entry of the user's initials
Last Edit Date	this field is set by the program at the date the file is saved
Job Title	allows a single line for entry of the job title
Subtitle	allows a single line of additional job or calculation information
Calculation Heading	allows a single line for the main calculation heading
Notes	allows the entry of a detailed description of the calculation

The titles are reproduced in the title block at the head of all printed information for the calculations. The fields should therefore be used to provide as many details as possible to identify the individual calculation runs.

4.2 Problem Type

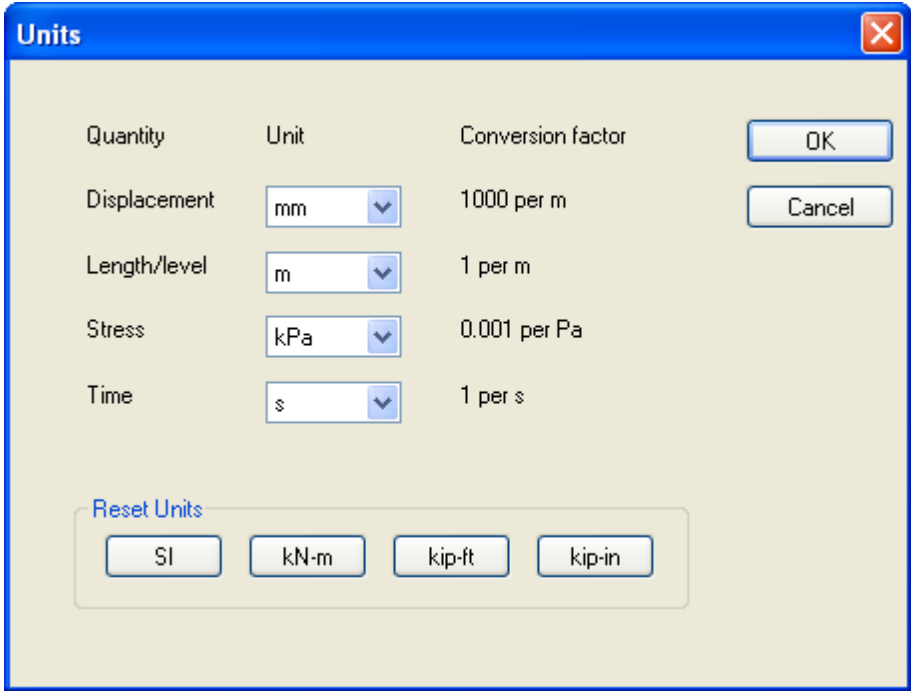
This general data is required to define the type of analysis to be carried out.



Selection of tunnelling or mining defines all the proceeding data entry.

4.3 Units

The Units dialog is accessible via the [Gateway](#), or by choosing Data | Units from the program's menu. It allows the user to specify the units for entering the data and reporting the results of the calculations. These choices are stored in, and therefore associated with, the data file.



Default options are the Système Internationale (SI) units - kN and m. The drop down menus provide alternative units with their respective conversion factors to metric.

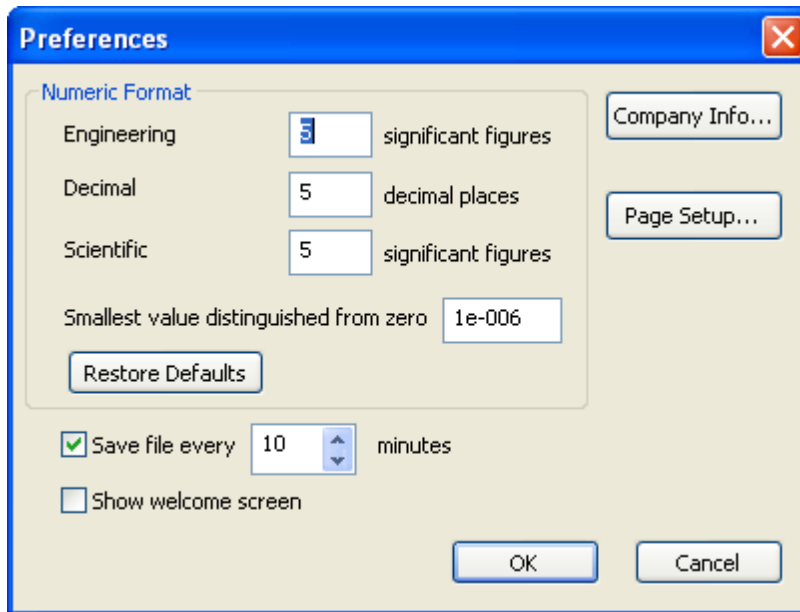
Standard sets of units may be set by selecting any of the buttons: SI, kN-m, kip-ft kip-in.

Once the correct units have been selected then click 'OK' to continue.

SI units have been used as the default standard throughout this document.

4.4 Preferences

The Preferences dialog is accessible by choosing Tools | Preferences from the program's menu. It allows the user to specify the units for entering the data and reporting the results of the calculations. These choices are stored in the computer's registry and are therefore associated with the program rather than the data file. All data files will adopt the same choices.



Numeric Format controls the output of numerical data in the Tabular Output. The [Tabular Output](#) presents input data and results in a variety of numeric formats, the format being selected to suit the data. Engineering, Decimal, and Scientific formats are supported. The numbers of significant figures or decimal places, and the smallest value distinguished from zero, may be set here by the user.

Restore Defaults resets the Numeric Format specifications to program defaults.

A time interval may be set to save data files automatically. Automatic saving can be disabled if required by clearing the "**Save file..**" check box.

Show Welcome Screen enables or disables the display of the Welcome Screen. The Welcome Screen will appear on program start-up, and give the option for the user to create a new file, to open an existing file by browsing, or to open a recently used file.

Company Info allows the user to change the company name and logo on the top of each page of print out. To add a bitmap enter the full path of the file. The bitmap will appear fitted into a space approximately 4cm by 1cm. The aspect ratio will be maintained. For internal Arup versions of the program the bitmap option is not available.

Page Setup opens a dialog which allows the user to specify the calculation sheet style for graphical and textual printing e.g. whether it has borders and a company logo.

4.5 Polylines

Polylines are used to:

- a) define areas over which generic building damage assessment and generic utility damage assessment are to be performed.
- b) define displacement polylines; which in-turn may be used to perform specific utility damage assessment.

The following input data is required to define a polyline.

Data may be input in dialog form by double-clicking within a cell of the Polylines Table View.

Ref.	Name	Coordinates
[m]		
Defaults		
1	Polyline 1	(50, 1.5e+002, 0) (1.5e+002, 1.5e+002, 0) (1.5e+002, 2e+002, 0)
2		

Name specifies the name of the polyline.

Coordinates specify the end points of the segments that make up the polyline.

4.6 Displacement Data

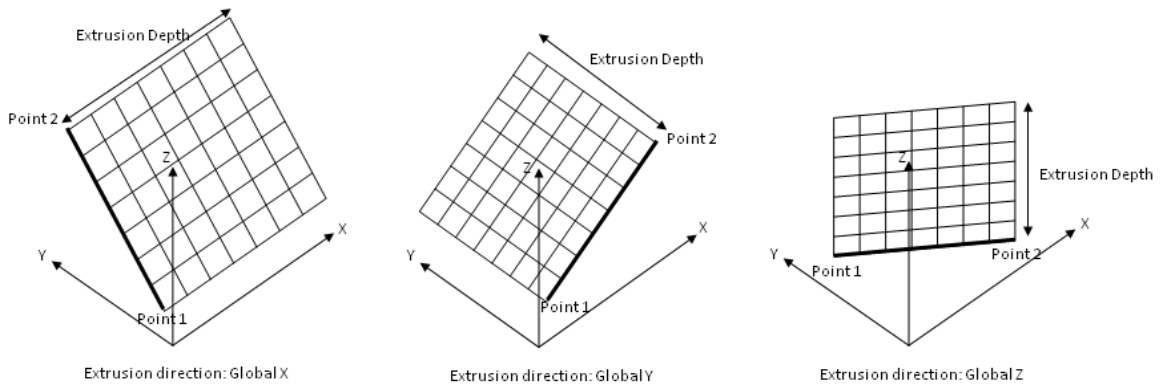
The positions at which displacement results are required can be specified using grids, lines, polylines or individual points.

Ref.	Type	Name	Polyline	Direction of extrusion	Line/Line for extrusion						No. of intervals across extrusion or along the line	Extrusion depth [m]	No. of intervals along extrusion	Calculate	Surface type for tunnels
					First point			Second point							
					X [m]	Y [m]	Z [level]	X [m]	Y [m]	Z [level]					
Defaults	Point		Polyline 1	Global X	0.000	0.000	0.000	1.000	1.000	0.000	10	1.000	10	Yes	Surface
1	Grid	Grid 1		Global Y	10.000	0.000	100.000	200.000		100.000	57	110.000	33	Yes	Surface
2	Line	Line 1			120.000	20.000	100.000	110.000	80.000	100.000	20			Yes	Surface
3	Line	Line 2			20.000	35.000	100.000	200.000	63.000	100.000	20			Yes	Surface
4	Line	Line 3			80.000	0.000	100.000	80.000	110.000	100.000	20			Yes	Surface
5	Line	Line 4			20.000	20.000	100.000	20.000	70.000	100.000	10			Yes	Surface
6	Polyline	Line 5	Polyline 1								20			Yes	Surface
7															

Grids, lines and polylines may be horizontal, vertical or inclined.

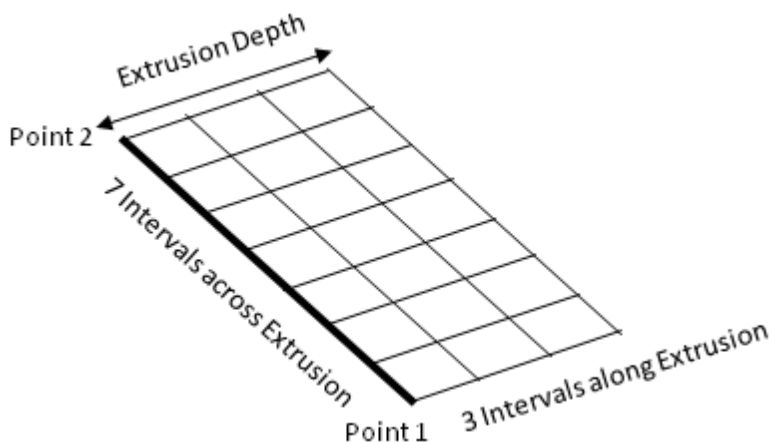
Grids are specified by extruding a line. The **Direction of extrusion** is specified as one of the Global

axes (X, Y or Z). A **Line for extrusion** must be entered by specifying its end coordinates. For example, if 'Global X' is the direction of extrusion then the table allows the specification of a line in the YZ plane.



The extrusion depth should not be zero. Negative extrusion depth extrudes in the opposite direction to the global directions.

The number of intervals is specified across and along the extrusion as shown below.



Lines can be entered in any orientation by specifying the co-ordinates of both ends.

Displacement Polylines can be associated with the polylines, which can be input via the [Polylines](#) table.

Points are specified by single x, y and z co-ordinates.

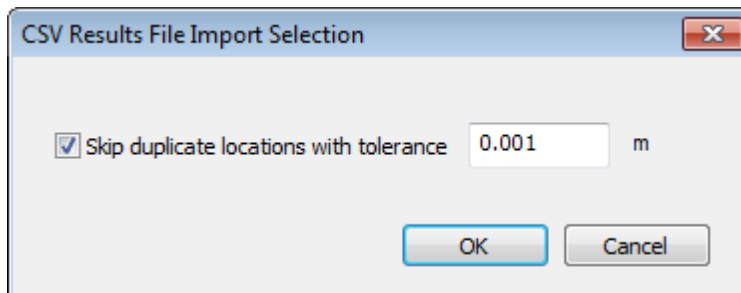
Calculate specifies whether displacement calculations are to be performed for the displacement data item.

Surface Type specifies whether displacements due to tunnelling are to be calculated for this displacement data item using the Surface or Sub-surface method. For more information see Tunnels - Analysis Parameters and [Tunnel Settlement Trough Width](#).

4.7 Data Import

4.7.1 Displacement Results (CSV)

Displacements from other programs may be imported from CSV files via 'File | Import | Displacement Results (CSV)...' from the program menu. On the selection of that option and the csv file subsequently, the 'CSV Results File Import Selection' dialog will appear..



'Skip duplicate locations with tolerance' option allows the user to ignore duplicate points. All the points that are at a distance within the tolerance limit specified from an existing point are ignored.

The purpose of Imported Displacements is to combine the displacements from other programs together with those from Xdisp. The combined displacements may then be shown on the [Tabular Output](#), the [Plan View](#) or the [3D Graphics View](#).

The import file should include rows of data beginning with one of the following keywords. Each row of data contains displacement results for a single coordinate.

- LOAD_RESULT
- POINT_RESULT
- LPOINT_RESULT
- GPOINT_RESULT
- INTERMEDIATE_LOAD_RESULT
- INTERMEDIATE_POINT_RESULT
- INTERMEDIATE_LPOINT_RESULT
- INTERMEDIATE_GPOINT_RESULT

Whichever of these keywords is used, the data will be imported and treated in the same way. The range of keywords is to allow the import of CSV files that have been exported from Xdisp or Oasys Pdisp, which may contain any of these keywords.

Displacements follow the sequence: Keyword,x Coordinate,y Coordinate,z Coordinate,x Displacement,y Displacement,z Displacement.

Units for data in the file are specified by the keywords UNIT_DISP and UNIT_LENGTH (displacement and length units respectively) followed by the index of the unit. Length and displacement units' indices are: 0 - metres; 1 - centimetres; 2 - millimetres; 3 - feet; 4 - inches.

Units information should appear in the file before the displacement results.

e.g.

```
UNIT_DISP, 2
UNIT_LENGTH, 0
LOAD_RESULT, 0.5, 43.5, 0, -0.4967472, -93.72664, 47.38838
```

```
I NTERMEDI ATE_LOAD_RESULT, 0. 5, 43. 5, - 2. 587683439, 0, 0, 38. 77201
I NTERMEDI ATE_LOAD_RESULT, 0. 5, 43. 5, - 4, 0, 0, 34. 85815
GPOI NT_RESULT, - 80, - 90, 0, 32. 98127, 27. 33411, - 0. 5642965
I NTERMEDI ATE_GPOI NT_RESULT, - 80, - 90, - 4, 0, 0, - 0. 5535589
I NTERMEDI ATE_GPOI NT_RESULT, - 80, - 90, - 6, 0, 0, - 0. 5062072
LPOI NT_RESULT, - 70, - 80, 0, 41. 05777, 32. 48021, - 6. 13E- 03
I NTERMEDI ATE_LPOI NT_RESULT, - 70, - 80, - 4, 0, 0, 3. 54E- 02
I NTERMEDI ATE_LPOI NT_RESULT, - 70, - 80, - 6, 0, 0, 0. 1545731
POI NT_RESULT, 0, 0, 0, 0. 7738549, - 31. 88898, 30. 52104
I NTERMEDI ATE_POI NT_RESULT, 0, 0, - 4, 0, 0, 26. 76711
I NTERMEDI ATE_POI NT_RESULT, 0, 0, - 6, 0, 0, 23. 55008
```

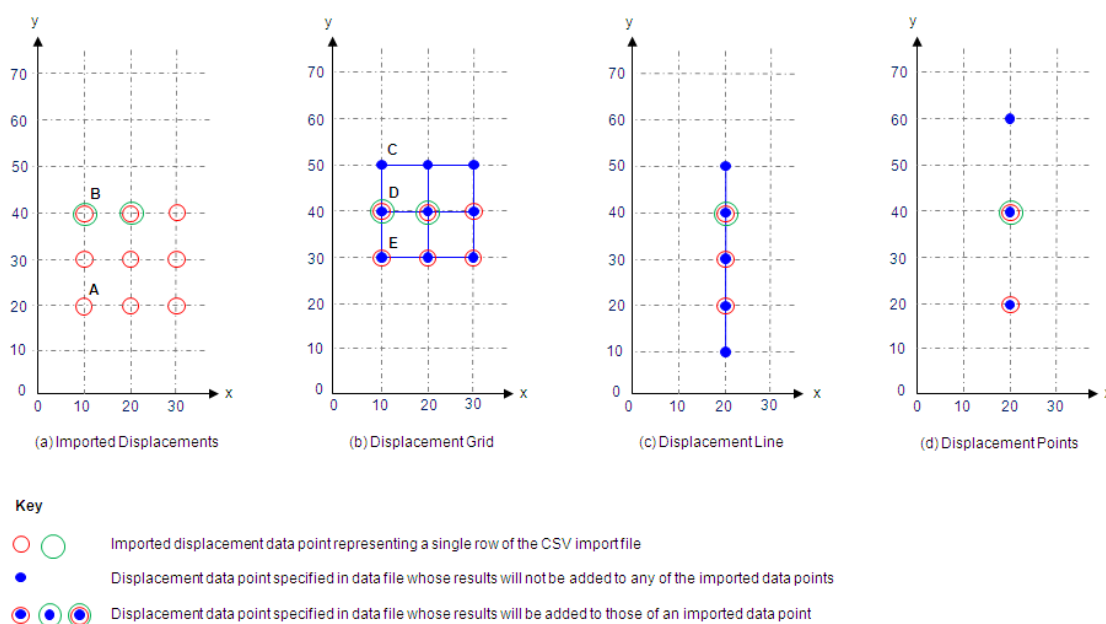
If units are not specified in the file then a dialog will be shown at the beginning of the import process for the user to specify the units of the data in the file.

These imported displacements may be viewed via 'Data | Imported Displacements...' from the program menu or via the [Gateway](#). Once imported they are non-editable. Imported displacements can be deleted by right-clicking in the Imported Displacements Table View and selecting 'Delete All' from the subsequent context menu.

In order that imported displacements may be combined sensibly with displacements that are generated by **Xdisp**, the following rules apply.

- 1) All coordinates of data in the import file are imported whether a match is found for them or not in the displacement grids, lines and points of the current Xdisp file.
- 2) The checking of whether coordinates match those of the displacement grids, lines and points in the Xdisp file is performed at the time of analysis. The tolerance for coincidence is 1 mm in all of the x, y and z directions. Those coordinates which match any in the Xdisp file will have their results added to those of that Xdisp file after analysis.
- 3) If there are multiple entries of displacements for the same point in the import file, all those displacements will be added to those calculated by Xdisp for the displacement position, whether that position is modelled by Xdisp as a displacement point, or as a point within a displacement line or grid.
- 4) Similarly, if one point in the import file is matched with more than one in the data file, e.g. if displacement points, lines or grids contain coincident positions, then the imported displacements will be added to each of the matching positions in the data file.

The diagram below illustrates a series of displacement coordinates in a CSV import file, a Displacement Grid, a Displacement Line, and three Displacement Points in an Xdisp data file. It shows how the results would be combined.



Coordinates such as 'A' are present in the CSV import file in one row of data only with one set of x, y and z displacements. Coordinates such as 'B' are present in the CSV file in two rows of data and so have two sets of x,y and z displacements. Coordinates such as 'C' are present only in the Xdisp data file and not in the CSV import file. Their results will therefore only reflect the results from Xdisp's calculation of displacements. Coordinates such as 'D' are present in the Xdisp data file, but also in two rows of the CSV import file. Their results will therefore be the sum of those from Xdisp's calculation of displacements and the two rows of results in the CSV import file. Coordinates such as 'E' are present in the Xdisp data file and in one row of the CSV import file. Their results will therefore be the sum of those from Xdisp's calculation of displacements and that one row of results in the CSV import file.

If an imported result is intended to be added to results at each displacement point in the Xdisp data file, then care should be taken to ensure that the imported file contains one result for every data point. When importing results from Oasys Pdisp this is most easily achieved by creating the same set of Displacement Grids, Lines and Points in the two programs for export from one and import to the other. Having created the Displacement Grids, Lines and Points in one of the programs they can be input to the other by copying and pasting between the programs' [Displacement Data table views](#) by highlighting the required cells and via the right-click context menu options of 'Copy' and 'Paste'. Note that the last columns in the [Displacement Data](#) for the two programs may display different data, so only the first, common columns should be copied.

Caution should be employed if results are inspected for which not all points of Displacement Grids, Lines and Points have matching imported displacements.

The [Tabular Output](#) may be inspected for a summary of the displacements that have been imported and, after analysis, those which have been found to match displacement points in the Xdisp file.

4.7.2 AutoCAD (DXF)

Geometric data may be imported from DXF files via 'File | Import | AutoCAD (DXF)...' from the program menu.

The purpose of DXF import is twofold: firstly to allow tunnels, structures, utilities or excavations to be created quickly from existing AutoCAD or GIS data; and secondly to allow background lines and

circles to be imported for display on the [3D Graphics View](#).

Alignments of tunnels, structures, utilities or excavations may be traced in AutoCAD and, provided they are saved in the appropriate entity types and named layers, read into **Xdisp** to create complex geometries with minimal input by the user in **Xdisp** itself.

DXF files may be used only to specify the alignments, and, where appropriate, the levels of tunnels, structures, utilities and excavations. Other, non-geometrical data are set to default values by **Xdisp**. After the DXF file has been imported this data should be checked by the user, and, where relevant, reset to appropriate values.

Sample DXF files are supplied with the program. See [Sample Files](#) for more information.

Xdisp Element	Required Name of DXF Layer	DXF Entity	Interpretation	
Tunnels	"Tunnels"	POLYLINE	Series of tunnels	The DXF entity's vertices specify the end coordinates and levels of each tunnel.
		LWPOLYLINE	Series of tunnels	As POLYLINE, but tunnel levels are all set to 0m.
		LINE	Single tunnel	End points of a LINE specify the end coordinates and levels of one tunnel.
Structures ⁽¹⁾	"Buildings"	POLYLINE ⁽²⁾	Series of sub-structures	The vertices of the POLYLINE specify the end coordinates and levels of each sub-structure.
		LWPOLYLINE ⁽²⁾	Series of sub-structures	As POLYLINE, but sub-structure levels are all set to 0m.
		LINE	Single sub-structure	The end points of a LINE specify the end coordinates and levels of one sub-structure.
Utilities ⁽³⁾	"Utilities"	POLYLINE	Series of sub-utilities	The vertices of the POLYLINE specify the end coordinates and levels of each sub-utility.
		LWPOLYLINE	Series of sub-utilities	As POLYLINE, but sub-utility levels are all set to 0m.
		LINE	Single sub-utility	The end points of a LINE specify the end coordinates and levels of one sub-utility.
Excavations ⁽⁴⁾ ⁽⁵⁾	"Excavations"	POLYLINE	Base perimeter of a single excavation	The vertices of the POLYLINE specify the end coordinates and levels of each point on the base of the excavation's perimeter.
		LWPOLYLINE	Perimeter of a single excavation	As POLYLINE, but the levels of the excavation's base points are set to 0m.
		CIRCLE	Perimeter of circular excavation	The centre of the circular excavation and its diameter. The base of the excavation is set to 0m.

⁽¹⁾ For each building a corresponding [displacement line](#) will also be created.

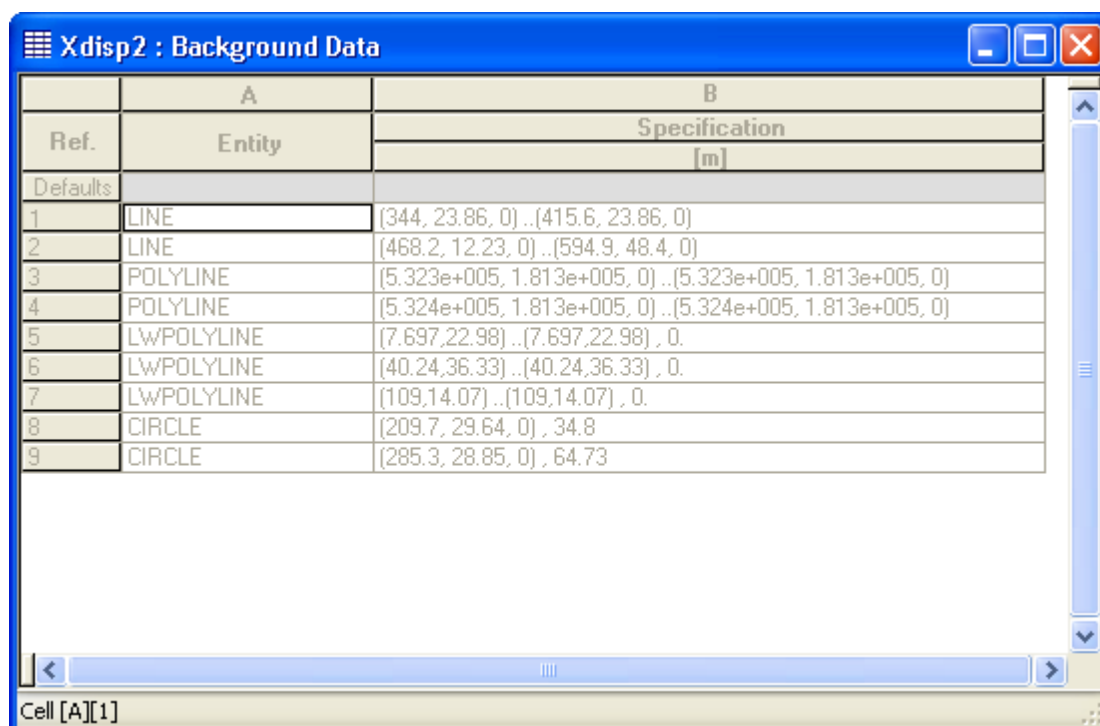
⁽²⁾ POLYLINES and LWPOLYLINES may therefore be used to define all the façades of a real building. In **Xdisp**, each façade will be represented as a sub-structure.

- (3) For each utility a corresponding [displacement line](#) will also be created.
- (4) POLYLINES and LWPOLYLINES can describe either a closed, or an incomplete, loop. If **Xdisp** encounters the latter, then it will close the loop by assuming a final side is intended between the first and last points of the (LW)POLYLINE.
- (5) The top level of the excavation is set to be 10 m above the highest base point.

On importing data from DXF, if Xdisp finds any DXF LINES, POLYLINES, LWPOLYLINES and CIRCLES that are not in a recognisably named DXF layer (as specified in the table above). Such entities will be imported as background data for display on the 3D Graphics View and in the Background Data Table View.

Once imported, tunnels, structures, utilities and excavations may be edited as for others input directly into the program. However, background data is edited, after importing, via the Background Data Table view.

The Background Data Table View, can be accessed via 'Data | Background Data' from the program menu or via the [Gateway](#). Once imported this data cannot be edited, but individual or all records can be deleted by right-clicking in the Background Data Table View and, from the subsequent context menu, selecting 'Delete' to delete selected data or 'Delete All' to delete all data.



	A	B
Ref.	Entity	Specification [m]
Defaults		
1	LINE	(344, 23.86, 0) ..(415.6, 23.86, 0)
2	LINE	(468.2, 12.23, 0) ..(594.9, 48.4, 0)
3	POLYLINE	(5.323e+005, 1.813e+005, 0) ..(5.323e+005, 1.813e+005, 0)
4	POLYLINE	(5.324e+005, 1.813e+005, 0) ..(5.324e+005, 1.813e+005, 0)
5	LWPOLYLINE	(7.697,22.98) ..(7.697,22.98) , 0.
6	LWPOLYLINE	(40.24,36.33) ..(40.24,36.33) , 0.
7	LWPOLYLINE	(109,14.07) ..(109,14.07) , 0.
8	CIRCLE	(209.7, 29.64, 0) , 34.8
9	CIRCLE	(285.3, 28.85, 0) , 64.73

The "Specification" field corresponding to an entity in the Background Data Table View gives its condensed information. Detailed information can be viewed via the wizard which is accessed by double clicking the wizard button on the [Xdisp Toolbar](#). A context sensitive dialog, depending on the type of DXF data item concerned, will then appear.

Background Data [Close]

Background Data 1 Entity: LINE

Geometry [m]

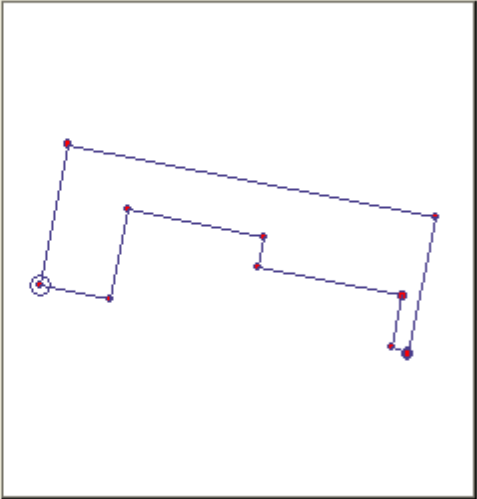
	x	y	z
End Point 1	344.001	23.858	0
End Point 2	415.584	23.858	0

OK Cancel

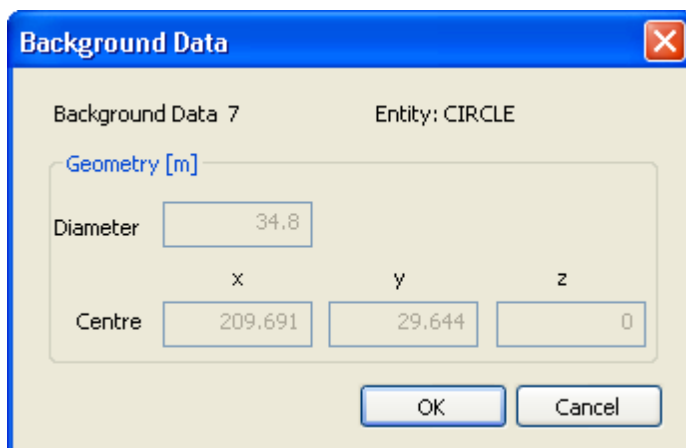
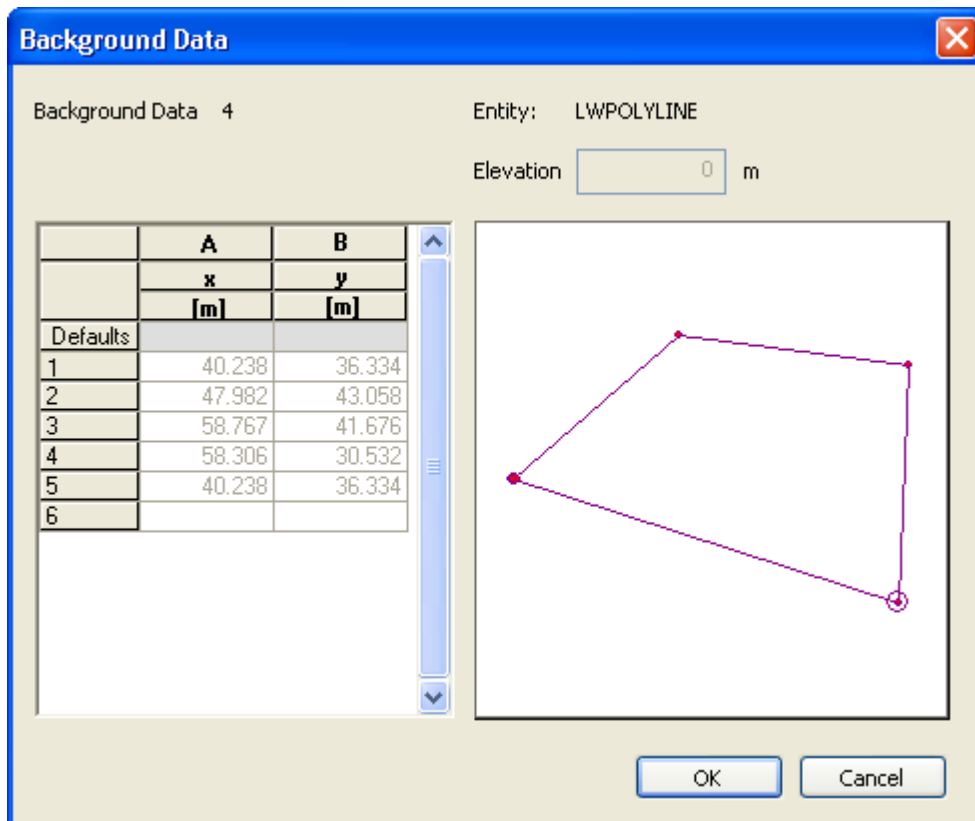
Background Data [Close]

Background Data 8 Entity: POLYLINE

	A	B	C
	x	y	z
	[m]	[m]	[m]
Defaults			
1	532637.063	181295.125	0.000
2	532638.000	181299.875	0.000
3	532625.313	181302.375	0.000
4	532624.375	181297.500	0.000
5	532626.750	181297.000	0.000
6	532627.375	181300.125	0.000
7	532632.063	181299.188	0.000
8	532631.875	181298.125	0.000
9	532636.875	181297.125	0.000
10	532636.500	181295.375	0.000
11	532637.063	181295.125	0.000
12			



OK Cancel



All background data can also be deleted via the 3D Graphics' View's context menu (i.e. by right-clicking on the 3D Graphics View and selecting "Delete Background Data" from the subsequent pop-up menu). Imported DXF background data in the 3D Graphics View can be displayed or hidden via the [Graphic Settings](#) property sheet.

4.7.3 Pdisp (PDD)

The following data from Oasys Pdisp may be imported from Pdisp data files via 'File | Import | Pdisp (PDD)...' from the program menu.

- Displacement data
- Background data

- Imported displacements
- Displacement results

The data for each may be appended to the existing data that has already been entered into the Xdisp model, or may replace it.

This allows, for instance, building damage assessment and utility damage assessment to be performed, in Xdisp, on ground movements that have been calculated from soil loads in Pdisp.

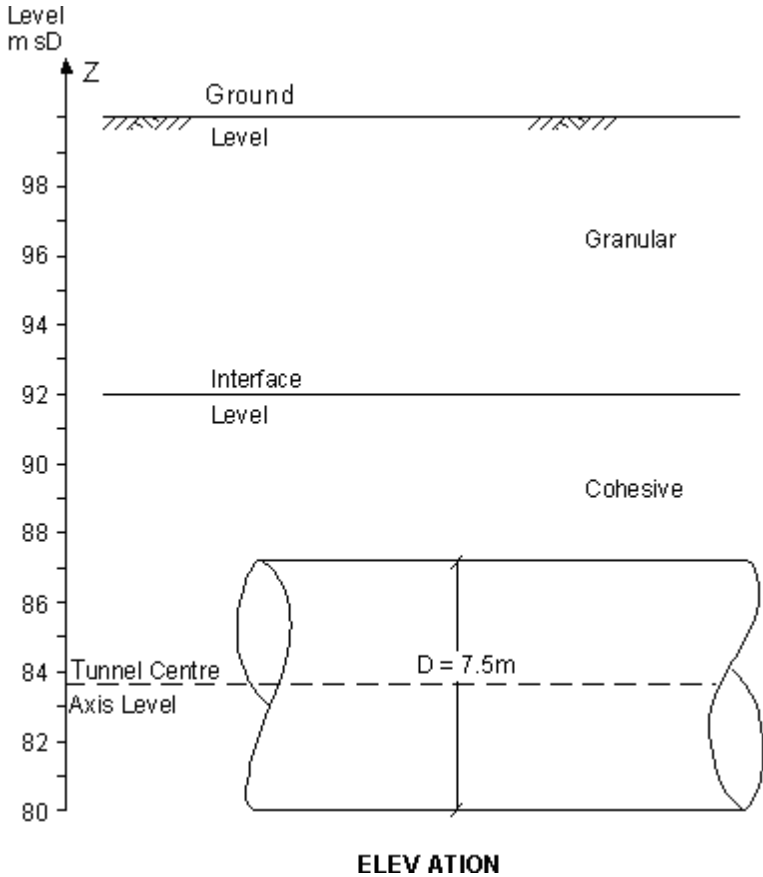
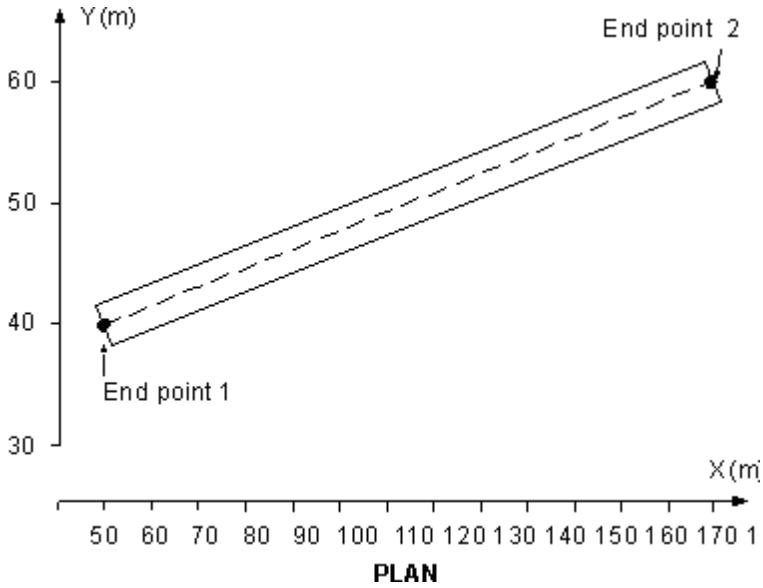
4.8 Tunnel Data

The following input data is required for the analysis of tunnels. Data may be input in dialog form by double-clicking within a cell of the Tunnel Table View.

B001.xdd : Tunnels													
Ref.	Name	Diameter	Endpoint 1			Endpoint 2			Ground Loss	Surface Displacement Calculations			
			x	y	z	x	y	z		k Derivation	Layers	Interface Level	
			[m]	[m]	[m]	[m]	[m]	[m]				[m]	[m]
Defaults	Tunnel #	5.00	0.00	0.00	0.00	10.00	10.00	0.00	1.00	O'Reilly and New	Single	50.000	50.000
1	Tunnel 1	5.00	75.00	100.00	-20.00	75.00	200.00	-20.00	5.00	User-specified k	Single		
2	Tunnel 2	5.00	125.00	100.00	-20.00	125.00	200.00	-20.00	5.00	User-specified k	Single		
3													

Surface Displacement Calculations												Sub-surface Displacement Calculations				Soil at Tunnel Level
k Derivation	Layers	Interface Level		k	Analysis Method	k Derivation	k	m	Ground Level							
		End 1	End 2						End 1	End 2						
O'Reilly and New	Single	50.000	50.000	0.40	New and Bowers	User-specified	0.40	0.50	[m]	[m]			Cohesive			
User-specified k	Single			0.40	New and Bowers	User-specified	0.40									
User-specified k	Single			0.40	New and Bowers	User-specified	0.40									

The parameters which define the geometry of the the tunnel are as follows:



Tunnel diameter (m) specifies the diameter of the tunnel.

Endpoint 1 and **Endpoint 2 (x, y, z)** specify the locations of the end points of the tunnel's centre-line (m). The tunnels may be skewed or inclined.

The parameters which define the anticipated volumetric ground loss due to tunnel collapse are as follows:

Ground Volume Loss Factor (V_L), see [Volume Loss](#).

Soil at Tunnel Level specifies the soil type (cohesive or granular) at the level of the tunnel. If dual-layered soils are specified i.e. the Selby k Derivation method is used to calculate surface movements, then the soil in the layer above this is assumed to be of different type.

k Derivation specifies the choice of k derivation method that is to be applied to this tunnel. Different methods may be chosen for surface and sub-surface displacements. See [Tunnel Analysis Methods](#) and [k Derivation Methods](#). If the Mair et al analysis method is chosen for sub-surface displacements, then a k derivation method is not required.

Layers specifies whether the tunnel lies beneath single or dual-layered soil (for surface displacement calculations only). This field is not editable. It is dependent on the k derivation method since only the Selby k derivation method is applicable to dual-layered soil. Other methods are applicable to single layer soils only.

Interface Level specifies the levels of the interface between the two possible layers of cohesive and granular soil. These levels are specified directly above the tunnel end points. They are only applicable if the Selby k derivation method is chosen.

k specifies the k value of the settlement trough. See [Tunnel Settlement Trough Width](#) and [Analysis Methods](#) for further information.

Analysis Method specifies whether the New and Bowers or Mair et al method is to be used for calculation of sub-surface displacements. Surface displacements are calculated using the O'Reilly and New method. See [Analysis Methods](#) for further information.

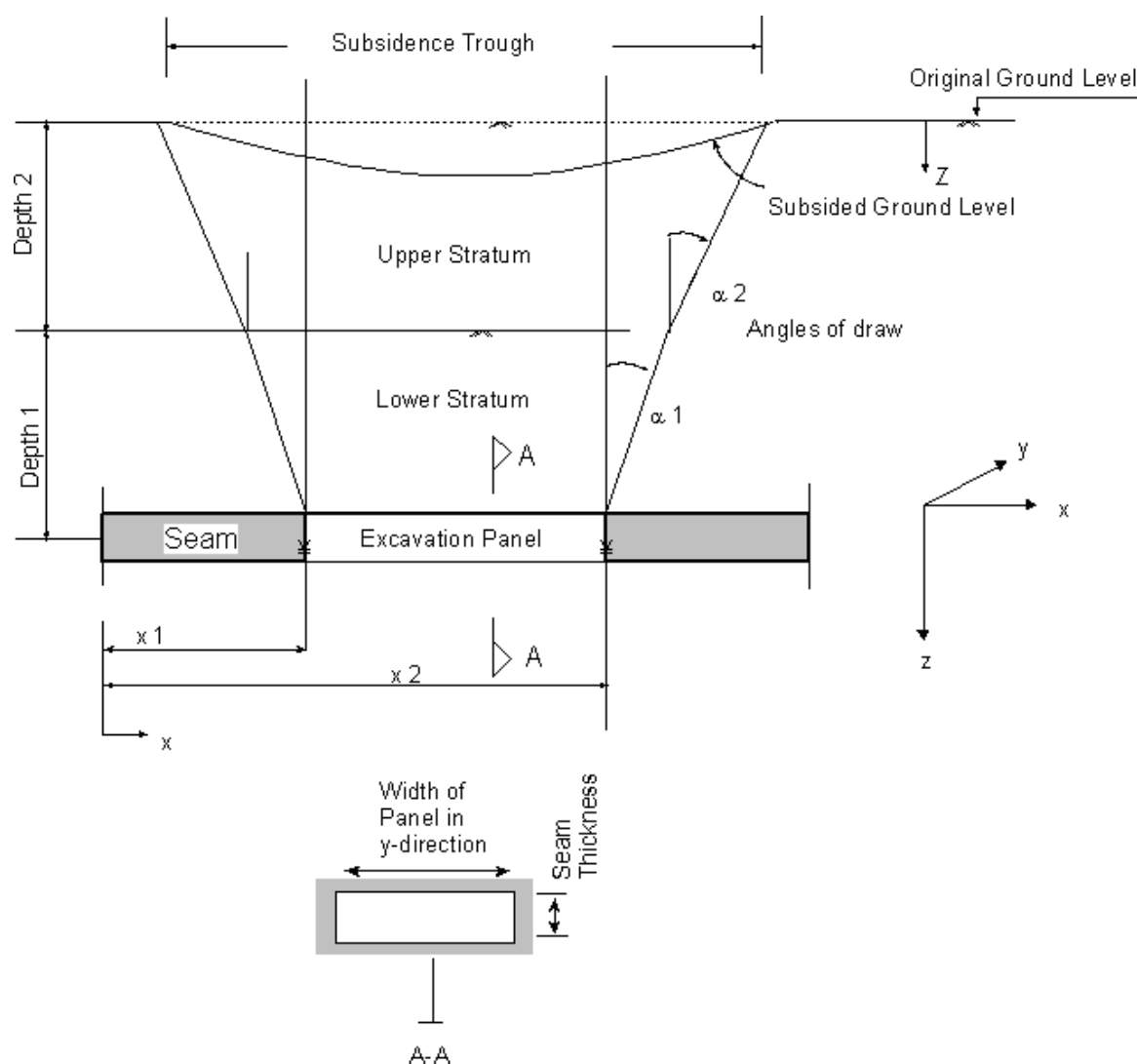
m specifies [Harris and Alvarado's](#) exponent 'm'. See [Tunnel Settlement Trough Width](#) and [Analysis Methods](#) for further information.

Ground Level specifies the level of the ground surface directly above each of the tunnel end points. Ground levels are required only if the Mair et al analysis method is chosen for the calculation of sub-surface displacements.

4.9 Mine Data

The following data is required for input of a mine:

	A	B	C	D	E	F	G	H	I	J	K											
												Name	Seam		Strata thickness		Angle of draw		Extraction area			
													Thickness	Width	Lower	Upper	Lower	Upper	X1	Y1	X2	Y2
		[m]	[m]	[m]	[m]	[°]	[°]	[m]	[m]	[m]	[m]											
Defaults	Mine #																					
1	Mine 1	3.00	10.00	10.00	0.00	35.00	0.00	-5.00	0.00	5.00	0.00											
2																						



- Seam **thickness** on the z axis.
- Seam **width** along the y axis. This should extend beyond the proposed extracted area specified below.
- The thickness (or depth) of the **upper** and **lower** layers of strata. The lower layer of strata is deemed to reach the centre of the mined layer.
- The **angle of draw** (α) in degrees for the upper and lower layers of strata.
- The **horizontal dimensions** to the edges of the extracted area X1, Y1, X2 and Y2. These are measured from the origin (0) on the x and y axis.

4.10 Circular Excavation Data

A circular excavation defines the volume of a circular embedded wall excavation together with the ground movement curves that are to be associated with it.

Name - specifies the name of the excavation.

New - creates a new excavation.

Copy - copies the excavation currently displayed.

Delete - deletes the excavation currently displayed.

Rename - renames the excavation currently displayed.

Vertical and Horizontal ground movement curves - specify the vertical and horizontal [ground movement curves](#) that are to be associated with this excavation.

Contribution - specifies whether the excavation is considered to contribute (positive) to the displacements or to detract (negative) from them. See [Irregularly Shaped Excavations](#) for further details.

Surface level - specifies the ground surface level at this excavation. If either of the Ground Movement Curves that are associated with this excavation are of surface-only type, then displacements will be calculated only for [displacement points](#), or points within [displacement lines](#) or [grids](#), that are at this level. A warning will be given otherwise. See the [Embedded Wall Excavations](#) method for more information.

If surface movement curves are selected... - this option is enabled only if any of the Ground Movement Curves that are associated with this excavation are of surface-only type. For such cases the displacements can be calculated for displacement entities below the surface too, by checking this option and specifying the level up to which the curves are to be applied. Displacements that are calculated are not adjusted for the depths of displacement points. They are calculated merely based on the horizontal distance from the excavation so will be the same for a point at the surface or below it.

Base level - specifies the level at the base of this excavation. Circular excavations are assumed to have horizontal bases.

Diameter - diameter of the excavation.

Centre (x) and (y) - coordinates of the plan centre of the excavation.

Enabled - if unchecked the excavation will be ignored in ground movement calculations. It will have no effect on results.

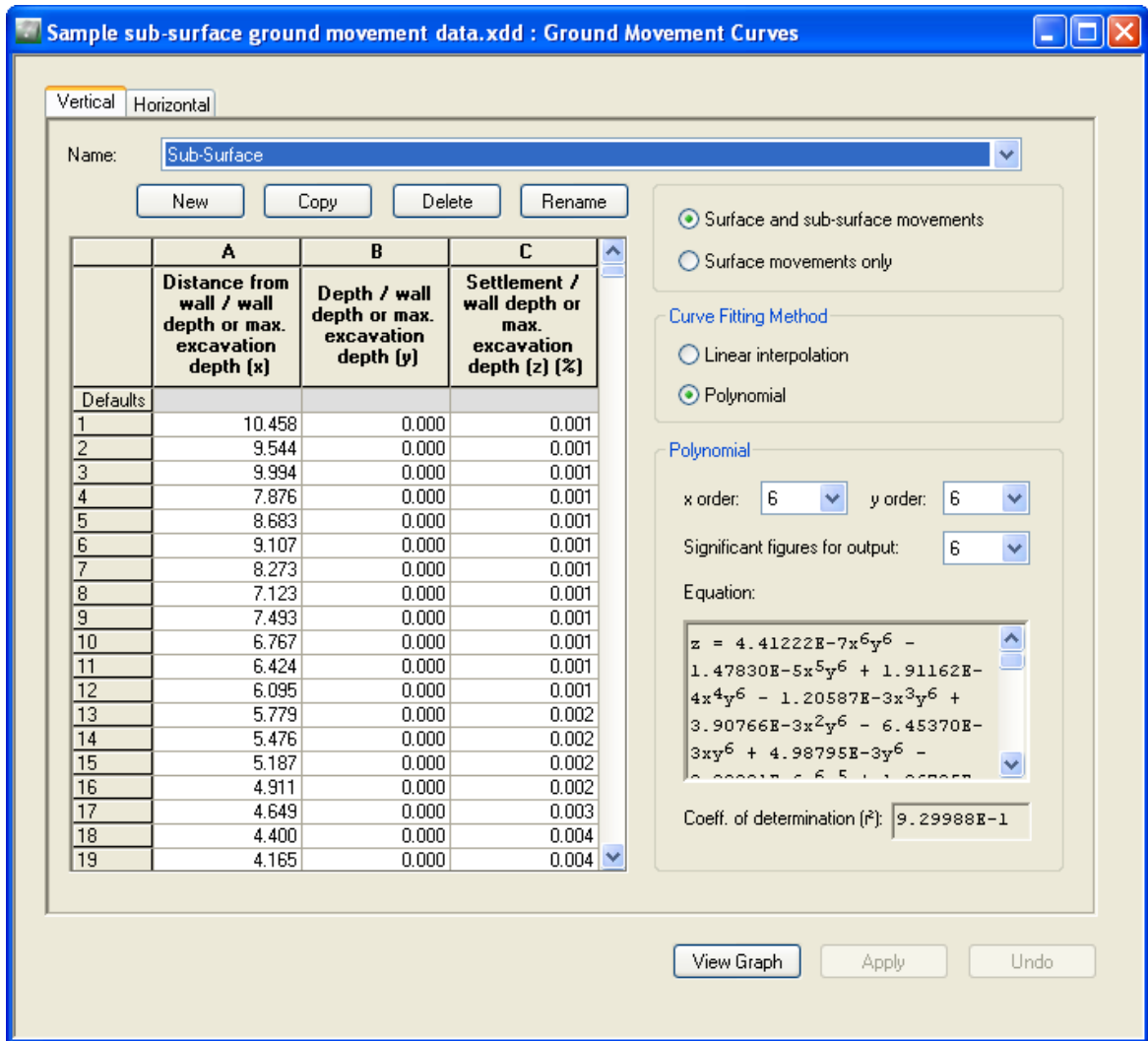
4.11 Ground Movement Curve Data

Ground Movement Curve input data is accessible via the Gateway or by choosing "Data | Ground Movement Curves" from the program's menu.

Ground Movement Curves describe the horizontal or vertical movement of a point adjacent to the side of an embedded wall excavation. They may be defined for both ground surface and sub-surface movements, or for ground surface movements only. The former are functions of distance from the wall/excavation, depth below the top of the wall/excavation and the wall/excavation's depth. The latter are functions of distance from the wall/excavation and the wall/excavation's depth only.

A number of ground movement curves for surface movement are provided by **Xdisp** to represent Figures 2.8 to 2.12 of [CIRIA C580](#). However, users may add their own surface movement curve data to supplement this set, or add their own surface and sub-surface data. In order for **Xdisp** to perform movement calculations for [displacement points](#) in the model, it will use, in its calculations, either a polynomial curve fit to these points (derived by the least squares method) or linear interpolation between them. If a polynomial is required, then the x and y orders must be specified. A graph of the resulting curve that is to be used is available by clicking the 'View Graph' button. **Xdisp** uses these curves to calculate soil movements that result from whichever embedded wall excavations refer to them in the [Excavation Details](#) dialog.

Included with the program is a [sample file](#) which contains an example data set named "Subsurface" for surface and sub-surface movements. This data has been sourced from a 3 dimensional finite element model for ground movements around an embedded wall excavation. Ground conditions modelled comprised Made Ground overlying River Terrace Deposits overlying London Clay. The finite element model used a Mohr Coulomb model to model the Made Ground overlying River Terrace Deposits and the BRICK soil model ([Simpson \(1992\)](#)) to model the London Clay. The plan dimension of the basement was approximately rectangular in shape and 120m by 100m in plan dimension. Displacements were taken normal to the secant pile retaining wall at 60m along one of the boundaries. It provides an example only for illustrative purposes and should not be used by 3rd parties for carrying out analysis. It is recommended that surface and sub-surface movement curves' data for use in **Xdisp** be sourced either from field data, or by finite element analysis. Further details of the analyses performed to create this data can be found in [Sample Sub-surface Ground Movement Curve](#).



Vertical/Horizontal - specifies whether the curve defines vertical or horizontal movement.

Curve Name - the title of the ground movement curve.

New - creates a new ground movement curve.

Copy - copies the currently selected ground movement curve.

Delete - deletes the currently selected ground movement curve.

Rename - renames the currently selected ground movement curve. Pre-programmed curves that are provided by **Xdisp** may not be edited. In order to adjust one of those curves the curve should first be copied. The copy can then be edited.

Surface and sub-surface movements - specifies that the curve is to provide data for both surface and sub-surface ground movements, so x, y and z data will be required.

Surface movements only - specifies that the curve is to be used to calculate surface ground movements only, so x and y data only will be required.

Curve coordinates - lists the x, y, and z coordinates that define the ground movement curve.

Linear interpolation - specifies that the curve that is to be fitted to the data points is to be calculated by linear interpolation between those points.

Polynomial - specifies that the curve that is to be fitted to the data points is to be a polynomial.

Order of polynomial - specifies the order of the polynomial that is to be fitted to the curve coordinates.

Significant figures for output - defines the number of significant figures that are to be used when displaying the polynomial equation.

Polynomial equation - displays the polynomial equation that **Xdisp** has calculated.

Coefficient of determination - displays the coefficient of determination (r^2) of the polynomial equation. Values closer to 1.0 than 0.0 indicate a better correlation between the coordinates that are used to create the polynomial equation, and those that would be generated by the polynomial equation.

View Graph - displays a [graph](#) of the currently selected ground movement curve.

Apply - applies, to the model's data, all changes that have been made to the set of ground movement curves.

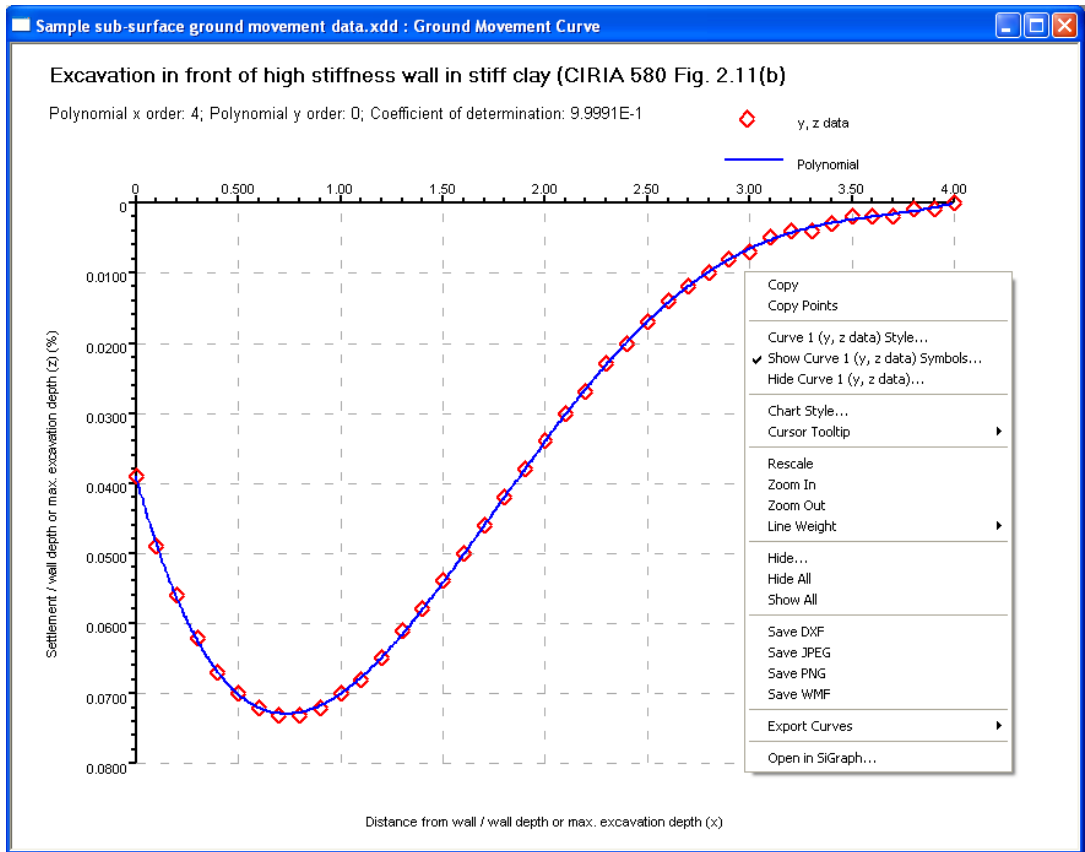
Undo - restores, from the model's data, the set of ground movement curves - thereby undoing any changes that have been made to since 'Apply' was last executed.

4.11.1 Ground Movement Curve Graphs

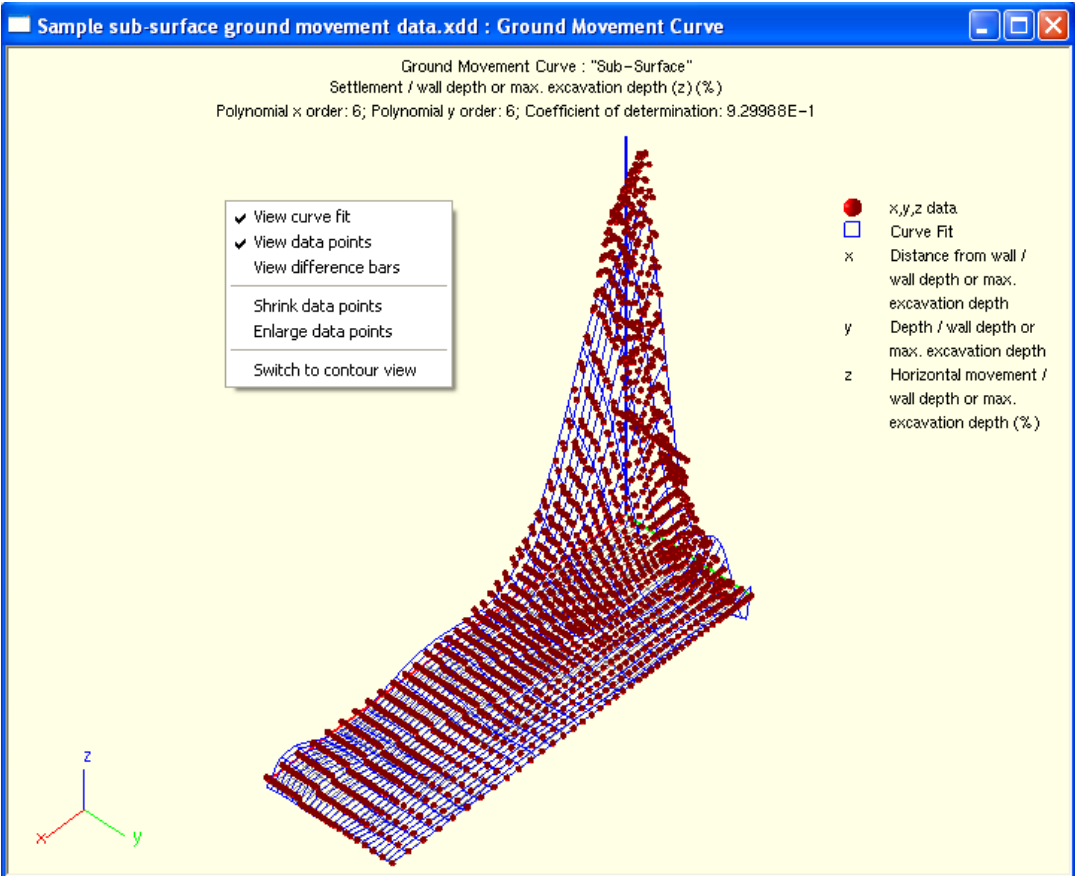
Ground movement curves' graphs are accessible by clicking the "View Graph" button on the [Ground Movement Curves' dialog](#). They illustrate the graph that is generated by **Xdisp** as a fit a ground movement curve's data points, and that will be used in the calculations for displacement points affected by excavations/walls that refer to that curve. The style of graph that is presented depends on whether ground movement curve data has been specified for surface and sub-surface movements, or for surface movements only.

Formatting options are available by right-clicking in the view.

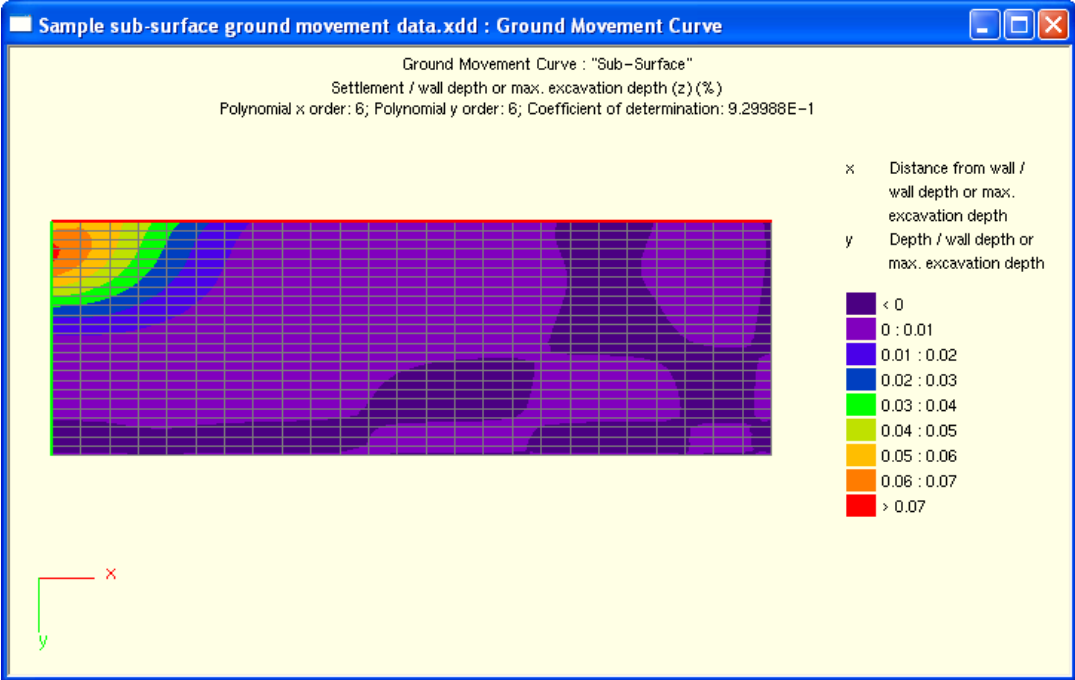
Surface Ground Movement Only Curves' - Graph



Surface and Sub-surface Ground Movement Curves' - Relief View



Surface and Sub-surface Ground Movement Curves' - Contour View



Right-clicking in the window opens a context menu to enable formatting of the view. The following options are available for the relief view of surface and sub-surface ground movement curves' graphs.

View curve - toggles the display of the curve that has been fitted to the data points.

View data points - toggles the display of the data points that are used in deriving the curve fit.

View difference bars - toggles the display of the difference bars, illustrating the difference between the data point's z value, and the z value calculated by the curve fit.

Shrink data points - halves the size of the spheres used to display the data points.

Enlarge data points - doubles the size of the spheres used to display the data points.

Switch to contour/relief view - changes the view from a coloured, 2 dimensional, contour view of values calculated from the curve fit, and the 3 dimensional relief view of the curve fit.

4.11.2 Sample Sub-surface Ground Movement Curve

The following defines the modelling assumptions used for the three dimensional finite element analysis that was used to provide the displacements given in the [sample data file](#): Sample sub-surface ground movement data.xdd.

Notation

B1	= lowest level of basement slab
c'	= cohesion
E'	= drained Young's Modulus
E _u	= undrained Young's Modulus
G	= tangent shear modulus
G _{max}	= maximum value of tangent shear modulus at very small strain
G _v /G _h	= ratio of vertical to horizontal shear stiffness
K _o	= coefficient of earth pressure at rest
LGF	= lower ground floor slab
mOD	= metres Ordnance Datum
S _u	= undrained shear strength
α	= adhesion factor between pile and soil
γ	= unit weight
λ, κ, τ, β _G , and β _∅	= constants in the BRICK soil model
∅ _{peak}	= peak friction angle

Introduction

The Oasys program LS-DYNA (DYNA) was used to carry out the 3D FE analysis. The modelling was used to establish ground movements around a deep basement constructed in Central London.

The site and proposed basement has maximum dimensions of approximately 105m (north to south) by 150m (east to west) and covers an area of 12,200m². Displacements in the sample file were taken at the centre of one of the basement retaining walls (at least 60m from any corner). Therefore the

displacements approximate to a plane strain condition.

Comparisons of the surface and sub-surface displacements were carried out with the following case studies:

- British Library excavation ref Simpson (1992)
- House of Commons car park excavation, ref Burland and Hancock (1977) and St John (1975)
- 3D LS-DYNA finite element analysis of Crossrail Paddington Box in London carried out by Arup

Reasonable agreement was obtained from these comparisons between the methods. Therefore data from the FE analysis described here was used as data in the sample file. It should be noted that all of the excavations were stiffly propped excavations carried out in London Clay.

Stratigraphy

Ground and groundwater conditions were initially assessed from information compiled in a geotechnical desk study. Following this, two phases of ground investigations were carried out to gain sufficient information to allow geotechnical design of the project. On the basis of the desk study and site investigations, the table below presents the design stratigraphy adopted for the geotechnical analysis.

Geotechnical Design Stratigraphy

Stratum	Top of stratum (mOD)	Thickness (m)
Made Ground(a)	+17.5 (ground level at north of site)	5m
Brickearth(a)	+12.5	2.5m
River Terrace Deposits	+10	4m
London Clay	+6	36m
Lambeth Clay	-30	12m

(a) Assumed not to be present below the majority of the former basement.

Soil Parameters

Geotechnical design parameters were derived for each stratum from the results of insitu and laboratory testing. The proposed soil parameters for each stratum, are summarised in the table below. The Made Ground, Brickearth and River Terrace Deposits were modelled in the analysis using the linear elastic perfectly plastic Mohr-Coulomb model without dilation. These materials were assumed to be drained in all stages of the analysis.

Summary of Geotechnical Parameters

Stratum	γ (kN/m ³)	c' (kN/m ²)	ϕ peak	S_u (kN/m ²)	E' (MN/m ²) d	E_u (MN/m ²) d	Kof	α
Made Ground	18	0	25	0	10	-	0.6	-
Terrace Gravel	20	0	36	0	30	-	0.4	-
London Clay	20			Modelled using BRICK				0.5
Lambeth Group (Clay)	20			Modelled using BRICK				0.4

- b S_u / depth profile outside secant wall (z increasing with depth from +5mOD)
- c S_u / depth profile inside secant wall (z increasing with depth from +2mOD) adjusted to account for excavation
- d For the retaining wall analysis. Lower values were used for considering settlements from pile or raft foundations
- e E_u / depth profile outside secant wall (z increasing with depth from +10mOD). Softening of the soil adopted on the passive side of the retaining wall.
- f For the London Clay and Lambeth Group (Clay), the K_o profile varied with depth and was dependent upon the stress history modelled in the BRICK soil model. An approximate average value is given in this table.

The finite element analysis used the constitutive soil model, BRICK (Simpson, 1992) to model the behaviour of the London Clay and fine grained strata within the Lambeth Group. Moderately conservative soil stiffness parameters (Pillai, 1996) were adopted in the analysis for the BRICK soil model. The BRICK model is non-linear and is strain-dependent. The shear stiffness / strain soil properties used for the BRICK model are defined in the table below.

BRICK Model Material Properties for London Clay and Lambeth Clay

Strain	G/Gmax
3.04E-05	0.92
6.09E-05	0.75
0.000101	0.53
0.000121	0.29
0.000820	0.13
0.00171	0.075
0.00352	0.044

0.00969	0.017
0.02223	0.0035
0.0646	0
$\lambda=0.1 \quad \kappa=0.02 \quad \iota=0.0019 \quad \beta G=4 \quad \beta \varnothing=2 \quad G_{vh}/G_{hh}=0.5$	

Groundwater Conditions

For both short and long term conditions in the London Clay and Lambeth Clay, a hydrostatic water pressure profile was adopted starting from an elevation of +8.5mOD. It was realised that a sub-hydrostatic pressure profile exists in the lower part of the London Clay and Lambeth Group (CIRIA, 1989). Given the depth of the excavation, this was considered to have a negligible effect on the design of the retaining walls and potential base heave during the proposed excavation.

Boundary Conditions

The model extends from +17.5mOD (existing ground level at Cheapside), to -42mOD (base of the Lambeth Clay). The Lambeth Sand, Thanet Sand and the Chalk layers were not included as they are stiffer materials in which little movement was expected.

The horizontal base of the model was restrained in all directions. All of the vertical boundaries were restrained in the x and y directions but are free to move vertically. The vertical boundaries were sufficiently far from the excavation to have no effect on ground movements calculated along the Central Line tunnels.

Analysis Sequence

The analysis sequence modelled the geological and historical development at the site to obtain an appropriate horizontal effective stress and strain state in the soil modelled using BRICK prior to modelling the anticipated construction sequence. Displacements were zeroed prior to the construction stages (Stage 6 onwards). For simplification a single construction sequence was adopted around the perimeter of the site to model the support of the existing wall. During the actual construction, numerous sequences were adopted to support the existing basement retaining walls, however, assuming a single sequence has a negligible effect when considering displacements at depth. The full sequence used in the DYNA finite element analysis is given in the table below.

Analysis Sequence Used in the DYNA FE Analysis

Analysis stage	Description	Remarks
Stage 1	Initialisation of the model (drained)	Model geological history of unloading to establish insitu K_0 profile

Stage 2	Excavate for Central Line tunnels (undrained)	Assume 2% volume loss
Stage 3	Place lining of tunnels (drained)	
Stage 4	Construct existing building (undrained)	"Wished" in-place existing building wall, slab and floors
Stage 5	Switch to drained	End of this stage represents current condition
Stage 6	Demolish existing building - Remove existing building surcharge, floors at +17.5mOD and +13.77mOD and place temporary prop at +16.5mOD (undrained)	Existing building wall remains in place. Displacements zeroed at this stage
Stage 7	Install secant wall for new building and fill gap between secant and existing walls (undrained)	1.18m diameter secant wall on the northern boundary and 0.88m elsewhere. Straight shafted bearing piles of up to 2.4m in diameter with plunged columns. The 1.18m secant wall on the northern boundary has male piles at 1.7m centres.
Stage 8	Install bearing piles, remove former building base slab at +10mOD, insert temporary props at +17.5mOD and +10mOD (undrained)	Install plunge columns
Stage 9	Apply percentage of new building loads on to plunge columns (undrained)	
Stage 10	Excavate to +1.9mOD, top down construction (undrained)	Bottom-up core construction not modelled
Stage 11	Place underslab drainage, construct 1m thick B1 slab and apply full new building load (undrained)	0.3m underslab drainage is placed below new building B1 slab
Stage 12	Switch to long term condition (drained)	Long term properties of concrete used

4.12 Building Damage Assessment

The two types of building damage assessment which can be performed are:

- [Specific Building Damage Assessment](#).
- [Generic Building Damage Assessment](#).

4.12.1 Specific Building Damage Assessment

4.12.1.1 Structure Data

Specific building damage : Specific Structures									
Ref.	A Structure Name	B Sub-Structure Name	C Displacement Line	D Line Length	E Start Distance Along Line	F End Distance Along Line	G Vertical Offsets from Line for Vertical Movement Calculations	H Vertical Displacement Limit Sensitivity	I Damage Category Strains
				[m]	[m]	[m]	[m]	[mm]	
Defaults	Building #	Sub #	Surface		0.000	0.000	0	0.100	Burland Strain Limit
1	Building 1	Sub #	Surface	99.999	0.000	100.000	0,0,0,0	0.100	Burland Strain Limit
2									

Press <TAB> to start a new record

J	K	L	M	Hogging			Sagging		
Poisson's Ratio	E/G	Height	Default Properties	2nd Moment of Area (per unit width)	Distance of Bending Strain from N.A.	Distance of N.A. from Edge of Beam in Tension	2nd Moment of Area (per unit width)	Distance of Bending Strain from N.A.	Distance of N.A. from Edge of Beam in Tension
		[m]		[m ²]	[m]	[m]	[m ²]	[m]	[m]
0.200	2.600	10.000	Yes						
0.200	2.600	10.000	Yes	333.333	10.000	10.000	83.333	5.000	5.000

A structure's geometry describes the location of the structure and its sub-structures, its height and settlement trough limit sensitivity. Its location is used to calculate the settlement and horizontal displacement along its length. These are then used to calculate hogging and sagging zones, deflection ratios and horizontal strains for input into the Burland [Building Damage Assessment](#)

method.

Structures contain Sub-Structures, as buildings contain façades. Thus the varying alignments of a building's façades may be associated for reporting purpose.

The following parameters in the table define the geometry:

Structure Name - a name to identify structure e.g. a building's name.

Sub-Structure Name - a name to identify a sub-structure e.g. one facade of a building.

Displacement Line - the [Displacement Line](#) that is to be used to describe the plan alignment of the sub-structure.

Line Length - the length of the Displacement Line that is the maximum length that the sub-structure can have.

Start Distance Along Line - the distance along the Displacement Line that defines the start point of the sub-structure.

End Distance Along Line - the distance along the Displacement Line that defines the end point of the sub-structure.

Vertical Displacement Limit Sensitivity - the minimum value that is to determine the extent of regions of settlement or heave for the sub-structure's building damage assessment calculations. This is an absolute value. It allows settlement or heave profiles, that tend towards zero very gradually, to be curtailed for the purposes of establishing the end hogging or sagging zones in building damage assessment.

Height - the height of the sub-structure from foundation to eaves' level.

Vertical Offsets from Line for Vertical Movement - the vertical offset to be applied to the displacement line before calculating vertical displacements for use in building damage assessments. A series of offsets may be specified in order to compare building damage results for different elevations e.g. for a piled building: basement level; equivalent pile level; and pile toe level. These vertical movements are used with horizontal movements at the level of the displacement line. See [Points of Inflexion, Gradient and Radius of Curvature](#) for further information. More than one value may be entered separated by commas ", ". A negative value represents a reduction in elevation.

The Burland method of building damage assessment assumes that a building's façade behaves as a beam in bending.

The following parameters in the table provide the information that is required by the Burland method to effect this approximation:

Damage Category Strains - the set of [Damage Category Strains](#) that this sub-structure is to adopt to describe the thresholds of each of the 5 damage categories (0 to 4)

Poisson's Ratio - the Poisson's ratio of the beam that is to represent the sub-structure. Values in the range of 0.2 to 0.3 are commonly adopted.

E/G - the Young's modulus : shear modulus ratio of the beam that is to represent the sub-structure (if the sub-structure is solid, isotropic, linear and elastic then a typical value would be based on Poisson's Ratio, ν , as $2(1 + \nu)$ so ranging from 2.4 to 2.6, if values of 0.2 to 0.3 are used for the Poisson's Ratio.

[Burland and Wroth \(1974\)](#) discuss the effect of E/G ratios but draw no conclusions about appropriate

values to use for 'typical' masonry or concrete structures. [Mair, Taylor and Burland \(1996\)](#) state, 'For the purposes of assessment of potential damage, framed buildings on shallow foundations can be considered using the same methodology as for masonry structures. It is more appropriate to adopt an E/G ratio of 12.5, rather than 2.6 used for masonry structures'.

[Melis and Rodríguez Ortiz \(2001\)](#) suggest 'for flexible buildings with big spans or steel structure, the ratio E/G can be as high as 12 or 15'.

Default Properties - set 'Yes' for Xdisp to calculate default values for 2nd Moment of Area and neutral axis distances as discussed below, or 'No' to provide specific values.

The following data is required for hogging and sagging zones of the building.

Distance of Bending Strain from N.A. - the distance of bending strain to be calculated from the neutral axis. For sagging of a linear isotropic elastic beam a value equal to the height/2 is commonly used. For hogging of a building with a rigid base slab a value equal to the height is commonly used.

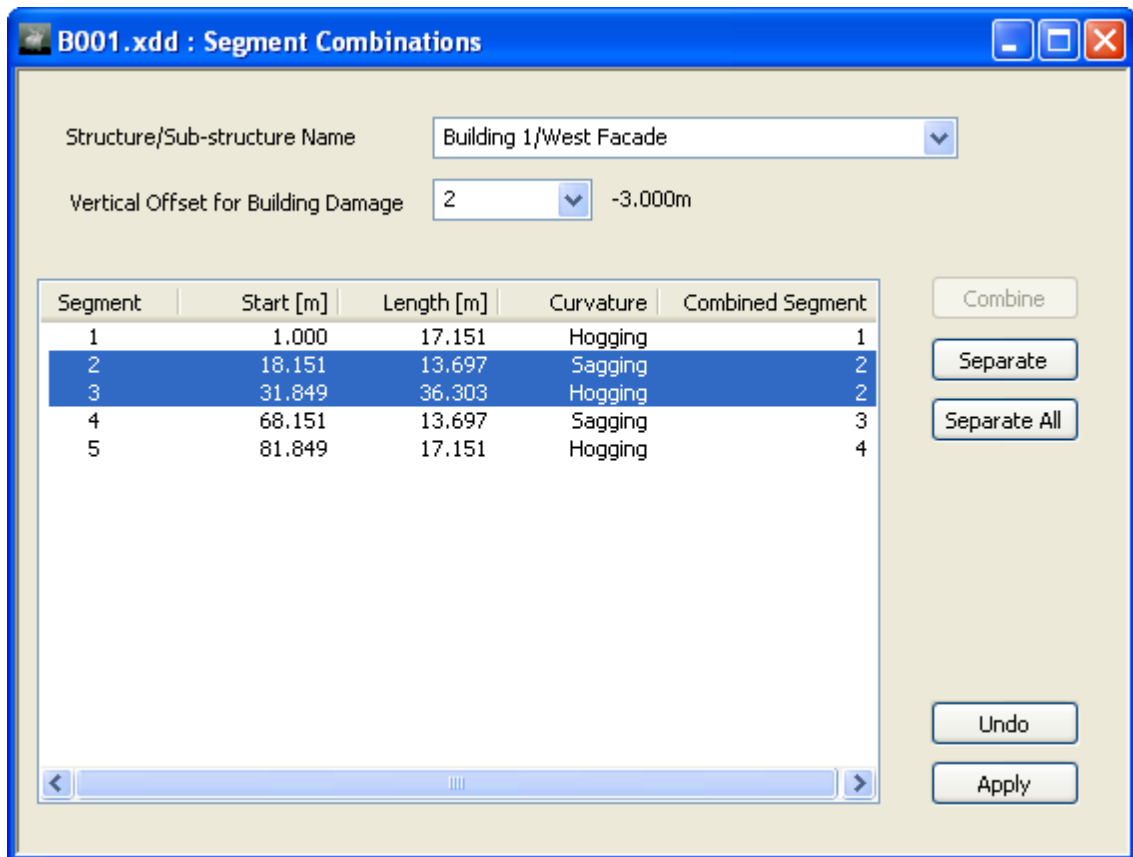
Distance of N.A. from Edge of Beam in Tension - distance of the neutral axis from the edge of the beam in tension. For sagging of a linear isotropic elastic beam a value equal to the height/2 is commonly used. For hogging of a building with a rigid base slab a value equal to the height is commonly used.

2nd Moment of Area (per unit width) - adopting the above for Distance of Bending Strain from N.A. and for Distance of N.A. from Edge of Beam in Tension - conventionally for an element of a structure undergoing hogging a value of $d^3/3$ is adopted. For an element of a structure undergoing sagging a value of $d^3/12$ is adopted, see [Mair et al \(1996\)](#).

4.12.1.2 Segment Combinations

The Segment Combinations dialog is available only if an analysis has been performed in order to determine the locations of hogging and sagging segments along a sub-structure's length.

Segments may then be combined in order to force short, insignificant, lengths of hogging or sagging segments to be absorbed into longer more significant neighbouring lengths.



To combine two or more adjacent segments, click the segment number that is to define the starting segment of the required combined segment, then <shift>+click the last segment of the required combined segment. The segments that are to be combined will then be highlighted. Click the 'Combine' button to combine these segments into one. The column labelled 'Combined Segment' then shows the revised number of the combined segments.

To separate all combined segments for the displayed sub-structure and vertical offset, click 'Separate'. To separate all combined segments for all vertical offsets in all sub-structures click 'Separate All'. These changes will not become persistent after the window is closed until 'Apply' is clicked.

To perform building damage assessment calculations on these revised groupings of segments, click 'Apply'. The results for both combined and uncombined segments will then be available in the for appropriate [Line Plots](#) and in the [Tabular Output](#).

4.12.2 Generic Building Damage Assessment

4.12.2.1 Structure Data

Ref.	Name	Polyline	L/H Values	Vertical Displacement Limit Sensitivity	Damage Category Strains	Poisson's Ratio	E/G	Default Properties	Hogging		Sagging		Vertical Offsets from Line for Vertical Movement Calculations	Transects		
									2nd Moment of Area (per unit width)	Distance of N.A. from Edge of Beam in Tension	2nd Moment of Area (per unit width)	Distance of N.A. from Edge of Beam in Tension		Interval	Length	Number of Displacement Points
				[mm]					[m ²]	[m]	[m ²]	[m]	[m]	[m]		
Defaults	Generic #	Polyline 1	0.1,0.16,0.25,0.4	0.100	Burland Strain Limits	0.200	2.600	Yes					0.000	3.000	10.000	11
1	Generic 1	Polyline 1	10	0.100	Burland Strain Limits	0.200	2.600	Yes					0.000	50.000	100.000	11
2																

The following parameters in the table define the geometry:

Structure Name - a name to identify the generic damage assessment data.

Polyline - the [polyline](#) whose transects are used to describe the plan alignment of assessment locations.

L/H Values - the series of L/H values which make up the buildings to be analysed along each transect of the polyline. These are input as comma-separated values in the cell.

Interval - the distance that defines the spacing between transects, along the polyline.

Length - the length of each transect.

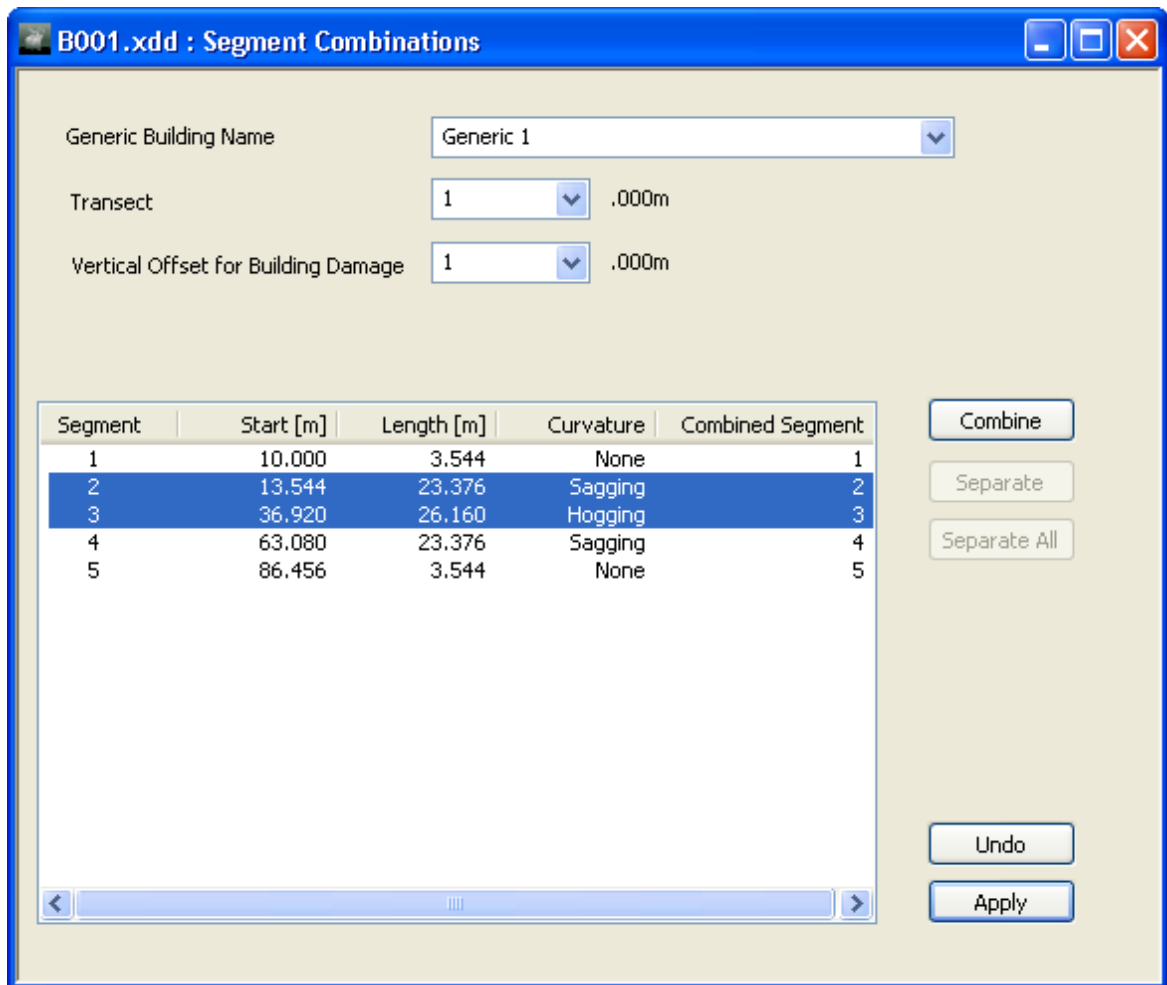
Number of Displacement Points - the number of displacement points along each transect at which displacements are to be calculated.

For details of other data see [Specific Building Damage Assessment - Structure Data](#).

4.12.2.2 Segment Combinations

The Segment Combinations dialog is available only if an analysis has been performed in order to determine the locations of hogging and sagging segments along a sub-structure's length.

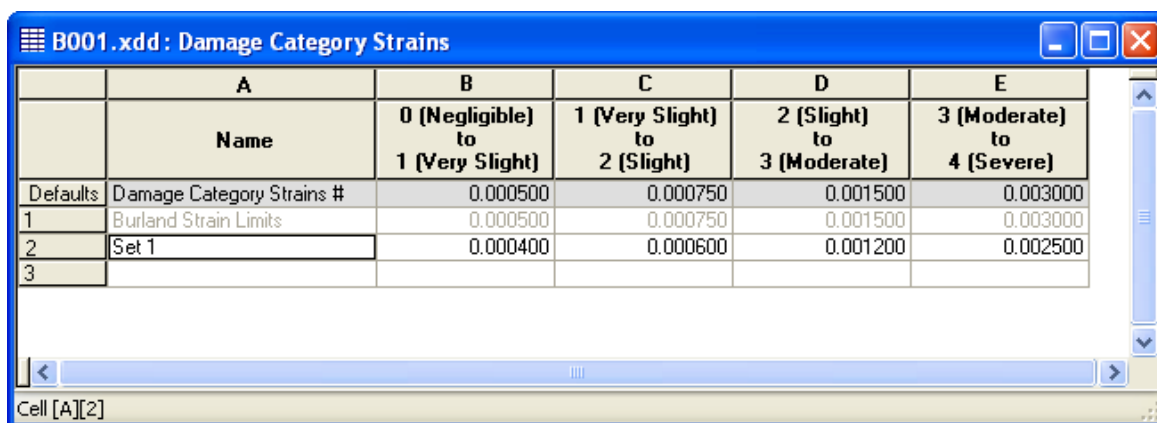
Segments of buildings with different L/H values along a transect may then be combined in order to force short, insignificant, lengths of hogging or sagging segments to be absorbed into longer more significant neighbouring lengths.



To combine or separate segments follow the procedure described in [Specific Building Damage Assessment - Segment Combinations](#).

4.13 Damage Category Strains' Data

Damage Category Strains are required to describe the relationship of damage category to deflection ratio and horizontal tensile strain for each of the four boundaries between damage categories. This data is used to determine a building segment's damage category as plotted on the [Building Damage Interaction Chart](#).



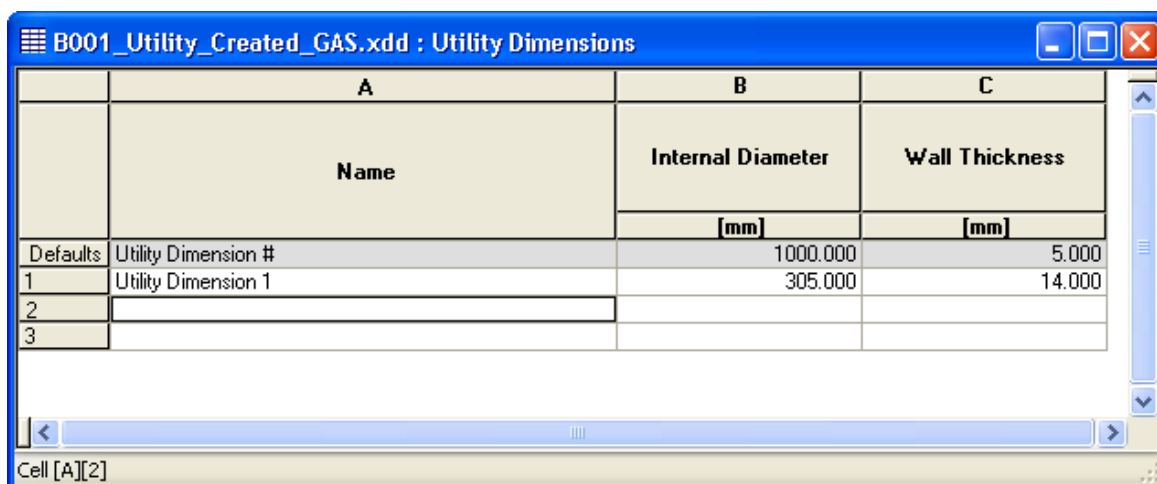
	A	B	C	D	E
	Name	0 (Negligible) to 1 (Very Slight)	1 (Very Slight) to 2 (Slight)	2 (Slight) to 3 (Moderate)	3 (Moderate) to 4 (Severe)
Defaults	Damage Category Strains #	0.000500	0.000750	0.001500	0.003000
1	Burland Strain Limits	0.000500	0.000750	0.001500	0.003000
2	Set 1	0.000400	0.000600	0.001200	0.002500
3					

Each [sub-structure](#) is assigned a set of Damage Category Strains that will be used in the assessment of building damage. A default standard set of values is provided that represents the values provided by Burland.

0 (Negligible) to 1 (Very Slight) - the value of horizontal strain that corresponds with a deflection ratio of zero, in order to define the boundary between Damage Categories 0 and 1 etc.

4.14 Utility Dimensions

Utility dimensions define the internal diameter and the wall thickness of a utility. Data may be input in tabular form in this table view, or in dialog form by double-clicking within a cell or by clicking the 'Wizard' button on the [Xdisp Toolbar](#).



	A	B	C
	Name	Internal Diameter	Wall Thickness
		[mm]	[mm]
Defaults	Utility Dimension #	1000.000	5.000
1	Utility Dimension 1	305.000	14.000
2			
3			

Name specifies the name of the dimension.

Internal Diameter specifies the internal diameter of the utility.

Wall Thickness specifies the wall thickness of the utility.

Xdisp provides some sample dimensions via the sample file "SampleDimensionsAndCriteria.xdd". These can be used by opening that file and copying the data from the Dimensions Table View into the same table of another data file. Alternatively the sample file may be saved with a new name and opened to form the basis of a new data file. The data values should be validated before use.

4.15 Utility Acceptance Criteria and Factors

The limiting criteria and factors for utility damage calculations are input into this Table View either in tabular form, or in dialog form by double-clicking within a cell or by clicking the 'Wizard' button on the [Xdisp Toolbar](#).

Ref.	Name	Acceptance Criteria												Factors											
		Pullout				Rotation				Allowable Strain				Radius of Curvature				Pullout		Rotation		Axial Strain		Flexural Strain	
		Threshold		Limit		Threshold		Limit		Tension		Compression		Threshold		Limit		Axial	Flexural	Tension	Compression	Tension	Compression		
		Check	[mm]	Check	[mm]	Check	[Deg]	Check	[Deg]	Check	[µε]	Check	[µε]	Check	[m]	Check	[m]								
	Acceptance Criteria #	Yes	100.000	Yes	400.000	Yes	0.025	Yes	0.150	Yes	98.000	Yes	1200.000	Yes	25000.000	Yes	25000.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	
1	LP: Cast Iron, <305mm, trafficked	Yes	0.100	Yes	0.400	Yes	0.025	Yes	0.150	Yes	98.000	Yes	1200.000	Yes	25000.000	Yes	25000.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	
2	LP: Cast Iron, 305mmx<D4610mm	Yes	0.100	Yes	0.600	Yes	0.020	Yes	0.120	Yes	148.000	Yes	1200.000	Yes	25000.000	Yes	25000.000	0.216	1.000	1.000	0.400	1.000	1.000	1.000	
3	LP: Cast Iron, 610mmx<D4914mm	Yes	0.100	Yes	0.700	Yes	0.015	Yes	0.090	Yes	148.000	Yes	1200.000	Yes	25000.000	Yes	25000.000	0.216	1.000	1.000	0.400	1.000	1.000	1.000	
4	LP: Cast Iron, <914mm, trafficked	Yes	0.100	Yes	0.700	Yes	0.010	Yes	0.060	Yes	148.000	Yes	1200.000	Yes	25000.000	Yes	25000.000	0.216	1.000	1.000	0.400	1.000	1.000	1.000	
5	MP: Cast Iron, <205mm, trafficked	Yes	0.009	Yes	0.034	Yes	0.002	Yes	0.013	Yes	98.000	Yes	1200.000	Yes	25000.000	Yes	25000.000	0.216	1.000	1.000	0.400	1.000	1.000	1.000	
6	MP: Cast Iron, 305mmx<D4610mm	Yes	0.009	Yes	0.051	Yes	0.002	Yes	0.010	Yes	148.000	Yes	1200.000	Yes	25000.000	Yes	25000.000	0.216	1.000	1.000	0.400	1.000	1.000	1.000	
7	MP: Cast Iron, 610mmx<D4914mm	Yes	0.009	Yes	0.060	Yes	0.001	Yes	0.008	Yes	148.000	Yes	1200.000	Yes	25000.000	Yes	25000.000	0.216	1.000	1.000	0.400	1.000	1.000	1.000	
8	MP: Cast Iron, <914mm, trafficked	Yes	0.009	Yes	0.060	Yes	0.001	Yes	0.005	Yes	148.000	Yes	1200.000	Yes	25000.000	Yes	25000.000	0.216	1.000	1.000	0.400	1.000	1.000	1.000	
9	Ductile Iron, <305mm, rubber gas	Yes	25.000	Yes	25.000	Yes	1.500	Yes	1.500	Yes	488.000	Yes	700.000	Yes	25000.000	Yes	25000.000	1.000	1.000	1.000	0.200	1.000	1.000	1.000	

Name specifies the name of the criteria/factors. This might, for instance, be the pipe type.

Pullout

- **Threshold**

- **Check** specifies whether pullout is to be checked against a threshold value as a measure of damage to the utility.
- **Value** specifies the pullout that is to be used as the threshold value.

- **Limit**

- **Check** specifies whether pullout is to be checked against a limiting value as a measure of damage to the utility.
- **Value** specifies the pullout that is to be used as the limiting value.

Rotation

- **Threshold**

- **Check** specifies whether rotation is to be checked against a threshold value as a measure of damage to the utility.
- **Value** specifies the rotation, in degrees, that is to be used as the threshold value.

- **Limit**

- **Check** specifies whether rotation is to be checked against a limiting value as a measure of

damage to the utility.

- **Value** specifies the rotation, in degrees, that is to be used as the limiting value.

Allowable Strain

• Tension

- **Check** specifies whether tensile strain is to be checked against a limiting value as a measure of damage to the utility.
- **Value** specifies the tensile strain, in micro strain, that is to be used as the limiting value.

• Compression

- **Check** specifies whether compressive strain is to be checked against a limiting value as a measure of damage to the utility.
- **Value** specifies the compressive strain, in micro strain, that is to be used as the limiting value.

Radius of Curvature

• Threshold

- **Check** specifies whether radius of curvature is to be checked against a threshold value as a measure of damage to the utility.
- **Value** specifies the radius of curvature, that is to be used as the threshold value.

• Limit

- **Check** specifies whether radius of curvature is to be checked against a limiting value as a measure of damage to the utility.
- **Value** specifies the radius of curvature, that is to be used as the limiting value.

Pullout Factor the factor that is used for the pullout calculations.

Rotation Factor the factor that is used for the rotation calculations.

Axial Strain Factor

- **Tension** specifies the factor that is used for the axial tensile strain
- **Compression** specifies the factor that is used for the axial compressive strain

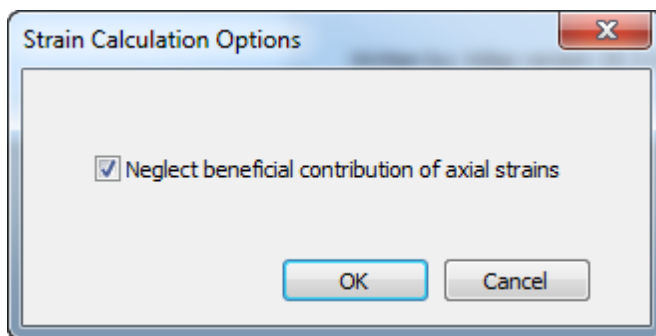
Flexural Strain Factor

- **Tension** specifies the factor that is used for flexural strain in calculation of total tensile strain

- **Compression** specifies the factor that is used for flexural strain in calculation of total compressive strain

Xdisp provides some sample criteria via the sample file "SampleDimensionsAndCriteria.xdd". These can be used by opening that file and copying the data from the Acceptance Criteria Table View into the same table of another data file. Alternatively the sample file may be saved with a new name and opened to form the basis of a new data file. The data values should be validated before use.

4.16 Utility Strain Calculation Options



Neglect beneficial contribution of axial strains - if this option is checked, the beneficial contribution of axial strain is ignored while calculating the total strain.

4.17 Utility Damage Assessment

The two types of utility damage assessment that can be performed are:

- [Specific Utility Damage Assessment](#).
- [Generic Utility Damage Assessment](#).

See [analysis methods](#) for more information on the assessment calculations.

4.17.1 Specific Utility Damage Assessment

The following data is required for the input of a utility for specific utility damage assessment. Data may be input in tabular form in this Table View, or in dialog form having opened the wizard by double-clicking within a cell or by clicking the 'Wizard' button on the [Xdisp Toolbar](#).

Ref.	Utility Name	Sub-Utility Name	Jointed	Dimension	Acceptance Criteria and Factors	Displacement Data Type	Displacement Line	Displacement Polyline	Line Length	Start Distance Along Line	End Distance Along Line	Pipe Segment Length
Defaults	Utility #	Sub #	Yes	Utility Dimension 1	Vitrified Clay	Line	Surface	Displ Polyline	[m]	[m]	[m]	[m]
1	Utility 1	Sub #	Yes	Utility Dimension 1	Vitrified Clay	Line	Surface		99.999	0.000	100.000	20.000
2	Utility 2	Sub 2	Yes	Utility Dimension 1	Vitrified Clay	Polyline		Displ Polyline	149.999	0.000	140.000	3.000
3												
4												

Utility Name - a name to identify a utility.

Sub-Utility Name - a name to identify a sub-utility.

If a utility has bends, then it may be specified as a series of sub-utilities, each referring to a separate displacement line. Alternatively it may be specified as a single sub-utility, referring to a single displacement polyline. However, see the [tabular output](#) section for the impact on results at bends.

Jointed - the type of utility. If yes, it is jointed, otherwise it is continuous.

Dimension - the [Utility Dimension](#) that is to be used to describe the internal diameter and the wall thickness of the utility.

Parameter Type - the [Parameters and Acceptance Criteria](#) that are to be used for the utility damage assessment.

Displacement Data Type - the type of displacement entity that is to describe the alignment of the utility, i.e. displacement line or displacement polyline

Displacement Line - the [Displacement Line](#) that is to be used to describe the alignment of the utility. The utility will therefore have no bends. This is active only when the displacement data type selected is a displacement line.

Displacement Polyline - the [Displacement Polyline](#) that is to be used to describe the alignment of the utility. The utility will therefore have bends. This is active only when the displacement data type selected is a displacement polyline.

Line Length - the length of the Displacement Line/Displacement Polyline that is the maximum length that the utility can have.

Start Distance Along Line - the distance along the Displacement Line/Displacement Polyline that defines the start point of the utility.

End Distance Along Line - the distance along the Displacement Line/Displacement Polyline that defines the end point of the utility.

Pipe Segment Length - the length of pipes that are used in the pullout and rotation calculations of the utility damage assessment.

4.17.2 Generic Utility Damage Assessment

The following data is required for the input of a utility for generic utility damage assessment. Data may be input in tabular form in this Table View, or in dialog form having opened the wizard by double-clicking within a cell or by clicking the 'Wizard' button on the [Xdisp Toolbar](#).

Ref.	Name	Jointed	Dimension	Acceptance Criteria and Factors	Polyline	Pipe Segment Length	Transects		
							Interval	Length	Number of Displacement Points
							[m]	[m]	
Defaults	Generic Utility #	Yes	Utility Dimension 1	Vitrified Clay	Polyline 1	3.000	3.000	10.000	11
1	Generic Utility 1	Yes	Utility Dimension 1	Vitrified Clay	Polyline 1	20.000	50.000	100.000	101
2									

Polyline - the [Polyline](#) whose transects are used to describe the alignments of utilities for damage assessment.

Interval - the distance that defines the spacing between transects, along the polyline.

Length - the length of each transect.

Number of Displacement Points - the number of displacement points along each transect at which displacements are to be calculated.

For details of other data see [Utility Damage Assessment - Specific](#).


4.18 Graphical Input

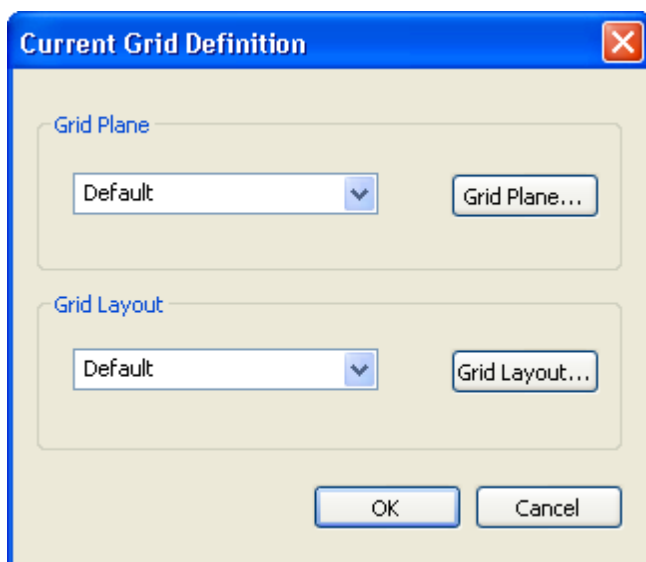
Elements may be input graphically via the 3DGraphics view which can be switched to input mode by clicking the "Input/Output" button () on the [Graphical Input Toolbar](#).

4.18.1 Defining Grids

Elements are entered on to a horizontal grid. A grid is a combination of a grid plane and a grid layout. The grid plane defines the elevation of the grid, whereas the grid layout defines the spacing between the grid points and the extent of the grid.

Grids are created using the "Current Grid Definition" dialog which may be accessed via:

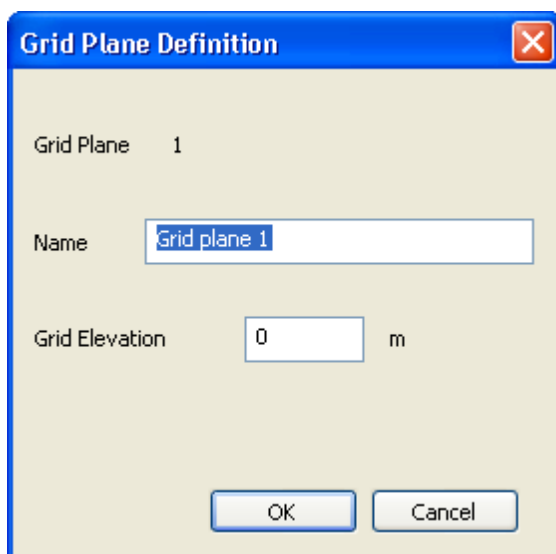
- "Sculpt | Define Current Grid..." from the program's menu when the 3D Graphics View is active;
- the Define Grid button () on the [3DGraphics Toolbar](#) when the 3D Graphics View is active.



The grid plane and the grid layout for the current grid can be selected from their corresponding combo boxes, the default grid plane and default grid layout will be used otherwise.

Grid Plane

A new grid plane can be created by clicking on <new> in the grid plane combo box. The data of the new grid plane can be accessed/edited via the **Grid Plane...** button on the "Current Grid Definition" dialog.




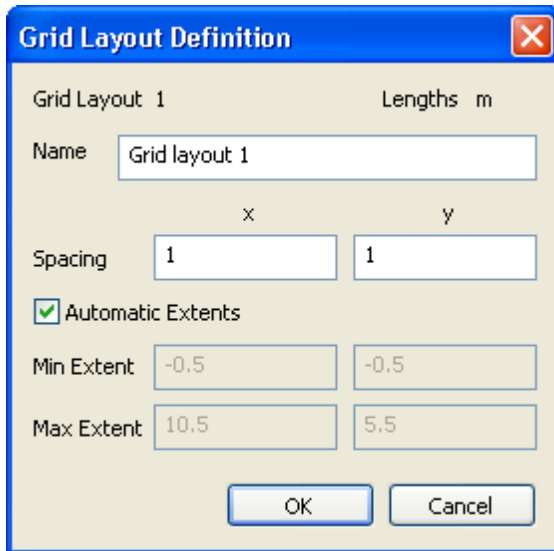
Name specifies the name of the grid plane.

Grid Elevation specifies the elevation of the grid.

The default grid plane is named "Default" and is of zero elevation.

Grid Layout

A new grid layout can be created by clicking on <new> in the grid plane combo box. The data of the new grid layout can be accessed/edited via the  button on the "Current Grid Definition" dialog.



Name specifies the name of the grid layout.

Spacing specifies the x spacing and y spacing of the grid.

If "Automatic Extents" is checked the program automatically extends the grid based on the elements present in the [3D Graphics View](#). The user can specify his own extents by de-selecting the "Automatic Extents".


Min Extent specifies the minimum x and y extents.

Max Extent specifies the maximum x and y extents.

The default grid layout has the following values:


- Name: Default
- Spacing: (1 m, 1 m).
- Min Extent: (-0.5 m, -0.5 m).
- Max Extent: (10.5 m, 5.5 m).

4.18.2 Input Of Elements

Elements may be input only when the 3DGraphics view is in the graphical input mode. The user can switch between input and the normal mode of the 3DGraphics view via the  button on the [Graphical Input Toolbar](#)

4.18.2.1 Tunnels

Tunnels may be input graphically in the [3D Graphics View](#) via:

- "Sculpt | Tunnel..." when the 3D Graphics View is active and is in Input Mode;
- the  button on the [Graphical Input Toolbar](#) when the 3D Graphics View is active and is in Input Mode.

A tunnel or a series of connected tunnels may be input by left-clicking at different points in the view to specify the ends of the consecutive tunnels. The end point of a tunnel or the end point of the last tunnel of the connected tunnels is marked through a double left-click. At this double left-click, the "Tunnel Data" dialog will pop up through which the other properties of the tunnel (or connected tunnels) can be edited. The dialog will initially have default values.

While adding a tunnel, the last input point (left-clicked point) can be erased by pressing the <ESC> key.

While adding a tunnel, a point which is already input can be deleted by:

- moving the mouse over the point so the cursor changes to a square;
- left-click by holding the <SHIFT> key.

Tunnel Data
✕

Tunnel 1 Name

Geometry [m]

Diameter

	x	y	z
End Point 1	<input style="width: 50px;" type="text" value="-3.6"/>	<input style="width: 50px;" type="text" value="5.8"/>	<input style="width: 50px;" type="text" value="0"/>
End Point 2	<input style="width: 50px;" type="text" value="15.1"/>	<input style="width: 50px;" type="text" value="7.5"/>	<input style="width: 50px;" type="text" value="0"/>

Analysis Parameters

Ground Loss %

Surface Displacement Calculations

k Derivation ▾

Layers ▾ k Value

Interface Level at End Point 1 m

Interface Level at End Point 2 m

Sub-surface Displacement Calculations

Analysis Method ▾

k Derivation ▾

k

m

Interface Level at End Point 1 m

Interface Level at End Point 2 m

Soil at Tunnel Level

Cohesive Granular

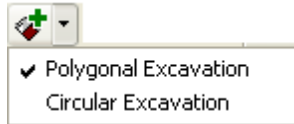
Input of a tunnel (or series of tunnels) may be cancelled by clicking the "Cancel" button or by closing the dialog.

4.18.2.2 Excavations

4.18.2.2.1 Polygonal Excavation

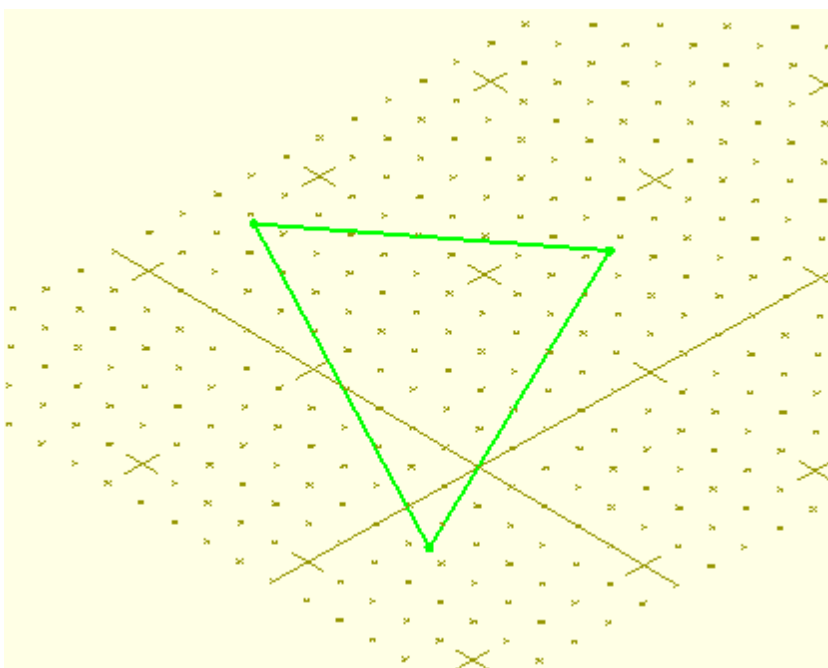
Polygonal excavations may be input graphically in the [3D Graphics View](#) via:

- "Sculpt | Excavation | Polygonal Excavation..." when the 3D Graphics View is active and is in Input Mode;

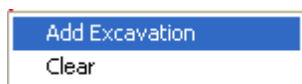


- the button on the [Graphical Input Toolbar](#) when the 3D Graphics View is active and is in Input Mode.

To input a polygonal excavation then click at each corner of the excavation's surface polygon in a particular (clockwise or counter-clockwise) order.



When the required surface polygon is established, to complete the addition of the excavation, double left-click at the final point, or right-click in the view and select "Add Excavation" from the subsequent context menu. The input may be cleared by selecting "Clear" from that menu.

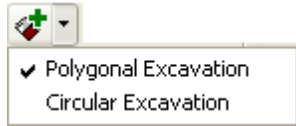


The "Polygonal Excavation" dialog will pop up after an excavation is added. The properties of the excavation can be edited in this wizard. Initially the dialog will have default values. The input of the excavation may be cancelled by clicking the "Cancel" button or by closing the dialog.

4.18.2.2.2 Circular Excavation

Circular excavations may be input graphically in the [3D Graphics View](#) via:

- "Sculpt | Excavation | Circular excavation..." when the 3D Graphics View is active and is in Input Mode;

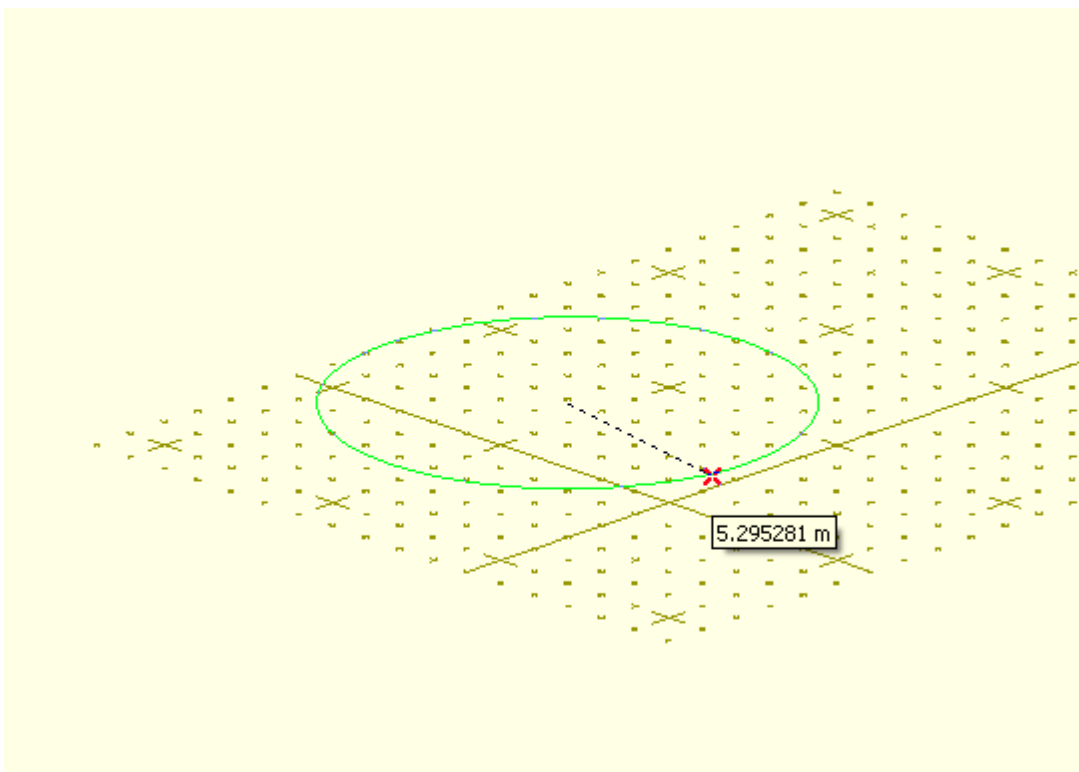


- the button on the [Graphical Input Toolbar](#) when the 3D Graphics View is active and is in Input Mode.

To input a circular excavation then left-click on the centre of the surface circle, move the mouse, and left-click again on the circumference of the circle to complete the input.

The user can edit the properties of the excavation via the dialog which pops up at the end of the second click.

To cancel the input after the first click press <ESC>.



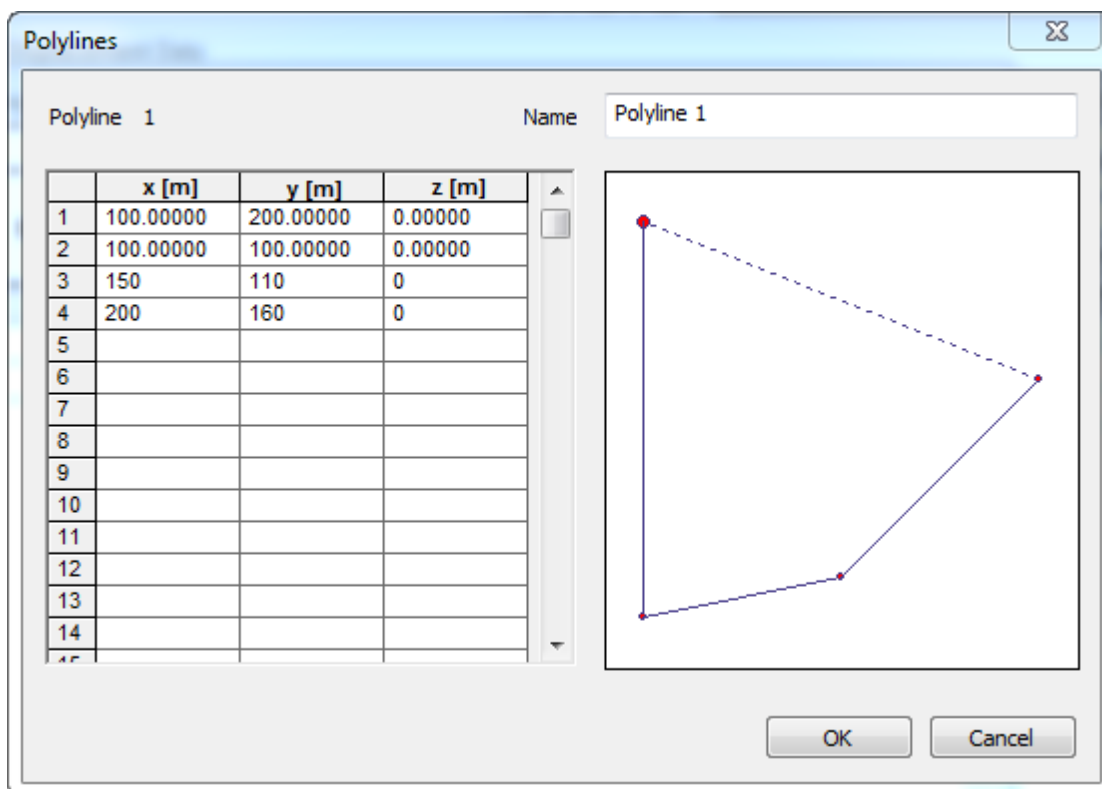
4.18.2.3 Polylines

Polylines may be input graphically in the [3D Graphics View](#) via:

- "Sculpt | Polylines..." from the program menu when the 3D Graphics View is active and is in Input Mode;

- the polylines button () on the [Graphical Input Toolbar](#) when the 3D Graphics View is active and is in Input Mode.

A polyline may then be traced by left-clicking at different points in the view to specify the ends of consecutive polyline segments. The final input point is input by a double left-click. The "Polyline Data" dialog will then pop up in which the other properties of the polyline can be edited. The dialog will initially have default values.



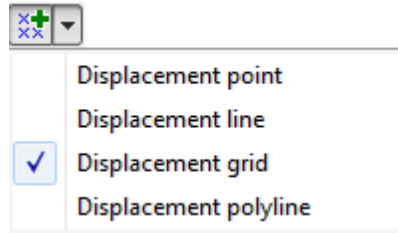
The input of polyline may be cancelled by clicking the "Cancel" button or by closing the dialog.

4.18.2.4 Displacement Entities

4.18.2.4.1 Displacement Point

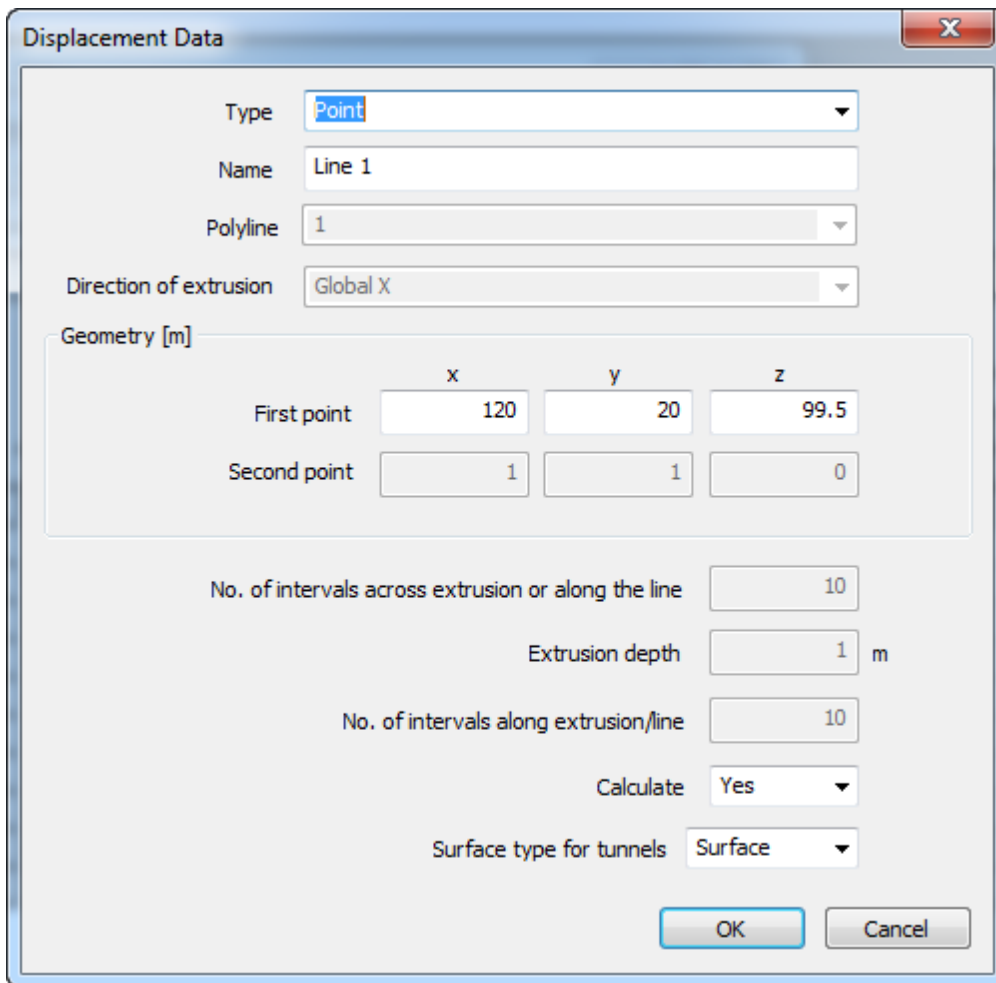
Displacement Points maybe input graphically in the [3D Graphics View](#) via:

- "Sculpt | Displacement | Displacement Point..." when the 3D Graphics View is active and is in Input Mode;



- the "Displacement point" menu item on the [Graphical Input Toolbar](#) when the 3D Graphics View is active and is in Input Mode.

Left-click at any desired point in the 3D Graphics View to complete the input. A dialog will then pop up in which the properties of the point may be edited.

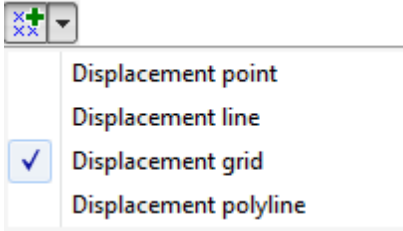


The input of the displacement point may be cancelled by clicking the "Cancel" button or by closing the dialog.

4.18.2.4.2 Displacement Line

Displacement lines may be input graphically in the [3D Graphics View](#) via:

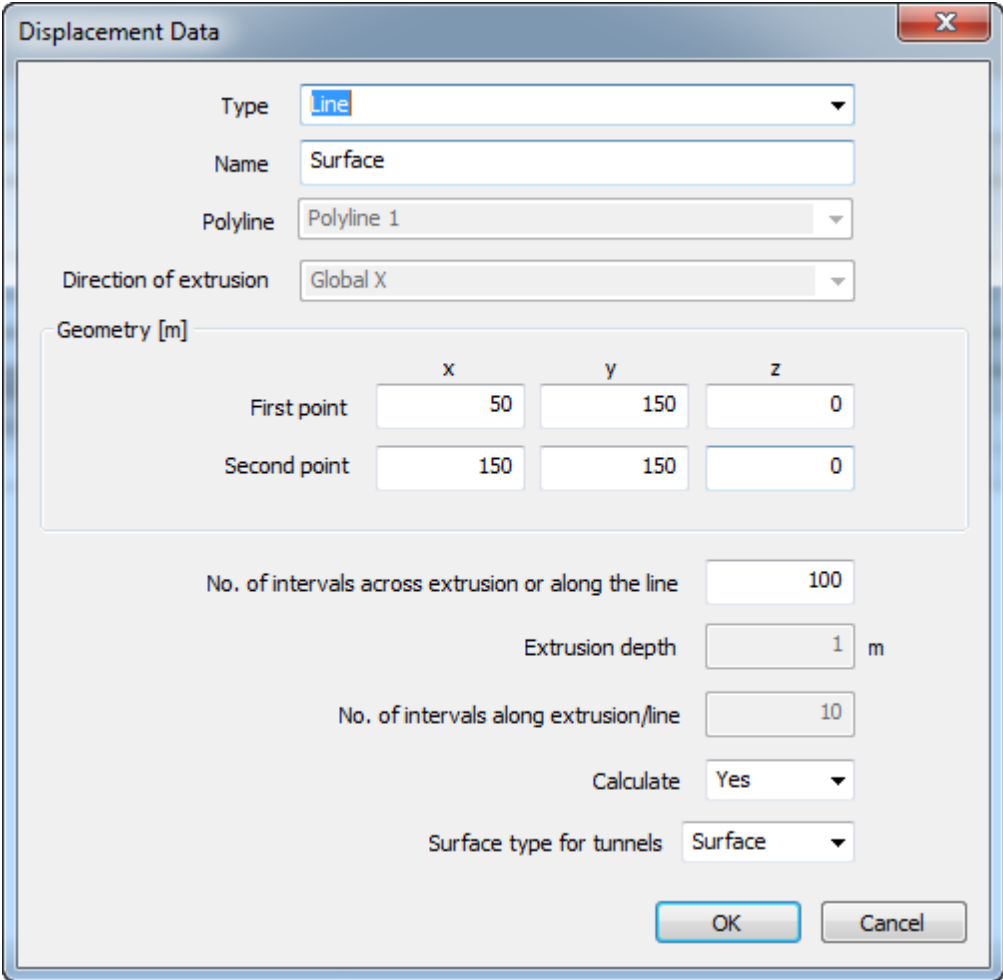
- "Sculpt | Displacement | Displacement Line..." when the 3D Graphics View is active and is in Input Mode;



- the "Displacement line" menu item on the [Graphical Input Toolbar](#) when the 3D Graphics View is active and is in Input Mode.

Left-click at the ends of the displacement line to complete the input. A dialog will then pop up in which the properties of the line may be edited.

To cancel the input of the displacement line after the first click, press <ESC>.

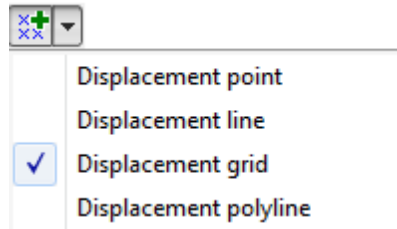


The input of the displacement line may be cancelled by clicking the "Cancel" button or by closing the dialog.

4.18.2.4.3 Displacement Grid

Displacement grids may be input graphically in the [3D Graphics View](#) via:

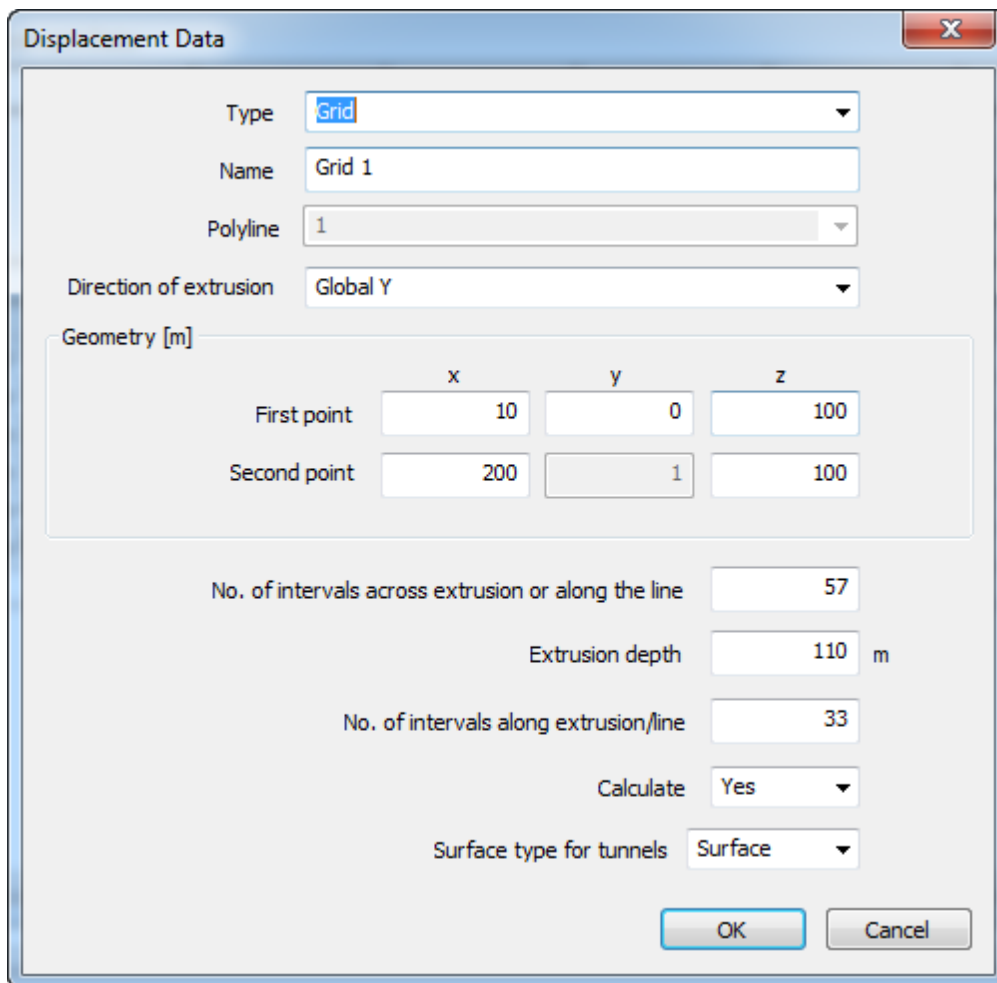
- "Sculpt | Displacement | Displacement Grid..." when the 3D Graphics View is active and is in Input Mode;



- the "Displacement grid" menu item on the [Graphical Input Toolbar](#) when the 3D Graphics View is active and is in Input Mode.

A displacement grid can be input only on the plane of the grid. Left-clicking at two opposing corners of the grid will complete the input. The displacement data dialog will pop up after the input in which the properties of the displacement grid may be edited.

To cancel the input of the displacement grid after the first click, press <ESC>.

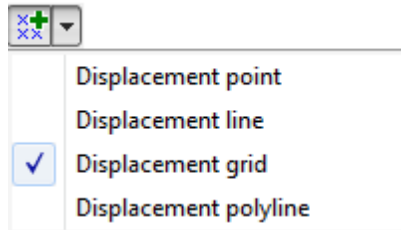


The input of the displacement grid may be cancelled by clicking the "Cancel" button or by closing the dialog.

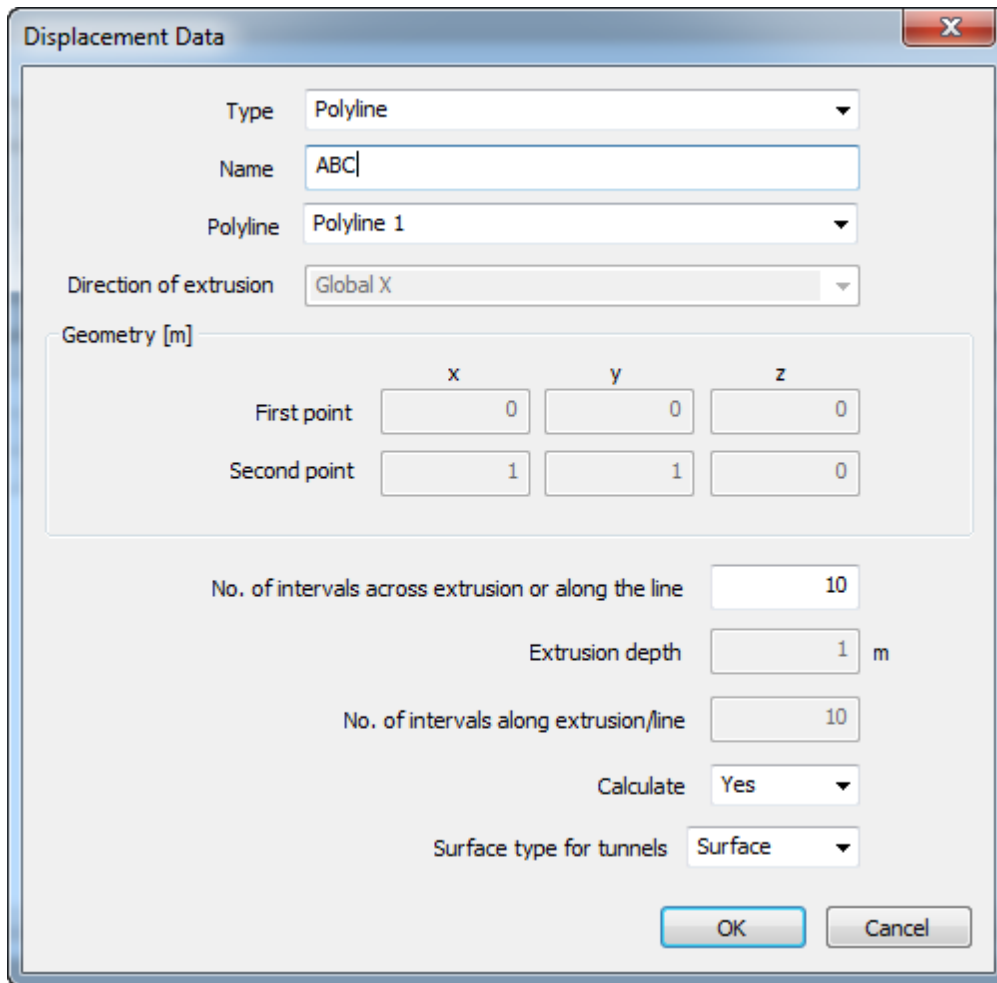
4.18.2.4.4 Displacement Polyline

Displacement polylines may be input graphically in the [3D Graphics View](#) providing there are polylines available via:

- "Sculpt | Displacement | Displacement Polyline..." from the program menu when the 3D Graphics View is active and is in Input Mode;
- the "Displacement polyline" menu item shown below on the [Graphical Input Toolbar](#) when the 3D Graphics View is active and is in Input Mode.



To input a displacement polyline left-click on a polyline. A displacement polyline with default properties will be added. The properties of the displacement polyline may be edited via the dialog that subsequently pops up.



The input of the displacement polyline may be cancelled by clicking the "Cancel" button or by closing the dialog.

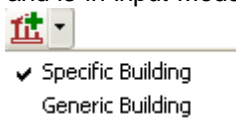
4.18.2.5 Buildings

4.18.2.5.1 Specific

Specific Buildings may be input graphically only when there are displacement lines available.

Specific Buildings may be input graphically in the [3D Graphics View](#) via:

- "Sculpt | Building | Specific Building..." from the program menu when the 3D Graphics View is active and is in Input Mode;
- the buildings button (shown below) on the [Graphical Input Toolbar](#) when the 3D Graphics View is active and is in Input Mode.



To input a building left-click on a displacement line. A building with default properties will be added.

The properties of the building may be edited via the dialog which subsequently pops up.

Specific Building Data

Specific 1 Structure: Building 1

Sub-structure: Sub #

Displacement Line: Displacement Line 1

Line Length: 31.2083 m

Distances along Displacement Line

Start: 0 m End: 31.2083 m

Vertical Offsets: 0 m

Settlement Trough Limit Sensitivity: 0.1 mm

Damage Category Strains: Burland Strain Limits

Poisson's Ratio: 0.2

E/G: 2.6

Height: 10 m

Default Properties: Hogging: 10 m Sagging: 5 m

Distance of N.A. from Edge of Beam in Tension: 10 m 5 m

Distance of Bending Strain from N.A.: 10 m 5 m

2nd Moment of Area (per unit width): 333.333 m³ 83.3333 m³

OK Cancel

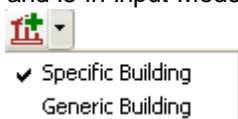
The input of specific building may be cancelled by clicking the "Cancel" button or by closing the dialog.

4.18.2.5.2 Generic

Generic Buildings may be input graphically only when there are polylines available.

Generic Buildings may be input graphically in the [3D Graphics View](#) via:

- "Sculpt | Building | Generic Building..." when the 3D Graphics View is active and is in Input Mode;
- the buildings button (shown below) on the [Graphical Input Toolbar](#) when the 3D Graphics View is active and is in Input Mode.



Then left-click on a polyline. A building with default properties will be added. The properties of the building may be edited via the dialog which subsequently pops up.

The screenshot shows the 'Generic Structure Data' dialog box with the following fields and values:

- Generic 1** (Label)
- Name:** Generic 1
- Polyline:** Polyline 1
- L/H Values:** 10.
- Vertical Offsets:** 0.000 m
- Vertical Displacement Limit Sensitivity:** 0.1 mm
- Damage Category Strains:** Burland Strain Limits
- Poisson's Ratio:** 0.2
- E/G:** 2.6
- Default Properties:**
- Hogging:**
 - Distance of N.A. from Edge of Beam in Tension: 4.3434281 m
 - Distance of Bending Strain from N.A.: 2.6815416 m
 - 2nd Moment of Area (per unit width): 2.0315979 m³
- Sagging:**
 - Distance of N.A. from Edge of Beam in Tension: 0 m
 - Distance of Bending Strain from N.A.: 0 m
 - 2nd Moment of Area (per unit width): 0 m³
- Transect:**
 - Interval: 50 m
 - Length: 100 m
 - Number of Displacement Points: 11

Buttons: OK, Cancel

The input of generic building may be cancelled by clicking the "Cancel" button or by closing the dialog.

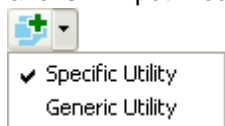
4.18.2.6 Utilities

4.18.2.6.1 Specific

Providing there are displacement lines or displacement polylines available, Specific Utilities may be input graphically in the [3D Graphics View](#) via:

- "Sculpt | Utility | Specific Utility..." from the program menu when the 3D Graphics View is active and is in Input Mode;

- the utilities button (shown below) on the [Graphical Input Toolbar](#) when the 3D Graphics View is active and is in Input Mode.



Then left-click on a displacement line or a displacement polyline. A specific utility with default properties will be added. The properties of the utility may be edited via the dialog that subsequently pops up.

Specific Utility Data

Utility 1 Utility

Sub-utility

Jointed

Dimension

Acceptance Criteria and Factors

Displacement Data Type
 Line Polyline

Displacement Line

Displacement Polyline

Pipe Length m

Distances along Displacement Line/Polyline

Line Length m

Start m

End m

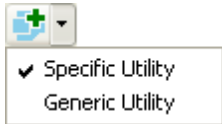
The input of specific utility may be cancelled by clicking the "Cancel" button or by closing the dialog.

4.18.2.6.2 Generic

Generic Utilities may be input graphically only when there are polylines available.

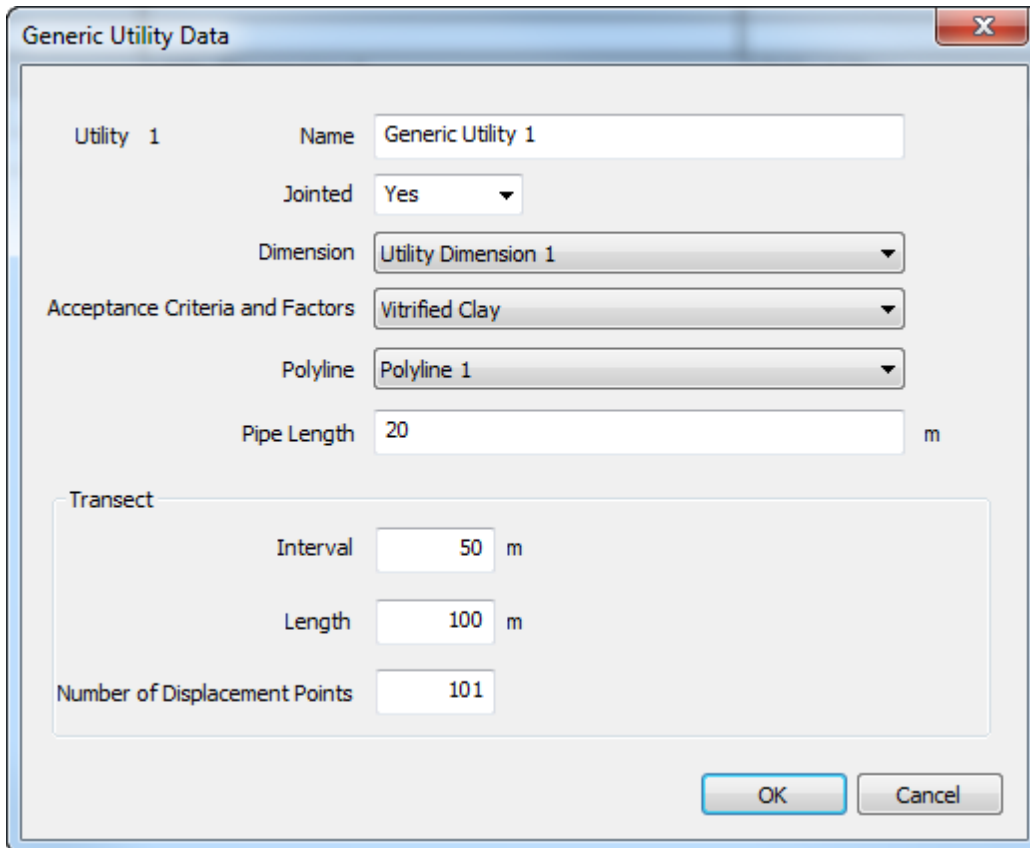
Generic Utilities may be input graphically in the [3D Graphics View](#) via:

- "Sculpt | Utility | Generic Utility..." when the 3D Graphics View is active and is in Input Mode;



- the button on the [Graphical Input Toolbar](#) when the 3D Graphics View is active and is in Input Mode.

To input a building left-click on a polyline. A generic utility with default properties will be added. The properties of the utility may be edited via the dialog which subsequently pops up.




The input of generic utility may be cancelled by clicking the "Cancel" button or by closing the dialog.

4.18.3 Selection

Selection of elements in the 3D Graphics View for editing or deletion is enabled only in the input mode and only when there are elements available.

The Selection Mode may be activated via:

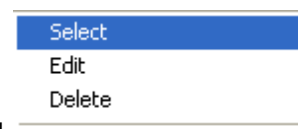
- "Sculpt | Select..." when the 3D Graphics View is active and is in Input Mode;
- the "Select" button  on the [Graphical Input Toolbar](#) when the 3D Graphics View is active and is in Input Mode.

The selection can be made in two ways:

- selection of an individual element;
- selection by dragging the mouse to surround or intersect a group of elements.

Selection of an Individual Element:

Moving the cursor over an element will highlight a part or whole of the boundary of the element which is in the close vicinity of the cursor. This is an indication that the element is available for selection.



Right-clicking on the highlighted element will pop-up the selection menu

The highlighted element can either be modified, deleted or selected

Clicking on "Edit" will pop-up the corresponding data dialog. Clicking on "Delete" will delete the element.

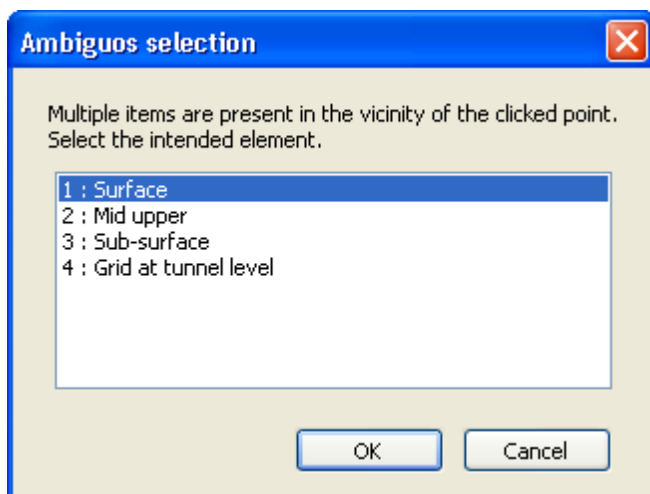
The element can also be selected so that editing and deletion operations can be performed later by right-clicking in any part of the view. The selection can be done via "Select" in right-click menu on the highlighted element or by left-clicking on the highlighted element.

Once elements are selected their boundaries are shown highlighted.

Selected elements can be modified via the "Edit" item in the menu which is presented by right-clicking in any part of the view. It can also be deleted through this menu or by pressing the <DELETE> key.

Multiple elements can be selected by holding the <CTRL> key while selections are made. Multiple selections can only be deleted, not edited.

If there are multiple elements available for selection at the cursor position, then the Ambiguous Deletion Dialog will pop-up if the user tries to perform any selection operation. This dialog lists all the elements in the vicinity. The required element in the list can then be selected.



Elements can be de-selected by re-selecting them individually.

Multiple elements can be selected by holding the left button down and dragging the mouse in the 3D Graphics View. On releasing the button all the elements falling completely within the area are selected. If the right button is pressed while dragging the mouse then those elements that are partially within the area are selected too.

Shortcuts

- Pressing <DELETE> button will delete all the selected elements.
- Pressing <ESC> will de-select all the selected elements.


Part V

5 Graphic Settings

The Graphic Settings property sheet allows the parameters that govern the format and content of the [3D Graphics View](#) to be specified.

These graphic settings are stored in the data file. The 'Apply' button applies the settings to the 3D Graphics View without closing the dialog. The 'OK' button applies the settings to the 3D Graphics View and closes the dialog.

This property sheet may be accessed via:

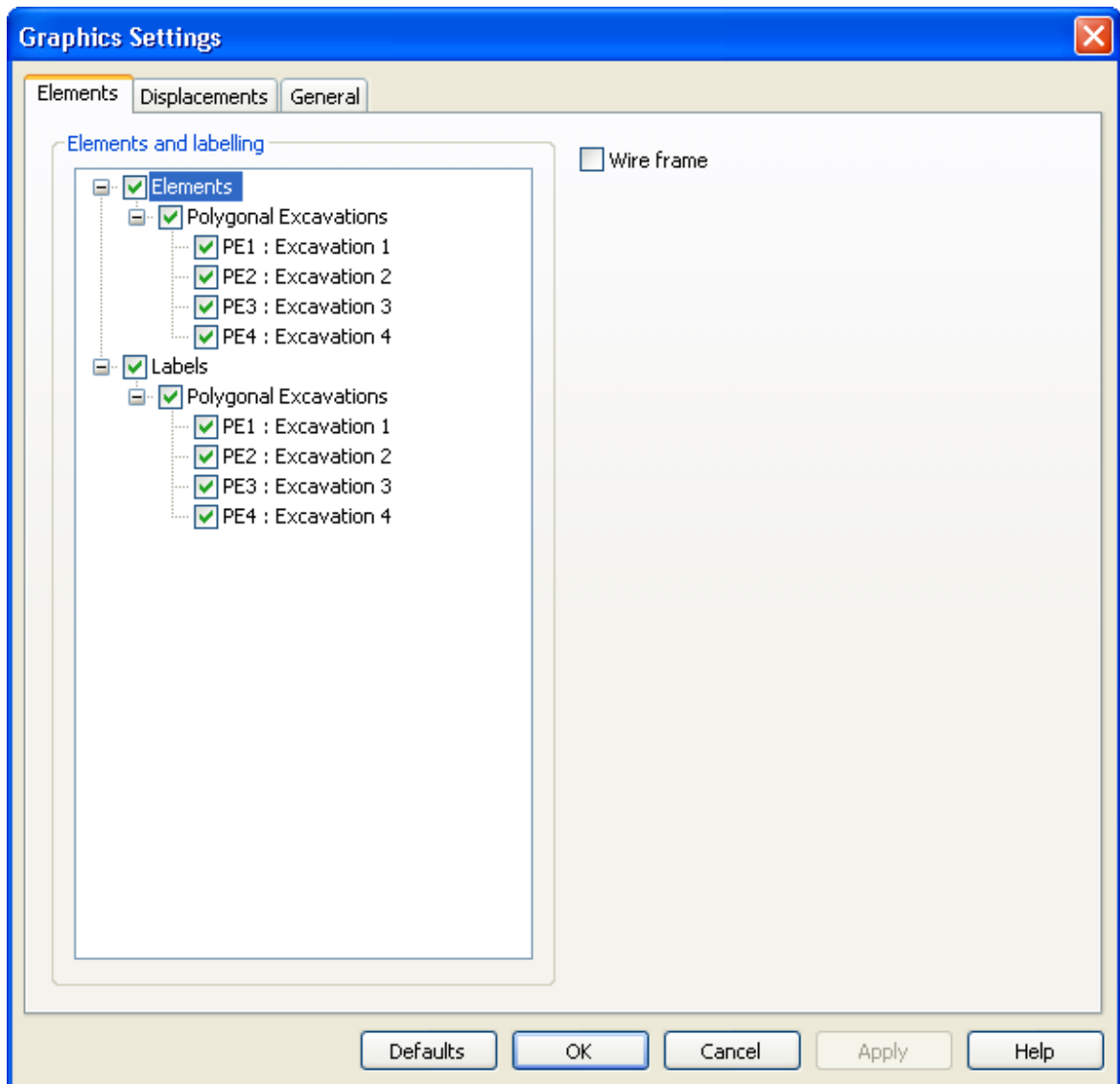
- "Edit | Wizard..." when the 3D Graphics View is active;
- the Wizard button  on the [Xdisp Toolbar](#) when the 3D Graphics View is active; or
- selecting "Graphic settings" from the context menu of the 3D Graphics View (the context menu is accessible by right-clicking in the view or typing the context menu key from keyboard).

The controls are separated into three different pages:

- Elements
- Displacements
- Preferences

Each of these is described in detail below.

Elements



Elements - elements to be viewed may be selected via the check boxes.

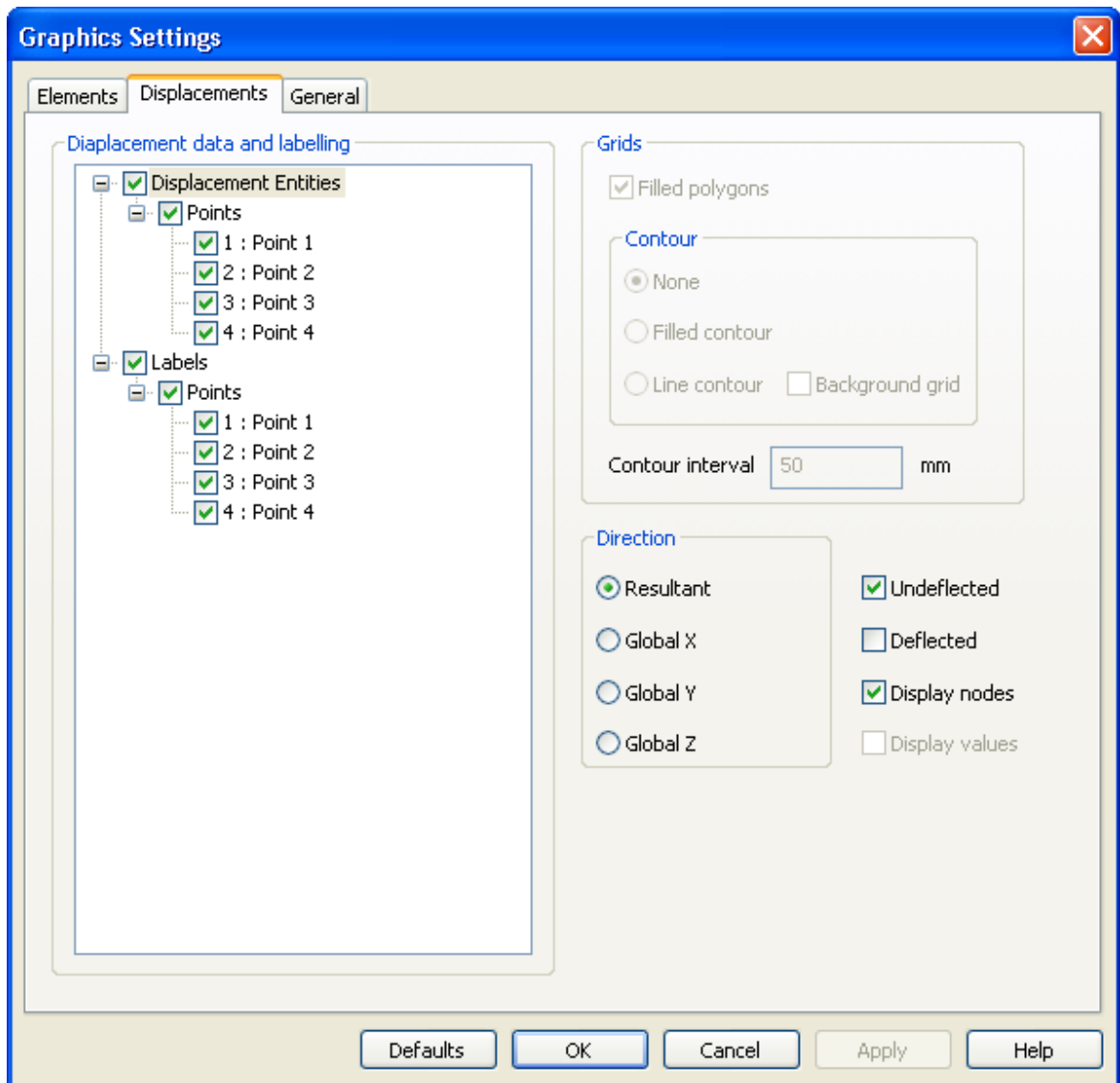
Labels - labels of the elements selected for viewing will be displayed if the appropriate check boxes in the labels branch are selected.

Labels (Radio Button) - Name, No. or No : format for the display of labels.

Wire frame - if this is checked then elements will be displayed as a wire frame.

Displacements

The Displacements' page specifies how the displacement results are to be displayed.



After performing an analysis, results are available for the Points, Lines and Grids specified in the [Displacement Data](#) table. The 3D Graphics View can illustrate these results. If no results are available then the locations of the proposed displacement data are shown.

Displacement Entities

Points, Lines and Grids to be viewed may be selected via the check boxes.

Labels

Labels of the entities selected for viewing will be displayed if the appropriate check boxes in the labels branch are selected.

Display nodes

When this is checked the nodes on the grids and/or lines will be highlighted with a small cube.

Display values

When this is checked the nodes will be annotated with displacement values. This button is enabled only if results exist.

Undelected shape

When this is checked the undelected positions of Points, Lines and Grids are displayed. This is required to view the locations of Displacement Data when there are no results.

Filled polygons

When this is checked the deflected nodes on a grid form a surface with filled polygons. When unchecked it displays polygons by outlines (i.e. as a mesh). This button is enabled only if results exist and when the 'Contour surface' button is unchecked.

Filled Contour

When this is selected filled contour surfaces are displayed with an interval specified in the 'Contour interval' edit box. This represents the deflection pattern on a grid. This contour surface is drawn on an undelected grid. This button is enabled only if results exist

Line Contour

When this is selected line contour surfaces are displayed with an interval specified in the 'Contour interval' edit box. This represents the deflection pattern on a grid. This contour surface is drawn on an undelected grid. This button is enabled only if results exist.

Background grid

This check box is enabled only when line contour is selected. The undelected grid on which the line contours are drawn may be viewed by checking this. Unchecking this option will display only the grid boundary and the contours.

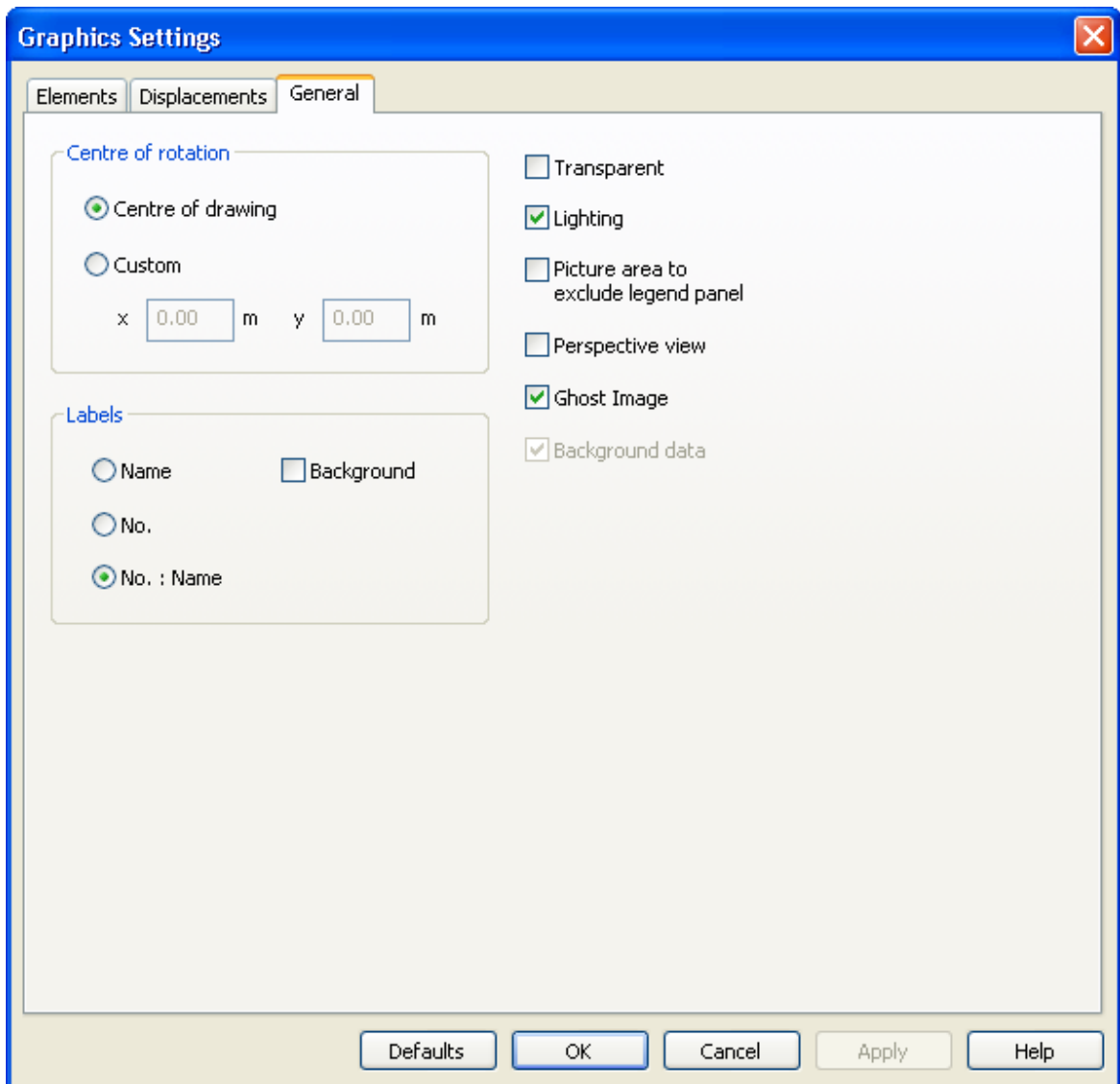
Contour interval

The value of the contour interval is automatically initialised with a default value based on the minimum and maximum extents of the deflection results. The contour surface can be viewed at another contour interval by changing this value. The minimum value that is required is such as to limit the number of contours to less than 50. The maximum value is the results' range.

Direction

The component of displacement in the x, y and z directions, or the resultant displacement, may be chosen for display. The contour surface or deflected shape will be based on this selection.

General



Centre of rotation

This specifies the co-ordinate of the centre for rotating and zooming.

Centre of drawing

When this is selected the centre of rotation is set to the centre of the model, the resulting x and y co-ordinates are displayed in the edit boxes. These cannot be edited directly.

Custom

When this is selected the edit boxes x and y are enabled so that the centre of rotation may be entered directly.

Labels

These controls specify how labels should appear.

Name

Labels will display only the name of the entity.

No.

Labels will display only the index number of the entity.

No. Name

The entity's index number and name are concatenated.

Background

When this is checked a white background is provided behind the text for all the labels in the view.

Transparent

When this is checked the surfaces become semi-transparent. The transparency depends on the sequence of the drawing order.

Lighting

When this is checked light falls on the model from a pre-defined position set by the program. This button is enabled only when lighting is appropriate.

Picture area to exclude legend panel

When this is checked the picture area that is used for the model excludes that of the legend. Otherwise the legend is superimposed on the model's image.

Perspective view

This toggles the view between orthogonal and perspective.

Ghost Image

When this is checked a ghost image will be drawn when the elements are rotated. This avoids time lag especially when there are many elements in the view.

Background Data

Selects whether to view the background data that has been imported via [DXF import](#).

Defaults

This resets all the settings to the program's defaults and applies them to the 3D Graphics View.

OK

This applies the current settings from all the pages to the 3D Graphics View, and closes the property sheet.

Undo

This undoes the changes to all those pages that have been modified since the 'Apply' button was last pressed.

Apply

This applies the current settings from all the pages to the 3D Graphics View without exiting the property sheet.

More:

[3D Graphics View](#)

[Set Exact Scale](#)

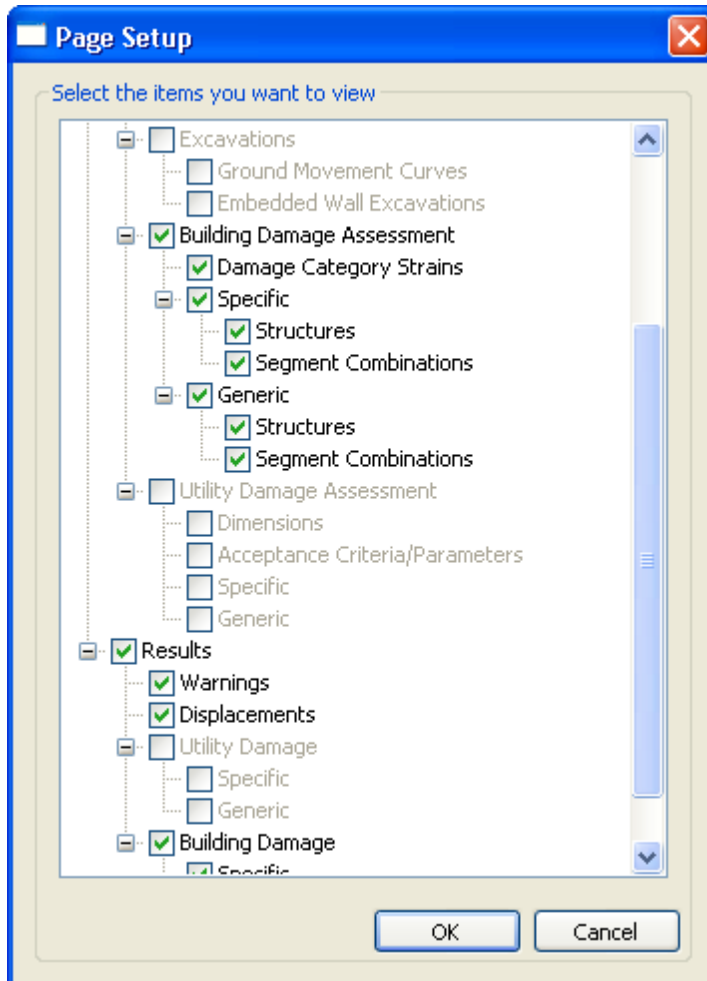
Part VI

6 Output

6.1 Tabular Output

Tabular Output is available from the View menu, the [Gateway](#) or the [Xdisp toolbar](#).

Upon selecting the Tabular Output the Page Setup dialog will appear.



This allows selection of what is to be viewed or printed. When the subsequent Tabular Output view is active the Page Setup dialog can be re-activated via the 'Wizard' button on the Xdisp Toolbar in order to refine the output that is being viewed.

The Tabular Output may be converted to a spreadsheet-like grid view in order to copy and paste into e.g. Microsoft Excel easily. Select "View -> Open Output in Grid View" from the program menu, while the Tabular Output is active, to open that Grid Output. The background of the Tabular Output's table rows may be alternately coloured for ease of reading by selecting "View -> Stripecy Output" from the program menu, while the Tabular Output is active.

Tables in the Tabular Output can be fully populated so that no cells contain blank entries by selecting "Output->Fully populate fields" from the program menu while the Tabular Output is active.

The font size of the Tabular Output can be controlled for printing, and so to size tables to fit better to page widths, via the font size control on the [Xdisp toolbar](#).

This output may include input data and results (if an analysis has been performed). The lists of tabulated output can be highlighted and then copied to the clipboard and pasted into most Windows type applications e.g. Word or Excel. Alternatively the output can be directly exported to various text or HTML formats by choosing 'File | Export' from the program's menu.

Name	Type : No.	Dist. [m]	x [m]	y [m]	z [m]	δx [mm]	δy [mm]	δz [mm]	δH// [mm]	δHperp. [mm]	Angle [°]
Displacement Point : 1			29.60000	154.50000	0.00000	11.285E-6	0.0	4.9712E-6	-	-	-
Point 1											
Displacement Line : 1			47.90000	197.90000	0.00000	0.12901	-0.024824	0.095207	0.025334	0.12881	270.45
Line 1											
		10.210	47.98000	187.69000	0.00000	0.20682	-0.0079713	0.15309	0.0095916	0.20675	270.45
		20.421	48.06000	177.48000	0.00000	0.22681	-512.39E-6	0.16838	0.0022895	0.22680	270.45
		30.631	48.14000	167.27000	0.00000	0.23444	-6.4603E-6	0.17456	0.0018433	0.23443	270.45
		40.841	48.22000	157.06000	0.00000	0.24171	0.0	0.18052	0.0018939	0.24171	270.45
		51.052	48.30000	146.85000	0.00000	0.24918	0.0	0.18665	0.0019524	0.24918	270.45
		61.262	48.38000	136.64000	0.00000	0.25685	0.0	0.19298	0.0020117	0.25685	270.45
		71.472	48.46000	126.43000	0.00000	0.26461	135.77E-6	0.19940	0.0019375	0.26460	270.45
		81.683	48.54000	116.22000	0.00000	0.26701	0.0042136	0.20182	-0.0021214	0.26704	270.45
		91.893	48.62000	106.01000	0.00000	0.21754	0.025650	0.16493	-0.023945	0.21773	270.45
		102.10	48.70000	95.80000	0.00000	0.086830	0.030626	0.066030	-0.029944	0.087067	270.45
Displacement Grid : 1			2.90000	88.30000	0.00000	0.0	0.0	0.0	-	-	-
Grid 1											
		7.90000	88.30000	0.00000	0.0	0.0	0.0	0.0	-	-	-
		12.90000	88.30000	0.00000	0.0	0.0	0.0	0.0	-	-	-
		17.90000	88.30000	0.00000	0.0	0.0	0.0	0.0	-	-	-
		22.90000	88.30000	0.00000	0.0	0.0	0.0	0.0	-	-	-
		27.90000	88.30000	0.00000	0.0	0.0	0.0	0.0	-	-	-
		32.90000	88.30000	0.00000	7.1709E-6	2.5982E-6	3.4066E-6	-	-	-	-
		37.90000	88.30000	0.00000	139.40E-6	57.316E-6	75.148E-6	-	-	-	-
		42.90000	88.30000	0.00000	0.0018003	855.52E-6	0.0011217	-	-	-	-
		47.90000	88.30000	0.00000	0.015350	0.0086404	0.011329	-	-	-	-
		52.90000	88.30000	0.00000	0.085546	0.059046	0.077417	-	-	-	-
		2.90000	79.57000	0.00000	0.0	0.0	0.0	-	-	-	-
		7.90000	79.57000	0.00000	0.0	0.0	0.0	-	-	-	-
		12.90000	79.57000	0.00000	0.0	0.0	0.0	-	-	-	-
		17.90000	79.57000	0.00000	0.0	0.0	0.0	-	-	-	-
		22.90000	79.57000	0.00000	0.0	0.0	0.0	-	-	-	-
		27.90000	79.57000	0.00000	0.0	0.0	0.0	-	-	-	-
		32.90000	79.57000	0.00000	0.0	0.0	0.0	-	-	-	-

Displacement and Strain Results

Name - name of the entity.

Type : No. - displacement entity type and its index

Dist. - the distance along a displacement line if applicable.

Coordinates - x, y and z (level)

Displacements

- in the x and y plan directions
- in the vertical z direction (positive being downwards)
- parallel and perpendicular to the Displacement Line and that that Line's angle to the x axis

An asterisk "*" at the right of a row indicates that a result includes an [imported displacement](#).

Principal Tensile Strain - major (%); minor (%); and angle (degrees)

Principal tensile strains and the strain angle for the x-y plane are available providing the model contains no excavations, no tunnels which use the Harris and Alvarado method or the Mair et al method, and no [imported displacements](#).

Building Damage Results

Horizontal Displacements - lists horizontal ground movements at all points along the displacement line that is associated with each Sub-Structure.

Vertical Displacements - lists vertical ground movements at all points along the displacement line that is associated with each Sub-Structure, once that line has been offset by each of the vertical offset distances.

Building damage results are thus calculated using each sub-structure's horizontal displacements, combined with each vertical displacements set, to give **n** sets of results per Sub-Structure, where **n** is the number of vertical offsets. See [Points of Inflexion, Gradient and Radius of Curvature](#) for further information.

Each Sub-Structure is divided into hogging and sagging segments and building damage results are calculated for each segment. The following summaries are presented:

Results for All Segments - lists results for each segment, of each Sub-Structure, of each Structure

Critical Values for All Segments within Each Sub-Structure - lists the critical values of all segments within each Sub-Structure. These values may therefore be drawn from more than one segment and vertical offset in the Sub-Structure.

Critical Segments within Each Sub-Structure - lists each Sub-Structure's critical segment, based on damage category and horizontal strain

Results for All Combined Segments - lists results for each combined segment, of each Sub-Structure, of each Structure

The segment lengths that are listed are those before accounting for imposed horizontal strains. However, points of inflexion, and therefore the segment lengths that are used in calculating deflection ratios and building damage categories, take account of imposed horizontal strains.

Generic Building Damage Results

Horizontal Displacements - lists horizontal ground movements at all displacement points along every transect.

Vertical Displacements - lists vertical ground movements at all points along every transect, once those transects have been offset by each of the vertical offset distances.

Generic building damage results are thus calculated using each transect's horizontal displacements, combined with each vertical displacements' set, to give **n** sets of results per transect, where **n** is the number of vertical offsets. See [Points of Inflexion, Gradient and Radius of Curvature](#) for further information.

Each Sub-Structure on a transect is divided into hogging and sagging segments and building damage results are calculated for each segment. The following summaries are presented:

Results for All Segments - lists results for each segment, along each transect, of each Structure

Maximum Tensile Strain - By Transect and L/H - lists the maximum tensile strain along each transect for each offset and for each L/H.

Maximum Tensile Strain - By Transect - lists the maximum tensile strain along each transect for each offset.

Results for All Combined Segments - lists results for each combined segment, along each transect, of each Structure

The segment lengths that are listed are those before accounting for imposed horizontal strains. However, points of inflexion, and therefore the segment lengths that are used in calculating deflection ratios and building damage categories, take account of imposed horizontal strains.

Utility Damage Results

Coordinates and Displacements - for each iteration lists the coordinates and displacements of a) all the joint locations where pullouts and rotations are calculated and b) locations at, one pipe length upstream and one pipe length downstream of a joint.

Pullouts and Rotations - for each iteration, it lists the pullouts and rotations calculated at joint locations in that iteration. At those locations, it checks whether the factored values are within their respective threshold and limit values and prints "OK" if passed and "FAIL" if failed.

Strains - At every displacement point on the sub-utility's length, it lists the peak flexural tensile strain orientation angle (with respect to global z-axis), radius of curvature, axial strain and flexural strain values. It checks whether the factored total strain values are within their respective threshold and limit values and prints "OK" if passed and "FAIL" if not.

Maximum Values - lists the maximum displacements, maximum rotations, maximum displacements and minimum radii of curvature in each sub-utility along with the coordinates of the respective locations at which they occur.

Note: If a utility is associated with a displacement polyline, then there will be gaps in results at bends, because each straight length of a polyline is treated as a displacement line for calculation purposes. There must be a pipe length both upstream and downstream of any displacement point in order for calculation of pullout and rotation to be performed at that point, and the distance of a displacement interval for strains.

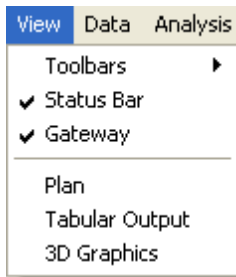
Generic Utility Damage Results

Utility damage results are calculated for all utilities on all transects. The Utility damage results' tables are output for all utilities on all transects.

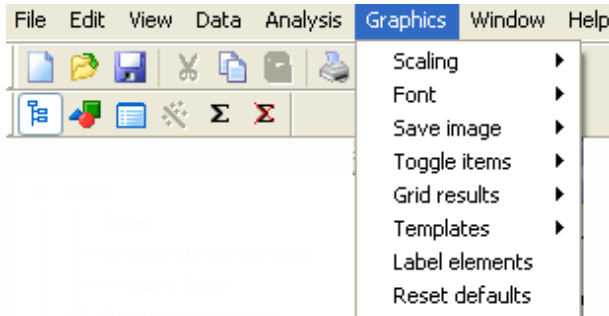
6.2 Graphical Output

Graphical output of data and results is accessed via the View menu, the [Gateway](#) or the [Xdisp toolbar](#). The following provides details of the available graphics' options.

6.2.1 General



This View menu allows selection of [Graphical Output](#) of the problem.



The Graphics menu is available if the Plan View is active. This menu allows the use of templates to save graphical display set-up, display of load or displacement data, annotation and scaling of the data displayed in the Plan View.

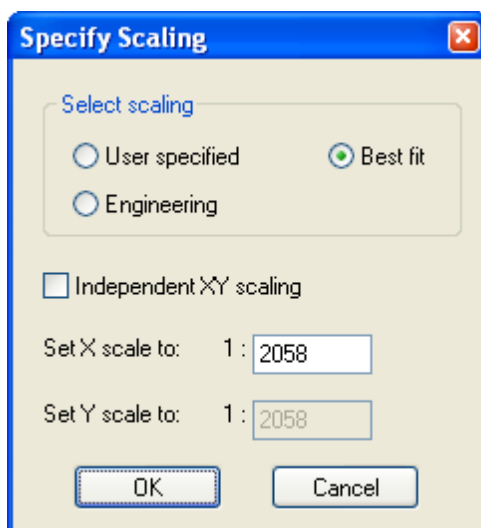
6.2.1.1 Templates

The Templates function works by following the procedure below.

1. Set up the Plan View which you would like to repeat for other files in the future.
2. Select the 'Save as template' option and save the view with a specific file name.
3. To reload the template select the 'Load template' option.
4. To return to the original view when the Plan View is open select 'Reset defaults'.

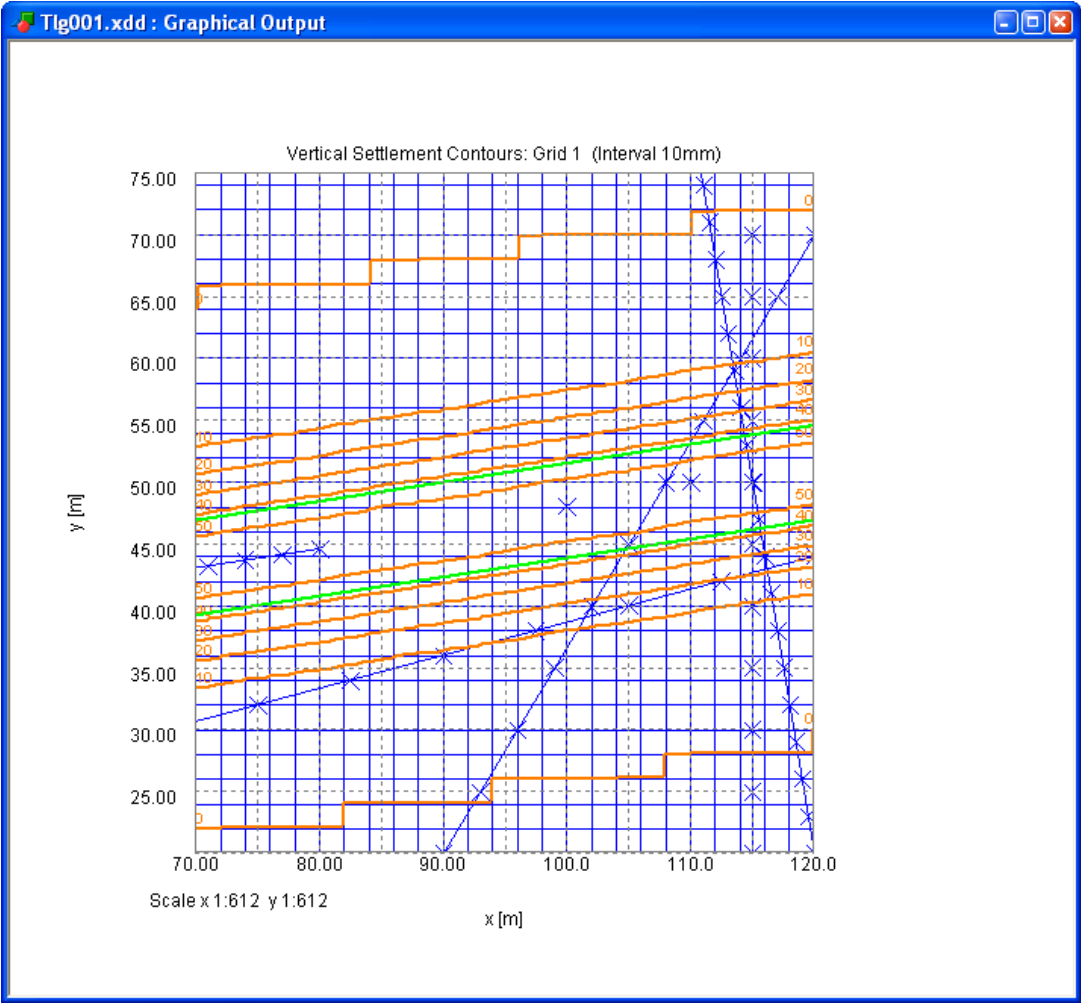
6.2.1.2 Set Exact Scale

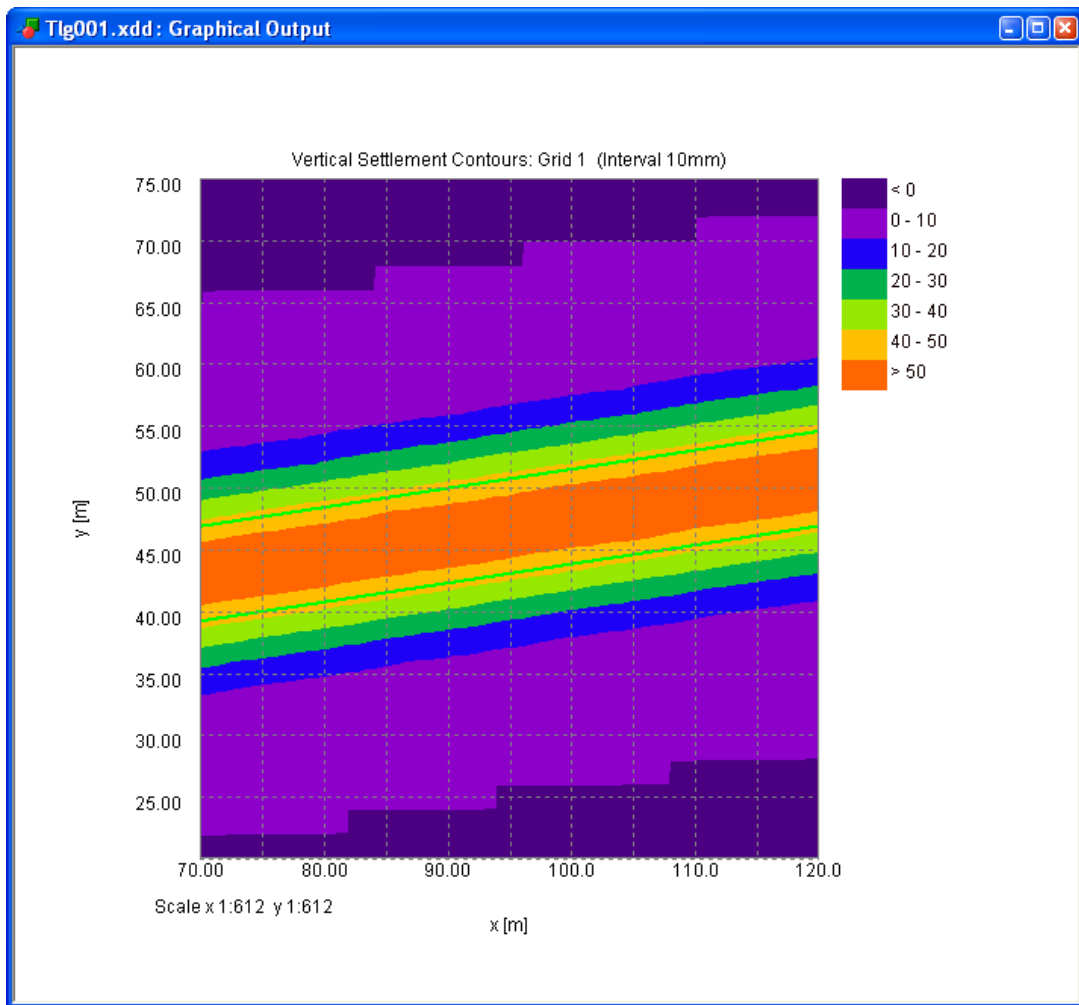
Selection of Set Exact Scale allows you to set any required scale for the Plan View. This is done using the Specify Scaling dialog.



6.2.2 Plan View

These plots show the plan area of the problem.

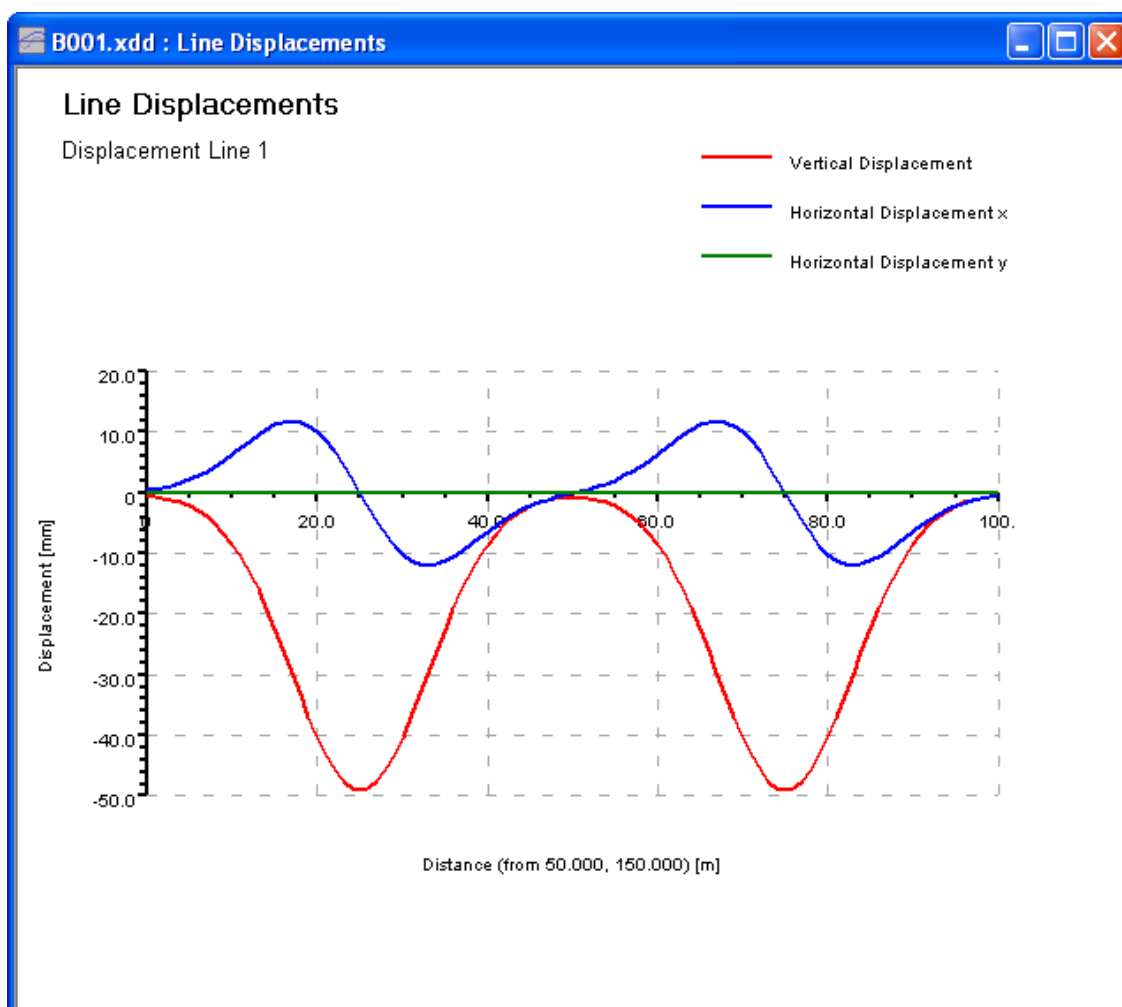




The [Plan Toolbar](#) presents commands for controlling the display on the Plan View.

6.2.3 Displacement Line Graphs

Displacement line graphs can be selected from the Plan View.



To display these graphs:

1. perform a successful analysis which includes results for a [displacement line](#);
2. display the [Plan View](#);
3. toggle the display of displacements on by clicking the 'Grids' button on the [Graphics' Toolbar](#);
4. activate the 'Line Graphs' button on the [Graphics' Toolbar](#);
5. place the cursor over the displacement line for which you wish to view results (the cursor will change to a cross-hair), and left-click.

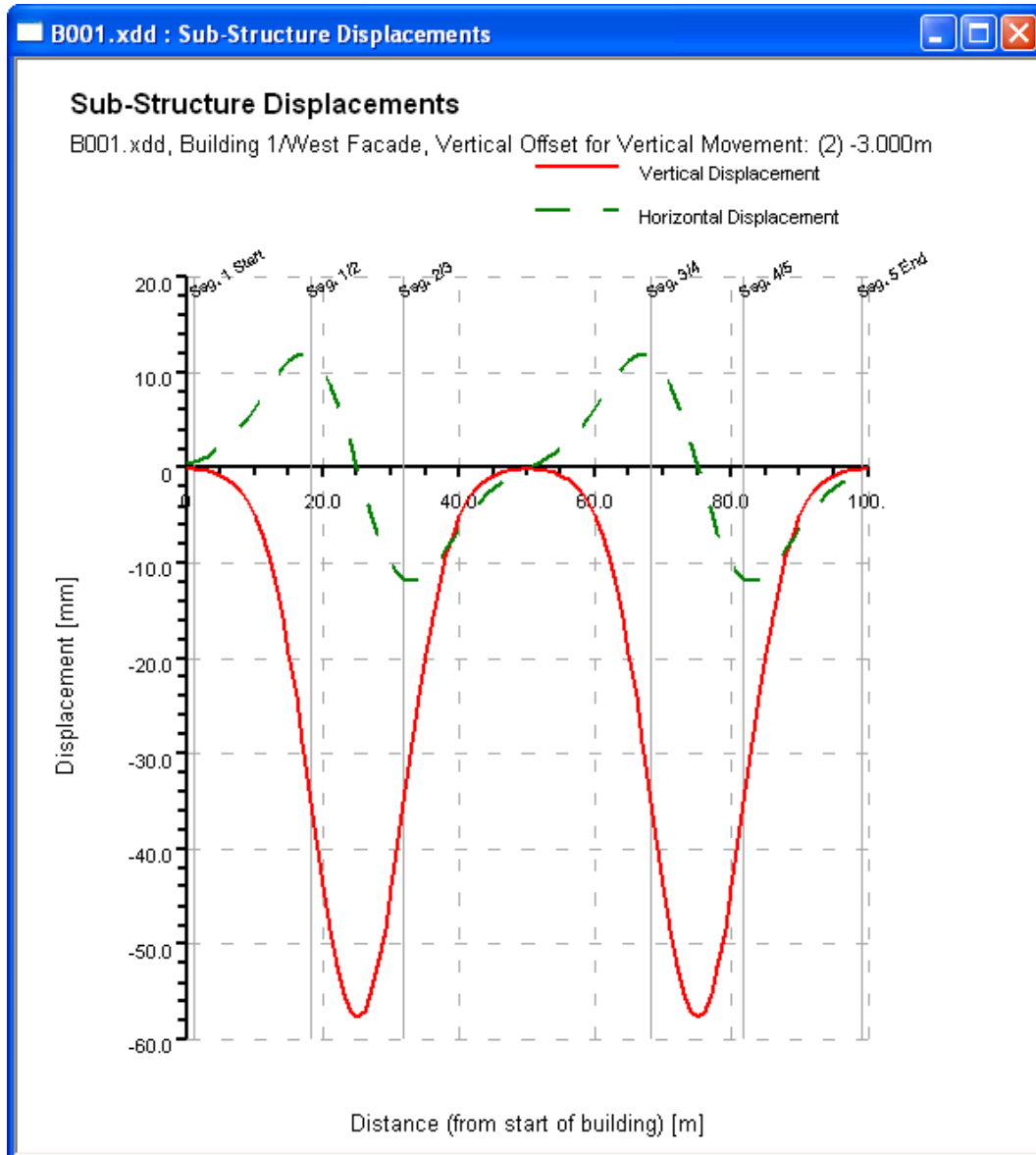
Line graphs are available for the display of the following displacement line results:

- vertical movement;
- horizontal movements.

Horizontal movements are reported in the global x and y directions.

6.2.4 Sub-Structure Displacement Line Graphs

Sub-Structure displacement line graphs display the settlement and horizontal displacement along a Sub-Structure's length. The settlement will correspond to that of the Sub-Structure's Displacement Line. The horizontal displacement is reported in the direction of the Sub-Structure, rather than in the global x or y directions.



To access a graph of displacements for a Sub-Structure:

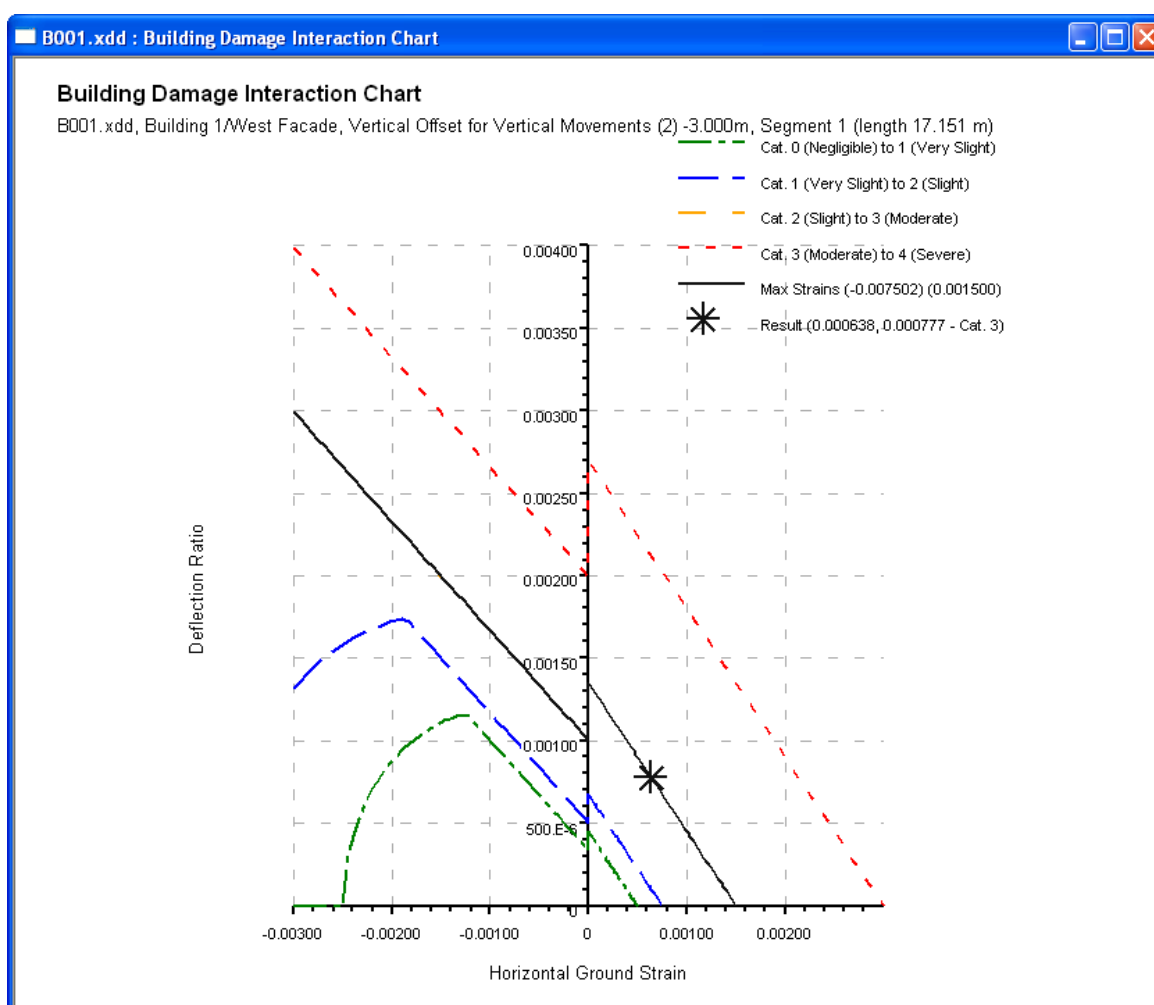
1. perform a successful analysis including structure data;
2. display the [Plan View](#);
3. display the alignments of Sub-Structures by choosing 'Graphics | Toggle Items | Structures | Specific' from the program's menu, or by checking the 'Specific' menu item present on the drop-down menu of the 'Structures' button on the [Graphics' Toolbar](#);
4. activate the 'Line Graphs' button on the [Graphics' Toolbar](#);
5. place the cursor over the Sub-Structure for which you wish to view results (the cursor will change to a cross-hair) and left-click;
6. select the required vertical offset for vertical movement calculations and click 'OK';

7. check the 'Combined Segments' check box if [combined segments](#) are available and required;
8. select the 'Building Displacements' Graphs' radio button and click 'OK'.

6.2.5 Building Damage Interaction Charts

A building damage interaction chart displays a plot of the point which defines the calculated damage category (from the calculated horizontal strain and deflection ratio of that segment) for a hogging or sagging segment of a Sub-Structure. The plot is made on a graph of the building damage category boundaries that are appropriate to that segment.

Maximum Tensile Strain is the maximum bending or shear (diagonal) strain after accounting for the horizontal strain. See [The Influence of Horizontal Strain](#) for more information.



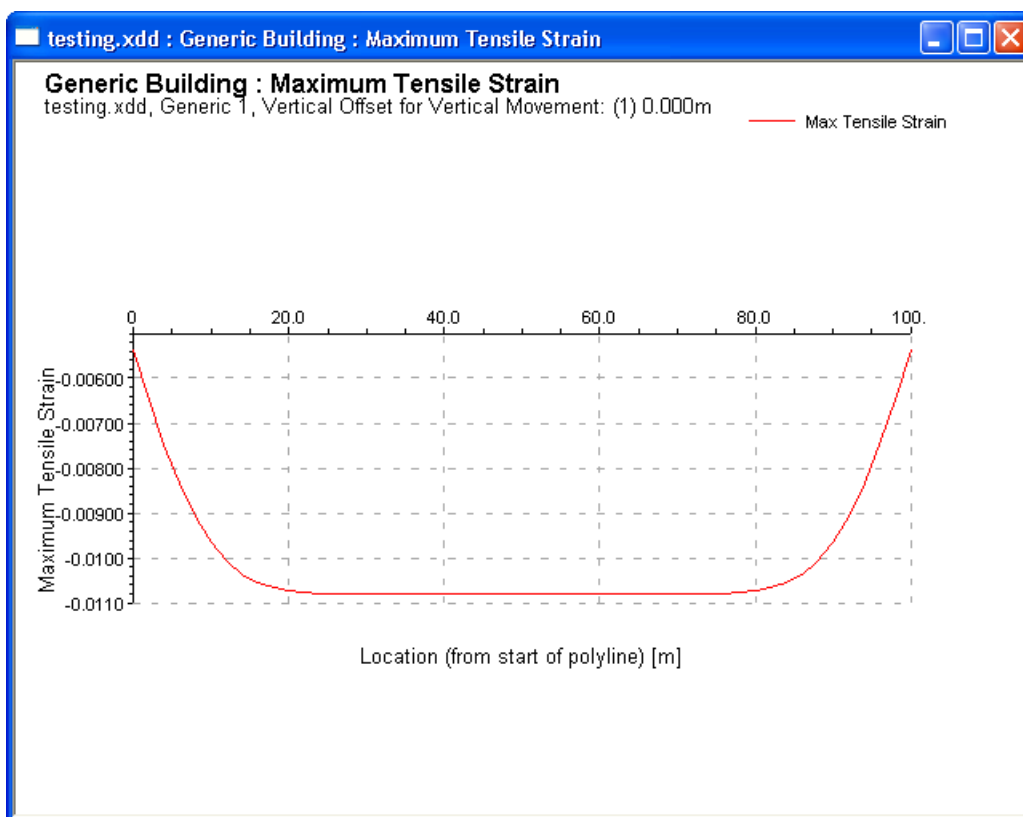
To access a graph of displacements for a sub-structure:

1. perform a successful analysis including structure data;
2. display the [Plan View](#);
3. display the alignments of Sub-Structures by choosing 'Graphics | Toggle Items | Structures | Specific' from the program's menu, or by checking the 'Specific' menu item present on the drop-down menu of the 'Structures' button on the [Graphics' Toolbar](#);
4. activate the 'Line Graphs' button on the [Graphics Toolbar](#);

5. place the cursor over the Sub-Structure for which you wish to view results (the cursor will change to a cross-hair) and left-click;
6. select the required vertical offset for vertical movement calculations and click 'OK';
7. check the 'Combined Segments' check box if [combined segments](#) are available and required;
8. select the 'Building Damage Interaction Chart' radio button and click 'OK';
9. if this Sub-Structure has more than one hogging or sagging segment a dialog appears offering selection of the desired segment, make this selection and click 'OK'.

6.2.6 Generic Building Maximum Tensile Strain Graph

The maximum tensile strain vs chainage graph shows the maximum tensile strain of each transect against its location along the polyline.



To access a plot of maximum tensile strain for a generic building:

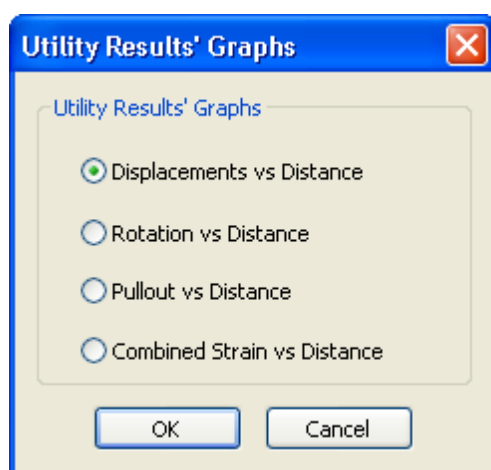
1. perform a successful analysis including generic structure data;
2. display the [Plan View](#);
3. display the alignments of generic sub-structures by choosing 'Graphics | Toggle Items | Structures | Generic' from the program's menu, or by checking the 'Generic' menu item present on the drop-down menu of the 'Structures' button on the [Graphics' Toolbar](#);
4. activate the 'Line Graphs' button on the [Graphics Toolbar](#);
5. place the cursor over the Generic Building for which you wish to view results (the cursor will change to a cross-hair) and left-click;
6. select the required vertical offset for vertical movement calculations and click 'OK'.

6.2.7 Utility Damage Assessment Graphs

Utility damage assessment graphs can be selected from the Plan View.

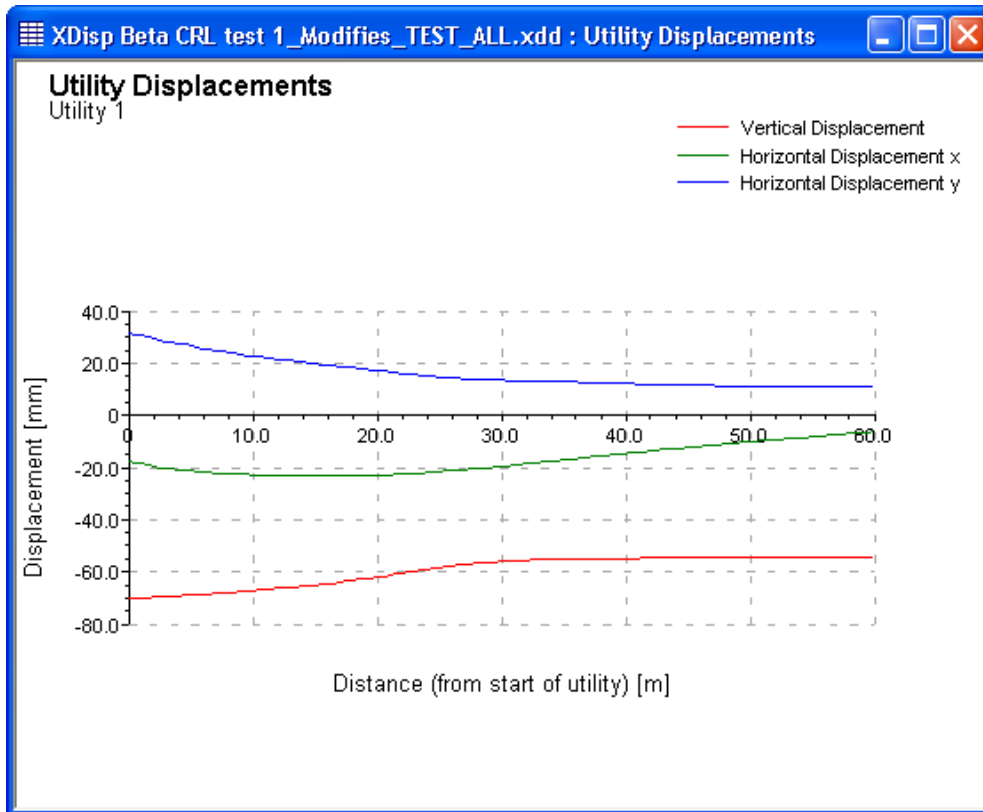
To access a utility damage assessment graph:

1. perform a successful analysis including utility data;
2. display the [Plan View](#);
3. display the alignments of Utilities by choosing 'Graphics | Toggle Items | Utilities | Specific' from the program's menu, or by checking the 'Specific' menu item present on the drop-down menu of the 'Utilities' button on the [Graphics' Toolbar](#)
4. activate the 'Line Graphs' button on the [Graphics' Toolbar](#);
5. place the cursor over the Utility for which you wish to view results (the cursor will change to a cross-hair) and left-click;
6. select the required graph from the 'Utility Results' Graphs' dialog which pops up after left-clicking and click 'OK'.



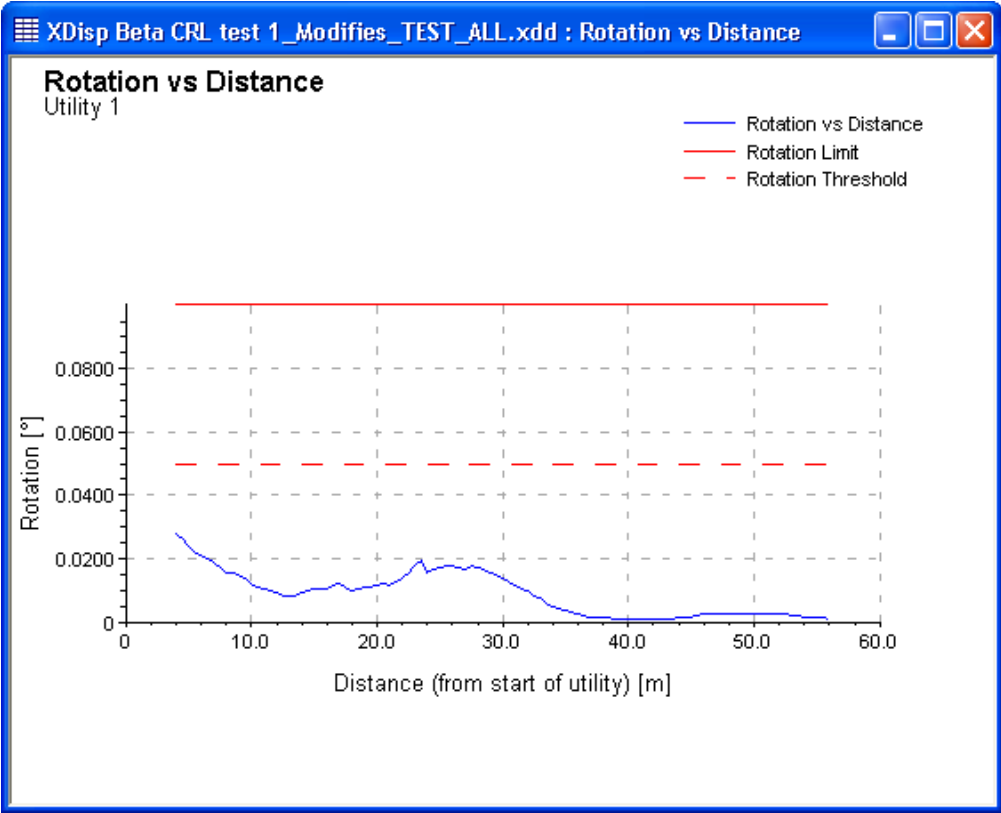
6.2.7.1 Utility Displacement Line Graphs

Utility Displacement Line graphs display the settlement and horizontal displacements along a Utility's length. The settlement will correspond to the settlement of the Utility's Displacement Line. The horizontal displacements are reported in the local x-y axes of the Utility (x is along the utility and y is perpendicular to the utility in xy plane), rather than in the global x or y directions.



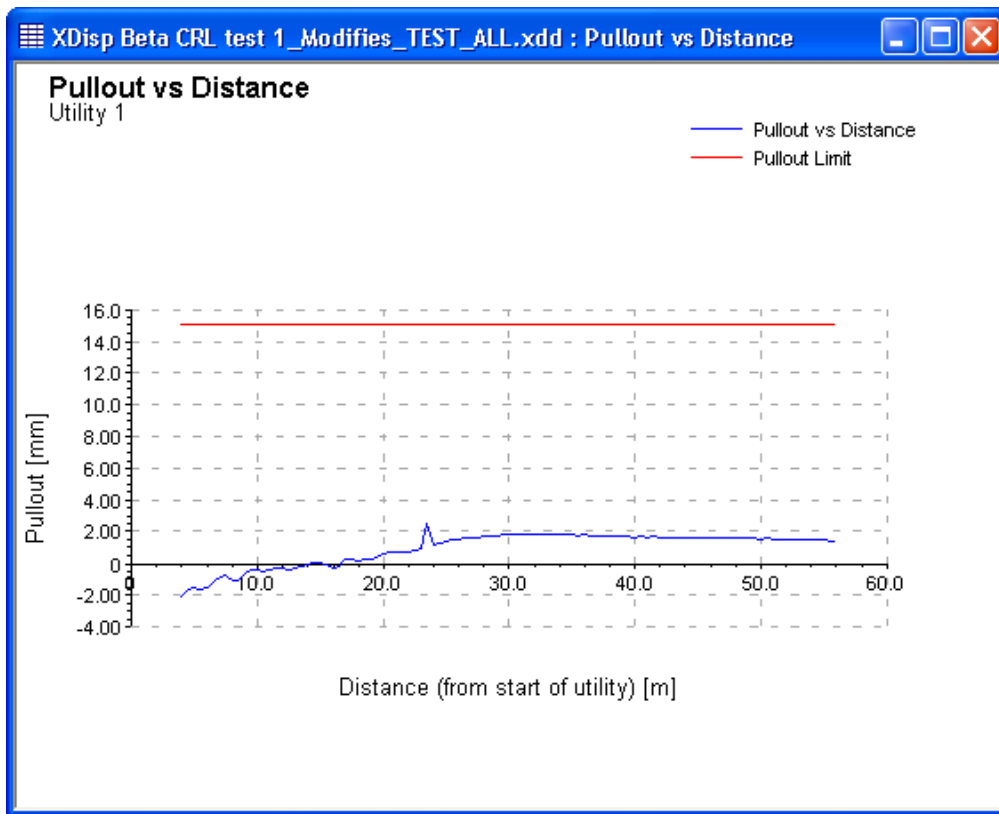
6.2.7.2 Rotation vs Distance

Rotation vs distance graphs show the rotation of each assessment point against location along the utility. It also plots the limiting values and threshold values of rotation.



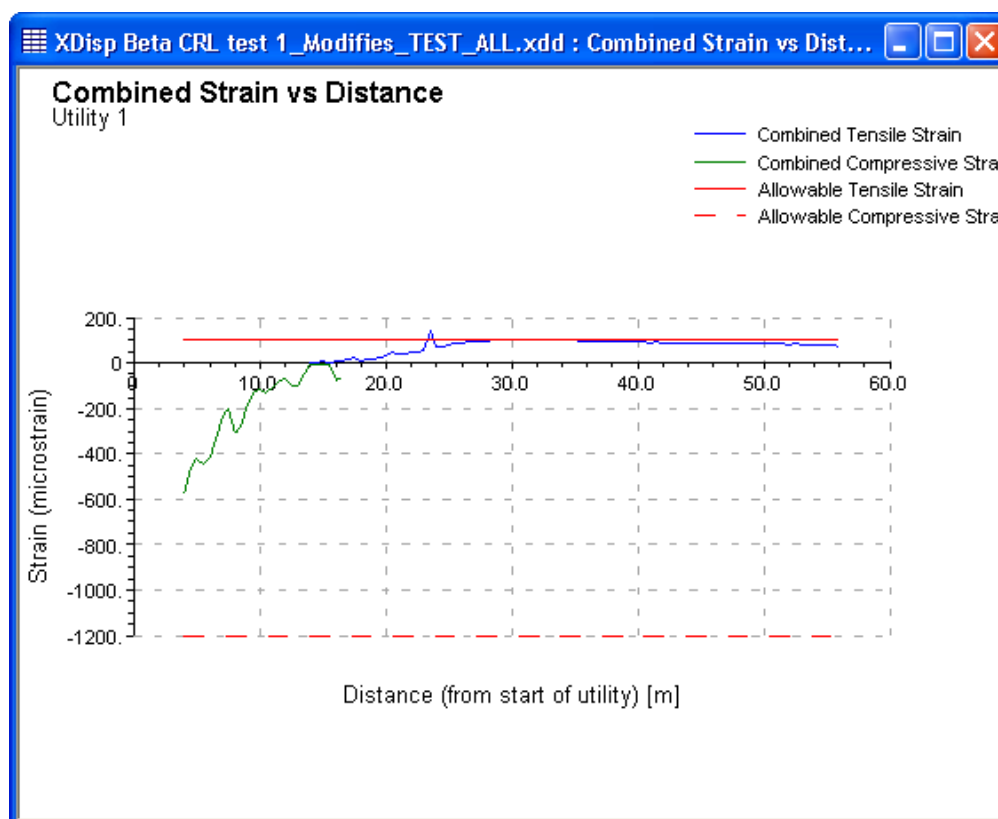
6.2.7.3 Pullout vs Distance

Pullout vs distance graphs show the pullout of each assessment point against its location along the utility. It also plots the limiting values and threshold values of pullout.



6.2.7.4 Combined Strain vs Distance

These graphs plot combined tensile strain, combined compressive strain, allowable tensile strain and allowable compressive strain values of assessment points against their locations along the utility.

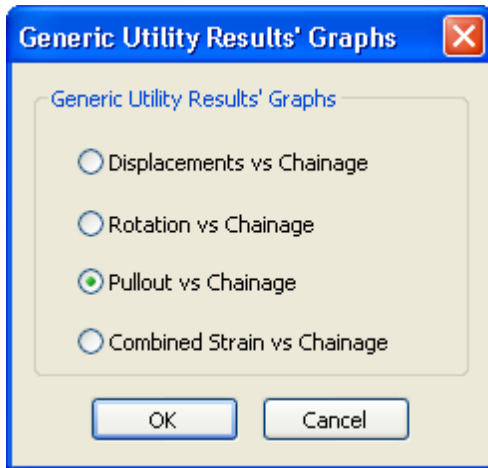


6.2.8 Generic Utility Damage Assessment Graphs

Generic utility damage assessment graphs can be selected from the Plan View.

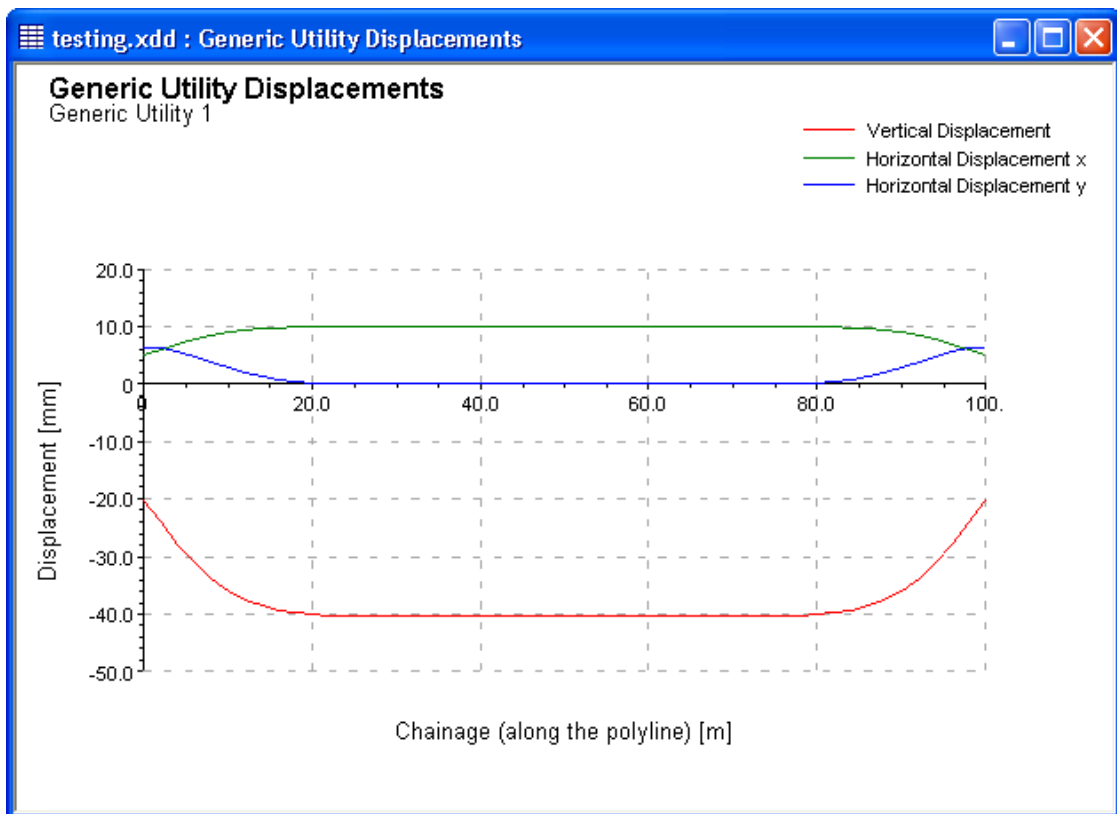
To access a generic utility damage assessment graph:

1. perform a successful analysis including generic utility data;
2. display the [Plan View](#);
3. display the alignments of Generic Utilities by choosing 'Graphics | Toggle Items | Utilities | Generic' from the program's menu, or by checking the 'Generic' menu item present on the drop-down menu of the 'Utilities' button on the [Graphics' Toolbar](#)
4. activate the 'Line Graphs' button on the [Graphics' Toolbar](#);
5. place the cursor over the Generic Utility for which you wish to view results (the cursor will change to a cross-hair) and left-click;
6. select the required graph from the 'Generic Utility Results' Graphs' dialog which pops up after left-clicking and click 'OK'.



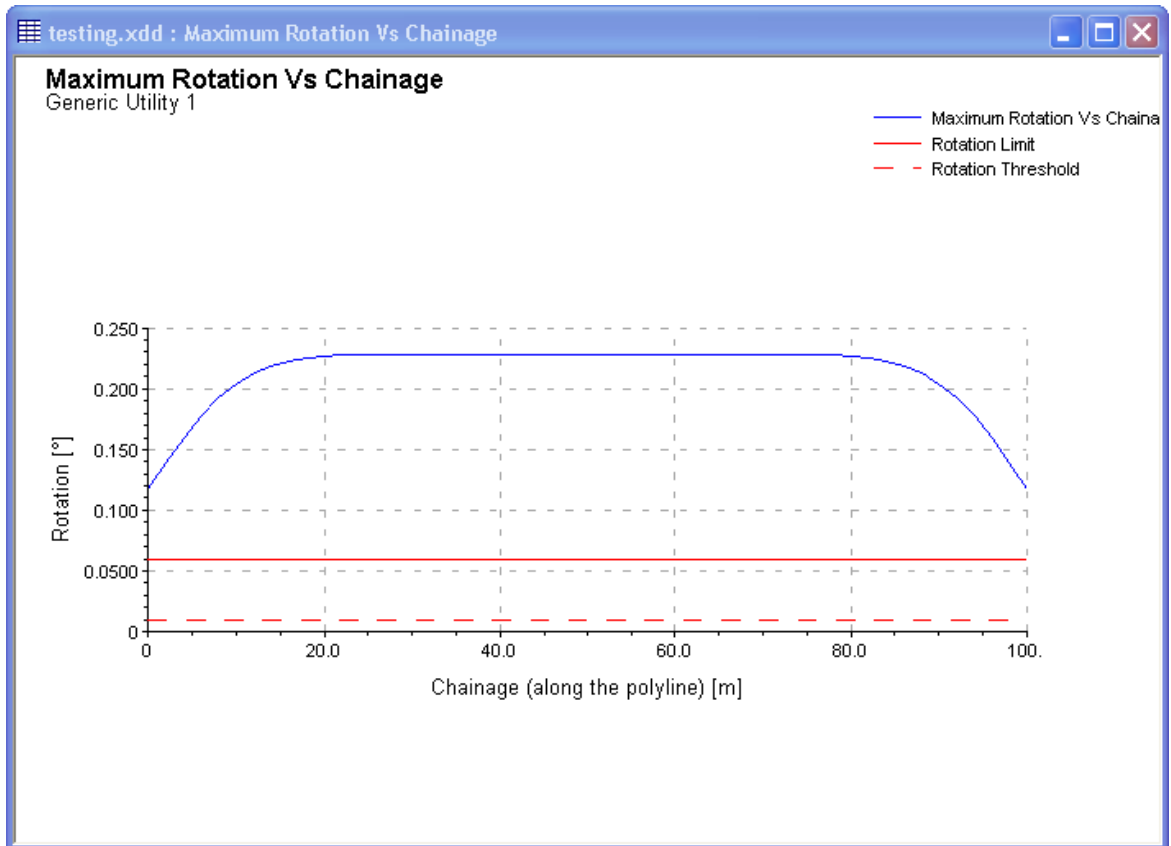
6.2.8.1 Generic Utility Displacement Line Graphs

This is a plot of maximum displacements registered in each transect against location along the polyline.



6.2.8.2 Maximum Rotation vs Chainage

Maximum rotation vs chainage graphs show the maximum rotation of each transect against location along the polyline. It also plots the limiting values and threshold values of rotation.



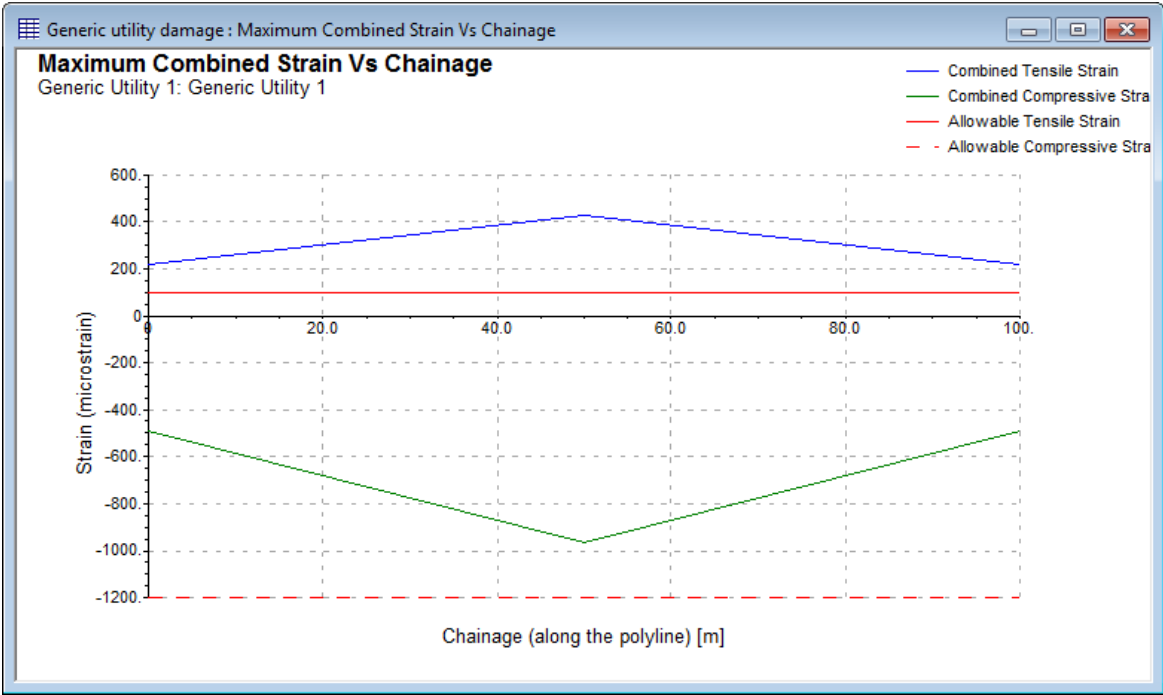
6.2.8.3 Maximum Pullout vs Chainage

Maximum pullout vs Chainage graphs show the maximum pullout of each transect against location along the polyline. It also plots the limiting values and threshold values of pullout.



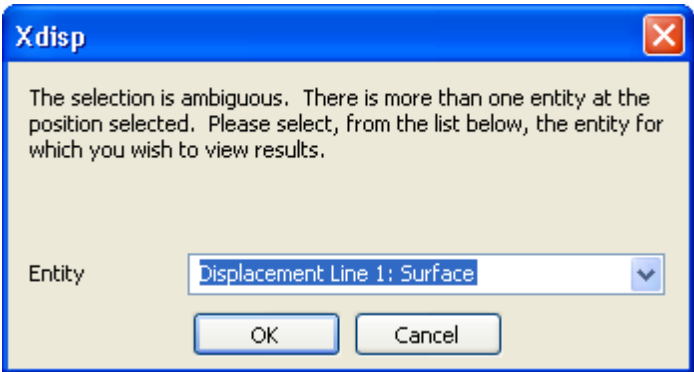
6.2.8.4 Maximum Combined Strain vs Chainage

These graphs plot maximum values of Combined Tensile Strain, Combined Compressive Strain, Allowable Tensile Strain and Allowable Compressive Strain of each transect against location along the polyline.



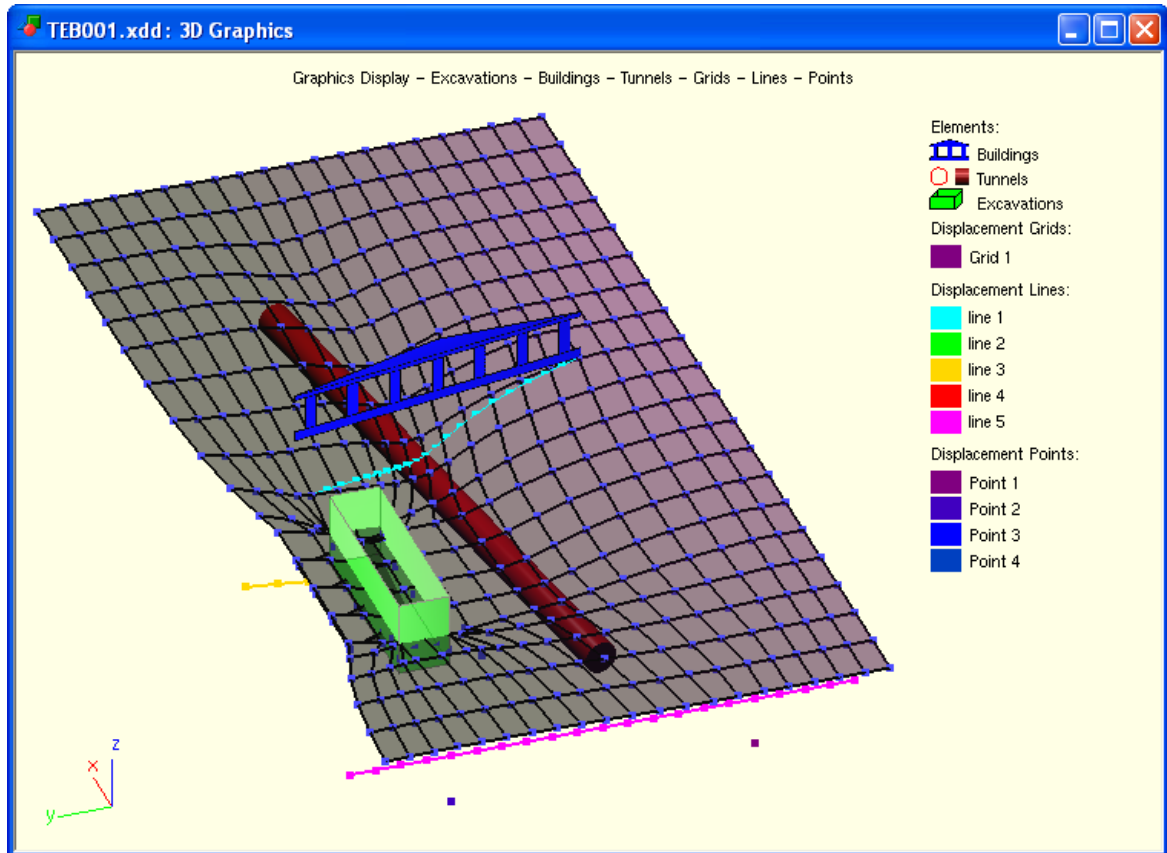
6.2.9 Ambiguous Selection

When selecting an element from the Plan View in order to view a results' graph, if there is more than one element present at the cursor location then left-clicking will pop up the Ambiguous Selection Dialog. This dialog lists all the elements present at that location. The element of interest may be selected from that list.



6.3 3D Graphics View

The 3D Graphics View displays a three dimensional plot of the model and its available results.



This view is dependent on parameters defined in the [Graphic Settings](#) property sheet.

Rotate

The model can be rotated by holding left-click and dragging the mouse. Horizontal drag rotates the model with respect to its z axis. Vertical drag rotates the model with respect to the axis parallel to a horizontal line through the centre of the view.

Zoom

The model can be zoomed in or out by scrolling the mouse wheel or by <ctrl> + drag up or down. The model can be zoomed to its original scale by pressing 'z' from keyboard.

Pan

The model can be panned by dragging the mouse with the mouse wheel (or middle button) held down.

Saving the view

The view point and zoom factor can be saved by selecting "Save default view settings" from the context menu of the view. The context menu is accessible by right-clicking in the view or by using the context menu key on the keyboard).

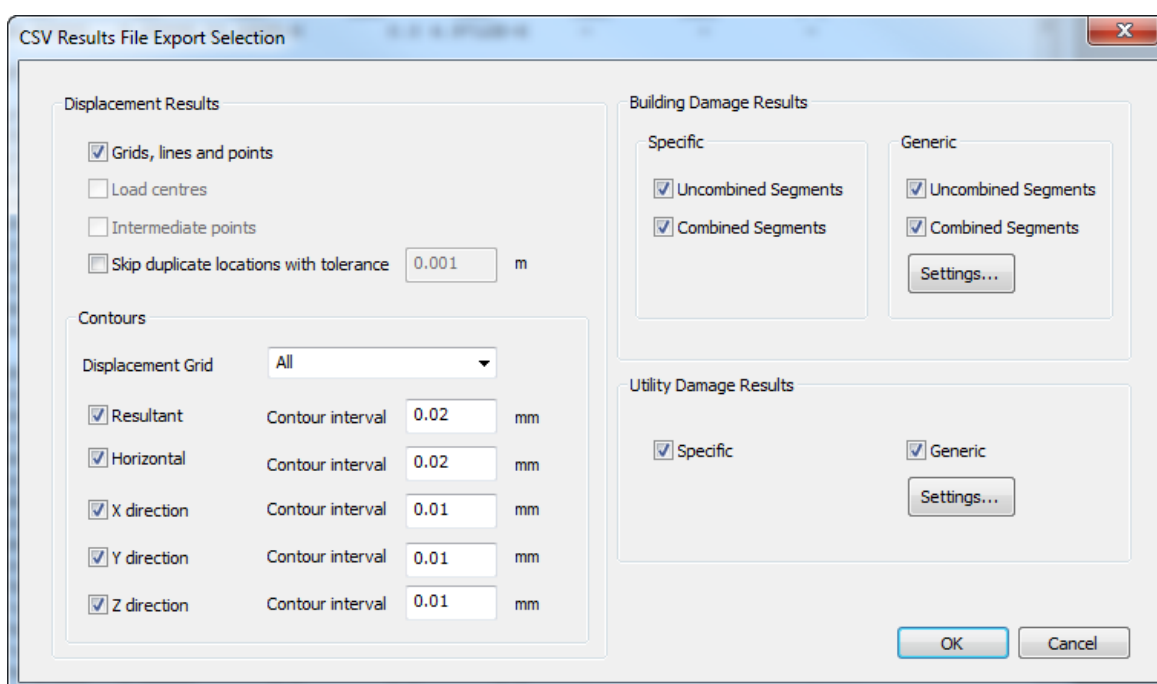
Printing

The view can be printed.

The [3D Graphics menu and toolbar](#) presents other commands that are specific to the 3D Graphics View.

6.4 CSV Results File

A comma-separated value (CSV) file of results may be output by selecting 'File | Export | CSV Results File ...' on the program menu. This option is disabled if there are no results, so an analysis must have first been performed. On selection of that menu option the CSV export selection dialog will appear.



The CSV output file may contain any of the following:

- grid, line and point displacements;
- alignments of displacement contours in any of the x, y, z or resultant directions;
- specific building damage results for uncombined and/or combined segments of sub-structures;
- generic building damage results for uncombined and/or combined segments of sub-structures;
- specific utility damage results.

If a grid is selected for a direction that contains results that are all zero, then that direction will be disabled.

'Skip duplicate locations with tolerance' option allows the user to ignore duplicate points. Only one instance of the result at each location is output. All subsequent results at that location are ignored. For instance, if one displacement line's end point is coincident with another's start point, then only one results will be output for that point.

One purpose of this output is to allow building damage segments/categories and displacement contours to be plotted on drawings in other design programs e.g. AutoCAD.

The output file includes keywords to identify the content of each row of data. Samples are given below which show the format.

Grid, line and point displacements follow the sequence:

Keyword,
x Coordinate,
y Coordinate,
z Coordinate,
x Displacement,
y Displacement,
z Displacement.

Contour data lines follow the sequence:

Keyword,
Grid No.,
Contour value,
x Coordinate 1,
y Coordinate 1,
x Coordinate 2,
y Coordinate 2.

They describe discrete segments of a contour line.

Specific building damage results' data lines follow the sequence:

Keyword,
Building No.,
Structure Name,
Sub-Structure Name,
Offset No.,
Segment No.,
Segment Start x,
Segment Start y,
Segment Start z,
Segment End x,
Segment End y,
Segment End z,
Damage Category.

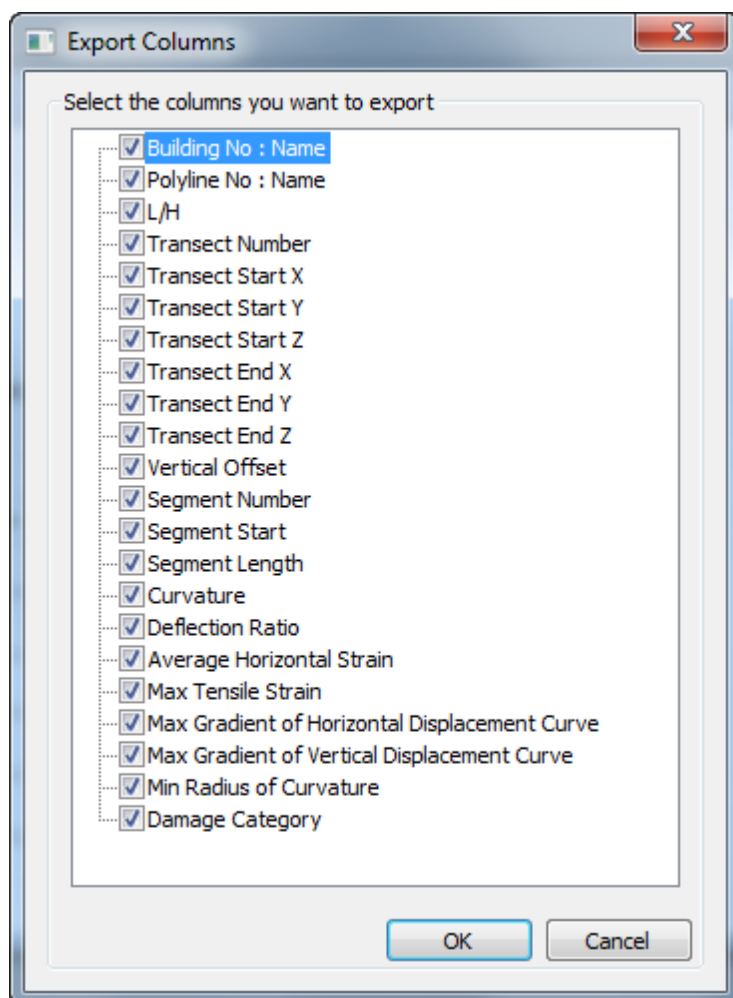
Generic building damage results' data lines follow the sequence:

Keyword,
Building No : Name.,
Polyline No : Name.,
L/H,
Transect No.,
Transect Start x,
Transect Start y,
Transect Start z,
Transect End x,
Transect End y,
Transect End z,
Vertical Offset,
Segment No.,

Segment Start,
Segment Length,
Curvature,
Deflection Ratio,
Average Horizontal Strain,
Maximum Tensile Strain,
Maximum Gradient of Horizontal Displacement Curve,
Maximum Gradient of Vertical Displacement Curve,
Minimum Radius of Curvature
Damage Category.

However, for generic buildings the user can choose the columns that they want to export via its Export Columns dialog that is accessed by clicking the Settings button present in the Generic Building Damage Results group box.

Note: Maximum Gradient of Horizontal Displacement Curve, Maximum Gradient of Vertical Displacement Curve and Minimum Radius of Curvature won't be exported for the combined segments.



Specific utility damage results' data lines for coordinates and displacements follow the sequence:
Keyword,

Utility Name,
Sub-Utility Name,
Iteration No.,
Distance (from the utility's start point),
x Coordinate,
y Coordinate,
z Coordinate,
x Displacement,
y Displacement,
z Displacement,
Horizontal Displacement along the utility,
Horizontal Displacement perpendicular to the utility,
x Displacement at $(n-L_p)$,
y Displacement at $(n-L_p)$,
z Displacement at $(n-L_p)$,
Horizontal Displacement along the utility at $(n-L_p)$,
Horizontal Displacement perpendicular to the utility at $(n-L_p)$,
x Displacement at $(n+L_p)$,
y Displacement at $(n+L_p)$,
z Displacement at $(n+L_p)$,
Horizontal Displacement along the utility at $(n+L_p)$,
Horizontal Displacement perpendicular to the utility at $(n+L_p)$,

Specific utility damage results' data lines for pullouts and rotations follow the sequence:

Keyword,
Utility Name,
Sub-Utility Name,
Iteration No.,
Distance (from the utility's start point),
x Coordinate,
y Coordinate,
z Coordinate,
Axial Pullout (left segment) - Unfactored,
Axial Pullout (left segment) - Factored,
Flexural Pullout (left segment) - Unfactored,
Flexural Pullout (left segment) - Factored,
Axial Pullout (right segment) - Unfactored,
Axial Pullout (right segment) - Factored,
Flexural Pullout (right segment) - Unfactored,
Flexural Pullout (right segment) - Factored,
Total Axial Pullout - Unfactored,
Total Axial Pullout - Factored,
Total Flexural Pullout - Unfactored,
Total Flexural Pullout - Factored,
Total Pullout - Unfactored,
Total Pullout - Factored,
Threshold Check,
Limit Check,
Rotation - Unfactored,
Rotation - Factored,
Threshold Check,
Limit Check,

Sagging vs Hogging.

Specific utility damage results' data lines for strains follow the sequence:

Keyword,
Utility Name,
Sub-Utility Name,
Distance (from the utility's start point),
x Coordinate,
y Coordinate,
z Coordinate,
Axial Strain - Unfactored,
Axial Strain - Factored,
Flexural Strain - Tension - Unfactored,
Flexural Strain - Tension - Factored,
Flexural Strain - Compression - Unfactored,
Flexural Strain - Compression - Factored,
Total Tension - Unfactored,
Total Tension - Factored,
Tension Check,
Total Compression- Unfactored,
Total Compression- Factored,
Compression Check,
Radius of Curvature,
Threshold Check,
Limit Check,
Peak Flexural Tensile Strain Orientation Angle (with respect to global z axis).

Generic utility damage results' data lines for coordinates and displacements follow the sequence:

Keyword,
Generic Utility No : Name,
Polyline No : Name,
Transect No.,
Transect Start x,
Transect Start y,
Transect Start z,
Transect End x,
Transect End y,
Transect End z,
Iteration No.,
Distance (from the utility's start point),
x Coordinate,
y Coordinate,
z Coordinate,
x Displacement,
y Displacement,
z Displacement,
Horizontal Displacement along the utility,
Horizontal Displacement perpendicular to the utility,
x Displacement at $(n-L_p)$,
y Displacement at $(n-L_p)$,
z Displacement at $(n-L_p)$,
Horizontal Displacement along the utility at $(n-L_p)$,
Horizontal Displacement perpendicular to the utility at $(n-L_p)$,

x Displacement at $(n+L_p)$,
y Displacement at $(n+L_p)$,
z Displacement at $(n+L_p)$,
Horizontal Displacement along the utility at $(n+L_p)$,
Horizontal Displacement perpendicular to the utility at $(n+L_p)$,

Generic utility damage results' data lines for pullouts and rotations follow the sequence:

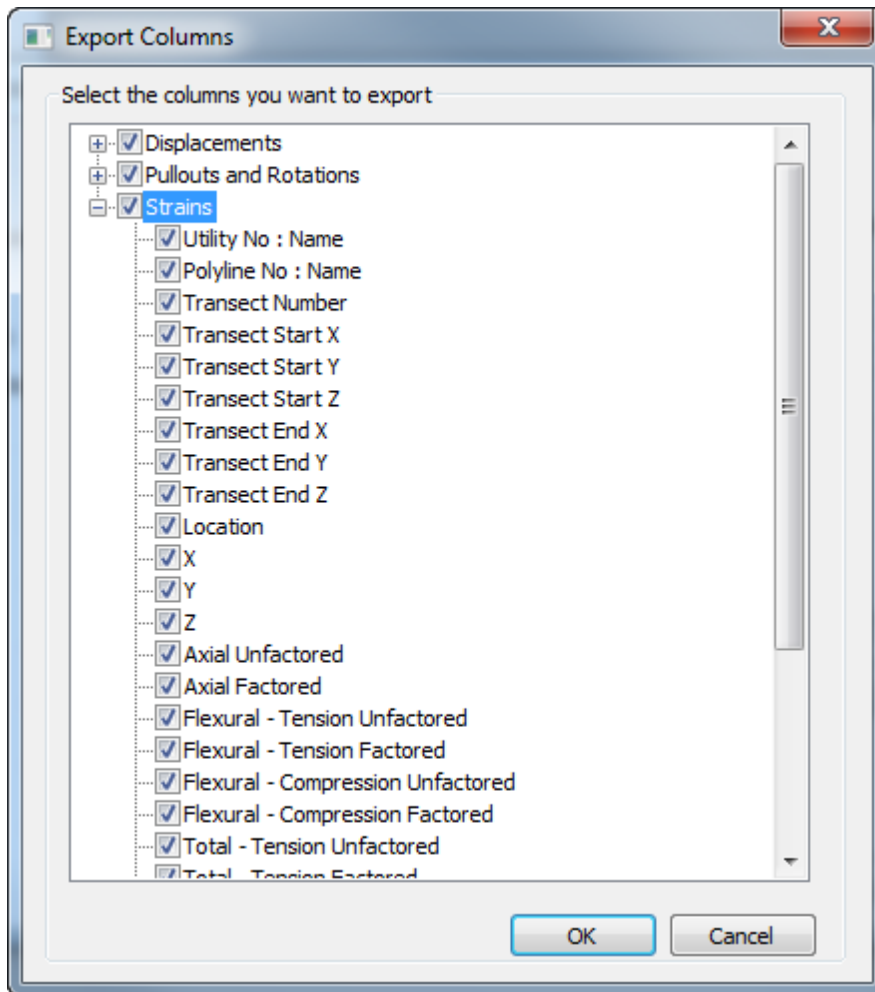
Keyword,
Generic Utility No : Name,
Polyline No : Name,
Transect No.,
Transect Start x,
Transect Start y,
Transect Start z,
Transect End x,
Transect End y,
Transect End z,
Iteration No.,
Distance (from the utility's start point),
x Coordinate,
y Coordinate,
z Coordinate,
Axial Pullout (left segment) - Unfactored,
Axial Pullout (left segment) - Factored,
Flexural Pullout (left segment) - Unfactored,
Flexural Pullout (left segment) - Factored,
Axial Pullout (right segment) - Unfactored,
Axial Pullout (right segment) - Factored,
Flexural Pullout (right segment) - Unfactored,
Flexural Pullout (right segment) - Factored,
Total Axial Pullout - Unfactored,
Total Axial Pullout - Factored,
Total Flexural Pullout - Unfactored,
Total Flexural Pullout - Factored,
Total Pullout - Unfactored,
Total Pullout - Factored,
Threshold Check,
Limit Check,
Rotation - Unfactored,
Rotation - Factored,
Threshold Check,
Limit Check,
Sagging vs Hogging.

Generic utility damage results' data lines for strains follow the sequence:

Keyword,
Generic Utility No : Name,
Polyline No : Name,
Transect No.,
Transect Start x,
Transect Start y,
Transect Start z,
Transect End x,
Transect End y,

Transect End z,
Iteration No.,
Distance (from the utility's start point),
x Coordinate,
y Coordinate,
z Coordinate,
Axial Strain - Unfactored,
Axial Strain - Factored,
Flexural Strain - Tension - Unfactored,
Flexural Strain - Tension - Factored,
Flexural Strain - Compression - Unfactored,
Flexural Strain - Compression - Factored,
Total Tension - Unfactored,
Total Tension - Factored,
Tension Check,
Total Compression- Unfactored,
Total Compression- Factored,
Compression Check,
Radius of Curvature,
Threshold Check,
Limit Check,
Peak Flexural Tensile Strain Orientation Angle (with respect to global z axis).

However, for generic utilities the user can choose the columns that they want to export via its Export Columns dialog that is accessed by clicking the Settings button present in the Generic Utility Damage Results group box.



Dimensions for output data are chosen by the user in the "Save As" dialog that follows the "CSV Results File Output Selection" dialog. Length and displacement units' indices are: 0 - metres; 1 - centimetres; 2 - millimetres; 3 - feet; 4 - inches. Angle units' indices are 0 - radians; 1 - degrees.

Units information should appear before the results.

e.g.

```

UNI T_DI SP, 2
UNI T_LENGTH, 0
CONTOUR_RESULTANT, 1, 10. , 30. , 22. 94968, 27. 96293, 23. 98147
CONTOUR_RESULTANT, 1, 10. , 27. 96293, 23. 98147, 26. 13617, 25.
CONTOUR_RESULTANT, 1, 10. , 26. 13617, 25. , 23. 26587, 26. 63294
. . .
CONTOUR_X, 1, - 60. , 90. , 80. 55464, 89. 26049, 80. 36975
CONTOUR_X, 1, - 60. , 89. 26049, 80. 36975, 88. 89082, 80.
CONTOUR_X, 1, - 60. , 95. 56882, 75. , 91. 57434, 74. 21283
. . .
CONTOUR_Y, 1, - 60. , 48. 88889, 80. , 49. 25906, 79. 62953
CONTOUR_Y, 1, - 60. , 49. 25906, 79. 62953, 50. , 79. 4441
CONTOUR_Y, 1, - 60. , 49. 77666, 85. , 49. 81781, 84. 90891
. . .
CONTOUR_Z, 1, 0. , 50. , 0. 4412712, 48. 84946, 0. 5752676
    
```

CONTOUR_Z, 1, 0., 48. 84946, 0. 5752676, 43. 20705, 0.
CONTOUR_Z, 1, 0., 60., 0. 3418683, 59. 22948, 0. 3852612
...
BDA_SPECI FI C_RESULT_UNCOMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 1, 1, 50., 150., 0., 66. 96732, 150., 0., 2
BDA_SPECI FI C_RESULT_UNCOMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 1, 2, 66. 96732, 150., 0., 83. 03243, 150., 0., 1
BDA_SPECI FI C_RESULT_UNCOMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 1, 3, 83. 03243, 150., 0., 116. 9676, 150., 0., 3
BDA_SPECI FI C_RESULT_UNCOMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 1, 4, 116. 9676, 150., 0., 133. 0326, 150., 0., 1
BDA_SPECI FI C_RESULT_UNCOMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 1, 5, 133. 0326, 150., 0., 150., 150., 0., 2
BDA_SPECI FI C_RESULT_UNCOMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 2, 1, 50., 150., 0., 67. 15132, 150., 0., 3
BDA_SPECI FI C_RESULT_UNCOMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 2, 2, 67. 15132, 150., 0., 80. 84868, 150., 0., 2
BDA_SPECI FI C_RESULT_UNCOMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 2, 3, 80. 84868, 150., 0., 117. 1513, 150., 0., 3
BDA_SPECI FI C_RESULT_UNCOMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 2, 4, 117. 1513, 150., 0., 130. 8487, 150., 0., 2
BDA_SPECI FI C_RESULT_UNCOMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 2, 5, 130. 8487, 150., 0., 148., 150., 0., 3
BDA_SPECI FI C_RESULT_UNCOMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 3, 1, 50., 150., 0., 64. 3278, 150., 0., 3
BDA_SPECI FI C_RESULT_UNCOMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 3, 2, 64. 3278, 150., 0., 75. 6722, 150., 0., 2
BDA_SPECI FI C_RESULT_UNCOMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 3, 3, 75. 6722, 150., 0., 114. 3278, 150., 0., 3
BDA_SPECI FI C_RESULT_UNCOMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 3, 4, 114. 3278, 150., 0., 125. 6722, 150., 0., 2
BDA_SPECI FI C_RESULT_UNCOMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 3, 5, 125. 6722, 150., 0., 140., 150., 0., 3
BDA_SPECI FI C_RESULT_COMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 2, 1, 50., 150., 0., 67. 13972, 150., 0., 3
BDA_SPECI FI C_RESULT_COMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 2, 2, 67. 13972, 150., 0., 117. 1397, 150., 0., 1
BDA_SPECI FI C_RESULT_COMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 2, 3, 117. 1397, 150., 0., 130. 8603, 150., 0., 2
BDA_SPECI FI C_RESULT_COMBI NED_SEGMENTS, 1, Bui l di ng 1, Wèst
Facade, 2, 4, 130. 8603, 150., 0., 148., 150., 0., 3
...
BDA_GENERI C_RESULT_UNCOMBI NED_SEGMENTS, Bui l di ng 1 : Generi c
1, Pol y l i n e 1 : Pol y l i n e
1, 10, 1, 50, 200, 0, 150, 200, 0, 0, 1, 0, 13. 54408393, Hoggi ng, 2. 29E-
02, 2. 65E- 02, 5. 03E- 02, - 2. 93E- 04, - 1. 59E- 03, 5312. 377171, 1 (Ver y
Sl i ght)
BDA_GENERI C_RESULT_UNCOMBI NED_SEGMENTS, Bui l di ng 1 : Generi c
1, Pol y l i n e 1 : Pol y l i n e
1, 10, 1, 50, 200, 0, 150, 200, 0, 0, 2, 13. 54408393, 23. 37606931, Saggi ng, 4.
62E- 02, - 3. 24E- 02, 6. 55E- 03, 1. 01E- 03, - 1. 59E- 03, 11144. 33635, 0
(Negl i gi bl e)
BDA_GENERI C_RESULT_UNCOMBI NED_SEGMENTS, Bui l di ng 1 : Generi c
1, Pol y l i n e 1 : Pol y l i n e
1, 10, 1, 50, 200, 0, 150, 200, 0, 0, 3, 36. 92015324, 26. 15969351, Hoggi ng, 3.

33E-02, 2.86E-02, 6.31E-02, -3.16E-04, 1.59E-03, 10204.52383, 1 (Very Slight)
BDA_GENERIC_RESULT_UNCOMBINED_SEGMENTS, Building 1 : Generic
1, Polyline 1 : Polyline
1, 10, 1, 50, 200, 0, 150, 200, 0, 0, 4, 63.07984676, 23.37606931, Sagging, 4.62E-02, -3.24E-02, 6.55E-03, 1.01E-03, 1.59E-03, 11144.33635, 0
(Negligible)
BDA_GENERIC_RESULT_UNCOMBINED_SEGMENTS, Building 1 : Generic
1, Polyline 1 : Polyline
1, 10, 1, 50, 200, 0, 150, 200, 0, 0, 5, 86.45591607, 13.54408393, Hogging, 2.29E-02, 2.65E-02, 5.03E-02, -2.93E-04, 1.59E-03, 5312.377171, 1 (Very Slight)
BDA_GENERIC_RESULT_UNCOMBINED_SEGMENTS, Building 1 : Generic
1, Polyline 1 : Polyline
1, 10, 2, 50, 150, 0, 150, 150, 0, 0, 1, 0, 13.53985052, Hogging, 4.58E-02, 5.31E-02, 0.100628865, -5.86E-04, -3.18E-03, 2656.829187, 2
(Slight)
BDA_GENERIC_RESULT_UNCOMBINED_SEGMENTS, Building 1 : Generic
1, Polyline 1 : Polyline
1, 10, 2, 50, 150, 0, 150, 150, 0, 0, 2, 13.53985052, 23.38483934, Sagging, 9.24E-02, -6.47E-02, 1.31E-02, 2.02E-03, -3.18E-03, 5567.203645, 0
(Negligible)
BDA_GENERIC_RESULT_UNCOMBINED_SEGMENTS, Building 1 : Generic
1, Polyline 1 : Polyline
1, 10, 2, 50, 150, 0, 150, 150, 0, 0, 3, 36.92468986, 26.15062029, Hogging, 6.65E-02, 5.72E-02, 0.126163781, -6.32E-04, -3.18E-03, 5104.761728, 2
(Slight)
BDA_GENERIC_RESULT_UNCOMBINED_SEGMENTS, Building 1 : Generic
1, Polyline 1 : Polyline
1, 10, 2, 50, 150, 0, 150, 150, 0, 0, 4, 63.07531014, 23.38483934, Sagging, 9.24E-02, -6.47E-02, 1.31E-02, 2.02E-03, 3.18E-03, 5567.203645, 0
(Negligible)
BDA_GENERIC_RESULT_COMBINED_SEGMENTS, Building 1 : Generic
1, Polyline 1 : Polyline
1, 10, 1, 50, 200, 0, 150, 200, 0, 0, 1, 0, 36.92389142, Sagging, 4.08E-02, -1.08E-02, 1.28E-02, 0 (Negligible), , ,
BDA_GENERIC_RESULT_COMBINED_SEGMENTS, Building 1 : Generic
1, Polyline 1 : Polyline
1, 10, 1, 50, 200, 0, 150, 200, 0, 0, 2, 36.92389142, 26.15221715, Hogging, 3.32E-02, 2.86E-02, 6.31E-02, 1 (Very Slight)
BDA_GENERIC_RESULT_COMBINED_SEGMENTS, Building 1 : Generic
1, Polyline 1 : Polyline
1, 10, 1, 50, 200, 0, 150, 200, 0, 0, 3, 63.07610858, 23.38363447, Sagging, 4.62E-02, -3.24E-02, 6.55E-03, 0 (Negligible)
BDA_GENERIC_RESULT_COMBINED_SEGMENTS, Building 1 : Generic
1, Polyline 1 : Polyline
1, 10, 1, 50, 200, 0, 150, 200, 0, 0, 4, 86.45974304, 13.54025696, Hogging, 2.29E-02, 2.66E-02, 5.03E-02, 1 (Very Slight)
...
UNIT_DISP, 2

UNIT_LENGTH, 0

UDA_SPECIFIC_RESULTS_COODS_DISPS, Utility 1, Sub
1, 1, 20, 70, 150, 0, 10.0678, 0, 40.27141, 10.06785, 0, 0.46361, 0, 0.37089,

0. 46361, 0, - 6. 3250, 0, 8. 44476, - 6. 3250, 0
 UDA_SPECIFIC_RESULTS_COODS_DIPS, Utility 1, Sub
 1, 2, 21, 70, 150, 0, 8. 64098, 0, 43. 20492, 8. 64098, 0, 0. 65264, 0, 0. 54387, 0
 . 65264, 0, - 5. 290, 0, 6. 6315, - 5. 290, 0
 UDA_SPECIFIC_RESULTS_COODS_DIPS, Utility 1, Sub
 1, 3, 22, 72, 150, 0, 6. 845, 0, 45. 633, 6. 845, 0, 0. 9029, 0, 0. 7851, 0. 9029, 0,
 - 4. 3356, 0, 5. 1298, - 4. 335, 0
 . . .
 UNIT_DIPS, 2

 UNIT_LENGTH, 0

 UNIT_ANGLE, 1
 UDA_SPECIFIC_RESULT_PULLOUTS_ROTATIONS, Utility 1, Sub
 1, 1, 20, 70, 150, 0, 6. 32531, 6. 32531, 2. 23968, 2. 23968, - 4. 75156, -
 4. 75156, 2. 23968, 2. 23968, - 11. 07688, - 11. 07688, 4. 47935, 4. 47935,
 4. 47935, 4. 47935, -
 , OK, 0. 20548, 0. 20548, - , OK, Sagging
 UDA_SPECIFIC_RESULT_PULLOUTS_ROTATIONS, Utility 1, Sub
 1, 2, 21, 71, 150, 0, 6. 714, 6. 714, 2. 474, 2. 474, - 5. 482, -
 5. 482, 2. 474, 2. 474, - 12. 197, - 12. 197, 4. 948, 4. 948, 4. 948, 4. 948, -
 , OK, 0. 2269, 0. 2269, - , OK, Sagging
 UDA_SPECIFIC_RESULT_PULLOUTS_ROTATIONS, Utility 1, Sub
 1, 3, 22, 72, 150, 0, 7. 00959, 7. 00959, 2. 6651, - 6. 1008, -
 6. 1008, 2. 6651, 2. 6651, - 13. 1104, - 13. 1104, 5. 3302, 5. 3302, 5. 3302, -
 , OK, 0. 24452, - , OK, Hogging
 . . .
 UNIT_DIPS, 2

 UNIT_LENGTH, 0

 UNIT_ANGLE, 1

 UDA_SPECIFIC_RESULT_STRAINS, Utility 1, Sub
 1, 1, 51, 150, 0, 219. 69, 43. 938, 42. 663, 42. 663, - 42. 663, -
 42. 663, 262. 351, 86. 600, OK, - , - , - , 14638. 051, Fails, Fails, 0
 UDA_SPECIFIC_RESULT_STRAINS, Utility 1, Sub
 1, 2, 52, 150, 0, 287. 49, 57. 498, 55. 882, 55. 882, - 55. 882, -
 55. 882, 343. 372, 113. 38, Fails, - , - , - , 11175. 00, Fails, Fails, 0
 UDA_SPECIFIC_RESULT_STRAINS, Utility 1, Sub
 1, 3, 53, 150, 0, 368. 39, 73. 667, 71. 67, 71. 67, - 71. 67, -
 71. 67, 440. 0571, 145. 347, Fails, - , - , - , 8713. 573, Fails, Fails, 0
 . . .
 UNIT_DIPS, 2
 UNIT_LENGTH, 0
 UDA_GENERIC_RESULT_COODS_DIPS, Utility 1 : Generic Utility
 1, Polyline 1 :
 Polyline1, 2, 50, 150, 0, 150, 150, 0, 1, 20, 70, 150, 0, 10. 06785, 0, 40. 27141
 , 10. 06785, 0, 0. 46361, 0, 0. 37089, 0. 46361, 0, - 6. 32503, 0, 8. 44476, -
 6. 32503, 0
 UDA_GENERIC_RESULT_COODS_DIPS, Utility 1 : Generic Utility
 1, Polyline 1 : Polyline 1, 2, 50, 150, 0, 150, 150, 0, 1, 40, 90, 150, 0, -
 6. 32503, 0, 8. 44476, -
 6. 32503, 0, 10. 06785, 0, 40. 27141, 10. 06785, 0, 6. 32503, 0, 8. 44476, 6. 325
 03, 0

UDA_GENERI C_RESULT_COODS_DI SPS, Utility 1 : Generic Utility
1, Polyline 1 : Polyline
1, 2, 50, 150, 0, 150, 150, 0, 1, 60, 110, 150, 0, 6. 32503, 0, 8. 44476, 6. 32503,
0, - 6. 32503, 0, 8. 44476, - 6. 32503, 0, - 10. 06785, 0, 40. 27141, - 10. 06785, 0
UDA_GENERI C_RESULT_COODS_DI SPS, Utility 1 : Generic Utility
1, Polyline 1 : Polyline 1, 2, 50, 150, 0, 150, 150, 0, 1, 80, 130, 150, 0, -
10. 06785, 0, 40. 27141, - 10. 06785, 0, 6. 32503, 0, 8. 44476, 6. 32503, 0, -
0. 46361, 0, 0. 37089, - 0. 46361, 0
UDA_GENERI C_RESULT_COODS_DI SPS, Utility 1 : Generic Utility
1, Polyline 1 : Polyline
1, 2, 50, 150, 0, 150, 150, 0, 2, 21, 71, 150, 0, 8. 64098, 0, 43. 20492, 8. 64098,
0, 0. 65264, 0, 0. 54387, 0. 65264, 0, - 5. 2906, 0, 6. 63154, - 5. 2906, 0
UDA_GENERI C_RESULT_COODS_DI SPS, Utility 1 : Generic Utility
1, Polyline 1 : Polyline 1, 2, 50, 150, 0, 150, 150, 0, 2, 41, 91, 150, 0, -
5. 2906, 0, 6. 63154, -
5. 2906, 0, 8. 64098, 0, 43. 20492, 8. 64098, 0, 7. 40794, 0, 10. 58978, 7. 40794
, 0
...
UNI T_DI SP, 2
UNI T_LENGTH, 0
UNI T_ANGLE, 1
UDA_GENERI C_RESULT_PULLOUTS_ROTATI ONS, Utility 1 : Generic
Utility 1, Polyline 1 : Polyline
1, 1, 50, 200, 0, 150, 200, 0, 1, 20, 70, 200, 0, 3. 16266, 3. 16266, 1. 17549, 1. 1
7549, - 2. 37578, - 2. 37578, 1. 17549, 1. 17549, - 5. 53844, -
5. 53844, 2. 35098, 2. 35098, 2. 35098, 2. 35098, -, OK, 0. 10785, 0. 10785, -
, OK, Saggi ng
UDA_GENERI C_RESULT_PULLOUTS_ROTATI ONS, Utility 1 : Generic
Utility 1, Polyline 1 : Polyline
1, 1, 50, 200, 0, 150, 200, 0, 1, 40, 90, 200, 0, - 2. 37578, -
2. 37578, 0. 52159, 0. 52159, 0, 0, 0. 52159, 0. 52159, 2. 37578, 2. 37578, 1. 04
317, 1. 04317, 3. 41895, 3. 41895, -, OK, 0. 04785, 0. 04785, -, OK, Hoggi ng
UDA_GENERI C_RESULT_PULLOUTS_ROTATI ONS, Utility 1 : Generic
Utility 1, Polyline 1 : Polyline
1, 1, 50, 200, 0, 150, 200, 0, 1, 60, 110, 200, 0, 0, 0, 0. 52159, 0. 52159, 2. 3757
8, 2. 37578, 0. 52159, 0. 52159, 2. 37578, 2. 37578, 1. 04317, 1. 04317, 3. 4189
5, 3. 41895, -, OK, 0. 04785, 0. 04785, -, OK, Hoggi ng
UDA_GENERI C_RESULT_PULLOUTS_ROTATI ONS, Utility 1 : Generic
Utility 1, Polyline 1 : Polyline
1, 1, 50, 200, 0, 150, 200, 0, 1, 80, 130, 200, 0, 2. 37578, 2. 37578, 1. 17549, 1.
17549, - 3. 16266, - 3. 16266, 1. 17549, 1. 17549, - 5. 53844, -
5. 53844, 2. 35098, 2. 35098, 2. 35098, 2. 35098, -, OK, 0. 10785, 0. 10785, -
, OK, Saggi ng
...
UNI T_DI SP, 2
UNI T_LENGTH, 0
UNI T_ANGLE, 1
UDA_GENERI C_RESULT_STRAI NS, Utility 1 : Generic Utility
1, Polyline 1 : Polyline
1, 1, 50, 200, 0, 150, 200, 0, 1, 51, 200, 0, 109. 84, 21. 968, 22. 391, 22. 391, -
22. 391, - 22. 391, 132. 23088, 44. 35934, OK, -, - 0. 42356, OK, 2. 79E
+04, OK, OK, 17. 70068
UDA_GENERI C_RESULT_STRAI NS, Utility 1 : Generic Utility
1, Polyline 1 : Polyline
1, 1, 50, 200, 0, 150, 200, 0, 2, 52, 200, 0, 143. 74, 28. 747, 29. 329, 29. 329, -


```

29. 329, - 29. 329, 173. 06558, 58. 0767, OK, - , - 0. 58226, OK, 2. 13E
+04, Fails, Fails, 17. 70068
UDA_GENERI C_RESULT_STRAI NS, Utility 1 : Generic Utility
1, Poly line 1 : Poly line
1, 1, 50, 200, 0, 150, 200, 0, 3, 53, 200, 0, 184. 18, 36. 835, 37. 616, 37. 616, -
37. 616, - 37. 616, 221. 79246, 74. 45105, OK, - , - 0. 78035, OK, 1. 66E
+04, Fails, Fails, 17. 70068
UDA_GENERI C_RESULT_STRAI NS, Utility 1 : Generic Utility
1, Poly line 1 : Poly line
1, 1, 50, 200, 0, 150, 200, 0, 4, 54, 200, 0, 230. 91, 46. 183, 47. 202, 47. 202, -
47. 202, - 47. 202, 278. 1145, 93. 38433, OK, - , - 1. 01924, OK, 1. 32E
+04, Fails, Fails, 17. 70068
UDA_GENERI C_RESULT_STRAI NS, Utility 1 : Generic Utility
1, Poly line 1 : Poly line
1, 1, 50, 200, 0, 150, 200, 0, 5, 55, 200, 0, 283. 02, 56. 604, 57. 9, 57. 9, -
57. 9, - 57. 9, 340. 91916, 114. 50414, Fails, - , - 1. 29663, OK, 1. 08E
+04, Fails, Fails, 17. 70068
. . .
GPOI NT_RESULT, 150. , 240. , - 25. , 0. , 0. , - 1. e- 003
GPOI NT_RESULT, 150. , 250. , - 25. , 0. , 0. , - 1. e- 003
. . .
LPOI NT_RESULT, 50. , 150. , 0. , 0. 4636086, 0. , 0. 3708869
LPOI NT_RESULT, 51. , 150. , 0. , 0. 6526436, 0. , 0. 5438696
. . .
POI NT_RESULT, 5. , 150. , 0. , 0. 9029427, 0. , 0. 7851676
POI NT_RESULT, 55. , 150. , 0. , 1. 227543, 0. , 1. 115948

```

6.5 Exporting Building Damage Assessment Data

Building damage assessment data comprising charts, data, results and summaries may be exported in a pre-arranged folder structure by selecting 'File | Export | Building Damage Assessment Data...' on the program menu. This option is disabled if there are no building damage results, so an analysis must have first performed.

Tabular results are exported in CSV file format. Graphical results are exported in JPG, BMP or WMF file format.

This 'one-click' option avoids, for instance, the user having to select and open a graph of Sub-Structure results for every Sub-Structure in a model, in order to save the graphical images for reporting purposes. A comprehensive set of building damage results' data and line graphs is made available for ready inclusion in reports.

The nature of the exported data is shown below along with the folder and file structure that is created during the export process.

Folders	Files	Content/ Comments
<Run Filename>		The folder name is Xdisp data file name
<Structure Name>		One folder is created for each structure. The folder name is the structure name
	Building_Response.csv Classification_of_Damage.csv Critical_Sub_Structure.csv	
<Sub-structure Name>		One folder is created for each sub-structure. The folder name is the sub-structure name
	Classification_of_Damage.csv Strains_in_Sub_Structure_Offset_1.csv Strains_in_Sub_Structure_Offset_2.csv Strains_in_Sub_Structure_Offset_3.csv Sub_Structure_Details.csv Sub_Structure_Response.csv Horizontal_Displacement.csv Vertical_Displacement_Offset_1.csv Vertical_Displacement_Offset_2.csv Vertical_Displacement_Offset_3.csv BD_Interaction_Chart_Offset_1_Segment_n.jpg BD_Interaction_Chart_Offset_2_Segment_n.jpg BD_Interaction_Chart_Offset_3_Segment_n.jpg Sub_Structure_Displacement_Graph_Offset_1.jpg Sub_Structure_Displacement_Graph_Offset_2.jpg Sub_Structure_Displacement_Graph_Offset_3.jpg	One building damage interaction chart file is created for each vertical offset and segment where n is the segment number is created. <i>Note: chart title refers to "structure and sub-structure with segment details"</i> Graph of horizontal and vertical sub-structure displacements <i>Note: chart title refers to "structure and sub-structure"</i>

A log file is created with the information of data that could not be exported. This log is displayed automatically at the end of the export procedure.

If results are not available for a Sub-Structure then no damage data will be exported for the Structure.

Part VII

7 Toolbars and Keyboard Accelerators

[Toolbars](#)

[Keyboard Accelerators](#)

7.1 Toolbars

Toolbars provide a short cut to the more commonly used commands. Toolbars except can be docked (attached to the application frame) or floating (free to be positioned by the user). The toolbars can be switched on and off as required from the “View | Toolbars” menu command.

7.1.1 Standard Toolbar

The Standard Toolbar provides access to the following common Windows functions along with some that are specific to the program.



New — create a new model
Open — open an existing file
Save — save the model to file

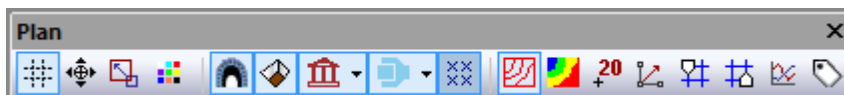
Cut — cut the data and place on clipboard
Copy — copy the data and place on the clipboard
Paste — paste the data from the clipboard into the model

Print — print the current view
Print Preview — preview the current view

About — opens the program's About Dialog e.g. to show version information
Xdisp Home — opens the programs home page on the internet
Email — opens an email to the Oasys support team

7.1.2 Plan Toolbar

The following graphical displays are available for the Plan View and can be displayed or hidden by toggling the individual icons on the Plan Toolbar or Graphics Menu.



Axis - Provides an axis and defined grid upon which the plan is drawn.



Engineering Scale - This allows the user to toggle between the default 'best fit' scale and the closest available engineering scale. e.g. 1:200, 1:250, 1:500, 1:1000, 1:1250, 1:2500.



Zoom Facility - The user can select an area to 'zoom in' to by using the mouse to click on a point on the drawing and then dragging the box outwards to select the area to be viewed. The program will automatically scale the new view. The original area can be restored by clicking on the 'restore zoom' icon as shown here.



Edit Colours - The user can edit the colours of lines in the Plan View.



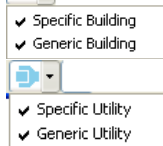
Tunnels and Mines - Toggles the display of tunnels and mines.



Excavations - Toggles the display of embedded wall excavation locations.



Buildings - Toggles the display of building alignments.



Utilities - Toggles the display of specific and generic utilities.



Grids, Lines, Points and Line Plots - All shown in blue as a grid or using crosses to define individual points and points along lines.



Contours - Right-click on the Plan View while either of these buttons is selected to choose the type of contour plot from the context menu. Contour lines or solid coloured contours are available depending on which button is selected.

Vertical displacement
 Horizontal displacement
 Major principal strain
 Minor principal strain

Contours of major and minor principal strain are available providing the model contains no excavations, and no tunnels which use the Harris and Alvarado method or the Mair et al method.



Vectors - Toggles the display of horizontal displacement vectors. Right-click on the Plan View while this button is selected to select the type of vector plot from the context menu.

Horizontal displacement
 Strain crosses

Strain crosses are available providing the model contains no excavations, and no tunnels which use the Harris and Alvarado method or the Mair et al method.



Line Graphs - Allows the user to plot the displacements along the selected displacement line, building damage results for the selected building, or utility damage results for the selected utility.



Change Displacement Grids - The user can move up or down to the results for different displacement grids.



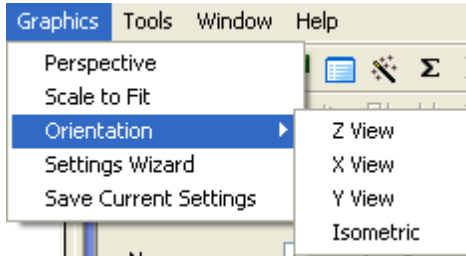
Annotation - Allows the use of the cursor to annotate the contours. Place the cursor over the required location and left-click or press <return>. If a displacement line is in the vicinity of a contour you wish to annotate then de-select the displacement grids icon and proceed with the annotation.









Labels - Toggles the display of labels for tunnels, buildings and embedded wall excavations.

7.1.3 3D Graphics Toolbar

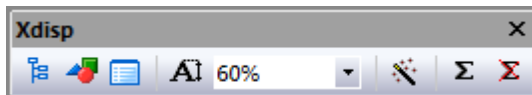
The 3D Graphics Menu and Toolbar provide access to the following functions.











-  - orientate the view so as to be looking down the X axis
-  - orientate the view so as to be looking down the Y axis
-  - orientate the view so as to be looking down the Z axis (i.e. a plan view)
-  - orientate the view so as to be viewing an isometric view
-  - view the currently displayed view in perspective (toggle on or off)
-  - resize the view so as to be scaled to fit the available window size.
when in graphical input mode it also resizes the grid if extents are not locked

7.1.4 Xdisp Toolbar

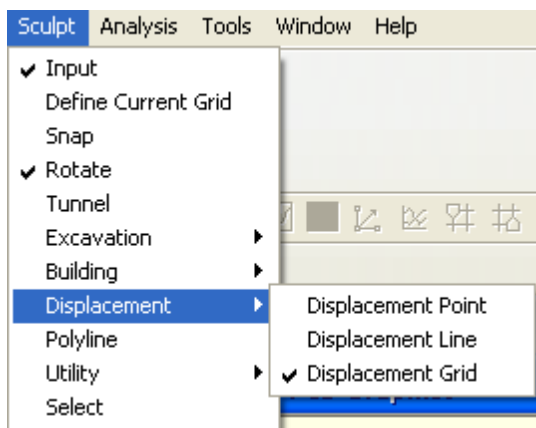
The Xdisp Toolbar provides access to the following functions.










-  - open or close the Gateway
-  - open the 3D Graphics View
-  - open the Tabular Output View
-  - specify a custom font scale to size text in the Plan View, or when printing the Tabular Output (dependent on which of those views is active)
-  - select from a list of font scales to size text as above
-  - open the context sensitive wizard
-  - perform an analysis
-  - delete the results


7.1.5 Graphical Input Toolbar



The Sculpt Menu and the Graphical Input Toolbar provide access to the following functions.




- 
Input - toggles the mode of the 3DGraphics view between Input Mode and Output Mode.
- 
Define Current Grid - to define grid planes and grid layouts and thereby set the current grid.
- 
Snap - allows the cursor to snap to the nearest grid point.
- 
Rotate - is the default cursor mode and allows models in the view to be rotated.
- 
Tunnels - allows input of tunnels.
- 
Excavations - by accessing the drop down menu of this button, the input mode can be set to polygonal or circular excavation to allow subsequent input of these elements.

Polygonal Excavation
 Circular Excavation
- 
Buildings - by accessing the drop down menu of this button, the input mode can be set to specific or generic building to allow subsequent input of these elements.

Specific Building
 Generic Building
- 
Displacement Entities - by accessing the drop down menu of this button, the input mode can be set to displacement point or displacement line or displacement grid to allow subsequent input of these entities.

Displacement point
 Displacement line
 Displacement grid
 Displacement polyline
- 
Polylines - allows input of polylines.
- 
Utilities - by accessing the drop down menu of this button, the input mode can be set to specific or generic utility to allow subsequent input of these elements.

Specific Utility
 Generic Utility
- 
Select - allows selection of elements for modification

7.2 Keyboard Accelerators

Key	Action
Ctrl+Num 1	Window bottom-left
Ctrl+Num 2	Window bottom
Ctrl+Num 3	Window bottom-right
Ctrl+Num 4	Window left
Ctrl+Num 5	Window middle (full)
Ctrl+Num 6	Window right
Ctrl+Num 7	Window top-left
Ctrl+Num 8	Window top
Ctrl+Num 9	Window top-right
Ctrl+C	Copy
Ctrl+F	Find
Ctrl+G	Go To
Ctrl+H	Replace
Ctrl+M	Modify
Ctrl+N	New
Ctrl+O	Open
Ctrl+P	Print
Ctrl+S	Save
Ctrl+Shift+S	Save As
Ctrl+V	Paste
Ctrl+W	Wizard
Ctrl+X	Cut
F1	Context Help
Esc	Quit
Tab	Next Cell
Return	Next Cell
Insert	Insert
Delete	Delete
Home	Beginning of Cell
Ctrl+Home	Beginning of Table
End	End of Cell
Ctrl+End	End of Table
Page Up	Scroll up
Page Down	Scroll down
↑Up	Row Up
←Lft	Column Left
→Rt	Column Right

↓Dn

Row Down

Part VIII

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